Department of the Built Environment

Supporting agency for sustainability

Exploring the contributions of universities and workplaces to the sustainability competencies and agency of engineering graduates

Meeri Karvinen

Aalto University

DOCTORAL THESES

Aalto University publication series
DOCTORAL THESES 24/2024

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Meeri Karvinen

A doctoral thesis completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Engineering, at a public examination held at the lecture hall A2 on 16 February 2024 at 12 noon.

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Aalto University publication series
DOCTORAL THESES 24/2024

ISBN 978-952-64-1655-7 (printed)
ISBN 978-952-64-1656-4 (pdf)
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)
http://urn.fi/URN:ISBN:978-952-64-1656-4

Images: Cover Janne Wikström

Unigrafia Oy
Helsinki 2024

Finland

NORDIC SWAN ECOLABEL
Printed matter
4041-0619

Author
Meeri Karvinen

Name of the doctoral thesis
Supporting agency for sustainability: Exploring the contributions of universities and workplaces to the sustainability competencies and agency of engineering graduates

Publisher School of Engineering

Unit Department of the Built Environment

Series Aalto University publication series DOCTORAL THESES 24/2024

Field of research Water and Environmental Engineering

Manuscript submitted 7 September 2023 **Date of the defence** 16 February 2024

Permission for public defence granted (date) 17 January 2024 **Language** English

☐ **Monograph** ☒ **Article thesis** ☐ **Essay thesis**

Abstract

The societal sustainability transformation requires actions from all organizations. University graduates have the opportunity to catalyze the transformation already in the early career, provided they have adequate competencies from the education, and the workplaces ensure sufficient opportunities to influence. Particularly engineering graduates play a significant role through a solution-oriented approach.

This dissertation investigates how universities support graduates in developing the required competencies and agency for sustainability using Nordic universities and the water and environmental engineering field in Finland as case examples. The thesis combines three research contexts, sustainability in higher education, engineering education and transition to working life, which together create a unique, broad theoretical framework for the explorations. The study utilizes surveys, interviews, and workshops to focus on the integration of sustainability in university operations, on the competencies needed for the early career ('employability') and for promoting sustainability, and on graduate role and agency in the workplaces.

The findings show that sustainability is generally considered as important. The employers are also satisfied with graduate contributions. However, Nordic universities could take a stronger 'whole university approach' in integrating sustainability to better support graduate sustainability agency. Supporting teachers in sustainability education revealed to need particular emphasis. In engineering, employability competencies are prioritized over sustainability. In promoting sustainability, graduates are expected to take a knowledgeable, independent, even transgressive role. While they do bring new insights and 'green' values, the graduates have challenges to connect their work to sustainability and they feel lacking power to influence. A hybrid graduate competency profile is suggested that promotes both employability and sustainability competencies: substance knowledge, key sustainability competencies, and sustainability knowledge.

Followingly, this dissertation encourages engineering educators to explore new pedagogical approaches that particularly develop the personal dispositions and agency of students and facilitate framing own work to a sustainability context. It further highlights the role of universities in supporting the teachers and workplaces in supporting the graduates. In addition, collaborative agency for sustainability among the graduates, workplaces and education is encouraged, as intensified collaboration around sustainability can clarify the role of the graduates in catalyzing the sustainability transformation in workplaces. It can also encourage teachers to try new approaches for teaching sustainability, students to develop adequate competencies, and workplaces to create practices that support graduates in contributing to sustainability.

Keywords sustainability in higher education, engineering education, graduate competencies, sustainability agency, early career

ISBN (printed) 978-952-64-1655-7 **ISBN (pdf)** 978-952-64-1656-4

ISSN (printed) 1799-4934 **ISSN (pdf)** 1799-4942

Location of publisher Helsinki **Location of printing** Helsinki **Year** 2024

Pages 201 **urn** http://urn.fi/URN:ISBN:978-952-64-1656-4

Tekijä
Meeri Karvinen

Väitöskirjan nimi
Tukea kestävyystoimijuudelle: Tutkimus yliopistojen ja työpaikkojen toimista tekniikan alan valmistuneiden kestävyysosaamisen ja -toimijuuden edistämiseksi

Julkaisija Insinööritieteiden korkeakoulu

Yksikkö Rakennetun ympäristön laitos

Sarja Aalto University publication series DOCTORAL THESES 24/2024

Tutkimusala Vesi- ja ympäristötekniikka

Käsikirjoituksen pvm 07.09.2023 **Väitöspäivä** 16.02.2024

Väittelyluvan myöntämispäivä 17.01.2024 **Kieli** Englanti

☐ **Monografia** ☒ **Artikkeliväitöskirja** ☐ **Esseeväitöskirja**

Tiivistelmä

Yhteiskunnallisen kestävyysmurroksen saavuttaminen vaatii toimia kaikilta organisaatioilta. Yliopistoista valmistuneilla on mahdollisuus edistää kestävyysmurrosta jo alku-uransa aikana edellyttäen, että heillä on koulutuksensa pohjalta tarvittava osaaminen. Työpaikoilla tulee myös varmistaa heille riittävät vaikuttamismahdollisuudet. Erityisesti teknisten alojen valmistuneilla on merkittävä rooli ratkaisukeskeisen lähestymistavan asiantuntijoina.

Tämä väitöskirja tutkii, miten yliopistot tukevat valmistuneiden kestävyysosaamista ja -toimijuutta, tapausesimerkkeinä pohjoismaiset yliopistot ja vesi- ja ympäristötekniikan ala Suomessa. Työ yhdistää kolme tutkimuskontekstia - kestävyys korkeakoulutuksessa, insinöörikoulutus ja työelämään siirtyminen - luoden tarkasteluille ainutlaatuisen, laajan teoreettisen viitekehyksen. Tutkimuksessa perehdytään kyselyiden, haastattelujen ja työpajojen avulla yliopistojen kestävyystoimien toteutukseen, tekniikan alan valmiuksiin, joita tarvitaan sekä alku-uralla ('työllistettävyys') että kestävyyden edistämisessä ja tarkastellaan valmistuneiden roolia ja kestävyystoimijuutta työpaikolla.

Tulosten perusteella kestävyyttä pidetään yleisesti tärkeänä ja valmistuneiden osaamiseen ollaan tyytyväisiä. Pohjoismaisten yliopistojen yliopistonlaajuisissa kestävyystoimissa on kuitenkin kehitettävää, jotta vastavalmistuneilla olisi paremmat edellytykset edistää kestävyyttä työssään. Erityisesti opettajien kestävyysopetuksen tukeminen vaatii kehittämistä. Tulosten mukaan työllistettävyysvalmiuksia pidetään tekniikan alalla tärkeämpinä kuin kestävyysvalmiuksia. Kestävyyden edistämisessä valmistuneiden odotetaan olevan osaavia ja halukkaita toimimaan itsenäisesti ja haastavan totuttuja käytäntöjä. Valmistuneet tuovatkin uusia näkemyksiä ja 'vihreitä' arvoja, mutta kokevat samalla toimijuutensa rajoittuneeksi. Heillä on myös haasteita yhdistää kestävyys työhönsä. Tulokset kannustavat kehittämään valmistuneille nk. hybridiosaamisprofiilin, jossa yhdistyvät työllistettävyys- ja kestävyysvalmiudet eli alan ydinosaaminen, kestävyyden avainkompetenssit sekä riittävä tieto kestävyydestä.

Tällaisen osaamisen tukemiseksi väitöskirja kannustaa kokeilemaan uusia pedagogisia lähestymistapoja insinöörikoulutuksessa, jotka kehittävät opiskelijoiden omaa näkemystä kestävyydestä sekä kykyä kytkeä työnsä kestävyyden kontekstiin. On myös tärkeää, että yliopistot tukevat opettajia ja työpaikat valmistuneita. Väitöskirja korostaa lisäksi valmistuneiden, työpaikkojen ja yliopisto-opetuksen yhteistoimijuutta, jotta valmistuneiden rooli kestävyysmurroksen kiihdyttämisessä olisi työpaikoilla selkeämpi. Tämä voisi kannustaa opettajia kokeilemaan uusia tapoja opettaa kestävyyttä, opiskelijoita kehittämään soveltuvaa osaamista sekä työpaikkoja luomaan valmistuneiden kestävyystoimijuutta tukevia käytänteitä.

Avainsanat kestävyys korkeakoulutuksessa, insinöörikoulutus, valmistuneiden osaaminen, kestävyystoimijuus, alku-ura

ISBN (painettu) 978-952-64-1655-7 **ISBN (pdf)** 978-952-64-1656-4

ISSN (painettu) 1799-4934 **ISSN (pdf)** 1799-4942

Julkaisupaikka Helsinki **Painopaikka** Helsinki **Vuosi** 2024

Sivumäärä 201 **urn** http://urn.fi/URN:ISBN:978-952-64-1656-4

Acknowledgements

It took me eight years to complete this doctoral thesis. These years have engaged me in several Nordic, Baltic, national, and university level projects. I have been privileged to teach brilliant international, Nordic, and Finnish students. My doctoral path has been guided, supported, and enriched by three supervising professors and a number of wonderful partners, co-authors, teachers, students, colleagues, and new friendships. Without the experience and learnings I gained from the projects and working with all these people, I wouldn't have had the courage and knowledge to finalize this thesis. I therefore dedicate this dissertation to collaboration and joint efforts. I would like to thank everyone I have worked with during these years, you have all had a unique impact in my thinking and thereby, this dissertation!

I will start these rather long acknowledgements from Dr. Jaana Sorvari. You volunteered to take the Nordic project I was coordinating to your team in 2015. That is how I found my way to the water and environmental engineering research group WAT. You soon started to encourage me to apply for doctoral study rights. Thank you so much for your trust and the needed nudging! As my first supervising professor, you treated me like a peer and co-teacher, which contributed substantially to my professional identity.

I want to also thank Dr. Riku Vahala for trusting the WAT development project under my coordination. You also kindly agreed to be my supervisor after the personnel changes. It was always easy and smooth working with you, thank you!

Professor Marko Keskinen, you have accompanied me for the whole doctoral journey as a colleague, mentor, and finally, as my supervisor. You have seen the highs and the lows of my path, always expressing such collegial appreciation and support that I don't know what else to say but a thousand thank you. You have always showed the needed compassion, trust, and opened up opportunities for me. It has been, and still is, a privilege to learn from you and work with you.

I'd like to thank my pre-examiners, Dr. Päivi Kinnunen and Professor Hannu Heikkinen for your valuable remarks and comments, which helped to improve and finalize my dissertation. Thank you, Professor Heikkinen also for agreeing to be my opponent – looking forward to discussing with you!

This work wouldn't have realized without the financial support granted by a number of parties. Thank you Nordic Council of Ministers for the Nordic project funding and for supporting the sustainability efforts of the Nordic higher education sector. Thank you Maa- ja Vesitekniikan Tuki Ry for enabling the research-based development of the WAT Master's Programme and for the smooth

collaboration during the project. Thank you Dr. Jaana Sorvari for also supporting me financially. Aalto ENG Doctoral Programme secured the finalizing phase of this dissertation by granting me funding for the final stretch, thank you!

Thank you for my co-authors, Dr. Jaana Sorvari, Dr. Helena Mälkki, Ullika Lundgren, Dr. Anu Vehmaa, Julia Sundman, Anni Kaikko, and Professor Marko Keskinen for the smooth co-writing! Thank you Anu, Julia, and Anni also for being the best project assistants and researchers in the WAT development project one could ask for. This thesis would not exist without your substantial efforts and professional way of working – I was always able to trust you.

For the first half of my thesis journey, Dr. Maire Syrjäkari worked as my advisor – thank you Maire for pushing me forward! The first steps of my doctoral journey were strongly supported by Dr. Helena Mälkki. Helena, with and from you I learned how things worked in the department. Without you, I wouldn't have attended the first conferences and wrote the first papers. Thank you for all the help and encouragement! Dr. Eeva Säynäjoki, thank you so much for your mentoring and friendship! Your positive and encouraging attitude helped me through some difficult times, and I really appreciate that you always found time to meet me.

My research was enabled by all the lovely people who put their time in answering the questionnaires, volunteering for interviews, and joining the workshops. Thank you, Nordic higher education staff and all the stakeholders of the WAT Programme who helped me collecting my data!

I want to express my gratitude to all of you, with whom I had the privilege to work in the Nordic Sustainable Campus Network NSCN. First of all, thank you Meri Löyttyniemi for trusting the coordination of the network to me and for leading the Nordic collaboration with such enthusiasm! Thank you also for helping me to get familiar with Aalto and its people during my very first years! Thank you for the NSCN core group members Jorulf B. Silde, Teresia Sandberg, Tomas R. Poulsen, Silla Lövdahl, Essi Römpötti, Saana Raatikainen, Ullika Lundgren, Eddi Omrcen, Dr. Ottar Michelsen, and Dr. Thomas S. Grindsted for our joint years, joyful moments and great efforts put to promote sustainability in the Nordic higher education! Thank you also for all the other Nordic and Finnish collaborators who helped with the Rio+20 survey and running the project!

I want to also thank all of my colleagues in the Finnish universities for openly sharing your views and practices around sustainability integration during the past years! Thank you for the whole SIRENE network for contributing to my knowledge and understanding, especially Professor Sirpa Tani, Dr. Anna Lehtonen, Dr. Essi Aarnio-Linnanvuori, Dr. Niina Mykrä, Dr. Petteri Muukkonen, Dr. Henrika Ylirisku, and Erkka Laininen for your dedication to SIRENE!

I want to thank Aino Peltonen and Heikki Särkkä, as well as Antti Louhio for your valuable help in organizing the stakeholder events of the WAT project and for supporting all of us in all the possible ways! Dr. Heidi Salo, Dr. Juho Uzkurt Kaljunen, and Dr. Matias Heino, thank you for kindly agreeing to facilitate the workshops in the Water & Environment Expo 2020, and thank you Dr. Maija Taka and Sara Saukkonen for all the help in the practical arrangements!

Thank you Opetiimi for all the workshops, questionnaire answers and chats over the years, for supporting me in my teacher role, and creating such a nice

working environment: Professors Olli Varis, Matti Kummu, Marko Keskinen, Harri Koivusalo, Anna Mikola, and Eliisa Lotsari, Dr. Teemu Kokkonen, Dr. Juha Järvelä, Dr. Nora Sillanpää, Dr. Heidi Salo, and Elina Paavonen! Thank you also for the former members Dr. Riku Vahala, Dr. Riina Liikanen, and Dr. Jaana Sorvari. I want to especially thank Teemu and Marko for our collaboration around teaching and curriculum development. I have learnt a lot from you! Special thanks also to the WAT students who have been one of my data sources and also a little bit my guineapigs when I have tried out different ways to discuss sustainability in the class.

Our smaller unit, the Water and Development Research Group WDRG, has been a safe nest to grow as an academic. Thank you Dr. Maija Taka for driving a culture of well-being for many years, and for all your help and supportive words during my journey. Thank you for all the fun activities, coffee break chats, lunches, and help for all the WDRG current and former colleagues, Johannes Piipponen, Vili Virkki, Anni Juvakoski, Dr. Josias Láng-Ritter, Thomas Banafa, Sara Heikonen, Sofija Djukanovic, Julia Sundman, Matleena Muhonen, Dr. Daniel Chrisendo, Dr. Vilma Sandström, Dr. Dandan Zhao, Dr. Ozias Hounkpatin, Dr. Venla Niva, Dr. Mika Jalava, Dr. Marko Kallio, Lauri Ahopelto, Xiaoqi Feng, Hanna Aarnio, Suvi Ojala, Dr. Juho Haapala, Dr. Amy Fallon, Dr. Miina Porkka, Dr. Matias Heino, and Dr. Mia Pihlajamäki. Special thanks to my roommates Matleena and Julia for the smooth room-sharing and lovely atmosphere, it's a pleasure to work with you!

For the last couple of years I've had the opportunity to develop sustainability integration in practice at Aalto. I want to thank the A! Co-Educator Team for enabling this work and for making it so enjoyable! Thank you for the educative, warm and fun collaboration Dr. Elina Kähkönen, Håkan Mitts, Melissa Georgiou, Dr. Tuomo Eloranta, Johannes Kaira, Riikka Evans, Katri-Liisa Pulkkinen and Noora Jaakkola, as well as our former team members Dr. Paulo Dziobczenski and Dr. Paula Schönach. I really hope we have the chance to continue working together around radically creative, entrepreneurial sustainability endeavors! Special thanks to Noora and Paula – without you, living through the pandemic would have been much worse! Thank you so much for the professional and personal support, friendship, and that I have got to learn from both of you.

Dr. Annukka Jyrämä, you have been a supportive colleague and interested in my research and work. Thank you for always finding time for a cup of coffee! You also connected me with Dr. Kirsi Hakio, thank you so much! Kirsi, with you we immediately found a deep connection that led to a successful funding application, research collaboration, and friendship. Thank you for your genuine and calming presence and opening up the door to awareness-based (design) thinking.

Dr. Mervi Friman, Dr. Lili-Ann Wolff, and Professor Tuuli Mattelmäki, with you, Noora Jaakkola, and Dr. Kirsi Hakio I experienced an amazing co-creative research and learning process! I enjoyed our meetings, your wisdom, and the way you listened to the viewpoints of the other disciplines, and I learnt so much on interdisciplinary research and co-writing from you, thank you! Thank you Mervi also for sharing your expertise on sustainability integration!

Sienet - Jonna Similä, Dr. Janne Wikström, Katri-Liisa Pulkkinen, and Dr. Salla Jokela - our meetings in Hanasaari around the Nordic City Challenge gave me energy to continue through the hard times and taught how projects can be productive and fun at the same time. I think we succeeded to make the Nordic cities at least a bit more sustainable! Tusen tack, love you! Thank you Janne also for all your help with the practical arrangements of my Karonkka!

I want to thank my friends and family for the needed relaxed moments to balance the hard work. My dear friends, Anu, Timo, Elina, Anna, Elsa, Santeri, and all the others of Foorumi, thank you for being there! "Suurperhe", I couldn't have survived all these years without you, so thank you Laura and Tuomas for your friendship, and also Potu and Matilda for all the great time we've had together. Thank you Sarita for being by my side for the whole of my life - we both know that distance can never take us apart! Jenni, you have literally walked with me for over twenty years now, quite a few kilometers! Thank you for every single one of them, all the glasses of wine, and the hours of training dogs! Thank you Robin for enabling all our walks and being such helpful with anything! Naturally, without your dogs, we would probably walk much less. So thank you all of you, Katla, Fauna, Flora, Malla-Kaarnikka and Nummi-Pusula, who already passed away, and Hekla, Pessi, and Vilkka for ensuring that we have more walks to come.

Thank you Kimmo, Ritva, Piritta, Kaj, Riku, Aino, Jyri and Lauri for the nice time spent together during these years. Maamo, thank you for all the help and support, wish you were still here.

Life would be much harder, if one didn't have a caring, supporting and kind person as a big sister. Thank you Miina, I can always count on you whatever the case. Of course I also want to thank my "big brother" Pasi for your support, as well as Topias, Timo, and Teemu for the joyful moments we have been able to share! I am forever grateful to my mother, Sini, for your everlasting support and love. I want to thank my father, Mara, and Sirpa for your support and encouragement during my journey.

Sampsa, you have always made it clear how proud you are of my work and my research. I know that and I love you. Aatami and Hermanni, you mean *every*thing to me! Always stay as you are and be as proud of yourselves as I am! Love you so much!

The very final words are dedicated to my furry travel companions who make me step out of the door every day, whatever the weather or mood. Thank you Hukka, who I had to let go during the long thesis process, Hämy and Hippu, who make me ride an endless rollercoaster of emotions each and every day, and thank you Haiku, the kindest creature on Earth. The almost 13 years we have already shared have taught me that a meaningful and deep relationship doesn't depend on a species, but on mutual respect and trust.

