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Health and well-being inequalities in industrially contaminated sites: The case of Ida-Viru County in Estonia

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Institute of Social Studies, University of Tartu, Estonia

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Study II: **Dahal, U.,** Veber, T., Åström, D.O., Tamm, T., Albreht, L., Teinemaa, E., Orru, K., Orru, H., 2022. Perinatal Health Inequalities in the Industrial Region of Estonia: A Birth Registry-Based Study. International Journal of Environmental Research and Public Health 19, 11559. https://doi.org/10.3390/ijerph191811559

Study III: **Dahal, U.,** Orru, K., Orru, H., Dijst, M., 2024. Green dreams, local realities: Complexities of the European Union's energy transition to ensure local health and well-being in a fossil fuel-based industrial region. Environmental Impact Assessment Review 106, 107520. https://doi.org/10.1016/j.eiar.2024.107520

MY CONTRIBUTION AS AN AUTHOR

As an author of this thesis, I have contributed to these studies as follows:

Study I: I co-authored this paper and, along with the first author, I prepared the original draft of the manuscript, carried out the analysis and reviewed and edited it.

Study II: I contributed to the conceptualisation, data analysis, original draft writing, review and editing.

Study III: I contributed to the conceptualisation, methodology, investigation, data curation, formal analysis, use of software for visualisation, writing of the original draft and manuscript editing.

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Reflecting on my PhD journey, I realise it has been an extraordinary blend of joy, resilience and profound learning, enriched by the remarkable people and the unique environment surrounding me.

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The support I received from the Institute of Social Studies department members as a doctoral student has been exceptional. Likewise, the Institute of Family Medicine and Public Health offered a vibrant and supportive community, enhancing my PhD journey with social connections and a sense of belonging. I have found that writing camps and doctoral seminars are a great way to progress in writing. The SURREAL project, a Marie Sklodowska-Curie Innovative Training Network on Urban Health funded by the European Union's H2020 under grant agreement No 956780 has given me many opportunities to network, learn and share. The interaction I had and the guidance I received from the members of the SURREAL consortium are truly valuable. Even the courses I have taken at the University of Tartu have complemented my understanding of my research at a broader level. In my PhD journey, friends and colleagues have been crucial, offering direct and indirect interaction and support that has greatly improved my experience.

My experiences at the Lossi 36, Tartu office have demonstrated the profound impact of a strategically located workspace. Embodying the '15-Minute City' concept, it provided everything I needed within a short walking distance, fostering an environment that motivated even a couch potato like me to embrace a more active lifestyle. That is why the city of Tartu deserves special recognition for being more than just a backdrop to my academic endeavours. Its serene atmosphere, coupled with accessible green spaces and a community that values healthy living, has played a crucial role in my well-being and productivity. With its unique charm and supportive environment, Tartu has truly been a home away from home.

I cannot conclude without expressing my appreciation to my husband, whose wisdom and perspective constantly reminded me that a PhD is but one milestone in a lifelong journey of discovery and learning. I am thankful for the patience of my family in Nepal, who could only send me their best wishes. This acknowledgement, while brief, cannot fully encapsulate the gratitude I feel towards everyone who has been a part of my PhD journey. Each interaction, whether big or small, has contributed to my growth and made this journey unforgettable.

LIST OF ABBREVIATIONS

ABOs	Adverse Birth Outcomes
BaP/B[a]P	Benzo[a]pyren
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CiSGA	Critically ill Small for Gestational Age
CLD	Causal Loop Diagram
CSDoH	Conceptual Framework of Social Determinants of Health
DoH	Determinants of Health
DPSEEA	Driving force-Pressure-State-Exposure-Effect-Action
EGD	European Union Green Deal
FGD	Focus Group Discussion
HiAP	Health in All Policies
ICS	Industrially Contaminated Sites
IDI	In-depth Interview
IUGR	Intra-uterine Growth Retardation
LBW	Low Birth Weight
NO_2	Nitrogen dioxide
OR	Odds Ratio
PAH	Polycyclic Aromatic Hydrocarbons
PICO	Population, Intervention, Comparison, Outcomes
PM_{10}	Particulate Matters (aerodynamic diameter $\leq$10 μm)
$PM_{2.5}$	Fine Particulate Matters (aerodynamic diameter $\leq$2.5 μm)
PoS	Production of Space
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PTB	Preterm Birth
SDoH	Social Determinants of Health
SGA	Small for Gestational Age
STS	Socio-technical System
TLBW	Term Low Birth Weight
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1. INTRODUCTION

Industrial areas impacting human health, often called industrially contaminated sites (ICS), generate significant amounts of air, water and soil pollutants. In the main European cities, the contribution of industries to air pollution-related mortality is estimated to be 13.8% (Khomenko et al., 2023). Fossil fuel industries are solely responsible for about 65% of mortality due to air pollution (Lelieveld et al., 2019). The pollutants in industrial areas range from particulate matter and sulphur oxides to heavy metals, with varying health impacts, including cardiovascular, respiratory diseases and adverse birth outcomes (ABOs) (De Sario et al., 2018). Such exposure to the industrial environment and health outcomes are more pronounced among people in vulnerable and economically disadvantaged situations. The latter often live closer to the industrial areas where air, water and soil quality tend to be lower, highlighting the role of socioeconomic disparities in health inequalities (Pasetto et al., 2019; Perlin et al., 2001).

The mitigation of air pollutants (e.g. soot) emitted from industries is not only a human health issue but also a matter of reducing contribution to climate change (Fuller et al., 2022). Climate change mitigation through curtailing emissions has been set as a major international goal by the United Nations Framework Convention on Climate Change (UNFCCC) and advocated also by the European Green Deal (EGD) (Kreienkamp et al., 2022). The EGD promises to shield citizens from environmental risks by transitioning from fossil fuel-based energy sources towards renewables, setting its goal "to protect the health and well-being of citizens from environment-related risks and impacts" (European Commission, 2019). The EGD's energy transition policy with a zero pollution action plan should support the achievement of several health and well-being related sustainable development goals (SDGs), such as reduction in deaths and illnesses from air pollution, including in cities (European Commission, 2022; United Nations General Assembly, 2015). However, Koundouri et al. (2024) found that the EGD policies, including the energy transition policy, are least aligned with the SDGs related to social sustainability, such as health and equality.

One of the key indicators of health and well-being in early life is adverse birth outcomes (ABOs), with environmental factors influencing foetal development, which affects health across the life course (Barker et al., 1993; Martens et al., 2019). Exposure to environmental hazards, including air pollution, often leads to ABOs such as low birth weight, intrauterine growth retardation and premature birth, which are linked to chronic adult diseases such as heart disease, hypertension and diabetes (Arima and Fukuoka, 2020; Swanson et al., 2009). Thus, the significance of ABOs extends beyond neonatal health, impacting lifelong health conditions. However, even though a critical life stage, the perinatal period has been under-explored in studies linked with the ICS (Lee et al., 2020; Poursafa and Kelishadi, 2011). Even though fine particles and particulate matter are the most studied pollutants, there is an insufficient and even mixed understanding of the relationship between ABOs and specific pollutants (such as benzene, polyaromatic hydrocarbons and heavy metals). The research on the pollutants from industrial sources, like power plants and petrochemical industries, is even less comprehensive (Melody et al., 2019; Moghaddam Hosseini et al., 2023; Nieuwenhuijsen et al., 2013). This thesis is motivated by the observed need for a comprehensive review of ABOs' relationship among people living in or near the ICS. Furthermore, it clarifies the unequal birth outcomes in the ICS of North-Eastern Estonia.

While industries, especially those in the fossil fuel sector, pose substantial risks to environmental public health, they are also pivotal for energy production, economic revenue and employment – the foundations of local well-being and health (Galgoczi, 2019; Oei et al., 2020; Oliveras et al., 2020; Żuk, 2023). For instance, in the coal mining regions of Turoszów, Poland, about 40% of people depend on mining and most of them fear that their financial situation will deteriorate due to the energy transition process (Żuk, 2023). Such changes from energy transition can impact the social determinants of health - socioeconomic, cultural and political situations leading to social inequalities, which in turn may lead to unequal health and well-being outcomes (Dahlgren and Whitehead, 2007; Marmot and Bell, 2016; Solar and Irwin, 2010). In EGD, there is already a low representation of sustainable development goals of good health and well-being (SDG3) and reduced inequalities (SDG10) (Koundouri et al., 2024). In response to such a lack of attention to social sustainability, the energy transition process might foster inequalities in people's health and well-being. This makes energy transition a typical "wicked problem". The remedies cause problems that are often unintended and unforeseen (Alford and Head, 2017; Tutton, 2017) as a solution for climate change can compromise social determinants of health.

Learning about these dynamics has intrigued me to question how industrial areas transitioning towards sustainability cope with the dual challenge of protecting environmental and social determinants of health. The persistent ICS-related health inequalities, coupled with the ongoing energy transition under the EGD, highlight a critical research gap: the impact of climate action on health and well-being, particularly its socioeconomic aspects (Pereira et al., 2021). Thus, another motivation of this thesis is derived from the lack of contextualised knowledge focusing on local health and well-being in the transition from a polluted to a cleaner environment.

This thesis aims to clarify the local health and well-being impacts of the existing fossil fuel-based energy system and its transition to a cleaner system. It explores the environmental and socioeconomic factors as possible sources of underlying health inequalities in Ida-Viru County (North-Eastern Estonia), an area impacted by oil shale industries. The same case study area illuminates the effects of the interaction between the transition of energy and health systems on health and well-being.

Estonia makes an exemplary case of energy transition as Sompolska-Rzechuła and Kurdyś-Kujawska (2021) found that the country was ranked better in SDG3 (health and well-being) implementation but at the expense of SDG13 (climate action) in the ranking of EU countries between 2010 and 2018. Creating synergies between these two SDGs was not prioritised, as was the case in most of the EU countries. In the fossil fuel-specific region of North-Eastern Estonia, the local population faces dual injustices in the energy transition scenario. They are put in the position to choose good environmental health (SDG3) by transitioning to sustainability or to maintain the jobs (SDG8) in the fossil fuel industry (Kanger and Sovacool, 2022). Addressing this challenge, the thesis explores the following research questions:

1. How does exposure to ambient industrial pollution during pregnancy affect birth outcomes?
2. Which segments of the population are disproportionally affected by adverse birth outcomes due to the current oil shale industry in Estonia?
3. How might climate action on energy transition, driven by the European Green Deal, affect the local people's health and well-being?

Addressing these questions, this thesis seeks to thoroughly understand the environmental health challenges in ICS, their unequal distribution and the broader implications of climate policies on local health and well-being. This thesis encompasses a comprehensive literature review, an epidemiological study and a qualitative analysis to understand the pattern of health inequalities both before and during the energy transition. In this thesis, **Study I** demonstrates the robust link between industrial pollutants adversely impacting birth outcomes. **Study II** presents the significant association between ABOs, air pollutants, mothers' ethnicity and mothers' education in Estonia – mothers in Ida-Viru County are disproportionately affected by environmental and socioeconomic factors. **Study III** provides a contextualised understanding of the energy transition prompted by EGD that impacts the socioeconomic dimensions of health and well-being. **Study III** shows that the already vulnerable people in Ida-Viru County are at risk of aggravated vulnerability in the energy transition process.

This thesis contributes to existing knowledge by juxtaposing the health and well-being impact of polluting ICS and the transition from those polluting ICS in Ida-Viru County directed by the EU. It also provides valuable insights for similar regions undergoing transition. The findings and perspectives of this thesis are useful for policymakers at the EU and national level to act on existing social inequalities in addition to current EGD policies.

1.1. Background of the study area

This thesis explores the relationship between industrially contaminated sites and public health. The thesis focuses on the case of Ida-Viru County and its industrially contaminated sites in the Northeastern county of Estonia. Estonia is a member state of the European Union. Estonia's energy production has long depended on a carbon-intensive oil shale energy system with the world's highest ecological carbon footprints per capita (Global Footprint Network, 2022; International Energy Agency, 2022; Ministry of Finance, Estonia, 2021). Also, it is one of the highest emitters of greenhouse gases per capita among OECD countries

(OECD, 2021). However, in 2023–2024 the share decreased due to lower electricity and higher carbon price (Kuusk, 2024). All the oil shale areas in Estonia are located in Ida-Viru County, making the county valuable for energy, revenue and employment ("Estonia 2035: Adopted by the Parliament," 2021).

1.1.1. Socioeconomic context

Even though Ida-Viru County is the source of the largest oil shale industry in Estonia, the poverty rate in Ida-Viru County is higher than the national figure and is increasing in trend (Statistics Estonia, 2024). According to the most recent data from 2022, the relative poverty rate in Ida-Viru County was 31.4%, compared to 22.5% at the national level (Statistics Estonia, 2024). In 2023, the unemployment rate for the 15-64 age group in Ida-Viru County (10.7%) was higher than the national rate (6.6%), making it the highest among all counties in Estonia. This pattern has been consistent in previous years (Statistics Estonia, 2024).

The population is concentrated in an industrial area in the northern part of the county. The majority of the population in the region is Russian (74%), and Estonians are 17.6% (Statistics Estonia, 2024). The population is ageing. As of January 2024, 15.35% are over 65 years in Ida-Viru County, while at the national level it was 11.51% (Statistics Estonia, 2024). Nevertheless, the population is ageing throughout Europe, with 21% of the population aged 65 and above in January 2023 (Eurostat, 2024). Such a decreasing and ageing population is expected to significantly impact health and welfare services and living and working conditions, requiring policy adaptation ("Estonia 2035: Adopted by the Parliament," 2021). These socioeconomic contexts make it urgent to study the unintended impact on the health and well-being of the energy transition currently ongoing in Estonia. This case study will add further knowledge to the existing literature about the unexplored interaction between energy systems and health and well-being systems in the energy transition context.

1.1.2. Health impact of the oil shale industry

Ida-Viru County has the lowest life expectancy in Estonia (75.75 Vs. 78.98 in 2023) (Statistics Estonia, 2024) and poor health outcomes due to the environmental impact of the oil shale sector (Idavain et al., 2020, 2019; Ministry of Finance, Estonia, 2021; Orru et al., 2018). Residents in Ida-Viru County have reported more health effects, including respiratory and heart-related syndromes, compared to residents in non-oil shale areas (Orru et al., 2018). Furthermore, the prevalence of asthma among children is higher in oil shale areas in Ida-Viru County (Orru et al., 2018). Also, the region has a higher-than-average incidence of chronic diseases and lung cancer among males (Idavain et al., 2020).

The need for studies on the health and socioeconomic impacts of oil shale industries has been raised, given the unidentified impact on health in Estonia due to environmental factors (Michelson et al., 2020; Pihor et al., 2013). The oil shale sector is responsible for poor air quality, surface and groundwater quality, and the impact on the health of workers and citizens in the region.

1.1.3. Socioeconomic changes from the just energy transition

The Just Energy Transition Mechanism was established to achieve the EU Green Deal aiming for green energy, to reduce poverty and to improve living conditions and quality of life ("EU Just Transition Fund," 2020; European Commission, 2022). The investment areas are renewable energy, clean energy technologies, emissions reduction, circular economy, site regeneration, enterprises, research and innovation, and upskilling and reskilling of workers ("EU Just Transition Fund," 2020). These activities are also being implemented in Ida-Viru County.

The country's economy will be highly affected by the climate-neutrality goal of the EU due to the loss of revenue from mineral extraction ("Estonia 2035: Adopted by the Parliament," 2021; Michelson et al., 2020). The most impacted areas will be public service provision and employment opportunities, and it is predicted that most young people will emigrate, wages will be lost and many people will have a risk of falling below the poverty line ("Estonia 2035: Adopted by the Parliament," 2021; Michelson et al., 2020). With these expected changes due to the energy transition, it is important to establish a contextualised knowledge of the socioeconomic dimension of local health and well-being.

CHAPTER 2. THEORETICAL BACKGROUND

This chapter lays out the theoretical background of the thesis. First, I clarify the use of the terms health and well-being and inequalities in them. Then, the theories and models applied in the studies are explained. Lastly, the systems thinking approach that operationally binds all the theoretical concepts is explained.

2.1. Health impacts and inequalities in industrially contaminated sites

What is health and well-being?

A vast body of scientific literature and health policies have used the WHO (2020) definition of health: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." This WHO health definition contrasts positive well-being with negative aspects, such as not being well and having illnesses and diseases. Well-being, however, has been conceptualised as broader than being in a positive health and well-being state. According to Bickenbach (2017), well-being encompasses a broader concept that includes factors such as the individual's subjective experiences and perceptions, environmental, social, and lifestyle factors, and the outcomes produced from the interaction of these factors. Thus, WHO's definition of health is criticised for not considering the changing pattern of diseases and illnesses nor the importance of primordial prevention (Bickenbach, 2017; Huber et al., 2011; The Lancet, 2009), which targets healthy populations and prevents risk factors across the multiple determinants of health, such as socioeconomic and environmental factors (Perez et al., 2022). In line with primordial prevention, Huber et al. (2011) suggest that health should be formulated as "the ability to adapt and self-manage in the face of social, physical, and emotional challenges." These broader conceptualisations recognise the inner and outer bounds of people, meaning, subjective well-being and social environment.

In this thesis, I use the term "health and well-being" as one concept to underline resilience in the face of socioeconomic challenges and proactively addressing social, physical and emotional well-being before the onset of diseases or negative health outcomes (Bickenbach, 2017; Huber et al., 2011; Perez et al., 2022; The Lancet, 2009). The thesis thereby recognises that health and well-being systems encompass both the objective outcomes utilised by science and health policies and the subjective experiences that contribute to positive well-being, preventing negative health conditions. **Study III** also uses the term "healthcare systems/ infrastructure," which is not interchangeable with the "health and well-being systems" but rather a small fragment of the latter.

Understanding health and well-being inequalities

To analyse how exposure to an environmentally polluted state impacts human health by the cause-and-effect chain, the driving force-pressure-state-exposure-effect-action (DPSEEA) (Briggs, 1999) framework is one of the fundamental conceptual models for **Studies I and II** (Figure 1). Epistemologically, the DPSEEA follows a positivist approach. In **Studies I and II,** the elements of DPSEEA used are oil shale industrial pressure on the environment, the polluted state of the environment, exposure to pollution, and the effect on birth outcomes from pollution exposure.

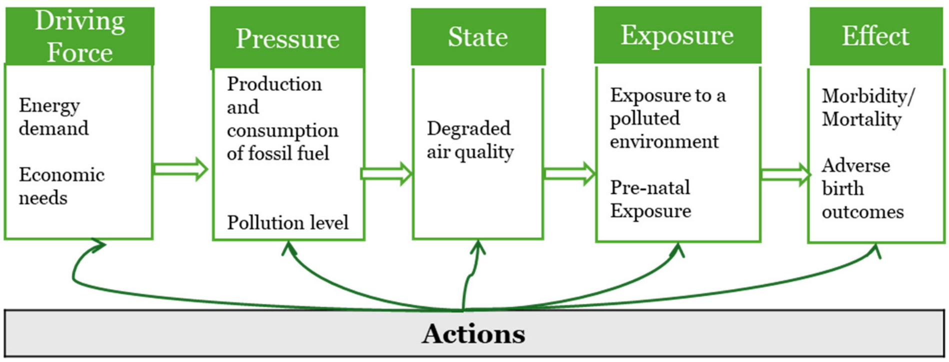


Figure 1. The DPSEEA framework (Briggs, 1999), adapted for Studies I and II

The DPSEEA framework does not capture the socioeconomic dimensions that can cause health and well-being inequalities. According to Dahlgren and Whitehead (2007), health inequalities are the "systematic, socially produced (and therefore modifiable) and unfair differences in health across the population." As per the determinants of health (DoH), unfair differences are determined by multiple factors such as individual characteristics, lifestyle factors, social and community networks, living and working conditions, and socioeconomic, cultural and environmental conditions (Dahlgren and Whitehead, 2007; Lucyk and McLaren, 2017). Compared to individual factors, the role of structural aspects is bigger, such as socioeconomic position and political context, leading to certain individual behaviours or circumstances (Marmot and Bell, 2016; Solar and Irwin, 2010). For instance, not everyone is equally exposed to and impacted by the polluted environmental state (Lin et al., 2001; Yang et al., 2004). People still live in industrially contaminated sites today for socioeconomic reasons (Pasetto et al., 2019; Perlin et al., 2001), which leads me to conclude that one should consider not only the environmental but also the socioeconomic dimensions that might be leading to social inequalities. Thus, the conceptual framework on the social determinants of health (CSDoH) frames the structural aspects as the root of inequality in health and well-being (Solar and Irwin, 2010). To put it in the language of "causes of the causes of health inequalities" (Marmot and Bell, 2016), structural aspects are the causes of social inequalities, which in turn may lead to health inequalities (Solar and Irwin, 2010). In **Study II**, the DPSEEA framework paved the way for adding the CSDoH to focus on the effects of social conditions, such as education and ethnicity, on health inequality. In **Study III**, I consider the structural aspect of the energy transition, such as the macroeconomic policies, governance and cultural values to understand the health and well-being inequalities.

2.2. Contextualising the energy transition and its impact on health and well-being

While conceptualising my PhD thesis, I frequently contemplated the optimal theoretical frames for the issues under my research. This reflection led me to consider the concept of "Health in All Policies" (HiAP). I realised that HiAP can serve as a pivotal policy integration concept in response to the understanding that health and well-being inequalities span across various socioeconomic dimensions, often extending beyond the capabilities of the health sector alone. Policy integration involves the rigorous coordination of sectoral interdependence to achieve mutual goals in two or more different policy sectors (Tosun and Lang, 2017). Horizontal governance is another term for policy integration that has been used in health and environmental policy studies (Tosun and Lang, 2017). Global health actors, including researchers, have embraced HiAP as a comprehensive approach to address these multifaceted health inequalities. HiAP is a horizontal, complementary policy-related approach that intends to deal with the determinants of health influenced by sectors other than health (Ståhl et al., 2006). HiAP has challenged the traditional approach to policy development, which is mostly siloed, calling for a more holistic approach that prioritises health and well-being in all developmental policies.

HiAP encouraged me to consider that factors outside the health sector influence health and well-being greatly. The DPSEEA and CSDoH frameworks highlight the significance of environmental and social factors in determining health inequality. Yet the question remains: What specific underlying interactions between systems lead to health inequalities, and how can we comprehensively understand the situation?

In a quest for answers to the above, I turned to the systems thinking approach to demonstrate the complex behaviour of systems. Systems thinking in public health and social science helps to understand the complex societal systems whose application is in formulating strategies and improving the system (Abidin et al., 2014; De Pinho and Larsen, 2015; Kwamie et al., 2021; Williams and Hummelbrunner, 2011). Public health researchers have called for more systems science approaches because the need for a holistic understanding of the root causes of health inequalities is greater than ever (Carey et al., 2015; Rutter et al., 2017). However, a noticeable gap exists in integrating social theories into these modelling practices in the health and well-being field. Causal loop diagrams and system dynamics models that are built without explicit theoretical framings depict the apparent process. Integrating social theories into systems modelling generates a more coherent model because social theories account for systematic interactions between social factors, context and phenomenon (Lane, 1999). I adapted the Systems Dynamics approach combined with social theories in **Study III**.

Systems thinking has led me to understand the social systems associated with a particular technology or industry. The energy transition context of Ida-Viru County is about the oil shale industry and the actors interacting around the oil shale industry.

2.3. Socio-technical systems (STS) theory

My research setting is the fossil fuel industry – the focal economic power that is closely interconnected with the lives of local population and the government. The perspective of socio-technical systems has helped to contextualise the social determinants of health and the root causes of health inequalities. The idea of socio-technical systems emerged due to a lack of understanding of how technology affects society, including health and well-being, and when social scientists were hesitant to consider technological reality (Ropohl, 1999, 1982). A socio-technical system (STS) is a system of provision of essential societal functions of everyday life, such as energy, communication, food, health or transportation, which is shaped by the actors, rules and technologies that also shape individual behaviour (Geels, 2005; Ropohl, 1999, 1982).

Ropohl (1999, 1982) argues that as technological developments grow, they naturally involve society via different processes, such as organisations, social systems, economic and social goals, cultural aspects and governmental interventions. Thus, from the sociological perspective, technological development is socialised, meaning that institutions lead and shape individual behaviour, integrating technology into a common culture (ibid).

Socio-technical systems theory underlines how well the human and technical resources are installed to fulfil the collective tasks (Eason, 2014; Klein, 2014; Ropohl, 1999, 1982). In literature, the most used STS theory is the hexagonal framework of socio-technical systems that conceptualises the complex interactive nature of work systems that involves people, goals and culture as social elements, and processes, infrastructures and technology as technical elements (Figure 2) (Challenger et al., 2009; Clegg et al., 2017; Davis et al., 2014). Geels (2005) also emphasised that the societal and technical properties are strongly interconnected and thus affect each other, as underpinned by the socio-technical systems theory (Cherns, 1976; Clegg, 2000; Eason, 2014; Klein, 2014; Ropohl, 1999). According to Geels (2005), societal functions are fulfilled by various socio-technical systems involving dimensions of technology, markets and user practices, infrastructure, symbolic meaning/culture, scientific understanding and public policies and regulations (Figure 2).

Scholars have used the STS theory in several settings, such as organisational and transportation systems (Clegg et al., 2017; Geels, 2005). I use STS in the interplay between energy and health and well-being systems. Since the industrially contaminated sites indicate the health-harming effects and the transition process indicates the social injustices, I use industry/infrastructure as a fundamental STS dimension for studying the interaction between energy and health and well-being systems. In **Study III**, I used STS to understand how socio-technical systems of energy and health and well-being interact and fulfil everyday life's basic needs. I applied STS to explore how the oil shale industry interacts with cultural significance and energy, economic demands and local income necessities. Furthermore, STS explores how the energy system is influencing the health and well-being system.

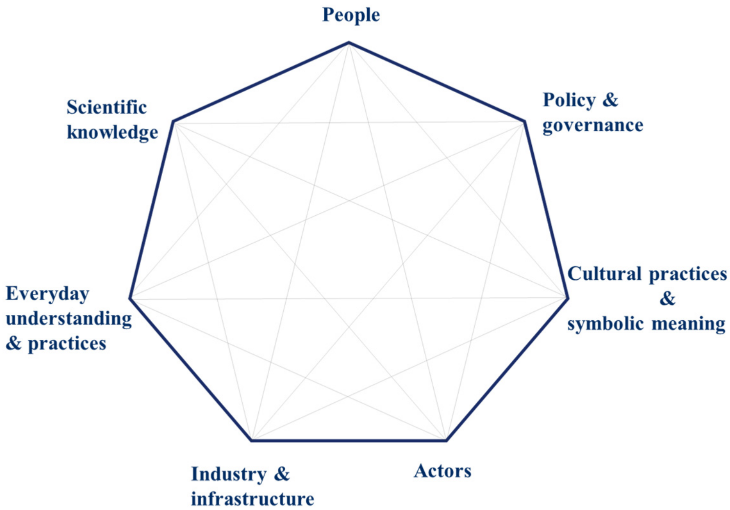


Figure 2. Dimensions of socio-technical systems, based on Challenger et al. (2009), Clegg et al. (2017), Davis et al. (2014) and Geels (2005)

While the people and processes dimensions of STS were helpful as a starting point to integrate the STS theory in **Study III,** later during the data analysis, along with my co-authors, we felt the need for further clarification on how social processes occur among different actors. Thus, in **Study III,** I started with the STS theory and subsequently incorporated the production of space (PoS) theory to frame the analysis on a theoretical basis. The added value of PoS to the analysis was the spatial dimension of social interactions and a more comprehensive understanding of the social processes in the context of the energy transition of the oil shale industrial region. I explored the social processes among actors, such as inhabitants, government and industrial personnel through the PoS theory.

2.4. The production of space (PoS) theory

Generally, we perceive that the physical space is natural and neutral. However, in the PoS theory, Lefebvre (1991) integrates the tangible and intangible concepts of space by combining the physical, social and mental spaces together. Lefebvre (1991) argues that the space is produced by social processes and experienced by social actors. The social process forms a spatial triad (Figure 3): spatial practice, representations of space and spaces of representation (lived space), which were useful to conceptualise the health and well-being impacts of the energy transition in **Study III**.

Spatial practice is a perceived space, which is about the actual use of the space and how people navigate and create meaning within it. It is about the physical and material aspects and people's everyday activities in that space. In Ida-Viru County, the oil shale industry is a physical and material space where people's everyday activities are mining and other industry jobs. *Representations of space is the conceived space*, which is about how space is mapped, visualised and described and what sort of symbolic and mental models are produced. Authorities, planners and technocrats conceive space this way to legitimise and control the space. In the oil shale industrial region of Ida-Viru County, the space is conceived by authorities as the energy and economic hub. Finally, *spaces of representation are lived spaces* of the inhabitants or users, where they produce subjective and emotional events such as feelings and memories in their minds. The lived mental space influences how people interpret the actual physical space as the sociocultural and personal circumstances shape them. Miners and other inhabitants in Ida-Viru not only do their jobs in industries as their everyday activities but also create meaning. For instance, it is a social and cultural space for them, and they might be quite attached to the oil shale industry.

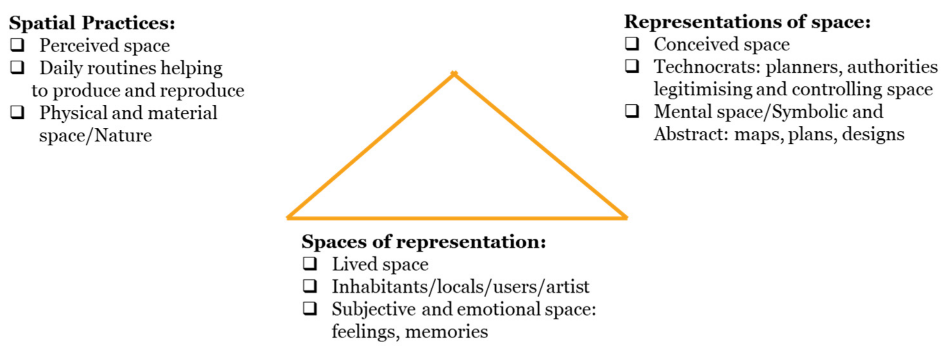


Figure 3. Spatial triad, Lefebvre (1991)

Study III complements the STS theory with the PoS model to benefit from their complementary perspectives on social interaction and structure. Integrating PoS with STS improved the understanding of the local population's real-life experiences and their tension with authorities and industries, thus avoiding the risk of being limited to the authorities' perspectives. The theoretical concepts discussed above have been crucial in constructing the narrative and thematically organising the results by modelling the system. The model is well representative of the social context and phenomenon due to the theoretical framing (Lane, 1999).

2.5. Summing up the theoretical scaffolding of the thesis

Finally, I summarise (Table 1) how the theoretical concepts have contributed to modelling the system, highlighting their strengths and limitations. The DPSEEA model acknowledges that policies in various areas, such as the environment, the economy and technology, drive health effects. However, it lacks interpretation of these policies as systems, and the cause-effect chain is considered linear. The cause-effect chain is investigated in **Studies I and II**. Further understanding of health is determined by various social, political and economic factors, which have been more pronounced by social determinants of health (Dahlgren and Whitehead, 2007; Solar and Irwin, 2010). These concepts were the starting point of this thesis' conceptualisation as they helped look for non-healthcare factors, such as the social dimension impacting health and well-being.

The limitation of social determinants of health is its deterministic approach, which reduces the system into different components and assumes that understanding the individual components leads to an understanding of the entire system (Solomon et al., 2022; Walker et al., 2010). Therefore, scaffolding through the concepts of the DPSEEA framework and social determinants of health, I sought to clarify how social dimensions interact with driving forces that lead to health effects. I incorporated socio-technical systems (STS) and the production of space (PoS) theory. STS considers aspects such as social norms around the oil shale industry, while the production of space (PoS) theory helps to shed light on how people create meaning through their lived experiences. Similarly, on the structural level, STS enables the consideration of the institutional, industrial and policy dimensions, while PoS addresses the process of authorities planning and managing the space and inhabitants using the space. HiAP, however, reminds us that health and well-being should be the business of every non-health sector's policy. This combination was beneficial in **Study III** as it helped to see the interplay among the social actors and structures in a specific energy transition context. The contextualised knowledge generated via the case study in **Study III** also aids in understanding the findings of **Studies I and II** (Flyvbjerg, 2006).

The systems approach illustrates interactions across different levels of social structure, while social theories provide a fundamental understanding of system models. Therefore, **Study III** captures the social interaction process in the system model, specifically the causal loop diagram. The benefit of the systems approach in understanding health inequalities is that it explicitly demonstrates the underlying causes (Diez Roux, 2011). Since the underlying causes are usually dormant in the structure and policy of the system, systems modelling would complement the existing understanding of health inequalities (Diez Roux, 2011).