Meeri Karvinen
18 January 2024
Helsinki

Contents

List of Abbreviations and Symbols

DESD	Decade for education for sustainable development (of the UN)
EfS	education for sustainability
ESD	education for sustainable development
EESD	engineering education for sustainable development
GAP	Global action programme (of the UN)
HE	higher education
HEI	higher education institution
HESD	higher education for sustainable development
HESI	Higher Education Sustainability Initiative
ILO	intended learning outcome
NSCN	Nordic sustainable campus network
OECD	Organization for Economic Co-operation and Development
SE	sustainability/sustainable education
SEE	sustainability in engineering education
SD	sustainable development
SDGs	Sustainable Development Goals (of the UN)
SHE	sustainability in higher education
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
WAT	Water and Environmental Engineering Master's Programme (of Aalto University)

List of Publications

This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their numerals.

1. Karvinen, M., Lundgren, U., Mälkki, H. & Sorvari, J. (2017). The Implementation of Sustainable Development in the Nordic Higher Education Institutions (HEIs). In: Leal Filho, W., Mifsud, M. Shiel, C. & Pretorius; R. (Eds.), Handbook of Theory and Practice of Sustainable Development in Higher Education: World Sustainability Series 3, 169–187. Springer International Publishing AG. doi:10.1007/978-3-319-47895-1.

2. Karvinen, M., Mälkki, H., & Sorvari, J. (2016). How sustainable Nordic higher education actually is? Exploring the role of sustainable development in teaching at Nordic Higher Education Institutions. In Proceedings of the 44th SEFI Annual Conference: Engineering Education on Top of the World: Industry University Cooperation, Tampere 12.-15.9.2023, 12 pp.

3. Karvinen, M., Vehmaa, A. & Keskinen, M. (2019). Muuttuvien työelämätaitojen sisällyttäminen tekniikan alan koulutukseen: tapaustutkimus Aalto-yliopiston vesi- ja ympäristötekniikan maisteriohjelmasta. Yliopistopedagogiikka, 2019(1), 20–41. (in English: *Integrating the changing working life skills in engineering education: a case study from Aalto University's Master's Programme in Water and Environmental Engineering*).

4. Vehmaa, A., **Karvinen, M.,** & Keskinen, M. (2018). Building a more sustainable society? A case study on the role of sustainable development in the education and early career of water and environmental engineers. Sustainability, 10(8), 2605–2623. doi:10.3390/su10082605.

5. Karvinen, M., Sundman, J., Kaikko, A. & Keskinen, M. (2023). The competencies and possibilities of engineering graduates to act for sustainability - insights from the employers of the water and environmental engineering field in Finland. Submitted to European Journal of Engineering Education, March 2023 (in review).

1. Introduction

The working life urgently needs people with adequate competencies to mitigate and halt the ongoing environmental degradation and its social and economic consequences (IPCC, 2018; IPBES, 2019; Rockström et al., 2023). Higher education has a key role in educating the experts and future leaders capable of tackling with and solving these complex sustainability challenges. Particularly engineers have a crucial role in the society as the innovators of new technological solutions and in being the experts of problem-solving.

However, as the pace of the global environmental changes is only accelerating (Steffen et al., 2015a; IPCC, 2022; Rockström et al., 2023; Richardson et al., 2023), immediate actions are requested from all organizations to contribute to a rapid sustainability transformation of the society. Therefore, university graduates play an important role already during their early career; they can bring new knowledge and insights from their education to the workplaces and help catalyzing the change (Wiek et al., 2011; Trevelyan, 2019). For this to realize, the education and the workplaces should ensure the catalyst role by supporting the development of adequate competencies and agency of the graduates and ensuring sufficient possibilities for them to act for sustainability in the workplaces.

Universities worldwide have responded to the request to promote sustainability in their operations (Lozano et al., 2013; 2015; SDG Accord, 2019). The measures taken have particularly emphasized lowering the ecological footprint of the universities (Wals, 2014; Ramos et al., 2015), while integrating sustainability in the education has only recently gained more attention (Sherman & Burns, 2015; Michel, 2020). In general, a whole university approach to sustainability (McMillin & Dyball, 2009; Kohl et al., 2022), as well as redesigning the university curricula and the supporting university structures (Sterling, 2001; Kolmos et al., 2016) have been suggested as means to ensure that the universities provide full support for the development of the necessary competencies of their students. This implies that universities manifest sustainability holistically and transparently in all their operations and link their research, campus management, and outreach activities to sustainability education (Cortese, 2003). Thereby, the students learn both informally through being exposed to a sustainability-oriented environment and formally through engaging in practical applications of sustainability (McMillin & Dyball, 2009; Kohl et al., 2022).

Many examples exist of the actions taken by the Nordic universities, particularly in Sweden (e.g., Holmberg et al., 2012; Finnveden et al., 2020). However, evidence is lacking on how the Nordic universities have succeeded to integrate

sustainability in the education in such a way that ensures the development of the important graduate competencies. Considering that the Nordic countries are renowned for embracing sustainability in their socio-economic models (Maassen et al., 2008) and have an ambitious sustainability strategy (Nordic Council of Ministers, 2019), it would be important to know, whether the Nordic universities are ensuring adequate competencies for their graduates through realizing a whole university approach.

A wide convergence exists on the competencies that ought to be developed to advance sustainability. Systems and futures thinking, interpersonal, values thinking, strategic thinking, and problem-solving have been suggested as the key sustainability competencies (Wiek et al., 2011), together with interdisciplinary competency (e.g., Barth et al., 2007), critical thinking (Rieckmann, 2012; UNESCO, 2017), self-awareness, and implementation competencies (Brundiers et al., 2021; Redman & Wiek, 2021). For engineers, specifically problem-solving and interdisciplinary collaboration, as well as self-knowledge and ethics have been identified important (Guerra, 2017; Thürer et al., 2018; Quelhas et al., 2019). In addition to the key sustainability competencies, engineering graduates are expected to possess certain working life skills, including a proactive attitude, teamwork skills and communication, project management, lifelong learning, and curiosity (Korte et al., 2015; Passow & Passow, 2017; Khoo et al., 2020). In engineering education, long traditions exist in considering the industry expectations, but the relevance of sustainability from the viewpoint of the stakeholders of engineering education has remained underemphasized (Thürer et al., 2018). In addition, the relative importance of the different competencies in the early career is an underexplored topic (Brunhaver et al., 2018).

Developing important competencies is only a starting point for the graduates to catalyze a societal sustainability transformation; another phase begins after the graduation. However, relatively little is known of how the graduates manage to apply and perform their competencies and act for sustainability in their early career workplaces. The picture that forms from the few existing studies suggests that apart from the acquired competencies, many workplace-related factors, including culture, norms, resources, and support provided affect the ability of the graduates to contribute to sustainability (Holdsworth et al., 2019a; Thomas et al., 2020; Chance et al., 2022). In addition, in the field of engineering, the transition phase to the working life has been shown to be generally challenging for the graduates due to a contextual change and contradicting expectations towards their task performance and competencies (Korte et al., 2015; Brunhaver et al., 2018; Trevelyan, 2019; Lutz & Paretti, 2021). Despite the potential of the graduates to bring new insights and to accelerate the sustainability contributions of their organizations, research is scarce on how the workplaces receive their insights and how the employers perceive the role of graduates in promoting sustainability.

The overarching aim of this dissertation is to explore how the graduates can act as catalysts of the societal sustainability transformation already in the beginning of their professional career. The dissertation approaches the topic from the perspective of three fields, sustainability in higher education (SHE),

sustainability in engineering education (SEE), and the transition phase of graduates from the education to the working life (Figure 1), with a special emphasis on SHE and SEE. The research particularly aims to provide new insights for engineering education and means to evaluate or renew curricula to better support the graduates in their early career and sustainability endeavours.

The explorations of this dissertation focus on the three research topics described above, the institutional sustainability contributions of universities, the important early career and sustainability competencies, and the role and possibilities of graduates to advance sustainability in the workplaces. More specifically, the dissertation first explores how the Nordic universities have integrated sustainability in their operations and surveys whether the observed integration measures reflect a whole university approach (see 2.2.3). Second, the dissertation analyses the importance of different competencies in the early career of engineering graduates and investigates, which competencies are specifically required for promoting sustainability. Third, the dissertation aims to understand how the engineering graduates are able to contribute to sustainability in the workplaces and how their sustainability efforts are viewed by the employers. The more specific research questions to investigate these topics are as follows:

RQ 1. How do universities support the possibilities of graduates to act for sustainability in the early career?

RQ 2. What competencies are needed from engineering graduates in the early career and for contributing to sustainability?

RQ 3. What is the role of engineering graduates in their workplaces regarding the advancement of sustainability?

The research questions are studied in the five published articles appended to this dissertation. The Articles 1-2 focus on the RQ 1 by screening and discussing the level of sustainability integration in the Nordic universities. In answering the RQ 1, I also utilize findings from the Articles 3-4. The Articles 3-5 address the RQs 2 and 3: The Article 3 is particularly focused on the working life relevance of the education and the relative importance of different competencies along the early career, while the Articles 4 and 5 explore the sustainability competencies and role of graduates in contributing to sustainability. The Article 4 takes the perspective of graduates, and the Article 5 approaches the topic from the employer viewpoint. Figure 1 illustrates how the five articles can be placed in the landscape of the research fields and topics.

In the Section 2, I define the key concepts used in the dissertation, create a picture of the research field of SHE and its connection to engineering education, describe shortly the transition phase of graduates to the working life, and define the research gaps. Section 3 presents the methodology of the dissertation and Section 4 the key findings. Section five summarizes the findings and discusses their educational and institutional implications, the limitations of the research, and future directions. Finally, the research and its implications are concluded in the Section 6.

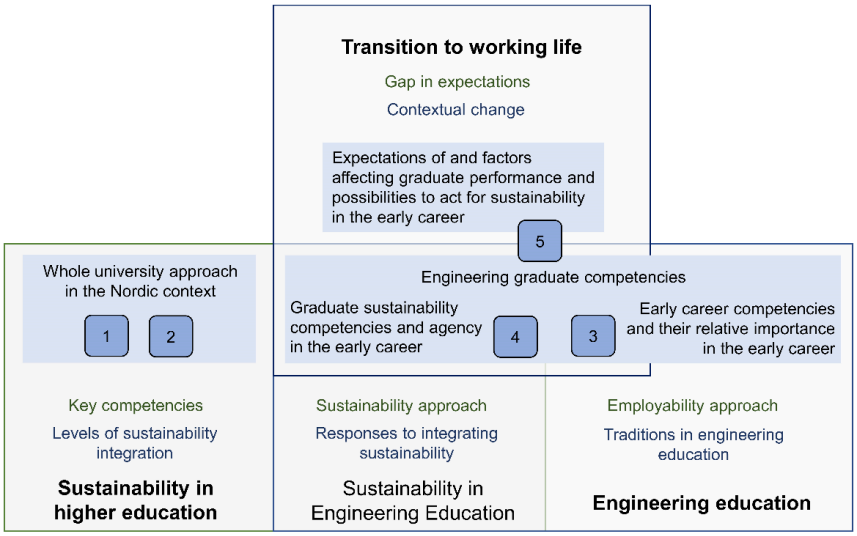

Figure 1. The five articles (1-5) of this dissertation in the landscape of the three key research fields, Sustainability in higher education (SHE), Engineering education (including Sustainability in engineering education, SEE), and Transition to working life. The main topics of the appended five articles are indicated with blue background. The theoretical framework of the thesis combines the three research fields and specifically comprises of a wider context of each field (blue font) and the approach of each field to competencies (green font).

2. Research background and gaps

This section first defines the key concepts and terminology used in the dissertation and then presents the research context: how the field of sustainability in higher education has evolved, how it connects to engineering education and what challenges relate to the working life transition phase. Finally, the section reviews previous research on the key topics of the dissertation and defines the research gaps.

2.1 Key concepts and terminology

The central concepts and terminology of this dissertation relate to the notions of sustainability and sustainable development, transformation, agency, and competencies. In the following, I briefly describe how these concepts are discussed in the literature and define how I understand them in this dissertation. The concept of sustainability education is also central in this dissertation and is discussed in detail in Subsection 2.2.2.

2.1.1 Sustainability, transformation, and agency

The concept of sustainability has been defined as wicked, value-laden, and ambiguous (Giddings et al., 2002; Brown, 2015; Pryshlakivsky & Searcy, 2013). The sustainability related challenges that people face in their daily life vary substantially depending for example on the geological location, economic situation, and political environment. These factors, as well as the culture and worldviews of the decision makers, affect how sustainability is viewed and the means that are considered essential in overcoming the challenges. The complexity of the sustainability concept thus stems from the need to balance between the different viewpoints and varying interests, yet common to all is the same fundamental goal of sustainability: to survive as a humankind on this planet.

Many definitions have been suggested to find the best way to communicate the problems we are facing as a humanity and how to best overcome those (Griggs et al., 2013). One of the biggest debates of the definitions relates to the relationship and hierarchy between the key dimensions of sustainability (environmental, socio-cultural, and economic). After the Brundtland definition of sustainable development (WCED, 1987) - development that meets the needs of the current generation without jeopardizing the needs of the future generations – the dominating view mostly considered the dimensions as equal (Giddings et al., 2002). This equality of the dimensions exists also in the most recent global agenda, the UN

Agenda 2030. It establishes the United Nations Sustainable Development Goals (UN SDGs), which describe 17 specific goals and 152 more detailed targets. The SDGs have been considered as an inclusive definition of sustainable development in contrast to the previous Millennium development goals that were criticized for overemphasizing the problems of the developing countries by the developed countries (Fehling et al., 2013). Due to the comprehensiveness of the SDGs and their visual design that allows for effective communication, the SDGs have become widely used all over the world by all sectors of the society, including education (see e.g., SDG Accord, 2019). However, the framework has been criticized for ambiguity with the used concepts and poor measurability and monitoring possibilities (ICSU, 2015; Swain, 2017). Scholars have also urged considering the interconnections, synergies, and trade-offs between the different targets when using the framework (ICSU, 2015; Taka et al., 2021).

Viewing the sustainability dimensions as equal also neglects the fact that the limited natural resources and the functioning of the natural ecosystems do not allow for an indefinite growth (Haberl et al. 2020; Wiedenhofer et al. 2020). This boundary thinking, or a nested hierarchy, of the sustainability dimensions emphasizes the dependence of the socio-cultural and economic dimensions on the functioning of the natural ecosystems and can be dated back to 1972 to the Limits to growth report by the Club of Rome (Meadows et al., 1972). It has also been suggested to be applied to the SDGs (Sukhdev & Rockström, 2016), prioritizing the SDG goals that aim at safeguarding the natural ecosystems. The boundary thinking is supported by the recent scientific evidence suggesting that human actions have already severely altered the functioning of the nine biophysical planetary systems that maintain the current stable conditions of the planet (Rockström et al., 2009; Steffen et al., 2015b; Persson et al., 2022; Richardson et al., 2023). Changes in the functioning of these systems would cause substantial challenges for the current human living conditions, which is why the aspects of social equity and justice have been connected to the boundary concept. For example, the model of Doughnut economics by Kate Raworth (2017) defines a 'safe and just operating space for humanity', where social boundaries create the floor and the biophysical planetary boundaries the ceiling of the safe operating space. The most recent concept to define the interplay between the environmental, social, and economic dimensions suggested in this discourse is Earth system justice by Rockström et al. (2023).

Despite the concept of sustainability is somewhat contested, certain convergences can be identified, for example that *sustainable development* is commonly referred to as the process that leads us towards a desired direction (away from unsustainability), while *sustainability* is the desired end state of the process (Axelsson et al., 2011). In this dissertation, I understand the terms sustainability and sustainable development having the same fundamental purpose: to describe ways to prevent, mitigate and overcome the current socio-cultural and economic challenges that stem from our detrimental ways to interact with and exploit the natural environment. I mainly use the term sustainability and in using it, lean on the boundary thinking. To be more specific, I lean on the most recent concept of Earth system justice that apart from respecting the intrinsic

value and rights of all human individuals, has a strong emphasis on posthumanistic philosophy (Wolfe, 2009) through respecting the intrinsic value of all non-human actors. Nevertheless, in the individual articles of this dissertation, the terms sustainability and sustainable development are used in a practice-oriented manner: the decisive factor behind the logic in using the terms stems from the respective context and literature utilized. For example, the Articles 1-2 are closely related to the UN Rio+20 process (see Subsection 2.2.1) and refer to the Decade for Education for Sustainable Development (DESD), therefore, the term used is sustainable development (SD). In addition, the questionnaire survey that served the Articles 3-4 was originally in Finnish and used the Finnish term for sustainable development (kestävä kehitys), as in the Finnish public discourse, it seems more firmly grounded compared to sustainability (kestävyys). Finally, in the Article 5, the theoretical background on the employability and sustainability agendas in engineering education were the decisive factor to use the term sustainability.

Overcoming the complex sustainability challenges requires a change that this dissertation refers to as societal *sustainability transformation*. A closely related concept of *sustainability transition* is also commonly used particularly in connection to engineering, as engineering practice plays a key role in the socio-technological system transitions (Markard et al., 2012). However, according to the observations made by Hölscher et al. (2018) in their comparative study of these two concepts, the change I refer to in my research is closer to transformation: based on their review of literature, transition is more often used to describe a change from one (non-sustainable) equilibrium to another (more sustainable), particularly in socio-technological systems, while transformation embraces the fundamental changes in human-environment interactions. Moreover, Hölscher et al. (2018) note that transformation is the concept used in the discourse of resilience and 'a safe and just operating space', which I have utilized in my studies to justify the need for sustainability education. In the sustainability education discourse, transition and transformation are used relatively interchangeably and extensive reviews are lacking on how these two concepts are applied in education and whether this has any implications on the epistemological understanding of the graduates; how they comprehend the required change and their role in it.

Graduate *agency for sustainability* relates closely to how the graduates perceive their role in the society and possibilities to have an impact, and to their self-efficacy (Brown & Bimrose, 2014). A closely related concept, professional agency, is thoroughly discussed and conceptualized by Eteläpelto et al., (2013), underlining i.e., the impact of the socio-cultural environment, power structures, and temporal features on the individual agency. Drawing from their conceptualization and how agency is discussed in the discourse of sustainability competencies (Wiek et al., 2011; Brundiers et al., 2021), I define graduate agency for sustainability as an ability to act upon own sustainability-related intentions in the workplaces, including the abilities to identify own role, motives, desires, and competencies, and to observe, reflect, set goals, and to act accordingly to drive change.

This dissertation additionally discusses *collaborative agency*, or co-agency, which is considered as highly important for example in the OECD Learning Compass for 2030 (OECD, 2019). Following the OECD (2019) definition, collaborative agency is understood here as the influence of peers, teachers, and other surrounding factors to the graduate sense of agency instead of only relying on the autonomy and innovative capacity of the graduates.

2.1.2 Competencies

Many variations exist in the terminology used in research concerning the skills related to the future, working life, or sustainability. These include competence, competency, ability, capability, capacity, attribute, and skill (Brundiers et al., 2021; Byrne et al., 2013; Sterling et al., 2017). Often this terminology is used interchangeably (Sterling et al., 2017) and Shephard, Rieckmann, and Barth (2019) argue that the terminology is confusing in the literature and inconsistent even inside individual papers. Therefore, I describe here the main viewpoints concerning the key terminology on competencies and define how the terminology is used in this dissertation.

The differentiation between the terms competence and competency is particularly ambiguous (Jaakkola et al., 2022). According to Mäkinen and Annala (2010) and Schaffar (2021), two interpretations exist of being competent: the other approach relates to how discipline specific knowledge and skills are performed and can be qualified (sociologist view), while the other is more comprehensive including the development of the personality and dispositions of a person (psychologist view) (see Jaakkola et al., 2022 for a review of the meanings of the two concepts). This is in line with what Lozano et al. (2012) argue: the instrumental and marketilizing approach of competence and outcomes-based education (referring to the narrower interpretation of being competent) fails to consider the need for societal transformation, and the need for developing agency.

Moreover, some scholars use different terms for different types of competencies. For example, in de Haan's (2006) comprehensive 'shaping competency', which consists of multiple specific competencies, a personal attribute related competency 'empathy, compassion and solidarity' is called *a capacity* instead of a competency. In general, personal attributes related competencies have divergent definitions in the sustainability education literature (Byrne et al., 2013; Jaakkola et al., 2022), which increases the complicatedness when aiming at reviewing the literature or discussing the personal attributes related competencies.

The terminology on competencies varies also in connection to the context, partly based on the disciplinary backgrounds of the specific studies. Literature exists of hard and soft skills, professional, generic and transferable competencies, all referring to what knowing, doing and being the graduates should be able to apply and express in order to get employed (Baytiyeh & Naja, 2012; Winberg et al., 2018), thrive in a profession (Pulakos et al., 2000; Sonnentag et al., 2008; von Stumm et al., 2011) or to promote sustainability (Wiek et al., 2011; Passow and Passow, 2017; Quelhas et al., 2019; Ortiz-Marcos et al., 2020; Brundiers et

al., 2021). Further, in educational psychology, the different components of personality and intelligence are divided into cognitive, conative, and affective domains (Snow et al., 1996), from which affective and conative are particularly relevant when discussing agency, as they include motivation, desires, self-control, self-knowledge, and positionality (conative) and the often unconsciously influencing values, attitudes, and emotions (affective) (Ruohotie & Koiranen, 2000).

In this dissertation, I understand competencies according to the above-described comprehensive interpretation, viewing the support for the development of personality as an important purpose of higher education. This relates closely to acknowledging self-awareness as a key sustainability competency (Jaakkola et al., 2022) and as a fundamental underpinning of graduate agency for sustainability, which is particularly discussed in Article 5. In the appended five articles, the usage of the terminology has been mainly driven by the disciplinary focus of the publication platforms and the audience to whom the publications are targeted to. In doing so, the aim has also been to understand the development and performance of competencies and the different terminologies from many disciplinary perspectives. However, the usage of the terms *competency* and *competence* varies in the Articles 1, 2, 4, and 5, illustrating the learning curve of the author during the research process: the Articles 1, 2, and 4 mainly reproduce the usage of the concept in the referenced scientific literature: *competence* dominates and is also applied in a plural form *competences* unlike in the more recent Article 5[1]. The Article 4 applies both *competence* and *competency*, partly because of the referenced literature but also because the authors had insufficient comprehension of the two concepts by the time the paper was written. Therefore, the Article 4 also works as a showcase of what Shephard et al. (2019) meant by the inconsistent use of terminology. Finally, the Article 5 applies the term *competency* consistently, resulting from the wider comprehension achieved by the author along the research process - particularly while collaborating with Noora Jaakkola and other colleagues around the research article Jaakkola et al. (2022).

To conclude, the five articles of this dissertation mainly apply the terms *competency* and *competence* to refer to a wide combination of skills, knowledge, and mindsets, and *skill* when referring to more specific, often cognitive, and metacognitive abilities. *Substance knowledge* in this dissertation refers to the core technical expertise and the most relevant contextual knowledge provided by engineering education and *personal ability* is used to describe the personality- and self-awareness related, affective and conative capabilities that have a particular relevance in graduate agency.

[1]The plural form of competence is contradictory. According to some dictionaries, such as the American English Merriam-Webster, *competence* has no plural, while *competency* has (competencies). This was also the feedback received from the linguistic review of the manuscript of Jaakkola et al. (2022), which influenced the way the term was applied in the Article 5, and in this dissertation. However, the Oxford dictionary recognizes a plural form for *competence* (competences), as well as the Cambridge English Corpus, which draws from how the language is used in practice. *Competences* is also commonly used in international English, for example in the European Union.

2.2 Research context and key study fields

This section includes five subsections that create a comprehensive picture of the background and previous research underlying the focus of this dissertation. The first two subsections build the basis by describing the role of higher education in the global and European sustainability agenda and how the term sustainability education has been evolving and conceptualized. The three latter subsections comprise the relevant research background for understanding the context of the research questions: the Subsection 2.2.3 defines sustainability in higher education as a research field and describes the central aspects that need to be considered when integrating sustainability in education, the Subsection 2.2.4 presents how engineering education has responded to the global sustainability agenda and finally, the Subsection 2.2.5 creates a picture of the transition phase of graduates from higher education to fulltime working life.

2.2.1 Higher education and the global sustainability agenda

Education has been acknowledged having a central role in environmental protection already since the first United Nations (UN) Environmental Programme (UNEP) conference in Stockholm in 1972 (UNEP, 1972). Thereafter, all the UN World summits on sustainable development (WSSD), starting from the Rio de Janeiro summit in 1992, have highlighted education as one of the key measures to advance sustainability. In the Johannesburg Rio+10 summit in 2002, education was the main theme and paved the way for launching the UN Decade for Education for Sustainable Development (DESD) 2005-2014 (UNESCO, 2006). After the Rio+20 summit in 2012, the process of promoting education for sustainable development (ESD) continued through the Global Action Programme (GAP) launch in 2014 (UNESCO, 2014), which highlights collaborative actions, institutional approach to sustainability education, and increasing the capacity of educators to empower the youth. Quality education is also one of the goals (Goal 4) of the Agenda 2030, with the SDG target 4.7. particularly highlighting ESD: “all learners acquire the knowledge and skills needed to promote sustainable development” (United Nations, 2015).

Apart from the global agenda, sustainability is strongly emphasized in the European education policy, including higher education (HE). For example, the European strategy concerning HE highlights the role of universities in pursuing a whole institution approach in integrating sustainability and in promoting the competencies needed for the green transition (European Council, 2022). The most recent contribution to promote such competencies as a policy objective in all European education is the GreenComp framework (Bianchi et al., 2022), which has a special emphasis on collective action for environmental sustainability. In addition, the key actor driving quality in education, the European Association for Quality Assurance in Higher Education (ENQA) has recently published the ENQA Strategic Plan for 2021-2025, in which social responsibility is one of ENQA’s four key values. Under the values, it is stated that ENQA “promotes social responsibility in quality assurance and its contribution to UN SDGs” (ENQA, 2020, 2). The Nordic countries are also renowned for their

sustainability endeavors (Nordic Council of Ministers, 2019) and for example in Sweden, the higher education act requires integrating sustainability in the education.

During the past two decades, sustainability has emerged as one of the key agendas of higher education actors themselves. The strengthening emphasis towards sustainability in the higher education institutions (HEIs) is indicated by the numerous signed commitments (Calder & Clugston, 2004; Lozano et al., 2013; SDG Accord, 2019) and by the increasing amount of scientific literature discussing sustainability integration in higher education (Lozano et al., 2015). Particularly the UN Rio+20 summit intensified the joint actions of the HEIs worldwide, as a higher education sustainability initiative was established (HESI, 2012). The HESI declared the signatories to commit to integrating sustainability in the campus operations, research, teaching, and outreach and currently among the over 650 signatories, 17 Nordic HEIs are represented (in July 2023; at the time of the questionnaire survey of this dissertation, in 2014, the number was 12). In Finland, the rectors of universities and universities of applied sciences even announced their joint programmes for sustainability education in autumn 2020 (UNIFI, 2020; ARENE, 2020).

This dissertation has utilized the conceptualizations stemming from this global HE agenda. Two of the appended studies (Articles 1 & 2) have a strong connection to the UN led global process through a Nordic development project 'Rio+20 in the Nordic HEIs'. The project and how it influenced the research design are described in more detail in the Section 3.

2.2.2 The varying conceptualizations of sustainability education

While the previous subsection described the role of higher education in contributing to the global sustainability agenda, this subsection describes how the concept of sustainability education has been evolving during the two past decades.

A continuum can be recognized in the development considering the global environmental and sustainability challenges in education. This continuum can be seen to have its beginning in the environmental education movement, which started after the UNESCO Intergovernmental Conference on Environmental Education in Tbilisi in 1977 and gradually widened to include a more comprehensive sustainability emphasis after the Brundtland report (WCED, 1987). Recently, Acosta Castellanos and Queiruga-Dios (2022) suggested that the UN DESD also shifted the emphasis of research from environmental education towards embracing education for sustainable development (ESD). Currently, several terms are used to describe education that aims to promote sustainability, including ESD, sustainability or sustainable education (SE), and education for sustainability (EfS). In addition, many closely related concepts are sometimes discussed under the umbrella of sustainability education, such as the aforementioned environmental education, global education, climate education, and multicultural education. In the context of universities, sustainability in higher education (SHE), and higher education for sustainable development (HESD) are commonly used terms, also used as synonyms. SHE, however, is particularly common in the U.S., where the nation-wide network for HE is called the

Association for the Advancement of Sustainability in Higher Education (AASHE), while in Europe, ESD appears to be more commonly used.

The different 'sustainability educations' described above are not only a matter of terminology, but they also reflect how the purpose of education is comprehended. Stephen Sterling discusses this thoroughly in proposing a concept of *sustainable education* (Sterling, 2001), in which he argues that a plain transmission of information reflects instrumental values and a vocational function of education. In the case of sustainability, Sterling defines this as an add-on education *about* sustainability, which becomes manifested in adding certain important aspects, such as biodiversity or equity, into education as separate entities. A more integrative approach that Sterling argues also being instrumental, is the built-in education *for* sustainability, which includes a presumption of a certain desired direction of education, a better society, towards which the education strives for. This socialization function of education, according to Sterling, only succeeds to promote efficiency and effectiveness, as it aims at accommodating the educational system to a changed environment (doing things better) instead of trying to see things from a new consciousness (doing better things).

The conclusion Sterling makes is a combination of liberal and transformative functions (or roles) of education in the form of sustainable education, or education *as* sustainability. This role of education considers both, the instrumental (what education is for) and intrinsic values (what education is) of education and requires a new participatory epistemology acknowledging that the ownership of education is democratic rather than directed by corporations or governments (Sterling, 2001). This has implications on teaching, as encouraging learners to take ownership on their learning requires meaningful and engaging education in contrast to passive and transmissive orientation. Views similar to Sterling's on the need for a paradigm change, institutional approach, and meaningful teaching of sustainability can be identified in research concerning the integration of sustainability in HE (e.g., McMillin & Dyball, 2009; Weiss et al., 2021b; Holdsworth & Sandri, 2021) and in engineering education (e.g., Kolmos et al., 2016; Mulder, 2017), which are discussed in more detail in the Subsections 2.2.3 and 2.2.4.

In this dissertation, while leaning on the thinking of Stephen Sterling, I use the term *sustainability education* instead of sustainable education, as it is more common in the Finnish discourse (kestävyyskasvatus), and it lacks the connotation of sustainable as lasting or durable. Sustainability education is thus defined here as education that has an intrinsic value, shared ownership, and a purpose of supporting personal growth, but that does include an instrumental strive towards safeguarding the planetary and socio-cultural boundaries (Rockström et al., 2023). However, the approach adopted in the appended articles of this dissertation can be considered mostly practical, seconding the views of Stevenson (2006), who argues that the problem is with the implementation of the aims of all the above-described 'educations' rather than with the definitions. In the context of engineering education, it must be noted that the educator community promoting sustainability started to use a concept of Engineering Education for Sustainable Development (EESD) in 2002, after which the term has been

established in the subsequent research (see Subsection 2.2.4). However, to be consistent with the terminology in this dissertation, I rather call this branch of research Sustainability in Engineering Education SEE (see also Figure 1).

2.2.3 Sustainability in higher education as a research field

As a field of research, sustainability in higher education (SHE) is defined by a relatively high number of descriptive and case studies (Barth & Rieckmann, 2016; Weiss & Barth, 2019). Relatively few articles aim at forming a wider view of the field or finding global patterns in sustainability integration (Barth & Rieckmann, 2016; Weiss & Barth, 2019; Weiss et al., 2021b), creating conceptual or theoretical frameworks (e.g., Wiek et al., 2011; Holdsworth & Sandri, 2021), or addressing the challenges that the terminological and conceptual variety existing in the research field might cause (Sterling et al., 2017; Shephard et al., 2019). In addition, the emerging nature of the research field might lead to scholars selecting different publication strategies (Barth & Rieckmann, 2016). These strategies, according to Barth and Rieckmann (2016), can be divided in two, from which the first one would be publishing in dedicated special issues that emphasize SHE approach or in new journals, thus committing to a new community. Another option is to link sustainability perspectives to an established disciplinary tradition, such as engineering education, and publish in traditional, disciplinary journals. The latter strategy mainly serves the disciplinary audience by respecting disciplinary perspectives, while it could also take a role of an 'icebreaker' within the discipline through driving a stronger SHE emphasis (Barth & Rieckmann, 2016). This dissertation, through drawing from and contributing to both the field of SHE and engineering education, aims to build bridges between these two fields of research to provide a view that exceeds the disciplinary traditions.

In addition, as "sustainability integration" is discussed in many levels in the field of SHE and in this dissertation, the next paragraphs describe how the integration is addressed in the research concerning these levels, namely institutional integration, curriculum development, and teaching sustainability in practice. However, the concept linking all these levels, the *whole university approach* is first defined.

Whole institution approaches (WIAs) is a notion used for all approaches in sustainability education that aim at a holistic commitment to sustainability in all organizational practices. The term WIA is used in many forms (Holst, 2023) and it includes for example the concepts whole university approach (McMillin & Dyball, 2009), and whole school approach, which is common particularly in in environmental education and ESD in schools (see e.g., Hargreaves, 2008; Mogren et al., 2019) and also adopted to the European education policy[2]. Very recently, Jorrit Holst (2023) characterized the WIAs as having coherence, continuous learning, participation, responsibility, and long-term commitment to sustainability and defined the approaches to particularly emphasize informal

[2] https://education.ec.europa.eu/sites/default/files/2022-02/input-paper-whole-school-approach-sustainability.pdf.

learning processes ("shadow", "hidden", or "living" curriculum). In practice, the WIAs imply that the organizations manifest their commitment to sustainability in all operations and engage the students in their organizational sustainability endeavors through the education.

The *whole university approach* follows the characteristics of the other WIAs. However, it has a narrower focus specifically on tertiary education and is therefore used as the key concept of this thesis. The concept can be seen to follow and implement the principles of the Talloires declaration, a ten-point action plan to promote institutional sustainability integration in higher education (ULSF, 1990). Therefore, the concept emphasizes what a deep and holistic commitment to sustainability means in the context of all university operations: campus operations, research, teaching, and outreach (Cortese, 2003). Similarly to the other WIAs, the overarching idea of the whole university approach is that in addition to the formal curriculum, the educational environment has a substantial effect on the sustainability-related mindsets of students and thus, learning (Orr, 1992; Rohwedder, 2004). Followingly, the teaching practices employed ideally engage students in the sustainable campus operations in order to help them perceive sustainability as a tangible instead of an abstract concept and to give them practical experiences of how sustainability can be managed and applied in the daily actions (McMillin & Dyball, 2009; Kohl et al., 2022). Moreover, through utilizing the campus as a living lab for experimenting and learning, the institution explicitly connects academia to campus operations, which are often seen as irrelevant for curriculum or research (McMillin & Dyball, 2009). Such holistic commitment and collaboration between the different university operations promotes knowledge sharing and benefits the sustainability endeavors of the whole institution, including leadership and policies (Kohl et al., 2022).

Serving the community as a key mission of universities is additionally emphasized in the whole university approach (Kohl et al., 2022). Cortese (2003) particularly advocated for a clear connection between theory and practice in integrating sustainability in universities and strongly emphasized the meaning of both internal and external joint learning for sustainability, consistent with Orr's learning organization (Orr, 2002). Cortese (2003) further argued that the joint internal efforts of a university (decision-makers, operative personnel, faculty, and students) and active stakeholder collaboration (alumni, nearby communities, funders, employers, accreditation organizations) around sustainability would better prepare the students for careers and citizenship. This view can clearly be seen also in the higher education declaration discussed in the Subsection 2.2.2 (HESI, 2012).

Curriculum development is tightly connected to the institutional support structures and commitment to sustainability. For example, Kolmos et al. (2016), applied Sterling's three approaches (add-on, built-in, and redesign) in proposing add-on, integrative and transformative curriculum change strategies in engineering, with increasing institutional levels of coordination, commitment to drive change, and to shared values and identity, respectively. In addition, Weiss et al. (2021b) recently conducted a comprehensive review of curriculum change that considers the integration of sustainability holistically and has many

similarities with the whole university approach and the thinking of Cortese (2003). The concluding model of Weiss et al. (2021b) consists of five interconnected aspects: 1) the impetus of change, including motivation and initiative for a change; 2) type of integration from disciplinary to inter- and transdisciplinary perspectives; 3) stages and dynamics considering collaborative efforts within the programme and the institution, but also with stakeholders; 4) depth of integration consisting of the add-on, built-in and transformative approaches (referring to Sterling), and 5) institutional drivers and barriers, which often relate to support from the leadership, and support provided for teachers (teacher training) and students in the change process.

The practical applications of how to integrate sustainability in teaching can be seen to form a continuum from the 2000s to present. The scholars first started to pay particular attention to how the varying aspects of sustainability - the different dimensions and basic sustainability literacy, practical tools, and the matter of values and attitudes – could be embedded in the learning outcomes of courses and programmes (e.g., Sipos et al., 2008), and which competencies would be needed from the graduates to promote more sustainable ways of acting and being in this world (de Haan, 2006; Barth et al., 2007; Rieckmann, 2012). Sipos et al. (2008), for example, proposed a head, hands, and heart approach in the learning outcomes, emphasizing the interplay and need for engaging knowledge, practical skills, and values education in the learning outcomes. One of the first sustainability competencies -related proposals was the shaping competency by de Haan in 2006, which was followed by many others in the field of SHE (Barth et al., 2007) as well as in disciplinary contexts, such as engineering (Svanström et al., 2008; Segalàs et al., 2009).

The key competency framework by Wiek et al. (2011) finally became the main point of reference for subsequent research on sustainability competencies, as it provided a conceptualization instead of providing just another 'laundry list' of important competencies. The conceptual framework consists of five key competencies: systems thinking, strategic thinking, anticipatory thinking, normative thinking, and the interpersonal competencies. This work paved the way for applying the concept of key competencies for sustainability: UNESCO (2017) has suggested eight key competencies for learning for the SDGs, while the OECD published a new competency framework (Learning Compass for 2030) with a strong emphasis on sustainability and transformation (OECD, 2019) and the European Union has its own GreenComp framework of four competency clusters (Bianchi et al., 2022), as mentioned already in the Subsection 2.2.1. These three frameworks also have a strong emphasis on the affective domain of learning as a self-awareness competency (UNESCO, 2017) and on both individual and collaborative agency (OECD, 2019; Bianchi et al., 2022). However, unlike the Wiek et al. (2011) framework, which is a scientific contribution and designed specifically for educating sustainability experts, the other mentioned frameworks represent applications of scientific literature and are meant to be utilized as common guidelines for all educators to develop sustainability competencies of the learners.

This dissertation mainly focuses on scientific contributions concerning higher education when discussing the key competencies to have a coherent reference point for objective explorations around a value-laden topic. For example, the European GreenComp framework (Bianchi et al., 2022), although having many merits in its research-based methodology, aims, and content, partly predefines, which values and behaviors should be achieved through the education. This is contradictory to what has been described as the aims of values- and sustainability education: through operationalizing learning outcomes that promote critical thinking, understanding of different values and perspectives, and reflection (Wiek et al., 2016), the students ought to be guided to develop their *own dispositions* (Shephard & Egan, 2018).