Table 1. Summary of the theories and concepts used in this thesis

Theories/Concepts	Key ideas	Contribution to this thesis	RQs* and studies
Driving force-pressure-state-exposure-effect-action (DPSEEA)	Cause-and-effect chain thinking to understand the impact on human health from the environmental state.	Analysis of the exposure-effect relationship.	Addressing RQ1 in Studies I–II.
Conceptual framework on the social determinants of health (CSDoH)	Social conditions (e.g. education, income level) and structural aspects (e.g. macroeconomic policy, governance) are the roots of inequality in health and well-being.	Outlining the underlying causes of health and well-being inequalities.	Addressing RQ2-3 in Studies II–III.
Health in All Policies (HiAP)	A holistic policy approach that prioritises health and well-being across the non-health sectors.	Analysing the structural aspects outside of health and well-being sectors as potential causes of health and well-being inequalities.	Addressing RQ3 in Study III.
Socio-Technical System (STS) theory	A system of provision of essential societal functions of everyday life, such as energy and health, is shaped by the actors, rules and technologies, shaping individual behaviour.	On the structural level, clarifying social interaction between institutes, industries, and policies.	Addressing RQ3 in Study III.
Systems Thinking Approach	Holistic thinking and modelling to expose the dormant mechanisms.	Binding all the concepts and modelling the underlying mechanisms.	Addressing RQ3 in Study III.
Production of Space (PoS) theory	Space is produced by social processes and experienced by social actors. Integrates the tangible and intangible concepts of space by combining the physical, social and mental spaces.	Understanding the social process of authorities planning and managing the space and inhabitants using the space addressing and creating meaning through their lived experiences.	Addressing RQ3 in Study III.

* Research Questions (RQs):
1. How does exposure to ambient industrial pollution during pregnancy affect birth outcomes?
2. Which segments of the population are disproportionally affected by adverse birth outcomes due to the current oil shale industry in Estonia?
3. How might climate action on energy transition, driven by the European Green Deal, affect the local people's health and well-being?

CHAPTER 3. METHODOLOGY

3.1. How is knowledge created? A philosophical background

Given the complexity of the research questions in my thesis, two major philosophical paradigms, positivism and critical realism, have guided the ontological, epistemological and methodological choices in my doctoral study (Denzin and Lincoln, 2013). In the following, I briefly explain these paradigmatic positions to indicate the epistemological basis of my methodological choices and explanations.

Studies I and II follow the positivist paradigm. The positivist stance recognises that there is an external reality independent of human thoughts and perceptions, and the researcher is separated from the study to generate knowledge using quantitative methods to generate number-based facts (Lane, 1999). Following the positivist paradigm, I used the DPSEEA framework to study the relationship between exposure and effect. In **Study I**, the external reality was the link between industrial air pollutants and birth outcomes. My co-authors and I hypothesised that exposure to industrial air pollutants impacts birth outcomes, and we synthesised global evidence based on quantitative studies to test this hypothesis. In **Study II**, the observed external reality was the association of adverse birth outcomes (ABOs) with air pollutants, mothers' ethnicity, education and age in Estonia. I, along with my co-authors in **Study II**, employed data from the Estonian birth registry and air pollution database to test the hypothesis: Ida-Viru County has perinatal health inequalities across socioeconomic strata, and industrial air pollutants impact the county more than the other regions of the country. Both studies generated number-based knowledge, where, as an investigator, I had no subjective interpretation of the findings. The positivist paradigm guided me to study the observable health effects of exposure to industrial pollution.

Critical realism, quite different from positivism, ontologically believes that the causal mechanisms of social phenomena remain unseen until discovered (Lawani, 2020). I explored the causal mechanisms of the interaction between energy and health and well-being systems and the impact on the latter. In other words, I explored the underlying mechanisms of the observable effects on health and well-being, conceptualising the ideas via the iceberg model (Figure 4). Even the concepts of social determinants of health did not help me to understand the social mechanisms. Thus, the critical realist paradigm helped go beyond the deterministic thinking of exposure and effect relationship. In the iceberg model, I show that the end impact on health and well-being is just the tip of the iceberg; the causes lie under the tip. I utilised the socio-technical systems (STS) and production of space (PoS) theories to observe and interpret reality. By following the critical realism paradigm, I aimed to richly explain the patterns that occur in the studied phenomenon of environment and health inequalities while showcasing the causal mechanism. In summary, the positivist paradigm supported studying the observable health outcomes, whereas the critical realist approach offered valuable insights into the underlying social processes leading to the observed health outcomes.

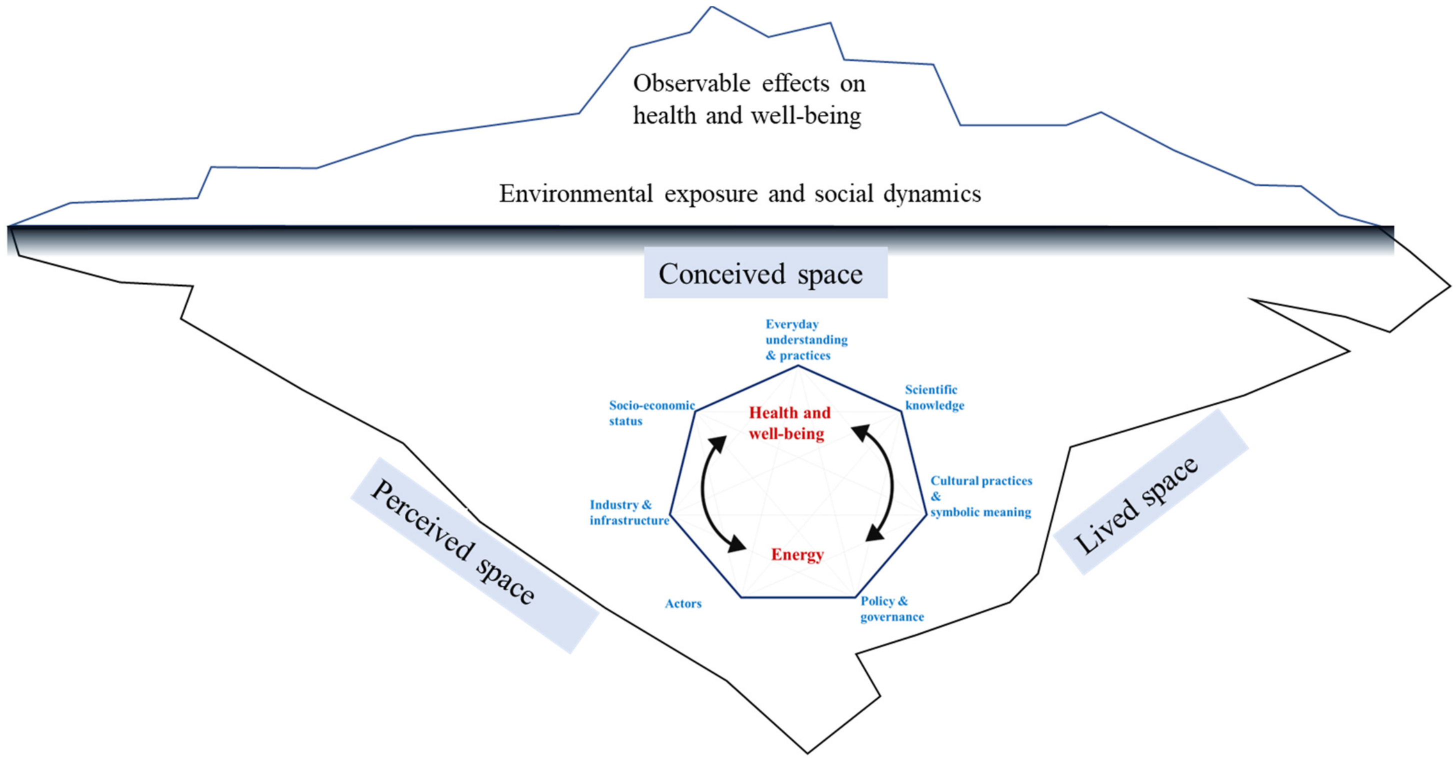


Figure 4. Iceberg model showing the observable and unobservable areas (Author's compilation based on the theoretical frameworks)

3.2. Study design, data collection and analysis methods

The research questions of this thesis require a multifaceted methodological approach to capture the relationships between industrially contaminated sites and their impact on health and well-being. This doctoral thesis uses three research methods: systematised literature review, quantitative epidemiological analysis and qualitative studies (Table 2).

In this thesis, I start with a systematised review **(Study I)** to synthesise the global evidence of the impact of air pollutants emitted from industrially contaminated sites on birth outcomes. The main goal of the systematised review is to synthesise the current evidence and identify the research gaps (Grant and Booth, 2009). Given the evidence from the systematised review and considering the ongoing political and societal changes in Estonia's oil shale industrial region, examining the health impacts associated with industrial contamination in the area becomes crucial. Thus, I follow the registry study with a special focus on Estonia's oil shale industrial region and its impact on birth outcomes in **Study II**. A registry-based cohort study enables analysis of the relationship between exposure and outcome variables based on non-concurrent data (Wang and Kattan, 2020). Finally, to capture the complexities of the political and societal transition of the industrial region, I follow a qualitative study based on the systems thinking approach in **Study III**. The systems thinking approach enables linking the direct and indirect impact of one system (energy system) to another system (health and well-being system) (Abidin et al., 2014; Kwamie et al., 2021).

Table 2. Synopsis of methodologies

Studies and Research Questions	Type of Study	Type of Data	Data Collection Method	Data Analysis Method
Study I, Research Question 1	Systematised literature review	Peer-reviewed scientific articles on environmental pollution from industrially contaminated sites and adverse birth outcomes across the world	Systematic literature search	Systematised review of included peer-review articles for the study
Study II, Research Question 2	Epidemiological Retrospective Cohort Study	Estonian birth registry about birth data, Estonian population registry data about home addresses, modelled and measured air pollution data and calculated distance to the industry	Data extraction from the Estonian birth registry and air pollution models	Multiple logistic regression analysis
Study III, Research Question 3	Qualitative study	Interviews with Estonian stakeholders and document sources from Estonia and the EU	In-depth interviews and focus group discussions with field experts. Review of documents such as reports, news and a master's dissertation.	The conceptual framework driven content analysis. Systems approach to develop causal loop diagram.

3.2.1. Data collection of the systematised literature review

Study I conducted a systematised review of peer-reviewed scientific articles from all regions to find evidence linking industrial pollutants and ABOs. This type of review is chosen for its efficiency in terms of resources and time, compared to other types of review, such as a systematic review or meta-analysis (Grant and Booth, 2009). While systematised and systematic reviews share similarities in their study processes, the key difference lies in the extent and the requirement of a pre-published rigorous protocol for systematic reviews (Grant and Booth, 2009). The systematised review in **Study I**, however, incorporates many elements of this protocol, as outlined by Pati and Lorusso (2018). The aim is to systematically collect, evaluate and present evidence from these globally sourced, peer-reviewed articles to answer the research questions (Grant and Booth, 2009).

From the literature search in the PubMed and Scopus databases, 246 records were extracted. In the end, 45 articles were included in the review. In the literature search, two methods were applied to search the articles:

I. Database literature search: The co-authors of the **Study I** conducted literature searches in PubMed and Scopus using relevant terms about adverse birth outcomes and air pollutants.
II. Snowball search: I conducted a snowball search in **Study I** to complement the traditional database search by my co-authors and ensured no important articles were missed. This search was conducted using the reference lists of the articles initially identified through database search.

To ensure the systematised review study's validity, together with the other authors of the study we established the inclusion and exclusion criteria by setting the boundaries for eligible studies and included only the most relevant articles (Pati and Lorusso, 2018). I reviewed and improved further the inclusion and exclusion criteria of the peer-reviewed full-text articles based on PICO (Population, Intervention, Comparison, Outcomes) for narrowing down the focus and collecting the most suitable search results (Pati and Lorusso, 2018). The included studies in the review study date from 1998 up to September 2020; however, most of the articles were recent.

The inclusion criteria, based on PICO, were the following:

1. Study **P**opulation: Mothers with a live-born child/children
2. Exposure to at least one industrial pollutant (**I**ntervention in the PICO framework): Pregnant mothers exposed to at least one industrial pollutant: $PM_{2.5}$, PM_{10}, PAH (including benzo(a)pyrene), benzene, BTEX or heavy metals
3. **C**omparative population: Pregnant mothers not exposed to industrial air pollution or exposure was significantly lower
4. Health **O**utcome measures: Studies on the effects of industrial air pollution for at least one of the adverse birth indicators: low birth weight

(LBW), preterm birth (PTB), small for gestational age (SGA), term low birth weight (TLBW)

The main exclusion criteria were:
1. Studies on indoor air pollution and occupational exposures
2. Studies with animal experiments

3.2.2. Analysing the systematised literature review

After collecting the data among published peer-reviewed full-text articles based on the PICO framework in the literature review **(Study I)**, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline (Moher et al., 2009) was followed for the analysis. For each article in **Study I**, two authors generated a report following the PRISMA checklist that covered the study design, study area, number of observed births, exposure, outcome(s) assessed and main result. Then, one author reported the results under the theme of air pollutants and distance to industrially contaminated sites and their impact on adverse birth outcomes. I reviewed those and added further analysis to the text.

3.2.3. Data sources of the epidemiological cohort study

The setting of **Study II** is Estonia and Ida-Viru County. Since the industrially contaminated sites are located in Ida-Viru County, a special focus was on that region to identify the inequality in perinatal health.

Outcomes variables
Study II employed the birth registry-based retrospective cohort study. This type of epidemiological study examines the effect of health risk factors on already-observed health outcomes, which are preterm birth and low birth weight in this study. A retrospective study based on the registry data is inexpensive and time-efficient as the exposure and outcome data are extracted from the database (Wang and Kattan, 2020).

The Estonian births are recorded in the national registry. We analysed records from 2004 to 2018, totalling 208,313 births in Estonia, which were extracted for analysis. Similarly, for the neighbourhood socioeconomic status (SES) indicator, from Statistics Estonia, county-level income coefficients from 2004–2018 were extracted. The birth registers include maternal and neonatal health data and demographic characteristics. The neonatal health indicators are the ABOs: preterm birth (PTB: ≤37 weeks of gestation) and low birth weight (LBW; birth weight ≤ 2500 g).

Exposure variable: Industrially contaminated sites
I included two types of exposure variables in the industrially contaminated sites:
1. Modelled concentration of air pollutants
2. Residential proximity to industrially contaminated sites

To assess the air pollution exposure, other co-authors built an exposure model based on measured and modelled air pollution to capture the temporal, spatial and residential differences in the following process (Figure 5).

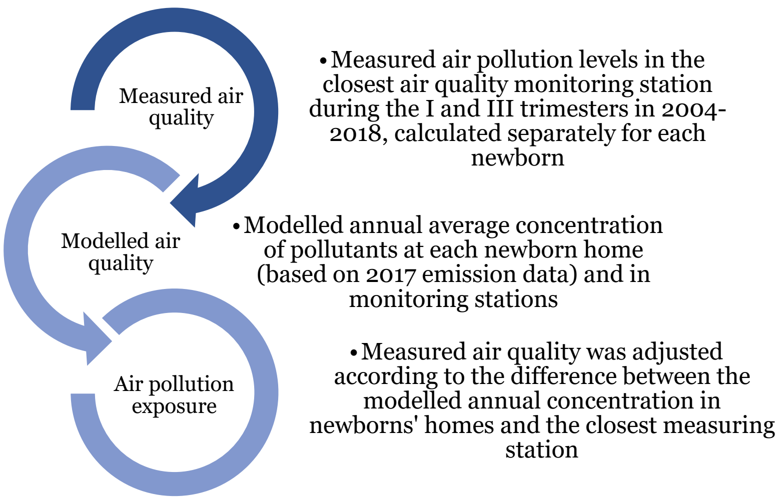


Figure 5. Air pollution exposure assessment

1. Measured air pollutants: To collect the measured concentration of air pollutants, particulate matter (PM_{10}), fine particles ($PM_{2.5}$) and nitrogen dioxide (NO_2), data from the air quality monitoring station in Estonia was obtained. Then, each child was assigned to the nearest air quality monitoring station based on their recorded address in the population registry at the time of their birth. Subsequently, each child's daily average air pollution exposure concentration was calculated based on the air pollutant readings obtained from the assigned monitoring station.
2. Modelled air pollutants: The modelled annual mean concentration of pollutants in 1 × 1 km grids was accessed from the Estonian Air Quality Management System, which is based on the Airviro modelling system. The dispersion modelling was based on emissions from different sources. From the national point source database, OSIS2017, the industrial emissions for the year 2017 were used as input for the dispersion modelling. The database contained more than 40 different substances and substance classes reported by companies and validated by the Estonian Environmental Board. In the modelling, the Estonian Environmental Research Centre used agriculture emissions, traffic emissions data from Traffic2017, and domestic heating emissions from the in-house database Localheating2017, which is based on the Estonian Building Register. Such hybrid modelling was used to get the air pollution estimates since there were only four monitoring stations.