The key sustainability frameworks have been applied and further developed by many scholars. Recently, intrapersonal/self-awareness and implementation competencies were suggested to be added to the Wiek et al. (2011) framework (Brundiers et al., 2021; Redman & Wiek, 2021). It has been further suggested that if the self-awareness competency would be included as a part of the framework, if would shift the framework more towards emphasizing the personal sphere of the learners (Jaakkola et al., 2022), implying that the framework would then manifest education with a deeper purpose than only the production of skilled workforce with necessary competencies (outcomes-based, instrumental education). The original framework has a more cognitive-oriented focus, concentrating on what and how to teach to ensure that the graduates can tackle complex sustainability problems in varying circumstances and environments. It has also been criticized for neglecting the development of wisdom and the ability to judge in emphasizing heavily the mechanistic problem-solving (Anderson, 2013).

The Wiek et al. (2011) framework has additionally been operationalized to learning outcomes (Wiek et al., 2016) and several studies have been published on how the different key sustainability competencies can be applied in pedagogical and didactic strategies (Lozano et al., 2017; Tejedor et al., 2019a). Lozano and colleagues (2017), for example, conclude that problem-based and situated learning, visioning, concept mapping, and active and reflective teaching methods promote the development of multiple key sustainability competencies. These approaches are supported also by other scholars (Tejedor et al., 2019a; Holdsworth & Sandri, 2021). Recent research has paid particular attention to contextualizing sustainability in teaching, which Sterling mentioned being essential for sustainable education already two decades ago (Sterling, 2001). Sandri (2020) emphasized that establishing a connection between the discipline and sustainability through providing a 'point of entry' for the students in disciplinary contexts would promote graduate abilities to apply sustainability in their future professions. In addition to the pedagogical approaches, the competency framework of Wiek et al. (2011) has been investigated in the context of assessment (Redman et al., 2021) and the UNESCO (2017) framework in varying disciplinary settings, including engineering (Rosén et al, 2019; Beagon et al., 2022). A few studies also address how to measure graduate performance of the key competencies (Holdsworth et al., 2019b; Thomas et al., 2020).

Finally, crucial aspects in sustainability education are the values-related motivational factors, desires, and positionality, addressed by the normative competency of Wiek et al. (2011), and the more recent self-awareness/intrapersonal competency (UNESCO, 2017; Brundiers et al., 2021; Jaakkola et al., 2022). In values-education, Shephard and Egan (2018) underline the importance of providing possibilities for the students to create their own dispositions by carefully considering how different values and perspectives are discussed in the classroom. Other scholars have suggested reflective practices, even mindfulness (Wamsler, 2019), and art-based practices (see Jaakkola et al., 2022) to promote the identification of own dispositions and way of being in the world. Sterling (2011) connects the transformation required in educational system and institutions (doing better things) also to personal transformations (seeing things differently), which touches upon the personal paradigms and worldviews through critical self-reflection, a common approach of transformative education (Mezirow, 1994). Also other scholars have identified the need for transformative or even a transgressive approach (Lotz-Sisitka et al., 2015) in education as necessary in striving towards a societal transformation (Macintyre et al., 2018). However, such a fundamental change may cause anxiety or other emotional reactions (Jaakkola et al., 2022) and can be challenging for all associated actors (Sterling, 2011).

Considering all the levels of integrating sustainability in education and the different perspectives on the pedagogical practices discussed above, it is clear that sustainability education requires special attention from the educational institutions. Moreover, successful and effective integration requires awareness and motivation from the educators to promote such graduate abilities that enable them to catalyze a societal transformation.

2.2.4 Sustainability in engineering education

Engineering education community has discussed the challenge to integrate sustainability for at least two decades (Perdan et al., 2000; Azapagic et al., 2005; Barcelona declaration, 2004; Segálas et al., 2012, Mulder et al., 2012; Mulder, 2017; Rosén et al., 2019; Gutierrez-Bucheli et al., 2022). However, in searching for best ways to educate future engineers, the historical patterns that have shaped the current engineering programmes need to be acknowledged and understood. This subsection thus first creates a general picture of the drivers and history of engineering education, then describes how the community of engineering education for sustainable development (EESD) started to forward the sustainability agenda, and finally, presents the current situation of sustainability integration in engineering education and the drivers through which the integration work is advanced.

The role of engineers has first and foremost been practical problem-solving and creating technical innovations for the benefit of the society. Thereby, engineering education has traditionally been characterized by the same practice-orientation, emphasizing technical competencies, skills for solving problems, and a high level of working life relevance. Jamison et al. (2011) define engineering education being driven by mainly three challenges, technoscientific, societal,

and sustainability, which produce various response strategies. According to Jamison et al. (2011), the dominating strategy is a market-driven transdisciplinary approach, which connects engineering to entrepreneurship, business, and competitiveness and results in emphasizing external needs over traditional qualities and criteria of scientific work. Another response has been a contextualization of the engineering science, embracing cross-disciplinary collaboration and engagement. Case (2017) draws, through a comprehensive historical review, a similar picture of a tension between engineering practice (employers) and the scientific approach (academics). The tension has it roots in the historical development of engineering education that only gradually started to receive a university status in the early 1900's, after being an apprenticeship and learning-by-doing type of education for centuries (Case, 2017). As Case (2017) describes this search for legitimacy of the education in the eyes of the educational institutions and the employers creates constant struggle in the engineering programmes. Kolmos and her colleagues (2016) call these different approaches to education as employability and sustainability agendas, while strongly advocating for a transformative change in engineering curricula toward the sustainability agenda. Jamison et al. (2014), however, proposed a *hybrid approach* for engineering education to answer both the market-driven and a more comprehensive, contextual approach in engineering education to create interaction between engineering science and practice.

In the context of sustainability challenges, it has become clear that also engineers need to participate more actively in defining the central challenges of the society and change the paradigm of the education; instead of seeing sustainability as something additional in the curricula, the field ought to think how it can contribute to a more sustainable future (Mulder et al., 2012; Mulder, 2017). The discussion of how the education ought to change emerged on the engineering education agenda already in the late 1990s, along with the United Nations sustainable development agenda. In 2002, the first EESD conference was organized and already in the second conference in 2004, the community published a declaration (Barcelona Declaration, 2004) stating that the world needs new kind of engineers to respond to the global challenges. The Barcelona Declaration (2004) defined a future engineer to be capable of connecting own work to societal challenges, to be societally aware and active and to have competencies for multicultural and inter- and transdisciplinary teamwork in varying societal and cultural contexts. Further, it was declared that the education needs to review the competencies being taught to integrate the appropriate knowledge, skills, attitudes, and values to the teaching through selecting suitable teaching strategies and methods. Having a holistic and highly ambitious view on engineering education, the Barcelona declaration also requested for training the trainers and for taking an institutional approach to implement a paradigm change towards sustainability as the key mission of the universities, thus reflecting similar emphasis on institutional change than Stephen Sterling (2001) and Anthony Cortese (2003) in the SHE discourse (see Subsections 2.2.2 and 2.2.3).

The requests of the Barcelona Declaration (2004) have been intensively studied by the scholars engaged in sustainability in engineering education (SEE).

Recently, particularly studies on institutional integration and policies relating to sustainability, as well as on innovative learning strategies and professional development of teachers have been increasing (Tejedor et al., 2019b). However, many of the studies conducted discuss the needed sustainability competencies and teaching strategies for developing them (see Segalàs et al., 2012). For example, inter- and transdisciplinary and collaborative competencies are generally among the most frequently mentioned competencies in the SEE research (Quelhas et al 2019; Ortiz-Marcos et al., 2020). Overall, most of the competencies suggested as crucial for future engineers to contribute to sustainability are in line with the key sustainability competencies (Wiek et al., 2011), emphasizing particularly the problem-solving competency (Rosén et al., 2019). However, apart from just widely understanding current phenomena and creating sustainable solutions, a view that highlights the importance of engineering actors in the society has become more common; engineers ought to be active players and have agency in their working communities and in the society (Svanström et al., 2008; Mulder, 2017; Quelhas et al., 2019; Ortiz-Marcos et al., 2020). Moreover, scholars have requested engineers to better understand the long-term impacts of their decisions and those of technological development (Mulder, 2017; Ortiz-Marcos et al., 2020).

Sustainability could also be driven top-down to engineering education through quality assurance and accreditation. However, Janssens et al. (2022) argued that sustainability has so far been less emphasized in the accreditation criteria. For example, the engineering-specific, European EUR-ACE accreditation standard has a relatively vague list of required learning outcomes, stating that the students ought to "understand the multidisciplinary and the non-technical context or constraints of engineering solutions (societal, health and safety, environmental, economic and industrial)". For the master's level the EUR-ACE emphasizes a more comprehensive understanding of the field and its contexts, ability to apply and create new solutions, a deeper level of independence in responsible decision-making and in engaging in lifelong learning, and a more critical awareness of the forefront in their branch. Similar observations were made by Byrne (2023) who showed that the EUR-ACE has very few mentions of sustainability or sustainable development and for example transdisciplinarity is totally absent in the accreditation criteria. However, he also noted that national criteria might be more comprehensive in addressing sustainability, as was the case with Ireland and Australia in his study (Byrne, 2023).

Apart from research and external steering, engineering educators have established ways to develop engineering programmes and teaching in practice. The most prominent framework is the international CDIO (conceive, design, implement, operate), which is an open platform, continuously developed by the worldwide engineering education community (Taajamaa et al., 2016). The CDIO framework is connected to the more formal EUR-ACE label by supporting the same activities that are evaluated for the official accreditation. However, the CDIO community has a more ambitious goal compared to the accrediting actors to embed sustainability explicitly and comprehensively to respond to the rapidly changing world (e.g., Malmqvist et al., 2019). Already the Syllabus version 1.0

of the CDIO - the goals defined for engineering education - included a comprehensive list of societal contexts -related outcomes and emphasized the role of engineers in the society. The revised Syllabus 2.0 brought sustainability explicitly in the learning outcomes by adding responsibility for the environment in the list, as well as "sustainability and the need for sustainable development".

The Syllabus 2.0 is actively being developed further to 3.0 (Malmqvist et al., 2022). For example, the current sustainability content of the Syllabus has been suggested to better align with the UNESCO (2017) sustainability key competencies and to include a basic sustainability knowledge base (Rosén et al., 2019). Moreover, the CDIO Standards - the 12 principles of effective practice - were suggested to be revised to explicitly address sustainability (Malmqvist et al., 2019), which led to including sustainable development as a novel Optional standard of the CDIO (Malmqvist et al., 2020). The Optional standard provides a description, rationale, and a self-evaluation rubric for "*A program that identifies the ability to contribute to a sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address sustainability challenges*"[3].

In Europe, Société Européenne pour la Formation des Ingénieurs (SEFI) has been an important platform and channel to negotiate, develop and direct European engineering curricula (see e.g., Augusti, 2007, Case, 2017). SEFI has recently put more emphasis on sustainability for example by dedicating the annual SEFI conferences to sustainability in 2017 and 2023 and by establishing a SEFI working group for sustainability. In the Finnish higher engineering education, the integration of sustainability has been on the joint agenda after 2009, when the National Collaboration Group for Finnish Engineering Education published a proposal for actions needed to realize a mission of an education for the benefit of people and the planet (see Takala & Korhonen-Yrjänheikki, 2013). According to a follow-up of this action plan, the fourteen HEIs[4] providing engineering education in Finland are committed to promote sustainability (Takala & Korhonen-Yrjänheikki, 2019). However, Takala and Korhonen-Yrjänheikki (2019) concluded that the strong commitments in the strategic level are yet to be implemented in the education. In addition, they saw that the prevailing paradigm of the Finnish engineering education is technocratic (Takala & Korhonen-Yrjänheikki, 2019), echoing Gutierrez-Bucheli et al. (2022) who argued that a similar paradigm prevails in engineering education in general. At the same time, the Finnish engineering education is very sensitive to the requests from the society (Korhola-Yrjänheikki, 2011) and has been argued to lack a thorough discussion on the philosophical grounds of the education (Naukkarinen, 2015).

To summarize, it seems that engineering education aims to integrate sustainability thoroughly in the education to ensure that future engineers have the necessary competencies for taking an active role in promoting sustainability in the society. Particularly the community of educators is active and committed to

[3] In CDIO webpage: www.cdio.org/content/cdio-optional-standards-30

[4] Includes seven universities and seven universities of applied sciences

develop the teaching. However, efforts are still needed to integrate sustainability in the education in practice and to find consensus on the philosophical grounds and ultimate purpose of engineering education (Jamison et al., 2011; Naukkarinen, 2015; Case, 2017; Mulder, 2017).

2.2.5 Transitioning from higher education to the working life

Recent graduates can be important actors in the sustainability transformation, mediators of new beneficial practices in workplaces, and contribute to more efficient implementation of the SDGs (Wiek et al., 2011; Trevelyan, 2019). However, the research on the transition phase from education to the working life provides evidence on many factors that may restrict the graduates from taking the desired initiatives, including a contextual gap between engineering education and working life, as well as workplace support. The following paragraphs shortly review these approaches and thereby facilitate understanding one of the key topics of this dissertation, the role and agency of engineering graduates in promoting sustainability in the early career.

The transition phase from the education to fulltime working life is often nothing but straightforward (Trevelyan, 2019; Korte et al., 2015; Baytiyeh and Naja, 2012). Despite these challenges are relatively well acknowledged in the field of engineering (see e.g., Lutz & Paretti, 2021), the transition phase has received surprisingly little attention in research (Korte et al., 2015; Stevens et al., 2014). While the early career workplace learning is partly technical and competency related (e.g., Paretti et al., 2017), Stevens and colleagues (2014) argue that the focus on this so-called competency gap and associated educational adjustments neglects the impact of a contextual change that the graduates experience. For example, Korte et al. (2015) noticed that a gap exists between the expectations of employers and graduates on how the graduates ought to take on their new tasks in a new environment. Gaps are reported also relating to the time span and comprehensiveness of projects between the education and professional environments (Trevelyan, 2019), and on navigating and communicating in the social environments of student peers and the new expert colleagues (Lutz & Paretti, 2021).

Adjusting to these new cultural and social contexts requires time and efforts from the graduates. In the workplaces, available assistance from colleagues has been suggested as central for supporting the growth and performance of the graduates (Egri & Herman, 2000; Holdsworth et al., 2019a, Sluss & Thompson, 2012; Brown & Bimrose, 2018). Despite the young generation is generally eager to learn, the young professionals have been noticed to expect more mentoring and attention from their managers compared to the earlier generations (Magni & Manzoni, 2020), as well as recognition from their peers and colleagues to strengthen their professional self-efficacy and perception of own expertise (Brown & Bimrose, 2018).

Against these viewpoints and challenges relating to the transition phase, it becomes clear how significant role the workplaces and co-workers can play in how the early career of the graduates unfolds. Similar challenges, such as gaps in expectations and expertise, might exist also in relation to the sustainability

contributions of the graduates. This implies that the workplaces ought to acknowledge the impact they have on the graduate performance and provide support not only for adjusting to a new environment, but also for the sustainability agency of the graduates.

2.3 The research gaps

The previous section created an overall picture of the three key research topics of this dissertation, namely sustainability in higher education, its connection to engineering education, and the transition to the working life. Following, this section reviews the central research relating to the three research questions. In each of the following subsections, I first present the research question, then review the relevant previous research and the gap in the research, and end by describing how this dissertation contributes to the existing understanding.

2.3.1 University education supporting sustainability

RQ 1. How do universities support the possibilities of graduates to act for sustainability in the early career?

Previous research concerning the sustainability efforts of universities mainly discuss the different integration levels separately, the institutional and curriculum change, teaching practices, and the learning outcomes reflected by graduate performance. This pattern in the research widely reflects the compartmentalized way the universities implement sustainability (Lozano et al., 2015). In the following, I justify why it is it is essential to take an overall look from the institutional level to graduate agency to understand how the universities support graduate abilities to act for sustainability. While the research question considers graduates in general, this dissertation has a special emphasis on engineering graduates.

Studies discussing the institutional level of integrating sustainability widely acknowledge the importance of the whole university approach to having effective sustainability education. The research mainly concerns the importance of institutional commitment in reaching a transformative institutional change (Sterling, 2001; Cortese, 2003; McMillin & Dyball, 2009; Kohl et al., 2022). In the whole university approach, existing research underlines the importance of committing to promote sustainability through all university operations, including campus, research, education, and outreach activities (McMillin & Dyball, 2009). Similar approach has been strongly advocated for being the key to successful curriculum change (Sterling & Thomas, 2006; Barth, 2013; Kolmos et al., 2016; Weiss et al., 2021a; 2021b), as it requires support and resources for designing the curriculum and courses, a high level of coordination and internal communication, and established connections to external actors, including alumni, employers, and other societal stakeholders of higher education (Sterling, 2001; Sterling & Thomas, 2006; Weiss et al., 2021a).

Institutional commitment is essential also in promoting sustainability integration in courses, as meaningful sustainability learning outcomes that are

effective in long-term have been suggested to require careful planning and design (Dvorak et al., 2010; Mintz & Tal, 2014). Moreover, regular course work has been shown to be insufficient in developing competencies that enable the implementation of sustainability in practice (Azapagic et al., 2005, Kagawa, 2007, Yavetz et al., 2009). Weiss et al. (2021a) particularly embraced the meaning of internal networks and professional development as a means to support sustainability integration in courses. The UN GAP (UNESCO, 2014) also highlighted the role of training the trainers in promoting sustainability education and the UN Economic Commission for Europe (UNECE) even proposed specific ESD competencies for the educators engaged in teaching sustainability (UNECE, 2011). Despite educator competencies have been acknowledged important also by recent research (Rieckmann, 2019; Vare et al., 2019; Leal Filho et al., 2021), many studies have indicated that the competencies, resources, and motivation of the teaching staff create a barrier for advancing sustainability through the courses (Borg et al., 2012; Thomas, 2016; Fiselier et al., 2018; Weiss et al., 2021a).

Recent studies in the field of engineering suggest that the education has so far succeeded to provide only limited competencies for the graduates to act for sustainability (Khoo et al., 2020; Chance et al., 2022). Khoo et al. (2020) showed that engineering graduates have limited knowledge of sustainability and the findings of Chance et al. (2022) indicate the graduates having difficulties in promoting sustainability in the workplaces. Therefore, apart from studying the institutional sustainability efforts, the teaching of sustainability or the longer-term effects of the provided education as separate topics, research that would link these levels is required.

The UNESCO (2016) strongly emphasizes considering also the national, local, and regional contexts in implementing sustainability integration. However, although the sustainability efforts and teaching of the higher education institutions (HEIs) have been studied in the global level, knowledge is lacking from regional levels (Weiss et al., 2021a). Yarime et al. (2010) noticed that research is particularly active in the Northern America, Europe, and Oceania, with Germany and Sweden emerging as the most active in Europe. Sweden differentiates from the other Nordic counties also by having had a higher education act since 2006 requiring that the universities promote sustainable development in their activities. The evaluation of the sustainability integration in all the Swedish HEIs was conducted around ten years later (Finnveden et al., 2020) indicating that the integration still lacks ambition particularly in sustainability-related target-setting and monitoring, and professional development of the teachers. Moreover, Swedish government agencies must have an environmental management system (EMS), which, according to Sammalisto (2007) has resulted in many universities having a certified EMS as well. Therefore, many of the Swedish studies discuss the effects of an EMS, leadership and strategy, and collaboration on sustainability integration (Sammalisto, 2007; Sammalisto & Brorson, 2008; Holmberg et al., 2012). Swedish scholars have also contributed to promoting sustainability in engineering education through studying the sustainability-promoting learning outcomes and competencies (Svanström et al.,

2008) and have led Nordic collaborative research efforts in developing the CDIO framework to include sustainability aspects (e.g., Malmqvist et al., 2019; Rosén et al., 2019). The Danish scholars in their part have been active in developing the engineering curricula (Kolmos et al., 2016) and the Finnish scholars have contributed to the field for example through studies on sustainability and quality assurance (Holm et al., 2014; 2015), and on sustainability integration and competencies (Takala & Korhonen-Yrjänheikki, 2013; Friman et al., 2018; Jaakkola et al., 2022). Despite the research contributions of the scholars from different Nordic countries, the development of the sustainability efforts of the Nordic HEIs as a region has remained unexplored.