3. Exposure model and its validation: First, the modelled concentrations were validated against the measured data obtained from the Estonian stationary monitoring stations and the measurement from the passive sampler campaigns. Later, the measured pollutant levels during the child's mother's first and third trimesters were adjusted based on the differences in the modelled pollutant level between the home address and the temporal trend from the nearest represented monitoring station. For measuring the pollutants, the following monitoring stations were used: Tallinn Õismäe (Baltic Sea bordering counties), Tartu (inland counties), and Narva and Kohtla-Järve (municipalities in Ida-Viru County).
4. Geographic visualisation: In the ArcGIS (v10.3, ESRI, Redlands, CA, USA) scripting environment ArcPy, the annual pollutant level per 1 × 1 km grid cell from the modelling was geocoded and linked for each child's home address (address recorded during birth).

3.2.4. Analysing the epidemiological cohort study: multiple logistic regression

In the epidemiological study **(Study II)** about adverse birth outcomes in industrially contaminated sites, I did a multiple logistic regression analysis on social inequalities. Multiple logistic regression analysis fits the model of the association between the binary dependent variable and a set of independent variables (Valveny and Gilliver, 2016). A parameter regularly used in multiple logistic regression is the odds ratio (OR), whose value can range from zero to positive infinity (Valveny and Gilliver, 2016). The OR of a health condition represents the odds of a health condition occurring in a group divided by the odds of the same health condition occurring in a reference group (Valveny and Gilliver, 2016). The formula of OR is:

$$\mathrm{OR} = \frac{p_A(1 - p_B)}{p_B(1 - p_A)}$$

where,
p_A is the probability of an adverse birth outcome in population A
p_B is the probability of an adverse birth outcome in population B

To calculate the OR, the dichotomous dependent variables are the indicators of adverse birth outcomes: preterm birth (PTB: ≤37 weeks of gestation) and low birth weight (LBW: birth weight < 2500 g). The independent variables are maternal exposure to air pollutants, maternal residential proximity to ICS and maternal sociodemographic characteristics (education, age, ethnicity). The reference population in each independent variable is those with low exposure to air pollutants, maternal residence more than 10 km distance from ICS, mothers with high school level education, mothers aged 25-29 and mothers of Estonian ethnicity.

We adjusted/controlled the confounding variables in the logistic regression model to avoid confounding bias. Confounding variables are the external factors that can affect both dependent and independent variables. Confounding bias means that the relevant variables from the regression model are excluded, which can result in an exaggerated or masked relationship or false association between dependent and independent variables (Wang and Kattan, 2020). Statistical control for the confounding variable can increase the study's internal validity.

The following three models were developed through multiple logistic regression analysis:

1. A crude model for the association between exposure and outcome variables, which means a model without adjusting to confounding variables.
2. An adjusted model for the individual-level sociodemographic variables, which includes the mother's education, ethnicity and age.
3. A fully adjusted model, which adjusts for the individual–level sociodemographic variables and the status of the pregnant mother. The confounding variables include the mother's education, ethnicity, age, in vitro fertilisation, earlier caesarean section, preeclampsia, preterm birth risk during pregnancy, miscarriage risk during pregnancy, gestational diabetes, mother's hypertension and chronic diabetes.

In **Study II**, I ensured the measures of health inequalities were taken in two ways. First, I analysed national and county levels in the above models to identify health inequality and explore how these levels differ. Second, I analysed various sociodemographic characteristics to identify inequality at the national and county levels. Independent variables on sociodemographic markers and residential proximity to ICS are the key indicators of perinatal health inequalities. The key inequality indicators of risk factors are the mother's education, ethnicity and residential proximity to ICS. Residential proximity to ICS, however, also serves as a marker of air pollution level as the closer distance exposes to higher levels of pollutants.

3.2.5. Data collection of the qualitative study

Research question three aimed to understand the interaction between energy and health and well-being systems and their impact on the latter. In Study III, I employed a qualitative study that followed a conceptual framework on the underlying causes of the impact on health and well-being. Specifically, I followed the general inquiry approach and incorporated the case study method based on qualitative research (Lim, 2024). The case study method is used to gain a contextual understanding of the dynamics and complexities of the ongoing Just Transition in Ida-Viru County, which may be impacting local health and well-being (Flyvbjerg, 2006; Lim, 2024).

Based on the conceptual framework, I developed the data collection guidelines (Figure 4). I collected two types of data, primary and secondary data, to collect as many diverse perspectives as possible and also to triangulate the data.

I started the study by reviewing secondary data such as public records, policies, reports, news articles, research reports, master's dissertation, publicly available interviews and presentations from high-level government meetings at the EU and Estonian levels. The review of secondary data aided in understanding the context and ongoing progress concerning the study topic of energy transition and health and well-being (Bowen, 2009).

Primary data collection methods included focus group discussion (FGD) and in-depth interviews (IDI) with various actors from April to July 2022. The FGD collected the data based on the interaction among the participants whose perspectives and understandings were discussed, challenged, and then a consensus was formed (Lambert and Loiselle, 2008). An IDI is a one-to-one interview to collect in-depth information on the study topic (Lambert and Loiselle, 2008). The primary data collection guidelines were semi-structured, allowing other participant information to be gathered via the open questions.

I conducted FGDs and IDIs in English and recorded and fully transcribed them using the NVivo transcription software. Primary data helped to gather the perspectives and current understanding of the experts working in different fields, including the situations of different sectors (Lambert and Loiselle, 2008). Key actors were from the local to national levels, working in public health research, local governance, ministries, NGOs and energy industries. Four FGDs were conducted with a maximum of six participants and lasted an average of 75 minutes. In two of the FGDs, my co-authors also moderated the discussion. Similarly, I conducted six IDIs that lasted an average of 70 minutes. These IDIs included environmental, education, local governance, energy transition and industry actors. Additionally, data from four IDIs recorded in 2019 about the industrial area and stakeholders' perceptions about the oil shale industry and its impact on health were reviewed to see if there were any similarities or differences from the data I gathered.

3.2.6. Analysing the qualitative study: content analysis and interpretation through a systems approach

I followed a case study approach in **Study III** and analysed the findings by theorising the observed reality to explain the phenomenon (Lawani, 2020). The theoretical frameworks guided me to analyse and interpret the findings. I applied thematic content analysis to review secondary data and code the primary data to identify the patterns and relationships within a complex topic from the participants' perspectives and the documents (Bowen, 2009; Graneheim and Lundman, 2004; Silverman, 2019).

Given the complexity of the research problem in research question three, thematic content analysis was chosen to allow us to analyse the underlying meanings and interpretations within the energy and health and well-being systems. After that, I did the systematic coding from the content analysis, which helped to narrow down the relevant data based on research question three about the interacting points between systems.

Afterwards, a systems approach helped to interpret the data and model the causal loop diagram (CLD) (Cassidy et al., 2022). Rutter et al. (2017) argue that the systems approach should be adopted in public health because it conceptualises health inequalities and poor health outcomes due to the interaction of the variety of connected independent elements within a system. The public health field has not engaged enough with a range of available systems methodologies in other science disciplines (Carey et al., 2015). Nevertheless, using the knowledge of the systems approach from other disciplines, such as the social, economic and behavioural sciences, is frequently stressed in public health (Mabry et al., 2008; Rutter et al., 2017). Thus, in Study III, CLD has served as a tool to interpret the data and visualise the interactions/complexities between the systems.

Developing the causal loop diagram (CLD)

One of the tools of system dynamics, the Causal Loop Diagram (CLD), is relevant to visualise the complexity of the mechanisms and consequences of the policy (Cassidy et al., 2022; De Pinho and Larsen, 2015; Lane, 1999). The policy in **Study III** is the EU Green Deal on Energy Transition. Codes and categories from the content analysis helped build the CLD to identify the interacting points in terms of pathways and feedback loops between the energy and health and well-being systems. CLDs show the system behaviour, interactions between elements in a system, and cyclic loops of the behaviour (Cassidy et al., 2022; De Pinho and Larsen, 2015).

While dealing with a specific complex situation like an energy transition, CLDs are useful for developing a comprehensive picture based on various actors' perspectives (Williams and Hummelbrunner, 2011). Actors' contrasting perspectives can help identify the behaviour pattern instead of the "either-or" situation (ibid). Understanding the causal relationship between elements can also help contemplate the leverage points (De Pinho and Larsen, 2015; Williams and Hummelbrunner, 2011).

It is important to draw the boundary while developing CLD by focusing on the problem of interest to make the modelling manageable as it is not possible to model the entire system (William and Hummelbrunner, 2011). Thus, **Study III** does not diagram the whole economic, social, educational and cultural systems but includes only the issues contributing to the health and well-being of the local population. The STS and PoS theories and the research questions substantively helped to set the boundaries on what to include and exclude in the diagram. Also, critical realism responds well to systems thinking in theorising the social structures, causes and mechanisms that are functioning in a complex system (De Souza, 2022).

The CLD comes to the rescue by bridging the gap between unobservable and observable structures (Figure 1, section 3.1) as it provides a simplified model of social reality. Thus, the CLD helped achieve the end goal of research question three: the impact on the health and well-being of the local population from the interaction of the two systems. I built the CLD using Vensim PLE software, which shows the cyclic loops and pathways/linkages without loops. Loops are either reinforcing or balancing, which are generated based on the coded data in NViVO. For example, Figures 6 and 7 represent CLDs where reinforcing and balancing loops are shown, respectively.

Figure 6. Reinforcing loop (extracted from study III, R10 is the numbering of one of the reinforcing loops)

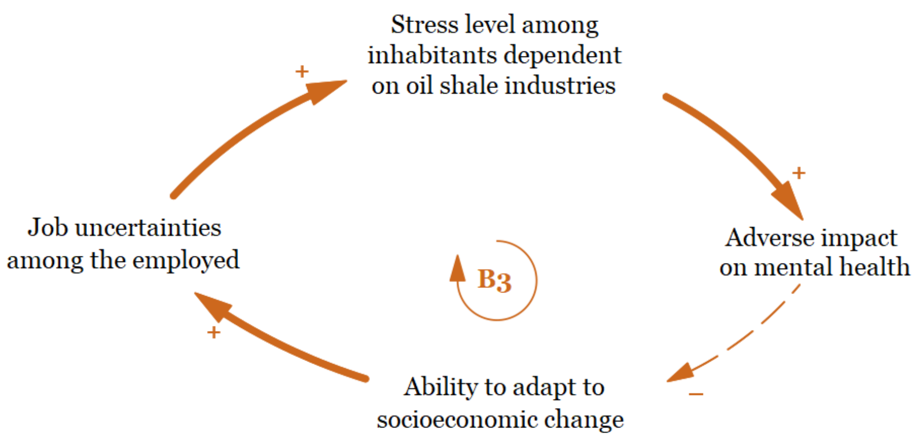
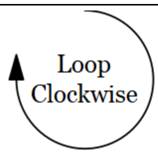
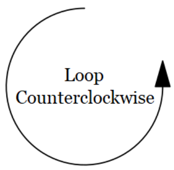


Figure 7. Balancing loop (extracted from study III, B3 is the numbering of one of the balancing loops)

Table 3. Symbols and meanings in the causal loop diagram (CLD)

Symbols	Meaning
A ——+→ *B*	Causality with positive polarity. It indicates that changes in element/variable A result in the same direction as those in element/variable B.
A - - - - - - -→ *B*	Causality with negative polarity. It indicates that the changes in element/variable A result in the opposite direction in element/variable B.
	- Feedback loop should be read clockwise. - A loop with the R symbol indicates a reinforcing loop, and it forms when all the arrows in the loop have the **same or even numbers** of positive polarities. - A loop with the B symbol indicates a balancing loop, and it forms when there are **one or more odd numbers** of negative polarities.
	The feedback loop should be read anti-clockwise.

In a reinforcing loop, an action results in a similar action either at a growing or declining rate, thus amplifying the system's behaviour (Cassidy et al., 2022; De Pinho and Larsen, 2015). In Figure 6, a reinforcing loop indicates that an increase in the adverse impact on mental health results in an increase in inequality in the care/treatment of mental health conditions. Similarly, in a balancing loop, an action results in resistance, limiting growth or maintaining stability and achieving equilibrium, thus reducing the impact of changes that prevent amplifying the system's behaviour (Cassidy et al., 2022; De Pinho and Larsen, 2015). In Figure 7, a balancing loop indicates that the adverse impact on mental health decreases the ability to adapt to socioeconomic changes, which increases the job uncertainties that further increase the stress level, thus adversely impacting mental health. The CLD developed reflects the phenomena in real life, whereas the existing theoretical understandings guide the systematisation and critical analysis of the results. The data expands from different time frames, demonstrating the dynamism of the interactions. However, the model I present is quite static, as I put all the loops and linkages together in one picture.

3.3. Methodological limitations

Even though this thesis employed a mixed method, there are some methodological limitations. Regarding the environmental indicators, air pollution and annoyance due to noise pollution are considered in **Studies I, II and III**, but not groundwater and soil pollution and their impact on health and well-being. These might further impact the food system, water quality systems, and agriculture, such as food and nutrition, and basic water supply quality impacts health and well-being. These associations can be studied from the planetary health perspective.

In **Study II**, the odds ratio value should be interpreted cautiously as the association does not necessarily reflect causality. For example, it cannot be concluded that mothers with lower education cause low-birth-weight babies. Rather, it should be interpreted as mothers with lower education have higher odds of having LBW and PTB babies. Additionally, confounding factors might have been over or under-controlled in the logistic regression analysis. For example, the smoking status of mothers was not included as the data was not reliable. Similarly, the residential location used in the study is the home address registered during the birth. This might not be true in every mother's case as mothers might have been travelling and living in a different place, which is difficult to track. The limitation of a retrospective cohort study is that there might be information bias, especially about whether the information was correctly recorded (Wang and Kattan, 2020).

In **Study III**, while CLDs can help visualise the behaviour pattern in feedback loops and cause-and-effect relationships (Cassidy et al., 2022; Williams and Hummelbrunner, 2011), they cannot predict behavioural patterns when there are multiple interacting feedback loops and delays (William and Humm). Similarly, whenever new information is available, that might change the CLD. Therefore, a higher number of IDIs could have strengthened the analysis. Also, "holism in the strict sense is not even an ideal"; thus, CLDs cannot describe the whole world but can only help make sense of the world (Williams and Hummelbrunner, 2011). Similarly, **Study III** dives into the socioeconomic reality of the local population dependent on oil shale industries but not specifically on the Russian-speaking ethnic groups, which would deserve specific research attention. After creating the CLD model, it was not validated with stakeholders. However, the model was developed based on the collected data and triangulated with data from different sources: FGDs, IDIs and documents. Nevertheless, as there is progress in the energy transition, discussions among stakeholders about the model could validate it and lead to the incorporation of new developments.

3.4. Ethical considerations

The birth registry-based study (**Study II**) followed the Declaration of Helsinki (World Medical Association, 2013). The declaration sets the ethical principles of medical research involving human subjects and outlines the ethical standards to protect the privacy and confidentiality of the research subjects. Ethical approval was obtained from the University of Tartu's Ethics Board for Human Research (protocol number 300/T–13, 20 January 2020; protocol number 322/M–35, 17 August 2020). Informed consent from the research subjects was not required as the study was registry-based.

Similarly, for **Study III**, ethical approval was obtained from the Ethics Board of the University of Tartu (protocol number 361/T-7). Following the ethical protocol, the interviewer sent the informed consent form to all interview participants and obtained the participants' written consent. The participants' names were pseudonymised or removed from the transcripts to maintain the confidentiality of the information.

CHAPTER 4. RESULTS

This thesis aimed to clarify the impact on local health and well-being from the existing fossil fuel-based energy system and its transition process to a cleaner system. This chapter presents the study's results on the impact of air pollution, social inequalities and environmental climate action on health and well-being. The following are the major findings from the studies:

1. Air pollution from industry sources and living close to industrially contaminated sites (ICS) leads to adverse birth outcomes (ABOs). The strong evidence of industrial air pollutants impact on ABOs are from petrochemical industries and power plants. Particulate matters and chemicals like benzene, BTEX, cadmium and polycyclic aromatic hydrocarbons provided strong evidence. This established evidence on the connection with ABOs in ICS in **Study I** also aligned with the case in Estonia, setting the stage for examining the social disparities in health in the Estonian case. Contrary to the usual findings on the impact of PM_{10} on preterm birth (PTB) and low birth weight (LBW), the analysis on the national level and Ida-Viru County level did not show similar significance. **(Studies I–II)**
2. In Estonian ICS, mothers with lower socioeconomic status (SES) in terms of lower education, Russian-speaking groups and those living closer to the oil shale industries were impacted more, resulting in ABOs. Furthermore, mothers in higher age groups were impacted more by ABOs. Against our assumption that Russian-speaking mothers in Ida-Viru County would have higher odds of ABOs compared to the national level, but it was found that they had similar odds of ABOs across the country. **(Study II)**
3. **Study III** found that, in the context of energy transition, the interaction between energy and health and well-being systems is impacting the latter. The energy transition process is impacting the socioeconomic dimensions of health and well-being, as demonstrated by a causal loop diagram. Thus, the disparities in health and well-being can be seen both before and after the energy transition process.

This chapter presents the results on the impact of industrial air pollution on birth outcomes, social inequality, and the case of the oil shale industry in Estonia. It then shows the interconnectedness of energy and health and well-being systems and the impact of energy transition on the latter.

4.1. Exposure to industrial air pollution during pregnancy impacts birth outcomes (RQ 1 and 2)

The review in **Study I** showed that exposure to air pollutants during pregnancy induced by ICS negatively impacts perinatal health. $PM_{2.5}$ is associated with ABOs: low birth weight (LBW), preterm birth (PTB), small for gestational age (SGA), term low birth weight (TLBW) and intra-uterine growth retardation

(IUGR). These outcomes were also associated with exposure to PM_{10}, except IUGR. However, the number of studies regarding LBW, PTB and SGA was higher. Interestingly, with PM_{10} exposure, PTB impacted first-time mothers more, and PTB was linked with very low birth weight, with babies weighing less than 1500 grams. In some studies, PM10 pollution from waste incinerators did not seem to increase the risk of these outcomes. Another pollutant, Polycyclic Aromatic Hydrocarbons (PAH), is associated with LBW, smaller head circumference, and IUGR. Similarly, benzo(a)pyrene is associated with LBW. BTEX, a mix of benzene, toluene, ethylbenzene and xylene, is associated with PTB, and while there were some studies (albeit very few) on LBW and SGA, no association could be confirmed. Benzene alone is associated with LBW and did not show any link with critically ill small for gestational age (CiSGA). Heavy metals such as cadmium, arsenic and lead are linked to LBW. There were mixed findings, with some, such as cadmium, showing positive and negative effects on LBW in different studies. Lead is linked to premature low birth weight, LBW, TLBW and SGA, but not with PTB. Since hundreds of pollutants can be found in the ambient air, many studies have also researched the effect of pollutants' mixtures, finding a positive link between SGA, TLBW, PTB, CiSGA and LBW. Finally, living closer to industrial sources increased the risk of having babies with LBW, PTB, SGA and TLBW.

4.2. An Estonian case of pregnancy exposure to industrial air pollution impacting birth outcomes (RQ 2)

From the above results of the systematised review in **Study I**, some metrics were further tested in the Estonian ICS case in **Study II** (Table 4). Among the pollutants, $PM_{2.5}$, PM_{10} and NO_2 (per 10 $\mu g/m^3$) were studied with ABOs, LBW and PTB indicators in **Study II**. In Ida-Viru ICS, the association between $PM_{2.5}$ and LBW was shown, where mothers exposed to 10 $\mu g/m^3$ higher concentrations of fine particles during III trimester had 1.56 increased odds of having LBW babies. Regarding the link with PTB, it was only shown at the national level, where the mothers exposed to 10 $\mu g/m^3$ concentrations of $PM_{2.5}$ have 12% higher odds of having PTB. With PM_{10}, none of the associations were found. However, the NO_2 effect was insignificant for PTB and LBW, although the effect was the opposite.

The data analysis (Table 4) revealed that in the case of LBW, only the fully adjusted model for III trimester exposure to $PM_{2.5}$ was statistically significant. The changes in the odds ratio (OR) value from the adjusted to the fully adjusted model suggest that the confounders were suppressing the association in the crude model. This indicates that exposure to $PM_{2.5}$ was not the sole contributor. Once the confounders were controlled, their effect was removed, revealing the isolated impact of $PM_{2.5}$ exposure.

Table 4. Associations between adverse birth outcomes and exposure to air pollutants (per 10 µg/m^3) during the first and third trimesters in Estonia and Ida-Viru County

	Ida-Viru County		Estonia		
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	NO_2
	OR (95% CI)				
Preterm birth (PTB)					
Adjusted model[2]					
I trimester	1.10 (0.98 – 1.24)	1.01 (0.73 – 1.39)	1.07 (1.02 – 1.13)	**1.09[1] (1.00 – 1.20)**	1.02 (0.94 – 1.10)
III trimester	1.09 (0.97 – 1.23)	1.26 (0.92 – 1.72)	1.03 (0.97 – 1.09)	1.01 (0.92 – 1.11)	0.91 (0.84 – 0.99)
Fully–adjusted model[3]					
I trimester	1.12 (0.99 – 1.26)	0.99 (0.70–1.37)	1.05 (0.99–1.11)	**1.12 (1.02–1.23)**	1.04 (0.96–1.13)
III trimester	1.12 (0.98–1.26)	1.30 (0.95–1.79)	1.03 (0.97–1.09)	1.03 (0.94–1.13)	0.90 (0.83–0.98)
Low birth weight (LBW)					
Adjusted model					
I trimester	1.10 (0.98–1.23)	0.99 (0.73–1.35)	1.05 (0.99–1.11)	1.05 (0.96–1.15)	0.96 (0.88–1.03)
III trimester	1.04 (0.93–1.17)	**1.50 (1.12 – 1.99)**	1.05 (0.93–1.17)	1.02 (0.93–1.13)	0.93 (0.85–1.01)
Fully–adjusted model					
I trimester	1.12 (0.99–1.25)	0.96 (0.70–1.33)	1.02 (0.97–1.08)	1.06 (0.97–1.17)	0.98 (0.91–1.06)
III trimester	1.06 (0.94–1.19)	**1.56 (1.16–2.08)**	1.06 (0.94–1.19)	1.03 (0.94–1.14)	0.92 (0.85–1.00)

[1]Bold values are statistically significant results; [2]Adjusted for individual-level socio-demographic variables (mother's ethnicity, mother's education, mother's age); [3]Adjusted for individual-level sociodemographic variables from adjusted model and maternal complications (in–vitro fertilisation, earlier caesarean section, preeclampsia, preterm birth risk during pregnancy, miscarriage risk during pregnancy, gestational diabetes, chronic diabetes, and hypertension).

Similarly, the mothers living closer to the industrially contaminated sites (ICS) were impacted by both LBW and PTB (Table 5). The odds ratio of LBW among mothers living ≤3 km from ICS was 1.51 and 1.18 for those living ≤ 5 km away compared to mothers living more than 10 km from ICS. Similarly, the odds ratio of PTB was 1.58 higher in a ≤3 km radius of ICS.

Table 5. Associations between adverse birth outcomes and mothers' residential proximity to oil shale industries

Residential proximity[1]	**≤ 3 km**[1]	**≤ 5 km**[1]	**≤ 10 km**[1]
		OR (95% CI)	
Preterm birth (PTB)			
Crude model	**1.63**[2] **(1.31–2.02)**	**1.41 (1.26–1.58)**	**1.37 (1.24–1.51)**
Adjusted model[3]	**1.54 (1.23–1.90)**	**1.38 (1.22–1.56)**	**1.35 (1.22–1.50)**
Fully–adjusted model[4]	**1.58 (1.26–1.98)**	1.07 (0.94–1.22)	1.01 (0.89–1.14)
Low birth weight (LBW)			
Crude model	**1.81 (1.48–2.23)**	**1.68 (1.51–1.87)**	**1.60 (1.45–1.75)**
Adjusted model	**1.55 (1.26–1.91)**	**1.48 (1.32–1.66)**	**1.42 (1.29–1.57)**
Fully–adjusted model	**1.51 (1.21–1.88)**	**1.18 (1.04–1.33)**	1.09 (0.97–1.23)

[1]Reference distance: >10 km. [2]Bold values are statistically significant results; [3]Adjusted for individual-level sociodemographic variables (mother's ethnicity, mother's education, mother's age); [4]Adjusted for individual-level sociodemographic variables from adjusted model and maternal complications (in–vitro fertilisation, earlier caesarean section, preeclampsia, preterm birth risk during pregnancy, miscarriage risk during pregnancy, gestational diabetes, chronic diabetes, and hypertension) and neighbourhood socioeconomic status (income coefficient).

4.3. Social inequalities and their relation to adverse birth outcomes in Estonia (RQ 2)

Exposure to air pollution and living near ICS impacted perinatal health, though mothers in socially disadvantaged positions were impacted more. Table 5 also indicates social inequality as people with lower SES tend to live near the industrial areas. In the Estonian case, mothers living closer to ICS had higher odds of having babies with adverse birth outcomes. Among the tested social indicators, babies born to mothers with lower education, higher age and of Russian or other ethnicities were disproportionately affected in Estonia.

LBW and PTB impacted mothers with lower education more in Estonia and Ida-Viru County; however, the odds were higher in Ida-Viru (Table 6). For instance, compared to mothers with high school level education, mothers with basic education had 3.32 times higher odds of LBW in Ida-Viru, while at the national level the odds were 2.48 times higher. However, the 95% confidence interval at the Ida-Viru County level is wider, depicting the uncertainties in the odds estimates.

A similar pattern can be seen in the effect of maternal age (Table 7), where PTB and LBW were seen among mothers having delivery at ≥40 years. Still, a higher odds ratio can again be observed in Ida-Viru County. For instance, mothers of ≥40 years had 2.30 times higher odds of PTB in Ida-Viru County, while at the national level it was 1.76 times higher.

The effect of ethnicity was not unique to Ida-Viru County (Table 8); Russians have 29% higher odds of LBW also at the national level. Regarding PTB, a significant association was shown only in the adjusted model with individual-level sociodemographic variables. The association was no longer significant when adjusted with additional factors such as maternal complications and neighbourhood socioeconomic status. This suggests that the effect of ethnicity in PTB might be influenced by the maternal complications and neighbourhood socioeconomic status in the adjusted model.

Table 6. Associations between adverse birth outcomes and mothers' educational level

Mother's education[1]	Ida-Viru County				Estonia			
	Basic[1]	Secondary[1]	Applied[1]	Higher[1]	Basic	Secondary	Applied	Higher
	OR (95% CI)							
Preterm birth (PTB)								
Adjusted model[3]	**2.53**[2] **(1.17–4.82)**	**2.35 (1.90–2.92)**	0.91 (0.76–1.11)	**0.73 (0.57–0.93)**	**2.23 (1.85–2.68)**	**1.43 (1.32–1.55)**	**0.90 (0.84–0.96)**	**0.74 (0.69–0.80)**
Fully–adjusted model[4]	**2.77 (1.26–5.35)**	**2.36 (1.89–2.94)**	0.91 (0.75–1.11)	**0.70 (0.55–0.90)**	**2.27 (1.86–2.75)**	**1.39 (1.28–1.51)**	**0.89 (0.83–0.96)**	**0.78 (0.73–0.84)**
Low birth weight (LBW)								
Adjusted model	**3.02 (1.59–5.29)**	**2.42 (1.98–2.95)**	0.88 (0.74–1.05)	**0.62 (0.49–0.79)**	**2.44 (2.05–2.92)**	**1.64 (1.52–1.77)**	**0.92 (0.86–0.98)**	**0.73 (0.68–0.78)**
Fully–adjusted model	**3.32 (1.73–5.88)**	**2.45 (2.00–3.00)**	0.88 (0.74–1.06)	**0.60 (0.47–0.76)**	**2.48 (2.05–2.99)**	**1.59 (1.47–1.73)**	**0.91 (0.85–0.97)**	**0.77 (0.72–0.83)**

[1]Reference: Mothers with high school level education; [2]Bold values are statistically significant results; [3]Adjusted for individual-level sociodemographic variables (mother's ethnicity, mother's age); [4]Adjusted for individual-level sociodemographic variables from adjusted model and maternal complications (in–vitro fertilisation, earlier caesarean section, preeclampsia, preterm birth risk during pregnancy, miscarriage risk during pregnancy, gestational diabetes, chronic diabetes, and hypertension) and neighbourhood socioeconomic status (income coefficient).

Table 7. Associations between adverse birth outcomes and mothers' age at delivery

Mother's age[1]	Ida-Viru County					Total Estonia				
	<20[1]	**20–24[1]**	**30–34[1]**	**35–39[1]**	**≥40[1]**	**<20**	**20–24**	**30–34**	**35–39**	**≥40**
	OR (95% CI)									
Preterm birth (PTB)										
Adjusted model[3]	1.04 (0.75–1.41)	**0.72[2] (0.58–0.89)**	1.10 (0.90–1.35)	**1.53 (1.22–1.92)**	**2.35 (1.69–3.26)**	**1.24 (1.09–1.40)**	**0.92 (0.85–0.99)**	**1.42 (1.31–1.53)**	**1.14 (1.06–1.21)**	**1.89 (1.69–2.10)**
Fully–adjusted model[4]	0.77 (0.55–1.07)	**0.67 (0.54–0.84)**	1.10 (0.90–1.35	**1.52 (1.21–1.91)**	**2.30 (1.63–3.20)**	**1.21 (1.06–1.37)**	**0.90 (0.83–0.97)**	**1.14 (1.06–1.22)**	**1.37 (1.26–1.48)**	**1.76 (1.57–1.97)**
Low birth weight (LBW)										
Adjusted model	0.90 (0.67–1.21)	0.83 (0.68–1.00)	1.12 (0.92–1.35)	**1.30 (1.04–1.61)**	**1.91 (1.35–2.63)**	**1.26 (1.11–1.42)**	0.98 (0.91–1.06)	**1.09 (1.02 –1.16)**	**1.38 (1.28–1.49)**	**1.91 (1.72–2.13)**
Fully–adjusted model	**0.68 (0.49–0.92)**	**0.78 (0.64–0.95)**	1.11 (0.91–1.35)	**1.32 (1.05–1.66)**	**1.96 (1.37–2.72)**	**1.21 (1.06–1.37)**	0.95 (0.88–1.02)	**1.09 (1.02–1.17)**	**1.33 (1.23–1.44)**	**1.78 (1.59–1.99)**

[1] Reference age is 25-29; [2]Bold values are statistically significant results; [3]Adjusted for the individual–level sociodemographic variables (mother's ethnicity, mother's education); [4]Adjusted for individual-level sociodemographic variables from adjusted model and maternal complications (in–vitro fertilisation, earlier caesarean section, preeclampsia, preterm birth risk during pregnancy, miscarriage risk during pregnancy, gestational diabetes, chronic diabetes, and hypertension) and neighbourhood socioeconomic status (income coefficient).