To summarize, current research on the sustainability integration in the HEIs draws a picture of the benefits of applying the whole university approach to promote sustainability education and graduate abilities to implement sustainability in practice. The educators turn the institutional sustainability efforts to the actual learning outcomes of students, if provided with adequate support to design their courses and programmes. Despite this, many universities have been noticed to emphasize campus operations over the education in their integration efforts (Wals, 2014; Ramos et al., 2015), and the curriculum change strategies have mainly followed the add-on and built-in rather than transformative strategies (Weiss et al., 2021b). Therefore, to understand how to best improve graduate abilities to promote sustainability, it is essential to connect an overall view on the sustainability efforts of the HEIs to the long-term effect of the provided education.

This dissertation provides new knowledge on the institutional level sustainability contributions of the Nordic universities[5], thus providing one lacking regional approach to the current research. In addition, this dissertation creates an overall picture of how the institutional efforts are reflected in practical coursework and further, in the sense of agency of engineering graduates in the early career. The findings provide a regional reference point for all the Nordic universities for mapping and developing their institutional support structures, particularly those that directly affect the teaching of sustainability. The findings facilitate focusing the development actions on different levels, institutional, curriculum, and teaching practices to create the best possible support for graduate sustainability agency.

2.3.2 Important competencies in the early career

RQ 2. What competencies are needed from engineering graduates in the early career and for contributing to sustainability?

Research on engineering education is abundant, particularly concerning the competencies needed in the working life, that is, the competencies associated with the employability approach. In addition, research on the necessary sustainability competencies and the role of engineers in contributing to sustainability

[5] The research included universities and universities of the applied sciences, however, as the engineering education part of this research only concerns one university, the context discussed hereafter is mainly universities instead of all the HEIs (see 3.2).

has been increasing during the past two decades, drawing also from the sustainability in higher education (SHE) research. This dissertation explores the relationship between the employability and sustainability competencies in the contemporary engineering education and practice. In the next paragraphs, I review what is currently known about the central competencies associated with these two approaches and describe how this dissertation aims to combine them.

Both undergraduate and professional engineers typically emphasize the necessity of having strong technical skills as the basis for being a good engineer (Passow & Passow, 2017; Brunhaver et al., 2018; Winberg et al., 2018). To complement the technical competency, particularly the practitioners acknowledge that the variety of engineering jobs and tasks requires also social skills, communication, and project management skills (Brunhaver et al., 2018). Teamwork, financial and business knowledge (Passow & Passow, 2017), as well as entrepreneurial abilities and personal abilities, including proactiveness, empathy, and ethical responsibility are also often referred to as important complementary skills for engineers (Korte et al., 2015; Khoo et al., 2020; Passow & Passow, 2017; Starrett, 2017). These competencies can be seen to form a typical, work life-driven graduate competency profile of engineers. In the field of water engineering, similar engineering expertise has been organized to a two-dimensional T-shaped competency profile, where the 'feet' of the T represent the technical and substance-specific core competencies, and the 'arms' the more generic competencies and understanding of the context (Uhlenbrook et al., 2012). Engineering education has widely acknowledged the need to develop both, the core technical skills, and the broader professional competencies through the careful and coordinated efforts put in designing the curricula (Winberg et al., 2018). However, connecting this approach further to sustainability is less common, despite a hybrid approach was suggested already a decade ago by Jamison et al. (2014).

In general, a wide convergence exists among the scholars of SHE on the important sustainability competencies (see Subsection 2.2.3). Of the key sustainability competencies, integrative problem-solving is of particular importance for engineers (Rosén et al., 2019). In addition, many other key sustainability competencies have been emphasized as important, including certain self-awareness-related competencies, such as self-knowledge (Quelhas et al., 2019), ethics (Thürer et al., 2018), and a proactive attitude (Beagon et al., 2022). The need for an interdisciplinary and holistic approach is also evident (Guerra, 2017; Quelhas et al., 2019). On the contrary, future-orientation has been reported to be lacking from students (Lambrechts et al., 2013) and perceived less important among engineering practitioners (Quelhas et al. 2019; Beagon et al., 2022), despite the ability to anticipate and vision the future was emphasized as important already in 2004 in the Barcelona declaration (Svanström et al., 2008). Apart from the specific competencies, many scholars have requested engineers to have agency for sustainability in the society (Svanström, 2008; Mulder, 2017; Quelhas et al., 2019; Ortiz-Marcos et al., 2020). Further, even a paradigm, transformative change has been requested from engineering education, echoing the views of Sterling (2001), to embrace sustainability as a part of engineering expertise instead of adding it as a complementary topic on top of the traditional

core engineering profile (Mulder, 2017; Gutierrez-Bucheli et al., 2022). However, also contrasting views exist, including that sustainability threatens the technical expertise of engineering graduates (Takala & Korhonen-Yrjänheikki, 2013), or that it is less relevant for the professional practice (Khoo et al., 2020).

In the context of the Finnish water and environmental engineering, which is the focus of this dissertation, graduate engineers are valued for the very similar competency profile described above: core technical expertise combined with abilities for holistic and interdisciplinary understanding (Heinonen & Takala, 2011; Salminen et al., 2015; Piri, 2022). Lundgren (2012) additionally noted that when working in an environmentally oriented field, future professionals need to have abilities for cross-disciplinary and -sectorial collaboration and understanding (Lundgren, 2012). The relevance of sustainability for working in an engineering field in Finland is apparent also in the light of the annual graduate surveys conducted by TEK (trade union for academic engineers and architects in Finland) (Piri, 2022).

To summarize, research is abundant in what competencies are valued and needed in general from the perspective of the employability approach. Similarly, a wide convergence exists among scholars of engineering education on the important sustainability competencies. However, studies that focus on the development of engineering education in practice hardly provide a combined view of the employability and sustainability approaches. There is additionally a shortage of research on what sustainability competencies the employers see important (Thürer et al., 2018). Moreover, the findings of Brunhaver et al. (2018) indicate that the relative importance of the different competencies changes along the early career, but research concerning these changes is scarce. Therefore, to understand what the graduate engineers currently need for employment and successful task performance (employability), and for being able to act for sustainability in the early career (sustainability), research that takes a combined approach and considers the employer views is needed.

This dissertation provides empirical evidence on how the relative importance of the different competencies changes from the employment to the early career stages and further combines this with explorations on which employability and sustainability competencies are important in the early career. The findings provide means to complement the current comprehension on the relevant graduate competency profile of engineers and specifically, the T-shaped profile of water engineers. Ultimately, the findings facilitate developing engineering education to consider such competencies that contribute to the working life needs, and to the need to accelerate societal sustainability transformation.

2.3.3 Graduates in the working life

RQ 3. What is the role of engineering graduates in their workplaces regarding the advancement of sustainability?

Current research in the field of sustainability in higher education (SHE) discusses widely, how the key sustainability competencies (Wiek et al., 2011) can be considered in the education (see Subsection 2.2.3). Studies during the past

decade include the operationalizing of the key competencies to related learning outcomes (Wiek et al., 2016), the most suitable teaching methods for supporting the development of the competencies (Lozano et al., 2017; Tejedor et al., 2019a), and how can the competencies be considered in assessing the learning outcomes (Redman et al., 2021). Despite the active research on integrating the sustainability key competencies in the education, research on graduate performance of the acquired competencies is only emerging.

The few existing studies on graduate performance focus on how to measure the applying of the competencies and pro-environmental behavior in the working life (Sandri et al., 2018; Holdsworth et al., 2019b; Thomas et al., 2020). These studies provide preliminary indications that the graduates feel lacking confidence, power, or possibilities to perform leadership for sustainability in their workplaces, even if being motivated to promote sustainability (Holdsworth et al., 2019a; Thomas et al., 2020). However, Holdsworth et al. (2019a) noticed that the perceptions of the graduates of their own sustainability competencies had relatively little impact on their observed performance. Instead, resources, workplace support and assistance, as well as the power associated with the position of the graduates have been identified affecting graduate sustainability contributions (Fernández-Manzanal et al., 2015; Holdsworth et al., 2019a) and in engineering (Chance et al., 2022). However, although these indications exist of the challenges faced by graduates in promoting sustainability, the research is strongly focused on the graduate views and on how to measure their performance. Therefore, more research would be needed to understand how the workplaces see the performance and role of graduates and their possibilities to contribute to sustainability.

Despite the lack of workplace perspectives to graduate sustainability contributions, some evidence exist on the perceptions of employers in engineering. The few existing studies indicate that the employers hold high expectations towards young engineers regarding their knowledge of sustainability (Hanning et al., 2012; Takala & Korhonen-Yrjänheikki, 2013). However, also contrasting views have recently emerged, indicating that the employers have yet to acknowledge sustainability as a relevant workplace competency (Khoo et al., 2020), and that workplaces may even be unsupportive of graduate sustainability actions (Chance et al., 2022). The general shortage of research on the graduate role in promoting sustainability in the early career workplaces together with these contradictory findings suggest that more research is needed to gain a clearer picture of how the graduate sustainability contributions are perceived and received in the working life, and what possibilities exist for the graduates to act for sustainability. Moreover, in the field of engineering, there is in general scarcity of research concerning the transition to the working life (Korte et al., 2015; Stevens et al., 2014).

This dissertation focuses on these research gaps through looking at the performance expected from the graduates, the possibilities of graduates to influence on sustainability, and to the factors affecting the influencing possibilities in the workplaces. The research includes the perceptions of both graduates and their employers, with the emphasis being more on the employer views. The

findings provide empirical evidence from the field of water and environmental engineering on how the sustainability competencies can be applied when transitioning to the working life. Further, the findings create a picture of the current role of engineering graduates in the early career workplaces in relation to sustainability and thus, facilitate developing both the educational and workplace practices that might contribute to how the graduates are able to accelerate the societal sustainability transformation.

3. Methodology

In this section, I first clarify the main premises and approach of this dissertation to the research topic. Then I describe the research process including the development projects, data collection and analysis methods applied, and how the trustworthiness of the research was ensured.

3.1 The premises and approach of the research

The main premises that directed the process and design of this dissertation were the relatively early stage of the research fields that the dissertation represents (Borrego & Bernhard, 2011; Barth & Rieckmann, 2016; Segalàs et al., 2018), and the practice-orientedness of the individual studies, as the research was conducted during two development projects. Moreover, although this dissertation can be considered as inter- or even transdisciplinary, it is rooted in educational sciences, as the key purpose is to develop university education. I first explain the main premises and philosophical underpinnings of the research and then describe the research approach.

This dissertation represents a multidisciplinary research field of sustainability in higher education (SHE) with a focus on its branch of sustainability in engineering education (SEE). As described in the Section 2, the field has been rapidly evolving during the two past decades, yet it may still be considered being in the early stages. In practice, this means that the notions and terminology used vary, and the studies published in the field are mostly case studies and draw from the respective case study disciplines and contexts. In this dissertation, the individual Articles 1-5 similarly draw from many disciplines, although establishing a firm connection to the key SHE and SEE literature. In the theoretical frameworks of the Articles 1-5, I combine literature representing engineering education research, curriculum research, educational psychology, university pedagogy, organization research, and career studies (Table 1). These disciplinary connections become illustrated in how I have defined the key concepts and terminology and discussed the results in the articles. The practice-orientedness of this dissertation created the initial motivation for the research and had an impact on the design of the appended articles. For example, the focus areas of the Nordic Sustainable Campus Network (NSCN) network, campus operations and education, were chosen as the key focus areas for the questionnaire designed for the Articles 1-2, thus excluding research and outreach activities.

As mentioned, the central purpose of this research is educational development, which is why the philosophical foundations were explored in this context. The following paragraphs describe these explorations and conclude the main philosophical approaches of this work.

In educational research, paraphrasing Atkins and Wallace (2012), the key driving force of the enquiry is teaching as a profession – to support learners in learning – whether through improving the system or the professional practice. Followingly, educational research is ultimately praxis-oriented and strongly human-centered, implying that the emphasis of research is more on interpretative than on positivist or deterministic paradigm (Cohen et al., 2011; Atkins & Wallace, 2012). Cohen and colleagues (2011) explain that an interpretative paradigm acknowledges that human behavior is not deterministic, but it includes individual interpretations, meaning-making, dynamic changes of situations (rather than static), and creativity in those situations, which results in reality being complex and multilayered. As this dissertation aims at understanding the complexity of what is happening in the transfer phase of the graduates, it could be considered as interpretative.

However, Heikkinen and colleagues (2005) describe that the reality of educational research rarely corresponds with only one philosophical approach but may simultaneously reflect one ontological approach with another type of epistemological philosophy. This is the case also with this dissertation: the research leans towards the interpretationist paradigm and constructivist-subjectivist epistemology, since the research participants are considered to strongly contribute to the social environment in which they operate (Cohen et al., 2011). At the same time, the dissertation presumes a certain reality in organizations and in graduate performance, which can be observed through semi-positivist means and developed to improve both education and graduate possibilities to act for sustainability. Therefore, following the landscape of educational sciences by Heikkinen and colleagues (2005), this dissertation is best placed to represent post-positivism - realism type of ontology and social constructivist -leaning epistemology.

While this dissertation builds mainly on the foundations described above, it also includes many elements of action research. According to Altrichter et al. (2002), action research is conducted *with* people instead of *on* people, and a typical action research cycle can be seen to consist of planning, acting, observing, and reflecting phases. From these standpoints the second research phase of this dissertation, which concerned the development of a specific master's programme (see Figure 2 and Subsection 3.2), corresponds to action research very well: the project aimed at monitoring and evaluating the impact and relevance of a curriculum renewal intervention that had been realized earlier. The evaluation was a collaborative effort, and the results were planned to be used to further improve the master's programme in question. Moreover, action research has been observed to improve the outcomes of a sustainability-related curriculum change process due to the increased sense of ownership of the participating actors (Benn & Dunphy, 2009), which further increases the suitability of action research as the foundation for this research. However, in addition to the specific

master's programme, this dissertation operated in a wider Nordic level in the first research phase (Figure 2). This first phase mainly focused on exploring the current stage of sustainability integration through a survey and it included a substantially lower level of collaboration and learning with the research participants compared to the second phase. Therefore, as participation and reflective, continuous, and joint learning are central elements of action research (Altrichter et al., 2002), it was not seen to be suitable as the foundation for the whole dissertation.

Apart from the philosophical underpinnings, the research approach of this dissertation is influenced by the novelty of the research topic. An exploratory approach with a strong emphasis on qualitative methods is typical of research topics that are only emerging and have been previously underexplored (Babbie, 2007). The aim of such research is to provide knowledge and initial interpretations, to gain deeper understanding and potential generalizations, and to advise future research (Stebbins, 2001). The exploratory emphasis of this dissertation is thus justified, as both the fields SHE and SEE and the topic of the dissertation represent emerging research areas. However, this dissertation also has elements of descriptive research, which can comprise of quantitative and qualitative approaches and of inductive and deductive reasoning (Casula et al., 2021). As Casula and colleagues (2021) write, descriptive research aims at utilizing existing literature in classifying the data or in creating initial categorizations from the data for example through employing quantitative surveys with open-ended, deepening questions. While the overall exploratory approach of this dissertation implies that the findings may not be primarily generalizable but directive, the descriptive approach connects the findings to the current understanding of the phenomenon, thus creating better possibilities for the findings to be useful also in other contexts.

Finally, it must be noted that this work has certain connections to critical education theory, which acknowledges ideological goals like democracy and power structures for the subsequent research (Cohen et al., 2011). As stated above, the purpose and motivation of this dissertation are strongly practice-oriented, and the dissertation discusses practical means to change or transform higher education and the institutions to better ensure a sustainable and just society. This could be interpreted as an ideological goal of research. However, as the aim of a sustainable and just society is based on scientific knowledge on the status of the biophysical planetary systems and our possibilities to thrive in this planetary situation (see 2.1.1.), I understand the goal being scientifically valid rather than ideological. Despite not being directly applicable with this research, critical theory can be consulted when elaborating on the possible means to influence on sustainability in higher education, as they may include ideological and political measures and touch upon the power structures that drive the curricula.

These premises explain and justify the chosen research methods of this dissertation described in the following subsection. The methods mainly aim at depth instead of breadth – in understanding better the studied phenomenon in its specific context rather than providing explanations or causalities of a reality

that is considered as highly dynamic, complex, and created by the people operating in it.

Table 1. Summary of the theoretical frameworks and theories, data sources, and data collection and analysis methods utilized in the five articles of this dissertation.

	Article 1	Article 2	Article 3	Article 4	Article 5
Disciplinary connections	Sustainability in higher education (SHE)	Sustainability in higher education (SHE)	University pedagogy; educational psychology; career studies; engineering education	Career studies, engineering education; SEE; SHE	SHE; career studies; engineering education; SEE; curriculum research
Theoretical frameworks and theories utilized	Whole university approach / institutional change	Whole university approach / institutional change	Socio-cognitive career theory; constructive alignment	Planned happenstance	Socio-cognitive career theory; integrative / transformative curriculum change
Research questions addressed	RQ 1	RQ 1	RQ 2; RQ 3	RQ 2; RQ 3	RQs 1-3
Data source	Staff members of Nordic HEIs	Teaching staff of Nordic HEIs	WAT graduates; teachers; students	WAT graduates	WAT employers
Data collection method	Questionnaire; Focus group workshops	Questionnaire	Questionnaires	Questionnaire; Semi-structured interviews	Questionnaire: Semi-structured interviews; Focus group workshops
Main data analysis methods	Descriptive statistics; data-driven content analysis	Descriptive statistics; data-driven content analysis	Descriptive statistics; data-driven content analysis	Descriptive statistics; general linear model GLM; data-driven content analysis	Descriptive statistics; data-driven content analysis

3.2 The development projects and research methods

The research process of this dissertation consisted of two subsequent phases that were related to two separate development projects (Figure 2). One of the main driving factors in determining the data collection methods used in the projects was the need to fulfil the twofold aim of this dissertation: to form a wide understanding of how the whole university approach to sustainability is realized in the Nordic HEIs and to provide insights for programme-level development on means that would support a catalyst role of the graduates. Therefore, the research process and data collection methods were designed to create a broad view that draws from a deeper understanding of a specific educational setting. This section briefly describes the two development projects, the respective research methods and ethical considerations related to the data collection and finally, the means to ensure the trustworthiness of the results.

The two first articles of this dissertation aimed at screening the current level of sustainability integration in the Nordic higher education institutions (HEIs) and at investigating, whether the HEIs implement a whole university approach to embedding sustainability in their operations (Articles 1 & 2). Data for this

research was collected during a wide Nordic project "Implementation of the Rio+20 in the Nordic Higher Education Institutions" (2014-2015), which was run by the Nordic Sustainable Campus Network (NSCN) and coordinated by the author. All the questionnaire results collected in the project were compiled into a comprehensive survey report (Karvinen et al., 2015). This dissertation only utilized the results concerning the integration of sustainability in campus operations and teaching (Article 1), and the whole university approach to sustainability in teaching (Article 2). In addition, to investigate how the approach of the Nordic HEIs to sustainability integration reflects to the learning outcomes of the graduates, findings from the research phase 2 (Articles 3-4) were utilized. As the Articles 3-4 concern only one university in Finland, the findings of this dissertation are discussed in the context of universities instead of all higher education institutions (which also include universities of the applied sciences).

The main method applied in the Articles 1-2 was survey research, which aimed at exploring the status of sustainability integration in the Nordic HEIs and to identify areas that potentially need to be developed. A questionnaire survey, which is commonly used in survey research (Cohen et al., 2011), was the main data collection method, while focus group workshops were utilized to complement the questionnaire and to improve the external validity of the research (Tobin & Begley, 2004; Cohen et al., 2011) (a detailed description of using the focus groups as a research method is provided below Figure 2). The data analysis methods were mainly qualitative, including descriptive statistics and inductive content analysis to categorize the open-ended answers of the questionnaire.