Table 8. Associations between adverse birth outcomes and mothers' ethnicity

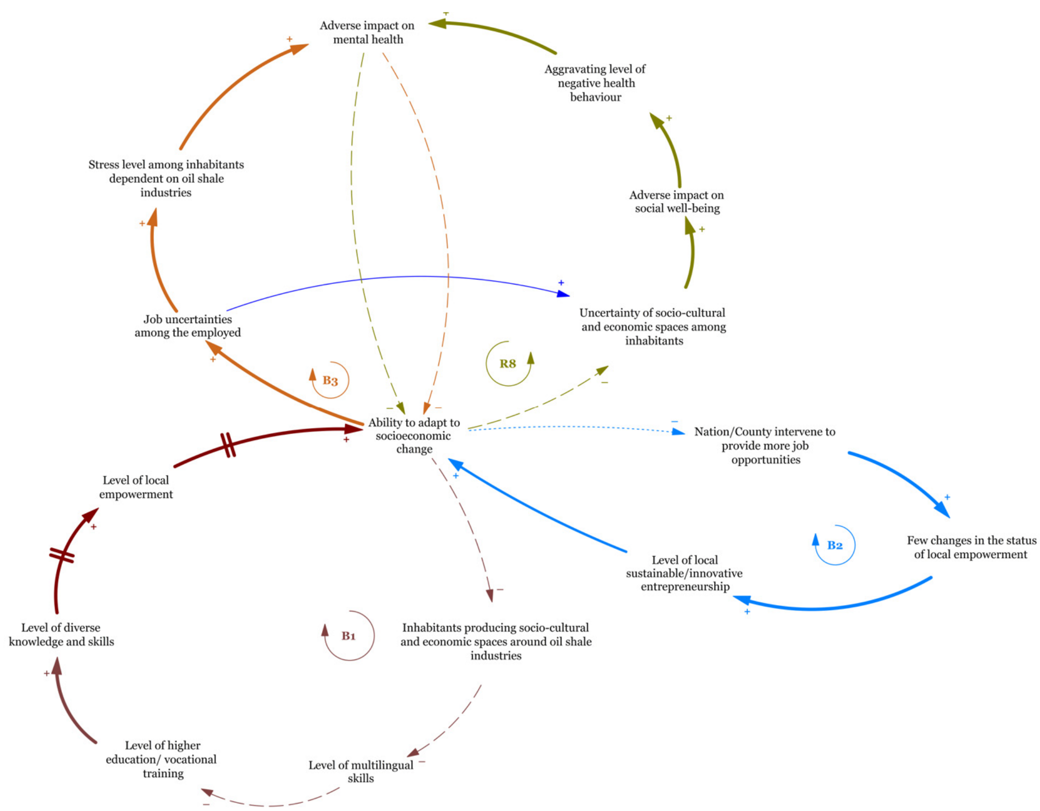
Mother's ethnicity[1]	Ida-Viru County		Estonia	
	Russians[1]	Other non-Estonians[1]	Russians	Other non-Estonians
	OR (95% CI)			
Preterm birth (PTB)				
Adjusted model[3]	1.09 (0.89–1.33)	0.92 (0.60–1.39)	**1.15**[2] **(1.09–1.22)**	1.14 (0.99–1.33)
Fully–Adjusted model[4]	1.08 (0.88–1.33)	0.93 (0.60–1.41)	1.05 (0.99–1.11)	1.10 (0.94–1.28)
Low birth weight (LBW)				
Adjusted model	**1.26 (1.04–1.54)**	1.09 (0.72–1.61)	**1.36 (1.29–1.43)**	**1.37 (1.19–1.57)**
Fully–Adjusted model	**1.29 (1.05–1.57)**	1.11 (0.74–1.67)	**1.29 (1.22–1.36)**	**1.34 (1.15–1.55)**

[1]Reference population: Mothers of Estonian ethnicity; [2]Bold values are statistically significant results; [3]Adjusted for the individual–level sociodemographic variables (mother's education, mother's age); [4]Adjusted for individual-level sociodemographic variables from adjusted model and maternal complications (in–vitro fertilisation, earlier caesarean section, preeclampsia, preterm birth risk during pregnancy, miscarriage risk during pregnancy, gestational diabetes, chronic diabetes, and hypertension) and neighbourhood socioeconomic status (income coefficient).

Given the above understanding of the impact of air pollution exposure and the social disparities in perinatal health largely related to the ICS, it becomes crucial to understand how the energy transition will affect the county.

4.4. The interplay between energy and health and well-being systems and the impact on the latter (RQ 3)

Study III presents a holistic picture of the interconnectedness of energy, health and well-being, which has not been shown before in the scientific literature. The systems modelling demonstrates the interconnections using the causal loop diagram (CLD) tool. In the CLD, 15 cyclic loops and 50 pathways/linkages without loops but contributing to cyclic loops were recorded. These loops and linkages in the CLD span the social, economic, environmental, energy transition and health and well-being elements. The CLD revealed that the existing socioeconomic condition in Ida-Viru County, including the changes induced by the energy transition process, affects health and well-being. The interaction between energy and health and well-being systems' impact on the latter was seen in various health and well-being dimensions, such as mental health and well-being, social well-being and behavioural health (Figure 8, excerpt from Study III). Local residents' health and well-being on behavioural health was about alcohol consumption and less physical activity. Similarly, in mental health, it was stress levels and uncertainties regarding future jobs and social space which impacted social well-being as well. Regarding physical health, negative environmental externalities already impacted local population, and mental health conditions could potentially exaggerate physical well-being. This impact will add more pressure to the already struggling healthcare infrastructure in Ida-Viru County. The already impacted physical health in terms of respiratory diseases, cancer, and care needed for babies with adverse birth outcomes, including the potential adult-stage diseases due to ABOs, put pressure on healthcare infrastructure. In addition, high-stress levels impacting mental health might lead to more hospital visits, where there are not enough human resources.



B1 Inhabitants' inability to adapt to socioeconomic changes
B2 Overlooking the fundamental aspect: empowering people
B3 Unadaptability circling to health and well-being
R8 Uncertainty circling to health and well-being

Figure 8. Factors impacting the inhabitants' ability to adapt to socioeconomic changes (excerpt from Study III)

The vicious cycle of lower socioeconomic status has contributed to the local population's poor adaptability to changes and low meaningful engagement in the energy transition process. One of the key premises of the EU Green Deal is that energy transition should improve local health and well-being by reducing exposure to the polluted environment, as shown in **Studies I-II**. However, the results in **Study III** indicate otherwise in the socioeconomic dimensions. The expert interviews and document analysis identified several existing socioeconomic problems (i.e. before implementing the energy transition activities), such as linguistic, education quality, social integration and livelihood dependency on mining. Similarly, interviews revealed a lack of traditions and support mechanisms in encouraging local inhabitants to develop self-determination, leadership and entrepreneurship skills. Moreover, the gathered data demonstrated that inhabitants in Ida-Viru County have embraced the oil shale technology in their everyday lives as income generation and socio-cultural exchange hubs, considering mining a tradition. While these problems appeared fragmented initially, examining them through a systems approach in an energy transition context clarified the connections among these social issues and their potential impact on health. One of the key dynamics found in the CLD was that local people's ability had not been strengthened to adapt to the socioeconomic changes led by the energy transition (Figure 5). While the energy transition process is inducing socioeconomic changes, the low levels of adaptability to these changes among local population are tied to the already existing socioeconomic problems in the region.

The inability to adapt or a lack of resilience in the long run applies not only to the local people but also to the county government, which is experiencing a vicious cycle of being unable to resolve the local socioeconomic challenges that aggravate health conditions. Ida-Viru County already has the highest unemployment rate in Estonia, and in many municipalities a large part of the revenue depends on the oil shale industry. By moving away from the oil shale industry, the government will lose revenue from income tax, environmental taxes and fees from mining rights related to this industry. Also, the state and regional authorities have not accomplished the goal of creating opportunities to establish new jobs to replace the existing direct and indirect income dependency on the oil shale industry. The gathered data indicates that about half of the workforce from the oil shale industry might require comprehensive retraining for new job opportunities.

Besides such ties to the existing socioeconomic problems behind such inadaptability, another reason is that local communities are not engaged enough in this energy transition process. The EU Green Deal is a top-down process, meaning EU stakeholders decided to bring this policy to fight climate change. Even though the member states could negotiate on the process, the impacted local communities were not. Hence, from the planning phase, the local population was not engaged enough in discussing and deciding what and how things would change and what their rights and responsibilities would be. Such lack of engagement is currently leading to uncertainty about their future jobs, livelihood and the cultural hub among communities, making it even harder for them to adapt (Figure

5). The unresolved social and economic problems have made it difficult for people to adapt to changes. Consequently, inhabitants are more stressed and uncertain about their future, which affects their mental health. Job uncertainties due to the collapse of mining activities also lead to uncertainties in the future socio-cultural space, impacting their social well-being. These impact local population's health behaviours, such as less physical activity and high alcohol consumption. These aspects will add to the local population's physical health and well-being, which are already being impacted by the industrial pollution in the region. Ultimately, these health and well-being issues burden the healthcare infrastructure, which is already fragile.

CHAPTER 5. DISCUSSION

This thesis provides novel insights into the interaction between energy and health and well-being systems and the implications of the energy transition on the latter. I analysed the multifaceted impacts of health inequalities in industrial areas from the environment and the macroeconomic policy of the European Green Deal targeted at the environment. **Study I** reviewed the global literature to establish the relationship between ICS-generated air pollution and ABOs. LBW and PTB were frequently reported as adverse birth outcomes due to exposure to air pollutants $PM_{2.5}$, PM_{10}, PAHs, heavy metals, benzene and living near the ICS. In **Study II**, among the studied exposure to pollutants $PM_{2.5}$ and PM_{10} and the ABOs LBW and PTB, the association was shown between $PM_{2.5}$ and LBW in Ida-Viru County. At the national level, the association between $PM_{2.5}$ and PTB was shown. Similarly, **Study III** demonstrated that the environmental policy intended to curb climate change disproportionately impacts those already affected by the negative environmental externality of the oil shale industry. I discuss the implications of these findings below.

Thesis 1: Curbing industrial air pollution alone is insufficient to improve the local population's health and well-being in the transition of oil shale industrial regions to sustainability.

The observed higher levels of health effects on birth outcomes among the lower SES and mothers living closer to the ICS are founded on the research based on the DPSEEA (driving force-pressure-state-exposure-effect-action) framework (Briggs, 1999). According to this framework, acting on the end effect on health is relatively easy but costly, yet it does not deal with the root causes. Similarly, action on severe effects, such as premature births needing intensive care, is hospital-based treatment. Action on the pressures on the environment, which is air pollution from the oil shale industry, would entail removing the air pollutant sources. The EU Green Deal aims to curb air pollution sources through the energy transition. This means that the health effects of the industrial air pollutants will be reduced more precisely after the phase-out of oil shale industries, assuming that the region has other cleaner industries. The phase-out of dirty industries should help achieve the SDGs targets of improved air quality and reducing air pollution-related morbidity and mortality.

However, those who already bore the air pollution consequences in the form of ABOs are not free from future health implications. The immediate impact of adverse birth outcomes is the higher risks of neonatal mortality and morbidity, including a higher level of hospitalisation (Tough et al., 2002). The future implications of adverse birth outcomes are higher risks of diseases such as obesity, diabetes and cardiovascular diseases during adulthood (Arima and Fukuoka, 2020; Barker et al., 1993; Jornayvaz et al., 2016; Swanson et al., 2009). Furthermore, in the Ida-Viru case, the local population is more impacted by other health conditions, such as cancer (Idavain et al., 2020), respiratory illness (Idavain et al., 2019) and annoyance by noise (Orru et al., 2018) and need further attention regarding health and well-being conditions. Such situations of non-communicable diseases and the future possibility of them due to the ABOs might be a hurdle to achieving the good health and well-being SDG by reducing the mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease.

The findings on higher maternal age and ABOs could be due to various reasons. Berger et al. (2021) report that advanced age with or without maternal complications had higher odds of ABOs than younger women. The higher odds in Ida-Viru County among mothers of advanced age might be due to the combined effect of air pollutants, advanced maternal age, maternal complications (Melody et al., 2020), and other socioeconomic factors.

When viewed through the lens of social determinants of health (Dahlgren and Whitehead, 2007; Solar and Irwin, 2010), it becomes evident that mothers of lower socioeconomic status (SES) are disproportionately affected by adverse birth outcomes (ABOs). The findings of **Study II** on unequal levels of adverse birth outcomes in low SES mothers imply that the health effect of social inequalities, such as education, ethnicity and residential proximity, is even more significant than air pollution itself. Regarding the social disparities and health outcomes, the initial assumption was that Russian-speaking mothers should have higher odds of LBW and preterm birth (PTB) in Ida-Viru County than at the national level, as the Russian-speaking mothers' SES could be worse in Ida-Viru County. Contrary to this assumption, the similar ethnic disparities observed in LBW among Russians, both in Ida-Viru and across the country, suggest that these disparities are not unique to Ida-Viru County but rather a national tendency. These findings support that health inequalities, as defined by Dahlgren and Whitehead (2007), are the socially produced, systematic and unjust differences in health across the population. The interplay between environmental and socioeconomic factors in health outcomes is often shown in the literature, as people with lower SES tend to live closer to ICS (Pasetto et al., 2019; Perlin et al., 2001). The real significance of these findings lies in other potential health outcomes disproportionately affecting residents in areas of oil shale industries.

The above findings encouraged exploring whether the energy transition will improve the overall health and well-being of the local population and, if not, identifying the root causes in **Study III**. One of the causes lies in technological advancements deeply rooted in society (Ropohl, 1999). Through a socio-technical system (STS) theoretical lens, one critical understanding achieved is how the government and the local population have embraced oil shale technology for a steady income and energy sources despite environmental and health costs. Technologies like oil shale met societal needs and shaped the actors' behaviours and cultures. Socialising the industry involves integrating these technologies into the lives of the local population via jobs. Through those jobs, inhabitants started creating meaning, self-identity and even pride related to the local mining industry. Thus, the impact of socialising oil shale technology was not only on the income sources but also on the lived space of inhabitants and subjective feelings around the industries, as demonstrated through the production of space (PoS) theoretical lens.

One of the significant implications of these findings is the health and well-being of the population. Since social inequalities have played a crucial role in health outcome disparities, existing health promotion policies targeted to specific conditions may not provide the intended results. For example, health promotion activities to improve mental health and well-being outcomes, such as awareness campaigns for increased physical activity and reduced alcohol consumption, would be insufficient. This is mainly because they do not tackle the "causes of the causes of" mental health issues linked to the socioeconomic changes resulting from the energy transition and the capacity of the local population to adapt to those changes. The socioeconomic changes brought by the energy transition have created future uncertainties among the local population that adversely affect their mental health and well-being. This situation challenges the European Union's Green Deal's motto of leaving no one behind. Similarly, it does not support the SDG of health and well-being. Thus, the energy transition process is a typical wicked problem that is not solvable but should be targeted to management (Head, 2019).

Thesis 2: Power dynamics over contemporary needs fuel inequalities via a cycle of lower socioeconomic status and lower community engagement

"Socially produced unjust differences in health outcomes" are often influenced by globalisation and macroeconomic policies (Solar and Irwin, 2010). The production of space (PoS) (Lefebvre, 1991) theory helped to explain that the social process of producing the space where local and government actors played different roles created systematic and unjust differences. The social process of producing the space led the local population to rely on oil shale for socioeconomic and cultural practices, and the government relied on revenue and energy sources fostering the injustices. The global trend of energy needs and economic growth fuelled these national priorities in energy and economy.

The theoretical concept of spatial triad depicts an ideal scenario where all sides of the triangle are equal. Lefebvre advocated for equal power, suggesting that every inhabitant, regardless of their background, ethnicity or nationality, has a right to shape their city (Shields, 2013). However, the empirical findings in **Study III** indicated that power is often distributed unevenly during the social process of producing the space. Therefore, in practice, the triad may never be equilateral. The unequal power between actors was due to various factors, such as the level of agency, which tends to be lower for inhabitants in Ida-Viru than the industry. The industry was seen leveraging its network with government authorities to influence supportive policies (Sillak and Kanger, 2020). However, inhabitants, primarily miners and their families, often lack such networks and the power to influence the current policies (Vihalemm, 2022). In addition, the inhabitants would need more significant support to adapt to socioeconomic changes, while the national government has an energy security and revenue interest. This puts the inhabitants in a situation where even though they have a right to shape their city, it is challenging around fossil fuel sources, where the physical space is often controlled by industrialists who benefit from wealth and power (Labban, 2008). As most of the oil shale industries are owned by the government in Estonia, a paradoxical situation of prioritising revenue, energy, economic well-being or health is created. Furthermore, the direction of the regional level, which the EU is taking towards climate neutrality, means that Estonia, as a member state, must follow suit (Kreienkamp et al., 2022). This leaves the interests of the inhabitants in Ida-Viru in limbo. Inhabitants suffered from injustice and pollution before the energy transition, and a sentiment of being alienated prevailed during the transition process. Even ethical questions arise as the inhabitants are put in the position of choosing between jobs or good health and well-being (Kanger and Sovacool, 2022). In this context, different people in an energy STS have unequal roles and control over the space, exhibiting power dynamics.

Beyond STS, PoS theory offered a deeper understanding of individuals' lived experiences. It helped explain how people create meaning through their interactions with space and how authorities plan and manage these spaces. The findings on the lack of active community engagement in the energy transition process in Ida-Viru County could be attributed to power imbalance among various actors (Vihalemm, 2022). This observation challenges the theoretical stance of STS and PoS, which suggest that social processes are constantly in motion, where the local communities are naturally active. However, the situation in Ida-Viru County **(Study III)** does not align with these theoretical expectations. **Study III** recommends a more bottom-up approach, meaning more individual actions, though collective at the local level. The concept of social determinants of health (Solar and Irwin, 2010) explains the lack of meaningful community engagement. It points out that such disparities are deeply entrenched in the structural, socioeconomic and political landscapes. This means that the residents' lower socioeconomic status, which was persistent before the transition, significantly contributed to this power imbalance.

These findings imply that the planned energy transition activities may not be sufficient. For instance, even the reskilling of workers in industrial areas is considered a reactive logic that is insufficient to tackle social injustices holistically (Crespy and Munta, 2023). Livelihood concerns among the local population, as in the case of Poland (Żuk, 2023), are valid in Estonia, such as the economic revenue and jobs (Galgoczi, 2019; Oei et al., 2020; Oliveras et al., 2020; Żuk, 2023). Above all, the symbolic ties to Ida-Viru County's oil shale industries threaten the sociocultural space. Uncertainties are not only about income but also about the community's ability to maintain their everyday sociocultural activities, which have been practised around industrial space. Thus, the existing social disparities and the insufficient attention to social injustices by the EU Green Deal might lead to the local population's reduced engagement in influencing the social process of the energy transition that directly affects their everyday lives.

My thesis results on the implementation of the energy transition reveal two significant policy implications related to the vicious cycle of lower socio-economic conditions. Firstly, due to the intricacies involved in the social processes while producing and re-producing the space before or during the energy transition, the social determinants of health are greatly influenced. This means that Health in All Policies (HiAP) (Leppo, 2013; Ståhl et al., 2006) is applicable in the context of the energy transition, where the EU Green Deal should holistically consider health and well-being factors. However, health and well-being experts should also actively contribute to devising EGD-like macroeconomic policies and make substantial suggestions to avoid health inequalities. Secondly, due to the impact on social determinants of health before/during the transition, the socioeconomic conditions of the local population are even more influenced, contributing to the low meaningful engagement in the transition process. If HiAP had been implemented at the EU level and local engagement had been promoted, the "ability to adapt and self-manage in the face of socioeconomic changes" (Huber et al., 2011) might have been improved. However, the meaningful engagement of the local population in the energy transition process is also not well addressed in the literature or is fragmented across disciplines (Suboticki et al., 2023). Authorities have been informing the local population about the energy transition, but their lack of engagement has fostered future uncertainties. Informing about the process does not foster meaningful local engagement yet; engagement does not guarantee justice (Suboticki et al., 2023). The expected health co-benefits from the energy transition policy (Fuller et al., 2022) might not turn into reality with the above-discussed underlying causes.

Even the redevelopment trajectory of industrial regions transforming into green areas can be complex and multifaceted, as observed in Ida-Viru County. Spatial, political, economic and sociocultural factors are critical in this transition (Ravaz et al., 2024). Transforming industrial sites into heritage or communal spaces has been considered important by inhabitants in many regions, such as coal mines being transformed into cultural spaces or the London Docklands into art museums (Ravaz et al., 2024). During the interviews, there were discussions about redeveloping industrial sites of Ida-Viru County into heritage sites, agricultural parks and economic centres. However, my thesis lacks enough data to determine whether residents, technocratic figures or both support these ideas. This limitation restricts my ability to conclude the interaction between governance and redeveloping the area as the sociocultural hub.

Despite ongoing efforts to create new economic opportunities in Ida-Viru County, replacing the 5,800 direct and 18,000 indirect jobs lost poses significant challenges in the short term. A lack of bottom-up initiatives in the region can exacerbate this situation. According to **Study III**, job security and sociocultural needs are essential for the residents. How political forces operate is crucial for social policy and meeting local needs. For example, many workers in northern Romania migrated abroad or returned to their hometowns due to job scarcity following the closure of the coal mines (Radu, 2018). However, in Estonia there is a strong political will to reduce the out-migration from Ida-Viru County and make the region more attractive. Nevertheless, there are other EU funding mechanisms that complement the Just Transition Fund (JTF), such as the European Regional Development Fund (ERDF) and the European Social Fund Plus (ESF+), and the existing funding of the Cohesion Fund, of which Estonia is also one of the beneficiaries (Kyriazi and Miró, 2023). According to Kyriazi and Miró (2023), during discussions in the European Council there was a proposal to cut the Cohesion Fund and redirect those funds to the JTF. However, several highly impacted member states, including Estonia, Hungary, Romania, the Czech Republic and Poland, continued to oppose this proposal and demanded to pledge for large funding. Understanding how these funding sources are being implemented across socioeconomic areas is beyond the scope of my thesis; however, they present an opportunity to mitigate the social consequences of the energy transition. During the interviews for Study III, a common sentiment emerged regarding the significant reliance on JTF funding, which amounts to 350 million euros, with little to no connection to other funding sources. This could be attributed to the fact that JTF activities were still in their early stages.

Reskilling workers is crucial to creating more employment opportunities in the redevelopment process, yet it presents both potential and limitations. Estonia has supportive welfare plans such as early retirement of the workers and unemployment benefits for those who have worked longer term in the oil shale industry. Im et al. (2023) noted that compensatory policies like unemployment benefits and pensions are important for social stability, but they can strain economies reliant on fossil fuels. In contrast, long-term social investment measures, such as active labour market policies incorporating training and education, help convert unemployed workers into green jobs. In Estonia's Territorial Just Transition Plan, there is an emphasis on retraining workers, with 49% of them needing this support (Ministry of Finance, Estonia, 2021). However, Crespy and Munta (2023) critique this approach, arguing that the current focus on retraining workers is narrow-minded and neglects broader social policy concerns in the EU, which often prioritises economic growth over addressing social inequalities. They emphasise the need for holistic measures to tackle the intersection of environmental and social issues, pointing out that the EU's approach to just transition is fragmented and lacks mechanisms to ensure distributional and procedural justice, per International Labour Organization recommendations. On the other hand, Kyriazi and Miró (2023) highlight that the JTF policy agenda in the European Parliament on social inequalities was driven by an active bottom-up approach involving civil societies such as trade unions and mass mobilisation such as the Yellow Vests protests.

While I discuss the redevelopment trajectory, it is also crucial to remember that the industry and policy alliance is strong in Estonia, where the industries might seek to prolong their operations, delaying the much-needed transition (Sillak and Kanger, 2020). Such delay might come at even greater welfare costs as there will be retraining for greener jobs and continuing the industry jobs in parallel, which might confuse the inhabitants and make them lose faith in their future. Furthermore, member states that fail to achieve climate neutrality by 2050 will receive a 50% reduction in JTF funding (Kyriazi and Miró, 2023). Their cascading impact is on the continued social inequality and environmental pollution impacting the health and well-being of the local population, as shown in **Studies I and II**.

In conclusion, the application of systems thinking has shown us that any action taken within an energy system ripples out, affecting the health and well-being of communities. This ties back to how air pollution is linked to ABOs, where the low SES mothers were impacted more in the fossil-fuel region. Also, while implementing the EU Green Deal policy on energy transition, analysis indicates that Ida-Viru County is being affected more due to various socioeconomic conditions. While it is valid for the national and EU-level actors that the energy transition is about the shift from a dirty energy system to a cleaner one, including the economic changes, for the inhabitants, especially those dependent on the oil shale industry, the focus has not been so much on phasing out dirty industry but on whether to transition despite the health and well-being effects, including the change in socioeconomic status.

CHAPTER 6. CONCLUSION

Energy transition policy can be considered a key to mitigating climate change, offering health and well-being benefits. Understanding the nuances of the energy transition process and how it impacts those who are already most exposed to environmental hazards and social inequalities has been the focus of this thesis. In Ida-Viru County, people living in or near ICS are already impacted more by ABOs due to the proximity and the fine particles. The reproduction process of fossil fuel areas involves several underlying interactions among actors, such as inhabitants and authorities. The social interaction among the inhabitants towards the oil shale technology and authorities prioritising economic and energy needs can be conflicted. In this thesis, I aimed to investigate the impacts of air pollution on health outcomes. I further delved into the case of Ida-Viru County, a fossil fuel industrial region of Estonia, to examine the health and well-being impacts of social inequalities and climate policy on energy transition. Based on the analysis, I can conclude the following:

Research Question 1, Study I

- Air pollutants from industrial sources such as $PM_{2.5}$, PM_{10}, polycyclic aromatic aydrocarbons (PAHs), BTEX (mix of benzene, toluene, ethylbenzene, and xylene), heavy metals such as cadmium, arsenic, lead, pollutants, mixtures and living closer to industrial areas are found to affect birth outcomes negatively.
- The main birth outcomes impacted by exposure to air pollutants during pregnancy are low birth weight (LBW), preterm birth (PTB), small for gestational age (SGA), term low birth weight (TLBW), and intra-uterine growth retardation (IUGR).

Research Question 2, Study II

- The odds ratio of having LBW babies in Ida-Viru County from exposure to $PM_{2.5}$ during pregnancy was 1.56.
- The closer the mothers had been living to an industrial area during pregnancy, the higher the odds were of having babies with LBW and PTB.
- In terms of social inequalities, pregnant women of Russian-speaking populations and those with lower education levels have been disproportionately affected by adverse birth outcomes.

Research Question 3, Study III

- While environmental health hazards are anticipated to decrease with the shift towards sustainable energy, the socioeconomic aspects of health inequalities persist and may even aggravate.
- Job uncertainties and misaligning the EU's energy transition framework with local contexts may increase the local population's vulnerability. Particularly concerning is the situation in regions like Ida-Viru County,

where the dependency on industries for economic stability is deep-rooted. The transition, therefore, may exacerbate existing socioeconomic disparities among the local population and lower the chances of engagement in decision-making to shape their city, leaving the local population in limbo.

- The mental and physical health of these communities has been impacted for decades, especially among individuals in the oil shale industry. This is compounded by a lack of governmental recognition for their cultural and symbolic ties to the industry, leading to increased mental health issues and resistance to change. The transition process's neglect of social sustainability is creating indirect effects on health and well-being, which were thus found to be profound. It also reveals that there is a disconnect between the top-level EU Green Deal's macroeconomic policy and the local-level needs.

Contrary to the importance of policy integration as advocated by the HiAP approach, a disjointed approach to the energy system and the health and well-being system in the energy transition process undermines the sustainable development goals of good health and well-being, decent work and reduced inequalities.

CHAPTER 7. RECOMMENDATIONS

The research presented in this thesis highlights that the EGD's energy transition process overlooks both local communities' existing and future causes of health and well-being inequalities. The underlying reasons for health and well-being inequalities range from socioeconomic and cultural needs to the power dynamics around the oil shale industries. The Just Transition Fund is deemed insufficient to address these local issues, potentially exacerbating health and well-being inequalities. This thesis thus calls for a more nuanced, culturally sensitive and holistic approach to policymaking, ensuring that the socioeconomic and health and well-being impacts of such large-scale transitions are equitably addressed at all governance levels. This is essential for the sustainable development of these regions and the holistic well-being of their populations. The following recommendations could create several opportunities to reduce health inequalities.

7.1. Further research recommendations

1. **Studying the long-term effects of adverse birth outcomes**

Based on **Study II**, a prospective longitudinal cohort of those born with low birth weight (LBW) and preterm birth (PTB) could be established to research future risk of non-communicable diseases (Arima and Fukuoka, 2020; Barker et al., 1993; Jornayvaz et al., 2016; Swanson et al., 2009). Compared to other regions, in Ida-Viru County, the local population is more impacted by other health conditions, such as cancer (Idavain et al., 2020), respiratory illness (Idavain et al., 2019) and annoyance by noise (Orru et al., 2018), and further attention is needed regarding health and well-being conditions.

2. **Promoting research on social inequalities, subjective well-being and health impacts**

Research on ethnic and regional stratification in other health conditions and diseases can illuminate the pattern of social inequalities across different diseases and health outcomes, as demonstrated in **Study II**. Also, one of the drivers of social well-being could be that Russian speakers generally have a weak sense of belonging to post-Soviet nations (Muiznieks et al., 2013). Thus, further research on the interaction between their environmental context, socioeconomic status, sense of belonging and existing health and well-being conditions could help understand the pathways towards unequal health and well-being outcomes.

3. **Interdisciplinary research to create a holistic understanding and identify actionable points regarding the impact of the energy transition on socioeconomic and health and well-being spheres**

Interdisciplinary research should be further pursued to simulate and model various development paths in the interaction of energy and health and well-being systems. Further modelling should be done based on knowledge across the disciplines, integrating socioeconomic, health and well-being, policy, political and technical data sources. Based on the work on **Study III** and the limitations of the causal loop diagram, mathematical modelling and stock and flow simulations are recommended to predict the system's behaviour (Williams and Hummelbrunner, 2011).

4. Intervention studies based on the participatory approach
Intervention studies based on the participation of citizens, employees, stakeholders and researchers across the different loops and linkages highlighted by the CLD in **Study III** could generate even more feasible action points. From the beginning, their active participation in defining the problem, analysing the data and formulating the recommendations could enrich the knowledge base and promote co-designing interventions. Researchers could provide a systematic platform for targeted discussion between citizen-researchers-stakeholders. Such engagement would help build the capacity of citizens to analyse and better understand the complexity of the social/community issues and improve the ownership of the interventions.

7.2. Policy recommendations

1. Boosting capacities to adapt and cope with future uncertainties
Empowering the local population should be one of the core strategies of the energy transition process, which will make the community more resilient despite socioeconomic changes. Addressing the two main issues of 1) inability to adapt to socioeconomic changes and 2) uncertainties about the future among the local population can have a ripple effect across other elements in the causal loops (**Study III**). State and local governments should have longer-term strategic plans to foster opportunities to strengthen the capacity of local population in various dimensions, such as education, language and new work skills, to adapt to socioeconomic changes.

The ingrained attitudes of the local population, including "mining as a tradition" and "miner as the foundation of state economy", need recognition and addressing for a more inclusive transition. Alternative views on energy transitions could be promoted through examples of positive transitions from similar cases across the EU.

To address uncertainties about the future, participatory foresight exercises (Koskinen et al., 2023) could be a solution to make the transition process more transparent and foster a sense of ownership/responsibility for the future. Engagement in analysing the current and plausible future states of health and well-being and the factors determining this in the context of alternative energy sources would improve understanding of the complexity of transitions. It would also help to build consensus on the leverage points to shape the future and overcome uncertainties.

At the community level, communal space promoting social well-being should be created in Ida-Viru County to compensate for the loss of communal space because of the phase-out of the oil shale industry. Such space can be created through community-level health and well-being promotion and economic and cultural activities. More public and media discussions on the impact of the current oil shale industries, the implications for climate change, and the energy transition are one way to restore community. However, not to let the local population feel that health and well-being are their responsibility entirely, actors from multiple sectors should be involved in those local discussions.

2. Building capacities for civil society and entrepreneurial initiatives

Meaningful community engagement can be supported by building the capacities of civil society organisations to advocate for a more inclusive and equitable social process of producing and re-producing space. Local civil society organisations can be crucial mediators in monitoring and interpreting the national and European-level policy processes and finding ways to advocate for local needs (Francesconi et al., 2021). To be able to perform in this role, strong capacity building regarding (EU) policy and financing processes needs to be targeted at the existing organisations as well as emerging initiatives. Building capacities to apply for external funding and access to peer support from networks of civil society organisations would make local organisations more capable of participating in policy dialogue.

Governments at all levels should take action following the systematic people-centric designs and innovations that would allow the local population to take responsibility and ownership, thus strengthening their capacity to deal with changes (OECD, 2021). Often, international companies are more active in using the Just Transition Funds and other sources to establish their business in Ida-Viru County, which will surely improve the economic situation. However, opportunities should be provided for "learning by doing" for the local inhabitants and government to foster the learning attitude and confidence to initiate new services and industries towards environmental, social and governance (ESG) investing. Establishing frames for goal-setting and supporting novel initiatives needs to be backed up by monitoring their expected and unintended consequences to follow up on people-centric and sustainable designs.

3. Health should be incorporated into all policies to prevent negative impacts on mental and physical health and well-being and promote health equity

The social determinants of health at the structural level must be addressed. This requires intersectoral actions across different systems, including the energy system. The Health in All Policies (HiAP) framework could help guide the development of intersectoral actions that fully consider the health impacts of decisions. Health experts should recognise their unique expertise and sense their responsibility to share it to ensure that health concerns are adequately reflected in assessing the impacts of strategic and local planning, including in the energy sector.

Even though the EU member states have autonomy to design the national programmes of adopting EGD-type initiatives, member states have unequal capacities to analyse and address the social and health complexities that may arise during the implementation. Therefore, EU-wide support mechanisms for the analysis capacities of member states could be introduced. One of the tools in this supportive toolkit could be based on the Health Equity Impact Assessments (HEIA) (Olyaeemanesh et al., 2023). HEIA's perspective would ensure that social equity and justice are considered beyond the direct health impacts and not leave anyone behind in the energy transition.