In the second research phase, this dissertation studied how university education ought to be developed to ensure that the graduates are able to contribute to sustainability in the early career. A case study approach in the field of engineering was applied to reach a deep understanding of the topic and to come up with potential solutions; in explorative case studies, the purpose of the research is often to focus on learning about the phenomenon in a specific context in detail, while allowing for reflections on a bigger picture (Atkins & Wallace, 2012). Mixed methods, including questionnaire surveys, semi-structured interviews, and focus group workshops, and data source triangulation were applied to reach a comprehensive picture of the problem and to improve the quality of the research (Tobin & Begley, 2004; Lambert & Loiselle, 2008; Atkins & Wallace, 2012). According to Atkins and Wallace (2012), triangulation improves the reliability of the research results, as it allows for more comprehensive approach to the research problem and reduces possible biases coming from using only one approach or tool to obtain the results. However, as noted by Tobin and Wallace (2004) and Lambert and Loiselle (2008), using mixed methods approach requires careful considerations of the equivalency and the epistemological paradigms of the used methods (see further elaborations below the Figure 2). The data was analyzed using descriptive statistics, conventional content analysis (Cohen et al., 2011) (Articles 3-5), and basic statistical methods including contingency tables and generalized linear models (Article 4).

The project, during which the data was collected in this second phase (WAT Development Project 2016-2020), related to the early stages of the renewed

Water and Environmental Engineering Master's Programme (WAT) of Aalto University and its graduates. Part of the project results have been published in a Master's Thesis (Vehmaa, 2018) and in a comprehensive Stakeholder survey report (Renko et al., 2020), while a part has been more extensively explored in the articles appended to this dissertation (Articles 3-5). The renewed WAT Programme started in 2016 with previous separate majors being combined to form one major with four study tracks: water supply and sanitation, water resources management, water and development, and environmental engineering[6]. Followingly, the students have only 15 ECTS of common studies, after which they are free to choose advanced courses from all the study tracks. Apart from these major structural changes, sustainability was added as a cross-cutting theme for the whole programme. Therefore, this case study concerned engineering education in an environmentally oriented field and in a programme that emphasizes sustainability. This had implications on the conclusions drawn from the results and on the applicability of the outcomes to other fields. These are discussed in the respective Articles 3-5 and in the Limitations of this dissertation (Subsection 5.4). However, it needs to be noted that the WAT alumni who participated this research had graduated before the major renewal of the programme.

The author of this dissertation was the coordinator of the WAT Development Project. In addition, the author has been a teacher or a responsible teacher in many courses of the WAT Programme, as well as coordinated the programme since 2016, and worked as a substitute university teacher in the programme during 2019-2021. The personal connections to the programme have brought deeper understanding of how to best develop the programme, but it also might have affected the objectivity of the interpretations in the Articles 3-5.

In both development projects, the data collection followed the 'Ethical principles of research in the humanities and social and behavioural sciences and proposals for ethical review' published by the Finnish National Advisory Board on Research Ethics (TENK) in 2009 (the 2nd edition was published in 2019 after the data collection phase). No formal ethical review was necessary, as no sensitive data was collected. However, to respect the autonomy, avoid any harm, and to ensure the privacy of the research participants, relevant information was provided on the aims and implications of the study and the interviewees were asked for their consent to participate, to record the interview, and to use anonymized answers for research purposes. In addition, the participants were informed for their possibility to withdraw from the study at any time. Not all participants agreed to the recording; these interviews were noted as carefully as possible. The anonymity of the interviewees was secured by pseudonymizing the transcriptions and notes taken: all the identifying information, such as the name or organization of the interviewee, were replaced with a code (e.g., 'I2, public sector', for a second interviewee working in an organization in the public sector).

[6] Environmental engineering was excluded from the programme after spring 2019, that is, after the research surveys of this dissertation were implemented. The WAT Programme currently has only the other three study tracks.

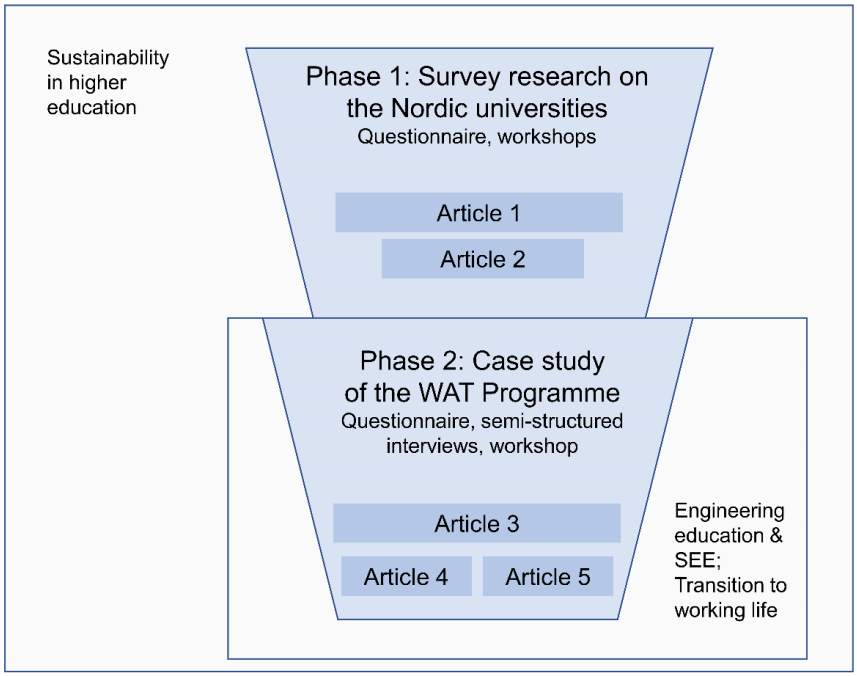

Figure 2. A simplified illustration of the research process and the main disciplines represented (SEE = Sustainability in engineering education). Both phases started with a wider approach (Articles 1 & 3) and were then narrowed down to the more detailed explorations in the Articles 2, and 4-5. The phase 2 results were used to discuss how to develop the institutional support of universities to sustainability integration, particularly in the areas that the phase 1 revealed to be the most underdeveloped.

Qualitative research methods are often resource intensive and sometimes contested for the tentativeness and subjectivity of the results and the lack of methodological rigor (Tobin & Begley, 2004; Thomas & Magilvy, 2011). Therefore, the trustworthiness in designing the research and in data gathering and analysis phases needs to be carefully considered. In the following, I describe how the trustworthiness was considered, consisting of the credibility and applicability of the used methods. Particular attention is paid to the use and credibility of focus groups as a part of the mixed methods approach, and to the qualitative data analysis processes.

In mixed methods research, the equivalency and methodological underpinnings of the different data collection methods need explicit consideration not to risk the trustworthiness of the research (Lambert & Loiselle, 2008). In this dissertation, the focus groups were used as a secondary source of data, while the questionnaires and interviews comprised the primary data for the conclusions. The trustworthiness of the conventional content analysis of the interviews and open-ended questionnaire responses was ensured by a stepwise process (see e.g., Elo & Kyngäs, 2008) in Articles 1-4, and by investigator triangulation in Article 5 (Cohen et al., 2011). In both cases, the data was first transcribed word-to-word and pseudonymized. In the stepwise process, one of the involved researchers then conducted an open coding to the manifest content (Graneheim & Lundman, 2004) of the transcribed text and formed initial list of thematic

categories. To ensure the credibility of the categorization, the list of codes and categories were reflected against the original data and iterated several times to reach a saturation point, where the codes and categories comprehensively represented the data (Graneheim & Lundman, 2004). In the next phase, the categories were further merged to form wider entities and to reach a sufficient level of abstraction (Elo & Kyngäs, 2008). The investigator triangulation followed the same principles of open coding and categorizing of the data; however, in this case the codes were first created separately by two researchers for a smaller sample of the transcribed data. The coding was then reviewed together and agreed on, after which the codes were applied to the whole data and categorized following the stepwise process described above. The results of the content analysis were reported as frequency tables and figures (Articles 1-5). In the Article 5, representative quotations of the categories were also provided (Article 5).

Credibility of qualitative research corresponds to external validity of quantitative research and indicates, how well the conclusions made of the results represent the existing views of the population in general (Cohen et al., 2011). All the five articles of this dissertation were produced in development projects, where it was possible to utilize wide groups of stakeholders as focus groups to review the credibility of the initial conclusions made of the primary data. The stakeholders consisted of the Nordic higher education community (Articles 1-2), and the various actors in the water and environmental engineering field in Finland (Article 5). However, using the focus groups to improve the credibility of the other data sets may include an assumption of one truth of the reality that needs to be confirmed (Tobin & Begley, 2004), which is against the philosophical underpinnings of this dissertation (see Subsection 3.1). To align with the presented epistemological paradigm and to recognize the possibility of multiple realities, the primary purpose of the focus groups in this research was complementary rather than confirmatory (Tobin & Begley, 2004; Lambert & Loiselle, 2008).

Focus groups differ from interviews in that they provide a means to draw from the interaction and shared views of the participants, contributing to the richness of the data (Kitzinger, 1994). Focus groups literally focus the attention of the participants to the specific research topic through a collective activity (Kitzinger, 1994). The collective activities used in the workshops of this dissertation consisted of introductory and case example presentations around the respective topic, including the preliminary interpretations made of the questionnaire and interview data (Articles 1 & 5). After the collective activities, the workshop participants were guided to discuss and provide their shared views on the workshop topic and also on the preliminary interpretations. The gathered notes of the researchers and views written down by the participants were combined to a single text document and categorized deductively utilizing the categories formed when analyzing the questionnaire and interview data. Results were reported mainly as written descriptions, and as tables (Article 1) and figures (Article 5).

The transferability of the research - how the results can be generalized to other contexts - has been mainly ensured through discussing the obtained results against previous research conducted in other countries and against theoretical frameworks. In the Articles 1-2, the key results were well in line with the global

observations on the same topic (Wals, 2014; Ramos et al., 2015), whereas in the Articles 3-5, the findings were mostly consistent with previous results on engineering graduate competencies (Passow & Passow, 2017; Winberg et al., 2018; Quelhas et al., 2019; Ortiz-Marcos et al., 2020; Beagon et al., 2022; Khoo et al., 2020) and previous surveys made on Finnish engineering graduates (Piri, 2022) and on the field of water and environmental engineering (Heinonen & Takala, 2011; Salminen et al., 2015; Takala, 2017).

4. Findings

In this section, I present the main findings of this dissertation following the order of the three research questions (RQs). First, the institutional level support existing in universities for providing the graduates best possibilities to develop and apply their emerging sustainability expertise is presented in the Subsection 3.1. Second, the competencies graduates need for the early career and for promoting sustainability are described in the Subsection 3.2. Finally, the results concerning the role and possibilities of graduates to influence on sustainability in their early career are summarized in the Subsection 3.3. In each subsection, I first present the research question and the central findings, and then describe the details of the central findings with references to the respective Articles 1-5.

4.1 Institutional efforts require development

RQ 1. How do universities support the possibilities of graduates to act for sustainability in the early career?

The key results based on the Articles 1-4 suggest that the institutional support structures of the Nordic universities need more attention to better enable and encourage graduate agency for sustainability. The investigated universities (Articles 1 & 2) emphasize sustainability measures relating to campus operations over the promotion of sustainability education. Particularly the institutional support for teachers to embed sustainability in their teaching and in curricula seem to be insufficient. The lack of support for sustainability in teaching is further reflected in the learning outcomes of students and it also seems to have long-term effects on how the graduates perceive sustainability being connected to their work (Articles 3 & 4; note that these articles only concerned one Finnish Master's Programme in engineering, see 3.2 and Figure 2).

The results of the Article 1 show that the surveyed universities have concentrated their sustainability efforts on improving the campus operations, such as energy efficiency and material consumption, whereas measures that would enhance the integration of sustainability in education have remained less emphasized. The Article 2 results further indicate that sustainability integration in teaching was generally modest at the time of the research survey, particularly considering embedding sustainability in the intended learning outcomes (ILOs) of major subjects, and teacher training (Figure 3). In addition, the development in the universities during the UN Decade of Education for Sustainability (DESD

2005-2014) shows that while sustainability efforts in teaching seem to generally have increased, the institutional support for integration - indicated by teacher training and by assessing and monitoring sustainability in teaching - shows clearly less increase. At the same time, the competencies and motivation of the teaching staff to integrate sustainability in their teaching were seen both as a key driver and one of the most severe barriers for implementing sustainability education (Article 2). Other significant drivers and barriers that emerged in the results of the Articles 1-2 highlight the role of institutional-level measures for sustainability: the most severe barriers included the lack of support from the leadership and the lack of resources (time, human resources, funding). The most important drivers related to sustainability-supporting strategy and target-setting.

According to the results of this dissertation, embedding sustainability in teaching seems to be mainly implicit in the studied master's programme and this is reflected in the learning outcomes of students. The teachers of the programme had consciously included technical, practical and communication competencies in the course ILOs or teaching methods, while the sustainability related competencies and leadership received less emphasis (Figure 4; Article 3). At the same time, the students of the master's programme reported to have learnt best those competencies that were included in the ILOs (Article 3). Moreover, the results of the Article 4 reveal that the graduates may have differing recollections of the sustainability contents of their education despite having studied in the same programme approximately during the same period of time. This suggests that sustainability had, when the respondents were students, been addressed in the programme in such a way that allowed students for ignoring it – and that this had long-term effects on how the graduates thought about sustainability and how they have been able to connect it to their work.

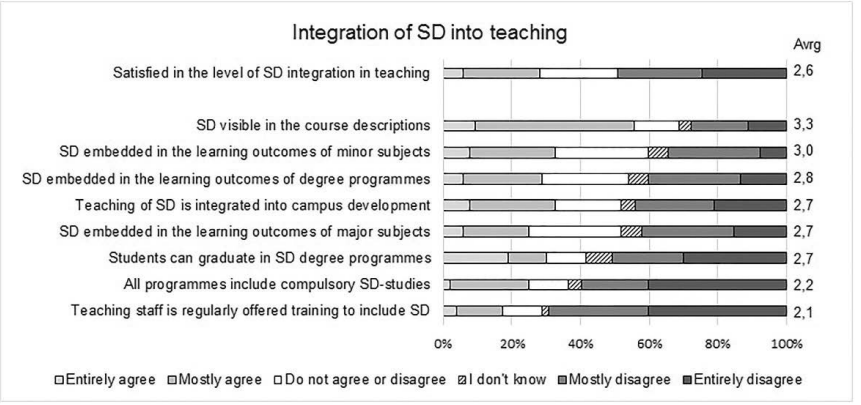

Figure 3. The level of sustainability integration in the education of the Nordic universities: teacher training and including sustainability in the intended learning outcomes is insufficient. n = 49. The averages were counted from the scale: 1 = Entirely disagree, 2 = Mostly disagree, 3 = Do not agree or disagree, 4 = Mostly agree, 5 = Entirely agree. SD = sustainable development. (Article 2).

4.2 Substance knowledge, personal abilities and key sustainability competencies needed

RQ 2. What competencies are needed from engineering graduates in the early career and for contributing to sustainability?

This research question addresses two themes: important competencies in the early career, and in advancing sustainability. The findings of the Articles 3-5 show that the graduate competencies that are required for getting employed and for the early career jobs align relatively well with what seems to be required to promote sustainability in the studied field. The competencies that are particularly important for both purposes include substance knowledge, certain personal abilities, integrated problem-solving, comprehensive thinking, and interdisciplinary collaboration. Interestingly, future-oriented thinking was considered as important only for promoting sustainability. Some contrasting views exist between the actors on the relative importance of the important competencies along the early career. Details of the results are presented first from the viewpoint of the career and then from the viewpoint of promoting sustainability.

According to the results of Articles 3-5, substance knowledge is important from the viewpoints of all the studied actors, namely teachers, graduates, and employers. It was particularly highlighted as the core of the education and having high importance in the employment and the early career stages (Article 4). The graduates considered knowledge of own field and practical competencies (time management, prioritization, project management) to have relevance specifically when applying for the first job and in performing tasks in the lower hierarchical positions (Figure 4). Moreover, over half of the surveyed employers saw substance knowledge and latest scientific knowledge as necessary future competencies in the field and as competencies that should be provided through the education (Figure 4; Article 5). The teachers of the studied master's programme also highlighted the role of substance knowledge (technical and scientific knowledge) in their teaching (Figure 4).

Personal abilities play a significant role in all stages of the early career. The graduates indicated that active initiative and self-coordination are needed in the lower hierarchical positions, while social skills (like negotiation), decision-making and leadership, and driving change become relevant only in the higher positions (Figure 4). The employers instead saw that the education ought to emphasize particularly social skills and lifelong learning but less for example the ability to challenge routines. Interestingly, the employers yet seemed to particularly appreciate attitude and motivation and challenging of the routines when recruiting recent graduates and when evaluating graduate performance (Article 5). In addition, one of the key personal abilities addressed by the employers was the ability to identify own competencies and to be able to communicate about own expertise in the working community (Article 5).

What competencies are then needed specifically for advancing sustainability? The results of this dissertation indicate that substance knowledge is, apart from being essential for the employment and early career task performance, an

essential baseline that allows for sustainability contributions in the varying projects and tasks. Moreover, according to the surveyed employers, the graduates also need to develop key sustainability competencies and knowledge of sustainability during the education (Article 5). Interestingly though, knowledge of sustainability gained the second least scores (after leadership) from the employers in recruiting graduates (Article 5). Despite only the employers were explicitly asked about the competencies needed to promote sustainability, the findings concerning the views of all the surveyed actors show that sustainability-related competencies, i.e., those that the scientific literature has identified as central to promote sustainability, are generally seen as relevant in the early career and as competencies required in the future. The competencies particularly emphasized by all the actors surveyed in the Articles 3-5, whether in relation to promoting sustainability or the early career in general, are integrated problem-solving, interdisciplinary collaboration competency, and comprehensive or systems thinking.

The surveyed actors, however, had varying views on some of these competencies, as well as of the relative importance of the sustainability-related competencies along the early career. Problem-solving was emphasized by the employers as the most important skill for promoting sustainability in the field (Article 5), while the teachers considered it as an important working life skill (Article 3) and the graduates as a central competency in expert positions (Article 4). The teachers gave less emphasis on the future-orientation compared to the graduates and the employers saw it being relevant only in promoting sustainability, not as a generally important competency in the field. The employers saw sustainability-related competencies very important and the teachers as moderately important part of the education (Figure 4). The graduates instead found these competencies relevant mainly when working in the higher hierarchical positions (Figure 4). Overall, the employers indicated a high emphasis towards the sustainability-related competencies, as they considered them as relevant in the future, for the education, and found the graduates having performed them relatively well (Article 5).