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SUMMARY IN ENGLISH

Health and well-being inequalities in industrially contaminated sites: The case of Ida-Viru County in Estonia

The doctoral thesis investigates the health impacts in industrial regions transitioning from fossil fuels to cleaner energy solutions. Fossil-fuel-related emissions are responsible for approximately 65% of mortality due to air pollution (Lelieveld et al., 2019). People in vulnerable situations often reside closer to industrial areas, primarily for employment, exacerbating social inequality (Pasetto et al., 2019; Perlin et al., 2001). To mitigate the environmental impact of industries, the European Green Deal (EGD) has established the zero pollution action plan. Concurrently, the Just Transition Fund (JTF) aims to support regions whose socioeconomic conditions are heavily reliant on fossil fuel industries (European Commission, 2019; Kreienkamp et al., 2022). However, EGD policies, including the energy transition policy, are least aligned with sustainable development goals related to social sustainability, such as health and equality (Koundouri et al., 2024). Persistent health inequalities in industrially contaminated sites, coupled with the ongoing energy transition under the EGD, highlight a critical research gap: the impact of climate action on health and well-being, particularly its socioeconomic aspects (Pereira et al., 2021). Thus, this doctoral thesis examines the impact of industrial pollution and social inequality on birth outcomes in Ida-Viru County in Estonia and systematically analyzes the effects of energy transition on human well-being and health.

Drawing from a systematic review of 45 peer-reviewed studies, Study I found that pollutants from power plants and petrochemical industries, including fine particulate matter ($PM_{2.5}$) and particulate matter (PM_{10}), are associated with pre-term birth, term low birth weight, and born short for gestational age. Proximity to industrial areas was identified as the strongest risk factor for low birth weight and pre-term birth.

The epidemiological study examined 208,313 birth records in Estonia, including Ida-Viru County, home to Estonia's oil shale industries (Study II). Infants born in Ida-Viru County exhibited significantly lower birth weights and a higher prevalence of premature births compared to national averages. The impact of low birth weight (LBW) on maternal ethnicity was consistent at both national and county levels, being significantly higher among non-Estonians. However, distinct health disparities in Ida-Viru County, compared to the national level, were attributed to $PM_{2.5}$, residential proximity to industrial sites, lower maternal education levels, and higher maternal age. Mothers living closer to industrially contaminated sites (ICS) compared to those living ≥10 km away were more affected by low birth weight (odds ratio for ≤3 km of ICS: OR = 1.51, 95% CI 1.21–1.88, for ≤5 km: OR = 1.18, 95% CI 1.04–1.33) and pre-term birth (for ≤3 km of ICS: OR = 1.58, 95% CI 1.26–1.98). This proximity indicates the impact of exposure to a mixture of pollutants and social inequality, as individuals in

lower socioeconomic positions tend to live closer to industrially contaminated sites.

The in-depth case study on Ida-Viru County revealed that the EU Green Deal's energy transition policy has a dual impact on the local community (Study III). The resulting causal loop diagram (CLD) illustrated that while energy transition offers environmental benefits, adaptation to this change may be hindered by the region's long-standing socio-economic, educational, and health inequalities, along with entrenched cultural norms. Efforts by state and local governments to create new jobs have not succeeded in replacing the economic dependence on the oil shale industry. Additionally, there has been a lack of traditions and support mechanisms to foster local inhabitants' self-determination, leadership, and entrepreneurship skills in the energy transition. In conditions of weakened civil society organizations, business, and administrative environments, the abandonment of the oil shale industry may exacerbate social inequality, which in turn negatively affects the physical and mental health and health behaviours of residents.

Adapting to the transition of the oil shale industry requires more than just the reactive measure of reorienting workers and businesses. Comprehensive measures that transcend energy, health, and well-being systems are necessary to prevent the aggravation of inequalities. Meaningful engagement of locals and participatory action research could contribute to co-creating solutions for redeveloping industrial regions. Future studies on just transition should analyse the impacts of both environmental factors and social inequality on the health and well-being of residents throughout their life course.

SUMMARY IN ESTONIAN

Tervise ja heaolu ebavõrdsus saastunud tööstusaladel: Ida-Virumaa juhtum

Doktoritöö uurib tervisemõjusid tööstuspiirkondades, mis siirduvad fossiilkütustelt puhtamate energialahenduste poole. Fossiilkütuste kasutamisel tekkiv saaste põhjustab hinnanguliselt ligi 65% õhusaastest tingitud varajastest surmadest (Lelieveld et al., 2019). Madalama sotsiaalmajandusliku staatusega inimrühmad elavad töövõimaluste tõttu suurema tõenäosusega tööstusalade läheduses, mis suurendab sotsiaalset ebavõrdsust (Pasetto et al., 2019; Perlin et al., 2001). Keskkonnamõjude leevendamiseks on Euroopa Liidu (EL) rohelise kokkuleppe raames kehtestanud nullsaaste tegevuskava. Samas õiglase ülemineku fond toetab piirkondi, mis sõltuvad kõige enam fossiilkütustel põhinevast tööstusest (European Commission, 2019; Kreienkamp et al., 2022). EL rohelepe ja energiapoliitika üleminekuplaanid ei ole siiski piisavalt kooskõlas sotsiaalse jätkusuutlikkuse eesmärkidega, sealhulgas tervise ja võrdsuse tagamisega (Koundouri et al., 2024). Tervisealane ebavõrdsus tööstuspiirkondades koos energiaüleminekuga toob esile olulise uurimislünga: kliimameetmete mõju tervisele ja heaolule arvestades sotsiaalmajanduslikku konteksti (Pereira et al., 2021). Käesolev doktoritöö uurib tööstussaaste ja sotsiaalse ebavõrdsuse mõju sünninäitajatele Ida-Virumaal ning analüüsib süsteemipõhiselt energiaülemineku mõjusid inimeste heaolule ja tervisele.

Doktoritöö raames koostatud süstemaatiline ülevaade 45 eelretsenseeritud teadusartiklist näitas, et elektrijaamade ja naftakeemiatööstuse saasteained nagu peenosakesed (PM_{10}) ja eriti peened osakesed ($PM_{2.5}$) on seotud enneaegsete sündide, madala sünnikaalu ning rasedusea suhtes väikesekasvulise lootega. Tööstuspiirkondade läheduses elamine on samuti oluline riskitegur enneaegsete sündide ja madala sünnikaalu esinemiseks.

Eesti sünniregistri andmetel tehtud epidemioloogiline uuring 208 313 elussünni andmetel näitas, et põlevkivitööstuse mõjupiirkonnas Ida-Virumaal sündinud lastel oli oluliselt madalam sünnikaal (<2,5 kg) ja kõrgem enneaegsete sünnituste (<37 nädalat) esinemissagedus kui Eestis keskmiselt. Statistiline analüüs näitas, et võrreldes Eesti teiste piirkondadega olid Ida-Virumaal sündinute terviseriskid seotud õhusaaste $PM_{2.5}$, emade madalama haridustaseme ja kõrgema vanusega. Madala sünnikaalu risk oli suurem ka mitte-eestlastel. Emadel, kes elasid tööstusalade lähedal, oli vastsündinute madala sünnikaalu esinemise risk kõrgem: šansside suhe kuni 3 km kaugusel elamisel võrreldes kaugemal kui 10 km elamisega oli 1,51 (95% CI 1,21–1,88) ning elamisel kuni 5 km kaugusel 1,18 (95% CI 1,04–1,33). Enneaegsete sündide esinemise šanss oli kuni 3 km kaugusel elamisel 1,58 (95% CI 1,26–1,98).

Ida-Virumaa juhtumiuuring toob esile ohu, et energiaüleminek võib süvendada sotsiaalset ebavõrdsust, kuigi ELi rohelise kokkuleppe ja õiglase ülemineku fondi eesmärk on toetada fossiilkütustest sõltuvaid piirkondi ning parandada kohalike elanike tervist ja heaolu. Kuigi üleminek puhtamatele energiaallikatele mõjub keskkonnale positiivselt, on selle muutusega kohanemist takistamas piirkonna pikaajaline sotsiaalmajanduslik, hariduslik ja tervisealane ebavõrdsus ning juurdunud kultuurinormid. Riigi ja kohalike omavalitsuste pingutused uute töökohtade loomiseks pole täitnud eesmärki asendada senine põlevkivitööstuse tulusõltuvus. Samuti puuduvad tõhusad sekkumised ja traditsioonid, mis toetaksid kohalike elanike enesemääramis-, juhtimis- ja ettevõtlusoskuste arengut energiaülemineku ajal. Nõrgestatud vabaühenduste, ettevõtlus- ja halduskeskkonna tingimustes võib põlevkivitööstusest loobumine süvendada sotsiaalset ebavõrdsust, mis omakorda mõjutab negatiivselt kohalike elanike füüsilist ja vaimset tervist ning tervisekäitumist.

Põlevkivitööstuse üleminekuga kohanemiseks ei piisa vaid töötajate ja ettevõtete ümberorienteerumisest. Kohalike elanike, vabaühenduste ja omavalitsuste suutlikkuse tõstmine aitaks paremini toime tulla sotsiaalmajanduslike muutustega ja vähendada tervisealase ebavõrdsuse süvenemist. Kohalike sisukas kaasamine ja tegevusuuringud toetaksid õiglasemate sekkumiste kujundamist tööstuspiirkondades. Edasistes õiglase ülemineku uuringutes tuleks analüüsida nii keskkonnast tingitud kui ka sotsiaalsest ebavõrdsusest tulenevaid mõjusid elanike tervisele ja heaolule kogu elukaare vältel.

PUBLICATIONS

CURRICULUM VITAE

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EDUCATION:

2021–2025 Marie Skłodowska-Curie Doctoral Student Network • Institute of Social Studies • University of Tartu, Estonia

2021–2024 Marie Skłodowska-Curie Innovative Training Network Schools on Urban Health • SURREAL consortium
- o Introduction to the systems approach • Luxembourg Institute of Socio-Economic Research (LISER), online
- o Behaviours, exposures and health • Universitair Medisch Centrum Utrecht (UMCU), Utrecht
- o Measurements and management of health • Institut national de la santé et de la recherche médicale (INSERM), Paris
- o Major future trends in health research • Barcelona Institute for Global Health (ISGlobal), Barcelona

03–13, 06/2024 PhD Summer Research School on Global Challenges • University of Bergen, Norway

02–08, 07/2023 Doctoral Summer School on Intervention Science • League of European Research Universities (LERU) • University of Heidelberg, Germany

09/2019 – 08/2021 MSc Global Health • University of Copenhagen, Denmark

WORK EXPERIENCE

2021–2026 Health Sociology Analyst • Institute of Family Medicine and Public Health • University of Tartu, Estonia

09–11/2022 Secondee • Luxembourg Institute of Socio-Economic Research, Luxembourg

09/2016–04/2018 District Coordinator for Ministry Programmes on Safe Abortion and Adolescent Health • Ipas Nepal

01/2016–08/2016 Sexual and Reproductive Health Rights and Child Rights Activist and Trainer • Centre for Agro-Ecology and Development (CAED) Nepal

KEY SKILLS

R, SPSS, NVivo, Zotero, Vensim, Microsoft Office Package, Systematic Review, Qualitative and Quantitative Research, Manuscript Writing and Publication, Writing Policy Brief, Thinking and Designing Systems Map

GRANTS AND FELLOWSHIPS

- Marie Sklodowska-Curie Innovative Training Network Fellowship for Early-Stage Researcher: Systems Approach for the Urban Environment and Health (SURREAL), Horizon 2020 (2021)
- Fellowship on human rights and social justice provided by Humanity in Action (2021)
- Master's dissertation grant from the World Diabetes Foundation, Denmark (2021)
- Danish Government Scholarship for MSc in Global Health (2019)

SELECTED CONFERENCES

13–16, 08/2024	Oral presentation PhD pre-conference and conference: 31st Nordic Sociological Association, Linköping University (campus Norrköping), Norrköping, Sweden
13–15, 02/2024	Poster presentation at the conference: People and Planet: From Theory to Solutions, Lahti, Finland
11–12, 10/2023	Oral presentation at the conference: Connecting Health and Climate Change, Stockholm, Sweden
8–10, 09/2022	Poster presentation at the conference: Urban Transitions 2022, Integrating Urban and Transport Planning, Environment and Health for Healthier Urban Living, Sitges, Spain
30/09/2022	Oral presentation at the International Workshop on Impacts of Early Life Exposure to Environmental Contaminants: Children's Health in the Anthropocene, University of Evora, Portugal

PUBLICATIONS

1. Dahal, U., Orru, K., Orru, H., Dijst, M., 2024. Green dreams, local realities: Complexities of the European Union's energy transition to ensure local health and well-being in a fossil fuel-based industrial region. Environmental Impact Assessment Review 106, 107520. https://doi.org/10.1016/j.eiar.2024.107520
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mental Research and Public Health 19, 11559. https://doi.org/10.3390/ijerph191811559
4. Veber, T., Dahal, U., Lang, K., Orru, K., Orru, H., 2022. Industrial Air Pollution Leads to Adverse Birth Outcomes: A Systematized Review of Different Exposure Metrics and Health Effects in Newborns. Public Health Rev 43. https://doi.org/10.3389/phrs.2022.1604775

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- Sissejuhatus süsteemipõhisesse käsitlusse • Luksemburgi sotsiaal-majanduslike uuringute instituut (LISER), veebis
- Käitumine, kokkupuude ja tervis • Universitair Medisch Centrum Utrecht (UMCU), Utrecht
- Tervise mõõtmine ja juhtimine • Institut National de la Santé et de la Recherche médicale (INSERM), Pariis
- Terviseuuringute peamised tulevikutrendid • Barcelona Globaalse Tervise Instituut (ISGlobal), Barcelona

03–13, 06/2024 Doktoriõppe suvekool globaalsete väljakutsete teemal • Bergeni Ülikool, Norra

02–08, 07/2023 Doktoriõppe suvekool sekkumisteadusest • Euroopa Teadusülikoolide Liiga (LERU) • Heidelbergi Ülikool, Saksamaa

09/2019–08/2021 MSc Global Health • Kopenhaageni Ülikool, Taani

TÖÖKOGEMUS

2021–2026 Tervisesotsioloogia analüütik • Peremeditsiin ja rahvatervise Instituut • Tartu Ülikool, Eesti

09–11/2022 Lähetatu • Luksemburgi sotsiaal-majanduslike uuringute instituut, Luksemburg

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01/2016 – 08/2016 Seksuaal- ja reproduktiivtervise õiguste ning laste õiguste aktivist ja koolitaja • Agroökoloogia ja arengu keskus (CAED) Nepal

VÕTMEOSKUSED

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TUNNUSTSED JA STIPENDIUMID

- Marie Sklodowska-Curie uuendusliku koolitusvõrgustiku stipendium varajases staadiumis teadlasele: linnakeskkonna ja tervise süsteemne lähenemine (SURREAL), Horisont 2020 (2021)
- Inimõiguste ja sotsiaalse õigluse stipendium, mille pakub Humanity in Action (2021)
- Taani Maailma Diabeedi Fondi magistritöö stipendium (2021)
- Taani valitsuse stipendium ülemaailmse tervise magistriõppe jaoks (2019)

VALITUD KONVERENTSID

13–16, 08/2024	Suuline ettekanne doktorikoolis ja konverentsil: 31st Nordic Sociological Association, Linköping University (campus Norrköping), Norrköping, Sweden
13–15, 02/2024	Posterettekanne konverentsil: People and Planet: From Theory to Solutions, Lahti, Finland
11–12, 10/2023	Suuline ettekanne konverentsil: Connecting Health and Climate Change, Stockholm, Rootsi
8–10, 09/2022	Posterettekanne konverentsil: Urban Transitions 2022, Integrating Urban and Transport Planning, Environment and Health for Healthier Urban Living, Sitges, Hispaania
30/09/2022	Suuline ettekanne rahvusvahelisel seminaril Impacts of Early Life Exposure to Environmental Contaminants: Children's Health in the Anthropocene, Evora ülikool, Portugal

PUBLIKATSIOONID

1. Dahal, U., Orru, K., Orru, H., Dijst, M., 2024. Green dreams, local realities: Complexities of the European Union's energy transition to ensure local health and well-being in a fossil fuel-based industrial region. Environmental Impact Assessment Review 106, 107520. https://doi.org/10.1016/j.eiar.2024.107520
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