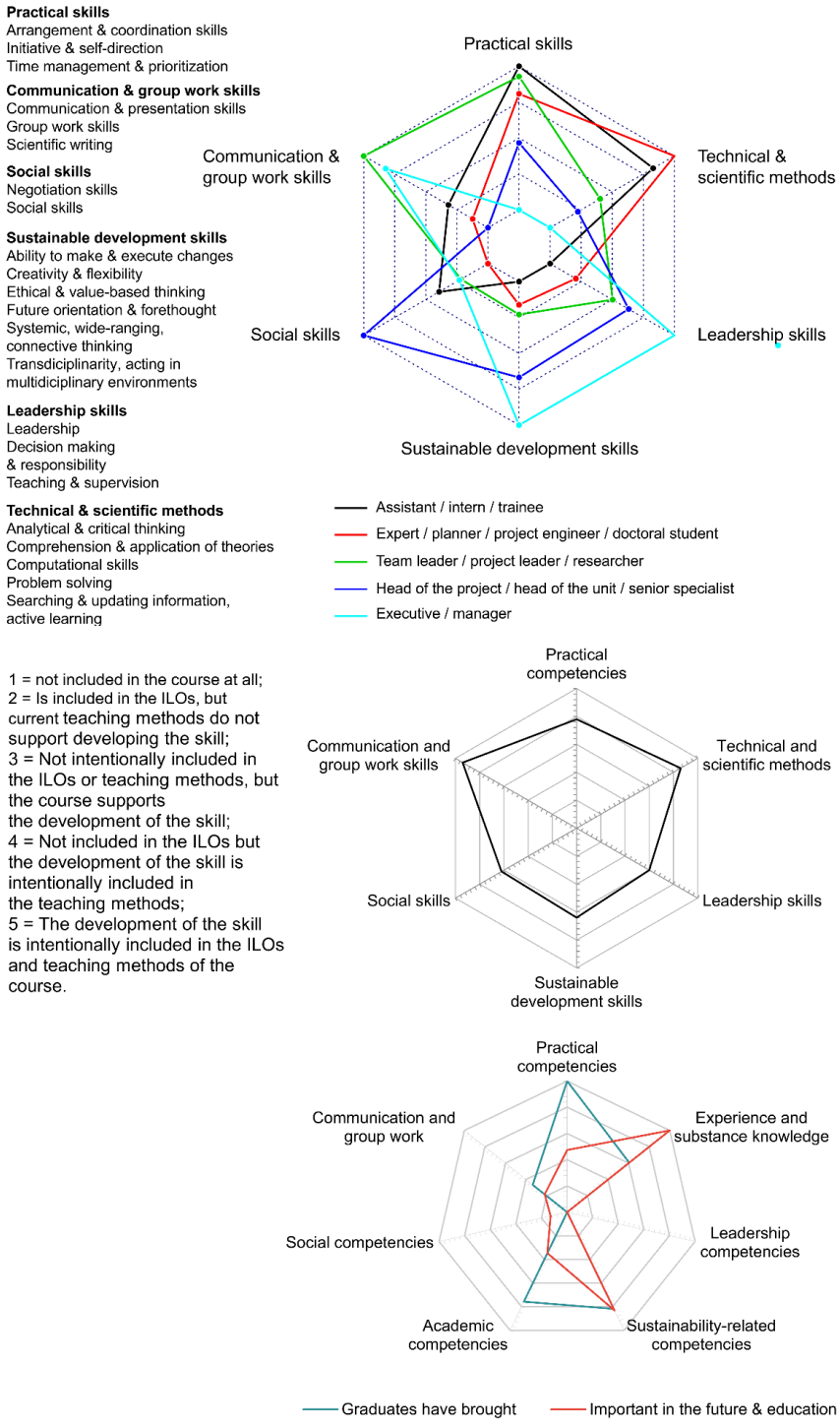

Figure 4. A summary figure showing the most important competency categories according to the graduates (top), teachers (middle), and the employers (bottom). Graduates: comparison of competencies needed in different work levels. Teachers: evaluation of how the competencies are embedded in courses. Employers: comparison of competencies the graduates have brought and what is needed in the future. Adapted from the Articles 4, 3, and 5, respectively. Note that different data collection methods are applied in the Articles 3-5 for the diagrams.

4.3 Contradictory views on the role of graduates

RQ 3. What is the role of engineering graduates in their workplaces regarding the advancement of sustainability?

The results of this dissertation indicate that while the working life seems to expect and value a knowledgeable, active, and independent, even transgressive role of the graduates in advancing sustainability, the graduates have challenges in connecting their work to sustainability and limited possibilities to influence on sustainability in their workplaces.

The role of the graduates in promoting sustainability seems to be ambiguous and the perceptions of it somewhat contradictory between the graduates and employers. The results on the employer views indicate a strong appreciation towards graduates who challenge old practices and bring new insights and sustainability-oriented values to the workplaces (Article 5). The participant views of the stakeholder workshop further indicate the importance of an active orientation from the graduates to get their emerging expertise best utilized in the workplaces (Figure 5). However, although the employers indicated being satisfied with graduate performance and competencies, the graduates seem to have only limited possibilities to act for sustainability in their positions (Articles 4 & 5). Moreover, the employers seem to expect the graduates to be capable of applying sustainability in their daily work very independently and see that the influencing possibilities of the graduates depend on their own knowledge and willingness to promote sustainability (Table 2). However, the Article 4 results reveal that these prerequisites may remain unrealized in practice: over one third of the graduates were unable to connect their work to sustainability and these graduates also evaluated their possibilities to influence sustainability weaker compared to the graduates who found their work being connected to sustainability (Article 4). Overall, the graduates estimated having only moderately power over sustainability-related decisions in the workplaces (Article 4).

The findings indicate that the workplaces could take a more active role in encouraging the sustainability actions of the graduates. The results of the Article 5 reflect an emphasis towards a traditional engineering graduate profile in recruiting the graduates, while the knowledge of sustainability of the graduates is seen less important. Moreover, some employers identified that their organizations could communicate more explicitly about their sustainability efforts to improve the possibilities of graduates to act for sustainability (Article 5). This view was strengthened by the responses of some graduates, who reported that their attitude towards sustainability had changed during the early career due to adjusting to the efforts of their organizations to mitigate climate change (Article 4). Moreover, the fact that both graduates (Article 4) and employers (Article 5, Table 2) found the hierarchical position of the graduates being the key hindering factor to influence on sustainability indicates that the organizations could put more effort in actively hearing from the graduates and encouraging their sustainability efforts. The current measures identified in the Article 5 to benefit from graduate expertise (Figure 5) show that many opportunities already exist in the workplaces to develop this kind of support.

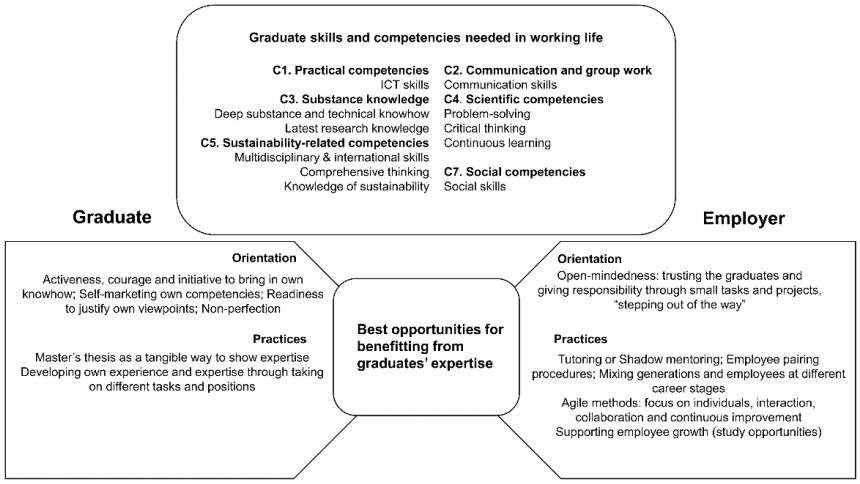

Figure 5. The views of the stakeholder workshop participants (n = 135) on what skills and competencies are acquired from the education and needed in the working life, and how the graduates and the workplaces could promote the utilizing of graduate competencies. (Article 5).

Table 2. Employer views on factors that enable graduates to influence on sustainability in the early career. Categories are based on conventional content analysis. Adapted from Article 5.

Factors enabling graduates to influence on sustainability (n = 48)			
Graduate orientation		**Workplace orientation**	
Knowhow and willingness	25 %	Prioritizing sustainability in organization	17 %
Taking initiative	23 %	Openness and listening	6 %
Collaborative orientation	6 %	Teamwork	2 %
Total	**54 %**	**Total**	**25 %**
Graduate actions		**Workplace actions**	
Through own projects	13 %	Mentoring	2 %
Applying sustainability in daily work	13 %	Orientating the graduate	2 %
Suggest solutions to clients	6 %		
Total	**31 %**	**Total**	**4 %**

5. Discussion

This dissertation investigated the competencies needed and possibilities of graduates to promote sustainability in the early career and the current institutional measures of universities to support the development of the important competencies. The following research questions directed the research:

RQ 1. How do universities support the possibilities of graduates to act for sustainability in the early career?
RQ 2. What competencies are needed from engineering graduates in the early career and for contributing to sustainability?
RQ 3. What is the role of engineering graduates in their workplaces regarding the advancement of sustainability?

In the following, I first summarize the key findings in respect of the three research questions and discuss the findings against previous research. Second, I discuss the implications of the findings on engineering education and the institutional support required. Finally, I discuss the limitations of this research and suggest ways forward in the research areas of this dissertation.

5.1 New scientific findings

This dissertation aimed at creating an overall picture of the connection between the institutional level efforts on sustainability integration in higher education and graduate possibilities to act for sustainability, as previous research particularly in the Nordic context has mainly focused on these levels separately. To study the RQ 1, the dissertation took a detailed look in the Nordic universities and followed an integration path of a specific engineering master's programme from teacher, student, and graduate perspectives. The findings indicate that the Nordic universities support graduate sustainability actions insufficiently, which manifests particularly through the shortcomings in 1) the whole university approach to sustainability, 2) competencies of teachers, and 3) in the outcomes of education as graduate competencies. I next elaborate on these shortcomings in more detail. First, previous research has shown that for higher education to efficiently promote sustainability, a whole university approach and a high level of institutional commitment are necessary (Sterling, 2001; Cortese, 2003; McMillin & Dyball, 2009; Kohl et al., 2022; Kolmos et al., 2016; Weiss et al., 2021b).

However, in line with a global trend (Wals, 2014, Ramos et al., 2015), the Nordic universities seem to invest clearly more in sustainable campus operations than to sustainability education. This reflects inadequate implementation of a whole university approach and insufficient institutional commitment to sustainability. Second, the Nordic universities have paid only little attention to training the teachers in sustainability, which has also been observed in a national level in Sweden (Finnveden et al., 2020). At the same time, teacher training has been identified as a key measure to advance sustainability integration in education (UNECE, 2011; UNESCO, 2014; Sherman & Burns, 2015). Moreover, this dissertation shows that the teachers would benefit from more support: in line with earlier studies (Borg et al., 2012; Thomas, 2016; Fiselier et al., 2018; Weiss et al., 2021a), the motivation and competencies of the teachers seem to be central factors affecting sustainability integration in the Nordic universities. Third, the education has resulted in varying learning outcomes on sustainability, as suggested also by Dvorak et al. (2010). The graduates have shortages in their sustainability knowledge and sense of agency, suggesting that the inadequate institutional commitment and teacher competencies have an impact on how the graduates can act for sustainability in the early career. Similar conclusions have been presented in earlier studies (Fernández-Manzanal et al., 2015; Chance et al., 2022).

The RQ 2 was investigated through surveying teacher, graduate and employer views in the field of water and environmental engineering. The aim was specifically to explore the important competencies for graduate engineers from the viewpoint of promoting employability and sustainability. These are both relevant targets of the contemporary engineering education (Passow & Passow, 2017; Winberg et al., 2018; Mulder, 2017; Gutierrez-Bucheli et al., 2022), but rarely explored together. In addition, the dissertation aimed at clarifying the relative importance of the different competencies along the early career, as suggested by Brunhaver et al. (2018).

The key finding is that similar competencies seem to be important both for the early career success and for promoting sustainability, but the relevance of the different competencies changes along the early career and the perceptions of the surveyed actors have some divergence. The competencies this dissertation shows being particularly important for employability and sustainability are substance knowledge, comprehensive (or systems) thinking, integrative problem-solving, interdisciplinary collaboration, and personal abilities, particularly initiative and recognizing own competencies. Substance knowledge is more relevant in the employment and first jobs, while the personal abilities seem to be significant for all purposes. Both are significant in promoting sustainability.

Many of the identified important competencies are already considered as established employability competencies for engineers (Passow & Passow, 2017; Winberg et al., 2018; Khoo et al., 2020), but they have also been identified as central in promoting sustainability in engineering (Quelhas et al., 2019; Ortiz-Marcos et al., 2020; Beagon et al., 2022). They additionally align with the key sustainability competencies (Wiek et al., 2011; Brundiers et al., 2021). Interestingly, the graduates seem to find the sustainability competencies relevant only

in higher positions, whereas the employers emphasize sustainability competencies more than the other actors. This is opposite to the recent findings of Beagon et al. (2022) who found that the different stakeholders of education held mainly converging views on the necessary sustainability competencies. However, in line with earlier observations (Lambrechts et al., 2013; Ortiz-Marcos et al., 2020; Beagon et al., 2022), the importance of futures thinking seems to be underemphasized among all the actors.

The role of graduates in contributing to sustainability (RQ 3) was approached in this dissertation through surveying graduates and employers in the field of water and environmental engineering, with the emphasis on the employer views. The dissertation thus complements the picture drawn by a few previous studies, which have mainly focused on measuring graduate performance of sustainability competencies (Holdsworth et al., 2019a; Thomas et al., 2020) and on graduate perceptions of their influencing possibilities (Chance et al., 2022).

The key finding is that the role seems to be ambiguous and perceived differently by the graduates and employers: while the employers emphasize graduate-related factors as central for them to influence on sustainability, the graduates, in line with earlier observations (Chance et al., 2022; Fernández-Manzanal et al., 2015; Holdsworth et al., 2019a), highlight workplace-related factors and support. The employers are generally very satisfied with graduate contributions and sustainability-embracing values and seem to value performance that reflects an active and independent role of the graduates. They for example find the motivation and willingness of the graduates being one of the key factors behind their influencing possibilities and presume the graduates to implement sustainability independently in their work. The employers also expect the graduates being knowledgeable of sustainability and appreciate them for challenging old practices, as also observed in other studies (Hanning, 2012; Takala & Korhonen-Yrjänheikki, 2019; Yamane & Kaneko, 2021; Beagon et al., 2022; Henry et al., 2023). Despite these positive employer perceptions, this dissertation shows that the graduates have challenges both in their knowledge of sustainability and sense of agency, as they face difficulties in connecting their work to sustainability and perceive having insufficient power to have an impact. Further, previous studies suggest that workplace-related factors, such as resources, low power, and lack of support, restrict graduate contributions despite their own motivation and willingness (Chance et al., 2022; Fernández-Manzanal et al., 2015; Holdsworth et al., 2019a). Therefore, this dissertation opens a discussion on how the workplaces support the sustainability efforts of the graduates.

5.2 Supporting sustainability through engineering education

The key findings summarized above concerning the graduate role and the important competencies have implications on the competency profile of graduate engineers, on the key competency discourse in the field of sustainability in higher education (SHE), and on the practical level of developing engineering education. I next elaborate on these implications, describing how the sustainability contributions of the graduates can be supported in engineering education.

The main focus of the elaborations is on the studied Water and Environmental Engineering Master's Programme (WAT) and the findings of Articles 3-5.

This dissertation provides empirical evidence that is mainly supportive of combining the employability and sustainability approaches in engineering education. This contribution is in line with the hybrid approach suggested by Jamison et al. (2014). The findings on one hand show that the WAT Programme has succeeded well in applying the T-shaped competency profile (Uhlenbrook et al., 2012) in the courses and in providing the graduates with good employability competencies (Passow & Passow, 2017; Winberg et al., 2018; Khoo et al., 2020): the graduates get employed quickly and the employers are very satisfied with their competencies, performance, and contributions. On the other hand, the clear sustainability emphasis is manifested through the important competencies, which were found being practically the same for the employability and sustainability purposes. The employers additionally perceived sustainability positively – they even expected the education to provide graduates who are knowledgeable of sustainability and capable of comprehensive thinking.

Despite both the employability and sustainability approaches are supported by the surveyed actors, sustainability remains less emphasized. This interpretation is based on two key reasons. Firstly, the findings indicate that all the studied actors seem to consider sustainability only as a secondary target for the early career graduates. While the employers do appreciate the sustainability-embracing values and a transgressive role of graduates in advancing sustainability, they prioritize other competencies over sustainability knowledge and leadership in the recruitment. Further, they acknowledge that the lower position restricts graduate possibilities to influence on sustainability, yet they expect the graduates to implement sustainability in their work based on own motivation and knowledge. Therefore, the employers seem to expect that the graduates concentrate on field-specific task performance instead of explicitly encouraging them to also consider sustainability. The graduate perceptions support this view, as according to them, sustainability-related competencies are required mainly in the higher hierarchical positions. The teachers in their part, highlight employability competencies in the intended learning outcomes of their courses, while the sustainability-related competencies are integrated implicitly. This implies that either of the surveyed actors is actively prioritizing sustainability and thus, is primarily supportive of the catalyst role of graduates in accelerating a societal sustainability transformation (Wiek et al., 2011; Trevelyan, 2019).

Secondly, the findings suggest that the sustainability-related competencies that all the actors acknowledged as relatively important are lacking the adequate context – sustainability. In the context of the key sustainability competencies, one needs to remember that the factor that makes them *sustainability* competencies is the sustainability-oriented target of the problem-solving process they are applied to (Wiek et al., 2011; Brundiers et al., 2021). Therefore, is seems that the graduates are currently lacking the appropriate target for their competencies to be *sustainability* competencies. This is particularly evident in the challenges the graduates revealed to have in contextualizing their work to sustainability and in their sense of sustainability agency. This reflects additionally an

underdeveloped implementation competency (Brundiers et al., 2021), which includes the ability to choose suitable strategies that best promote sustainability in different situations and particularly, the ability to implement these plans in practice. In addition, a transgressive orientation that emerged in this dissertation as the most valued graduate attribute from the employer viewpoint - and has been emphasized also in other studies (Beagon et al., 2022; Henry et al., 2023) - is one of the bases of the implementation competency. Education is therefore encouraged to promote the implementation competency and to help the students in establishing a connection between their field and sustainability and to set sustainability-connected targets for their problem-solving processes.

In addition to the two viewpoints discussed above, this dissertation suggests more attention to be paid to the personal sphere of the students. Personal abilities were observed significant both for the early career success and for promoting sustainability. Many of the highlighted abilities align with the definitions of the self-awareness competency that was recently suggested to be added to the key competency framework (Brundiers et al., 2021). Particularly initiative, perception of agency, recognizing own competencies, motivation, and willingness that emerged frequently in the explorations of this dissertation resonate with the five key definitions identified for self-awareness in Jaakkola et al. (2022): *1. awareness of one's emotions, desires, thoughts, values, assumptions, and behaviors, 2. emotional resilience, 3. awareness of one's positionality, 4. awareness of one's relation to others and compassion, 5. reflection supporting motivation and willingness to act*. The findings thus contribute to the ongoing discourse of the competency framework by providing empirical evidence for the support of including the self-awareness competency - and also the implementation competency - in the key sustainability competency framework (Brundiers et al., 2021; Redman & Wiek, 2021). The emphasis of the competency framework would thus shift towards emphasizing the personality development related targets of education (Jaakkola et al., 2022). Other scholars have also criticized the original framework of Wiek et al. (2011) and suggested the education to pursue wisdom and the development of personal values and dispositions (Andersson, 2013; Shephard & Egan, 2018). Followingly, the education that applies the framework, including engineering education, is urged to consider how the personal sphere can be supported in practice.

To conclude the above-discussed three viewpoints to graduate sustainability competencies and agency, the current situation in the studied water and environmental engineering field does not fully reflect a paradigm shift in the education (Mulder, 2017; Gutierrez-Bucheli et al., 2022), the requested ability to consider the long-term sustainability impacts of own work and decisions (Ortiz-Marcos et al., 2020), nor the agency of engineers to be active players in their working communities (Svanström et al., 2008; Mulder, 2017; Quelhas et al., 2019; Ortiz-Marcos et al., 2020). Therefore, the competency profiles prevailing in the engineering education, specifically the T-shaped profile of water engineers, would need to be complemented with a stronger sustainability emphasis to explicitly communicate the apparent need for field-specific sustainability expertise, and to better align with the hybrid approach requested by Jamison et al.

(2014). Therefore, the integration of sustainability in the education is suggested to consider the key sustainability competency framework (Wiek et al., 2011; Brundiers et al., 2021) and be explicit in connecting the disciplinary contents with sustainability. In practice, this would mean a conscious merger of the key sustainability competencies with the employability perspective, together with respective knowledge of sustainability and explicit emphasis on the personal abilities. A novel hybrid competency profile that would emphasize sustainability without compromising from the core engineering competencies could also mitigate the concerns that exist among some engineering practitioners towards sustainability in engineering education (Takala & Korhonen-Yrjänheikki, 2013; Mulder, 2017).

Good educational practices already exist that can be experimented and adjusted in implementing such a merger in the education. For example, in developing the curricula, the work done by the CDIO community is worth following: the approach that has been taken to embed sustainability in the existing engineering competencies resembles the idea of the proposed hybrid competency profile and could provide beneficial viewpoints and practices (see e.g., Rosén et al., 2019; Malmqvist et al., 2022). Other potentially beneficial examples include problem-based learning (PBL) and project courses, which are traditional practices in engineering education to bring about development in both substance specific and broader competencies (Guerra, 2017). However, to educate for the suggested hybrid competency profile, a central target would be to establish a connection between the discipline and sustainability. The disciplinary content could for example be reframed to a sustainability context, as Sandri (2020) and Holdsworth and Sandri (2021) suggest. Sandri (2020) proposed that framing (or reframing) assignments and disciplinary content could provide a 'point of entry' for sustainability and could thus be a key to connect disciplinary topics with a stronger sustainability emphasis: "*reframing through content expands learners' perceptions of professional practice to encompass sustainability*" (p.65). Moreover, this type of (re)framing might simultaneously challenge the disciplinary traditions and thus, contribute to a paradigm change requested from engineering education (Mulder, 2017; Gutierrez-Butcheli et al., 2022) and the active role requested from the engineers in the society (Svanström et al., 2008; Mulder, 2017; Kolmos et al., 2016; Gutierrez-Butcheli et al., 2022).

In addition, untraditional pedagogical practices might be required to address the important, yet underemphasized self-awareness and futures thinking competencies. For futures thinking, Trencher et al., (2018) and Beagon et al. (2022) proposed experimenting future-oriented methods, such as visioning, scenario-building, and back-casting. The teaching practices discussed in accordance with self-awareness competency include for example art-based and self-inquiry-based learning (Jaakkola et al. 2022) and contemplative practices like mindfulness (Wamsler 2019, Hensley 2020). These practices can be considered as transformative, as they facilitate deep reflection of self in relation to the surrounding world and may even challenge the existing personal paradigms. Therefore, they also require special attention from the educators, as changes in personal paradigms may raise strong emotions (see Jaakkola et al., 2022). At

the same time, Lotz-Sisitka et al. (2015) suggested that societal sustainability transformation requires not only transformative, but transgressive education that challenges students to practice how to drive change. These approaches are not totally new to engineering educators (Gutierrez-Bucheli et al., 2022; Rosén et al., 2022), nor do they belong to the traditional pedagogical practices. This implies further work among the educator community to first acknowledge the importance of the transformative approaches for the education and engineering practice, and then to develop the education to employ suitable pedagogies.

Finally, some recent development regarding the increased sustainability emphasis of the WAT Master's Programme needs to be elaborated shortly. The WAT Programme went through a major renewal in 2016 and sustainability was added as a cross-cutting theme to the programme. At the same time, the programme started to apply the T-shaped learning profile to a personal learning portfolio (Keskinen, 2016), in which the students are guided to reflect on their learnings and career preferences and nudged to contemplate on their personal interests, strengths and areas of improvement. This aims to promote their professional agency and could potentially be further developed to include reflections on personal dispositions regarding sustainability, thus including elements of the self-awareness competency. Further, in spring 2023, a new project course was launched that combines the solving of practical challenges from working life partners with workshops on futures and systems thinking. The students additionally write weekly learning diaries reflecting on their personal dispositions. However, results on the outcomes of these interventions in terms of graduate competencies and agency are yet to be investigated.

5.3 Institutional support to enable the catalyst role of graduates

In the previous subsection I elaborated on the role and possibilities of engineering education to support the graduates in their sustainability contributions. However, the role of institutional sustainability efforts of the universities and the workplaces cannot be underestimated when discussing the overall support for the graduates. In the following, I discuss how the findings of this dissertation relate to and can help in improving the institutional support for graduate agency both in the Nordic universities and in the working life organizations.

The situation of the integration of sustainability in the Nordic universities raises concerns. The findings of this dissertation indicate a lower commitment of the universities to sustainability education and to training the teachers compared to efforts put on a sustainable campus. The findings additionally show that if the integration of sustainability competencies in the courses is implemented in an implicit way, the learning outcomes relating to sustainability of graduates may vary. Previous research is, however, relatively unanimous with a view that sustainability education requires well-designed and coordinated efforts put on both teaching (Mintz & Tal, 2014; Dvorak et al., 2010) and curriculum (Sterling, 2001; Kolmos et al., 2016). The review of Weiss and colleagues (2021b) on curriculum change further shows that to restructure the curricula and teaching to embrace sustainability, the institutions need to support the

whole community to act and interact particularly through providing adequate professional development and internal networks. Moreover, as discussed in the previous subsection, the teaching practices suitable for promoting a hybrid competency profile would require also untraditional pedagogical practices and followingly, the educators would need more support to design and implement such teaching. Therefore, in the light of this dissertation and previous research and reports (Borg et al., 2012; Sherman & Burns, 2015; Thürer et al., 2018; Takala & Korhonen-Yrjänheikki, 2019; Finnveden et al., 2020; Weiss et al., 2021b; UNESCO, 2014), the Nordic universities could pay more attention to their institutional commitment to sustainability, particularly the support structures existing for the teachers.

Encouragingly, the review of Weiss et al. (2021b) suggests that the commitment of an institution to sustainability efforts in campus operations or research can lead the way to a more comprehensive whole university approach and a transformative change in curricula. Therefore, despite the above-expressed concern, the direction of the Nordic universities seems promising, as the commitment to sustainable campus operations is overall good. Moreover, the Nordic universities have recently started to accelerate their carbon neutrality[7] and biodiversity efforts[8] and indications exist that universities worldwide, including the Nordic region, are paying increasing attention to the competencies that teachers need, and to the professional development of their teaching staff (Vare et al., 2019; Leal Filho et al., 2021; Michel, 2020; Schönach et al., 2023). For example, in Aalto University, a pedagogical training course focused on sustainability education has been run since 2021 and according to preliminary indications, the training seems to provide an important platform for peer support and to promote the abilities of the participating teachers to connect their subject topic to sustainability (Schönach et al., 2023). This can be seen as significant development that promotes the teachers to take ownership on sustainability integration and may thus even lead towards an integrative or a transformative institutional change (Sterling, 2001; Kolmos et al, 2016; Weiss et al., 2021b).

Apart from the educational institutions, workplaces can have a substantial impact on how the graduate competencies realize in the early career (Lutz & Paretti, 2021). Explicit sustainability efforts of organizations can strengthen the sustainability commitment of graduates, as indicated by some of the surveyed graduates in this dissertation. However, also hindering structures exist. This dissertation, along with a few other studies (Fernandez-Manzanal et al., 2015;

[7] A selection of websites of Nordic universities that indicate ambitious work around carbon neutrality: Finland: https://www.aalto.fi/en/news/carbon-neutral-aalto-2030-action-plan-launches; https://www.helsinki.fi/en/news/sustainability/towards-carbon-neutrality-university-helsinki-calculates-its-carbon-footprint-and-draws-plan-reduce-emissions; Sweden: https://www.su.se/english/about-the-university/sustainable-development/the-university-s-climate; https://www.gu.se/en/about-the-university/vision-and-values/sustainable-development/sustainability-results-2022; Denmark: https://cbswire.dk/universities-denmark-is-firing-up-for-a-cross-university-initiative-to-reduce-the-danish-universities-co2-emissions/

[8] Examples from the Nordic universities' activities around biodiversity: Finland: https://tiedemuseo.jyu.fi/en/botanical-garden/biodiversity-on-campus; https://www.b2n.fi/kampusluonto; Sweden: https://www.slu.se/en/campaign-sites/biodiversity-campus-challenge/

Chance et al., 2022), shows that the hierarchical position of the graduates creates a boundary for the graduates to influence on sustainability. Moreover, a gap seems to exist between the employers and the graduates, both in how they perceive graduate role and competencies in promoting sustainability (active, knowledgeable and independent vs. lack of power and competencies) and what they think affects graduate possibilities to act (graduate-related factors vs. workplace-related factors). Similar gaps in expectations have been reported in the transfer phase of graduates to the working life in general (Korte et al., 2015; Trevelyan, 2019), implying that more communication and knowledge sharing could be required to mitigate the gap.

Interestingly, the findings suggest that the issue with graduate agency only concerns sustainability-related agency. The surveyed employers widely considered that the graduates do bring new insights and challenge current practices, indicating a relatively high level of professional agency of the graduates (see Eteläpelto et al., 2013 and references therein). Moreover, the findings show that some means already exist in the organizations to utilize graduate competencies and to support their agency, but these supportive measures seem to only apply to task performance and adapting the graduates to the working life, whereas the promotion of sustainability is mainly left for the graduates to tackle by themselves. Therefore, resembling what Eteläpelto et al. (2013) suggested for professional agency, the workplaces could invest more in creating an encouraging and enabling social context for promoting sustainability instead of solely relying on graduate sustainability knowledge and competencies (individual agency). The findings of this dissertation suggest that the graduates could be supported also through communicating clearly on the sustainability efforts and commitment of the organization, or through applying the existing support measures like mentoring also in the context of sustainability promotion.

The workplaces additionally have the possibility to take a more active role in driving a more sustainability-oriented competency profile of graduates, such as the hybrid profile. Despite the otherwise strong sustainability emphasis of the working life indicated by this dissertation, the recruitment seems to be less supportive of a respective expertise. Given that employment is of primary importance for the graduates, emphasizing the knowledge of sustainability and motivation to act for sustainability in the recruitment could create a substantial motivational factor for the students to develop field-related sustainability expertise. Emphasizing sustainability expertise in the recruitment and first positions could also provide an incentive for the educators to increase the sustainability emphasis of their teaching. Currently, the financial incentives for developing university education in Finland have a strong emphasis on the employability targets, while the integration of sustainability is mainly driven by general level policy outlines stating that universities contribute to sustainable growth (Ministry of the Education and Culture, 2018).

5.4 Limitations

There are some limitations and uncertainties in the methodology and research process that need to be considered in interpreting the findings of this dissertation. In the following, I clarify and discuss the main limitations (see Articles 1-5 for their specific limitations).

This dissertation took a holistic approach to sustainability integration in higher education and the impact of the integration on graduate competencies and possibilities to act for sustainability in the early career. The Nordic higher education institutions (HEIs) and the Water and Environmental Engineering Master's Programme (WAT) of Aalto University were used as case examples to investigate these research topics. The chosen approach is two-fold and in a sense also contradictory. On one hand, the holistic perspective gives a good overview of the research topic but compromises from beneficial explanatory details, such as causalities and mechanisms underpinning the observed results. On the other hand, the case study approach, together with the qualitative research emphasis, narrows the focus down to a level that restricts the generalizability of the findings. These two levels of the dissertation are partly explained by the projects that drove the research process and the need to balance between the two central purposes of this work: apart from contributing to the research fields of sustainability in higher education (SHE) and engineering education, the aim was to develop the WAT Programme in practice. Despite the limitations, the multitude of approaches and purposes can be seen an asset, as connecting different perspectives produces more insights and in the case of a novel research area, can be particularly beneficial for directing future research.

Some concerns relate also to the research process. The process took several years, the first survey being conducted already in 2014. Considering the accelerating pace the universities include sustainability in their activities, some of the results could be considered as outdated. To tackle the issue, this dissertation discussed the results against the recent development in the Nordic universities and noticed that the situation shows improvement. However, as far as the author is aware, similar comprehensive surveys than the one in this dissertation on the sustainability efforts of universities in the Nordic level are yet to be conducted. In addition to the time span of the process, the interdisciplinary and transdisciplinary nature of the research fields this dissertation represents needs to be addressed. Interdisciplinary research, paraphrasing Keskinen (2010, 30), can create a holistic view of a complex issue through bringing together data, methods, theories, and concepts from many disciplines. The commonly raised concern in such integrative research is the arbitrary combination of the disciplinary doctrines, also called as eclecticism in philosophy, which can create a risk of incoherence. While it may be that the outcome of interdisciplinary research is unable to create a logical argument from a disciplinary point of view, it may shed light to a complex phenomenon through utilizing multiple complementary perspectives. I have adopted this multiperspective approach in this dissertation, as the aim was to better understand a highly complex and multifaceted phenomenon of the effects of integrating sustainability in education on graduate agency for sustainability.

In addition, the chosen exploratory and descriptive methodology limits the possibilities to generalize the findings and a few challenges in the applied data collection and analysis methods cause uncertainty to the results. Firstly, the emphasis on the qualitative methods, particularly the interpretations of interview and focus group data, may result in subjective interpretations of the data and limit the possibility to apply the results in other contexts. Therefore, those analyses were mostly conducted by two authors and a detailed description of the analysis method was included in the respective articles. Moreover, almost all the interviews and focus groups were analyzed as complementary to questionnaire survey data, thus increasing the trustworthiness of the results. Secondly, the low number of respondents in the Nordic questionnaire survey raise questions on the validity of the results. However, the results aligned relatively well with previous findings and with a global trend, suggesting a satisfactory level of the external validity.

Thirdly, the engineering field this dissertation investigated has a substantial sustainability emphasis. This might have affected on the perceptions of the research participants and therefore, the findings are not directly applicable to other engineering fields. Fourthly, the questionnaire surveys were wide in their approach, as the whole dissertation, and covered multiple research targets instead of focusing on measuring certain specific issues. The questionnaires therefore lacked internal reliability measures, thus causing uncertainty to the gained results.

Finally, in studying competencies, varying ways in the use of terminology and in categorizing them is a common challenge (Shephard et al. 2019). For example, the different key sustainability competency frameworks referred to in this dissertation (Wiek et al., 2011; UNESCO, 2017; Brundiers et al., 2021; Bianchi et al., 2022) have differences in the number of competencies included in the framework. The definitions of the specific competencies may also vary between different scholars, as in the case of self-awareness / intrapersonal competency (Jaakkola et al., 2022). Similarly, the research participants may interpret given lists of competencies in varying ways. Due to this divergence in interpreting the different competencies, the results include some uncertainties. As for the challenge of categorizing the different competencies, the Articles 3-5 used consistent categorization in the analysis, aiming to improve the comparability and validity of the three articles. However, comparisons with other studies remain partly a challenge.

5.5 Future directions

The outcomes of this dissertation provide important insights for future research in the fields of sustainability in higher education (SHE) and engineering education. Both of these fields are abundant with studies concerning how to include sustainability in specific courses or programmes. As observed by this literature and by the findings of this dissertation, regular courses, implicit, or add-on integration of sustainability merely suffice in developing competencies that help graduates to implement sustainability in practice. While this dissertation was

strongly driven by programme development and particularly serves initiatives that aim to integrate sustainability in the curriculum level, more detailed explorations are encouraged that would focus on how the programme-level integration efforts can be realized in practice in the specific courses. Moreover, while certain teaching methods have been recognized effective in developing multiple important competencies, such as problem-based learning or project courses, degree programmes rarely comprise of courses that fully follow these resource intensive pedagogies (although exceptions exists, see e.g., Ulseth & Johnson, 2014, referenced in Kolmos et al., 2016). Therefore, there is a need for more contributions like those of Sandri (2020) and Holdsworth & Sandri (2021), particularly in the engineering fields, that provide insights on integrating sustainability in disciplinary courses and could help the educators to reframe the subject topic of their courses.

Following the encouraging direction of teacher training observed in the universities globally and in the Nordic region, future research could concentrate on exploring what specific support the teachers need. In addition, contributions on which approaches best facilitate them in finding connections between their field and sustainability, and in developing the suitable teaching and learning activities in their courses could facilitate institutions to provide suitable professional development. While some contributions already exist on these topics (e.g., Leal Filho et al., 2021; Schönach et al., 2023), teacher training that would contribute to better graduate sustainability competencies and agency requires more attention. This future direction of research could particularly include means to promote the transformative approaches in education, as it would contribute to the self-awareness and implementation competencies of graduates and facilitate them in facing the challenges brought by the transition to the working life. Moreover, according to this dissertation and earlier studies (Lambrechts et al., 2013; Quelhas et al., 2019; Beagon et al., 2022), futures thinking seems to be generally underemphasized by the different stakeholders of education, which suggests that studies that explore the reasons behind this are needed, as well as explorations on the means to integrate the competency in courses and programmes.

Finally, as noted in the limitations, major part of the findings of this dissertation only included one field of engineering in one country with an exploratory-descriptive research approach. Therefore, to better understand how the working life receives recent graduates and utilizes their sustainability competencies, more research in different fields and countries would be needed. For facilitating the catalyst role of the graduates, it would also be important to focus future research on how to overcome the factors that hinder graduate possibilities to act for sustainability. Based on this dissertation, such research could take for example an experimenting approach to measures that could facilitate knowledge sharing around sustainability in an organization or to measures that clarify how sustainability can be applied in daily work in an organization. Considering that the reality of the graduates in the early career is socially constructed, future research is also encouraged to take a deep interpretativist approach (Cohen et al., 2011) to explore the interaction between the graduates, workplace colleagues, and employers around sustainability-related issues.

6. Conclusions

The overarching aim of this dissertation was to evaluate and discuss how university graduates can catalyze societal sustainability transformation. It explored the topic in three interrelated contexts: sustainability in higher education, engineering education, and transition to the working life. The thesis surveyed the sustainability integration of the Nordic universities and used an engineering master's programme as a case to study competencies important for employability and sustainability, and the role of graduates in contributing to sustainability.

The findings show that the Nordic universities are putting efforts on integrating sustainability in their operations. However, taking a stronger whole university approach to the integration and developing the support for the teachers in sustainability education are suggested to promote graduate sustainability agency. The working life is generally very satisfied with graduate competencies and contributions. Particularly substance knowledge and the key sustainability competencies emerged as important both for employability and sustainability, suggesting a hybrid competency profile for engineering graduates. However, all the surveyed actors seem to prioritize employability and have diverging views on the relevance of sustainability competencies. As for graduate role, the employers expect an active, knowledgeable and independent role, while the graduates have shortages in competencies and feel a lack of power to influence.

To promote the catalyst role of graduates, the dissertation discussed two key future directions: 1) Providing the teachers with internal networks and pedagogical training, which can facilitate reframing the course topics to sustainability, integrating the key sustainability competencies in the education and encourage employing pedagogies that support sustainability agency; 2) Clarifying the graduate role through exploring workplace practices that improve knowledge sharing and support for graduate sustainability efforts.

This dissertation provides a novel insight on sustainability education in universities and in engineering, emphasizing the support required throughout the educational system and the working life to ensure best possibilities for the graduates to catalyze sustainability transformation. The dissertation suggests intensifying collaboration among graduates, workplaces, and educators around sustainability to mitigate the diverging views on the competencies and to clarify the role of graduates. Moreover, co-creating a clearer view of how sustainability can be implemented in field-specific projects and daily tasks can help the students to develop adequate competencies and agency, the educators to reframe the teaching to promote a hybrid competency profile, and the workplaces to provide suitable support for the graduates. Further, this *collaborative agency for sustainability* (OECD, 2019) can lower the threshold for the graduates to act for sustainability despite the hindering effects of an expectation gap in the transition phase, power structures, and possible shortages in the competencies.

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Aalto-DT 24/2024

ISBN 978-952-64-1655-7 (printed)
ISBN 978-952-64-1656-4 (pdf)
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

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