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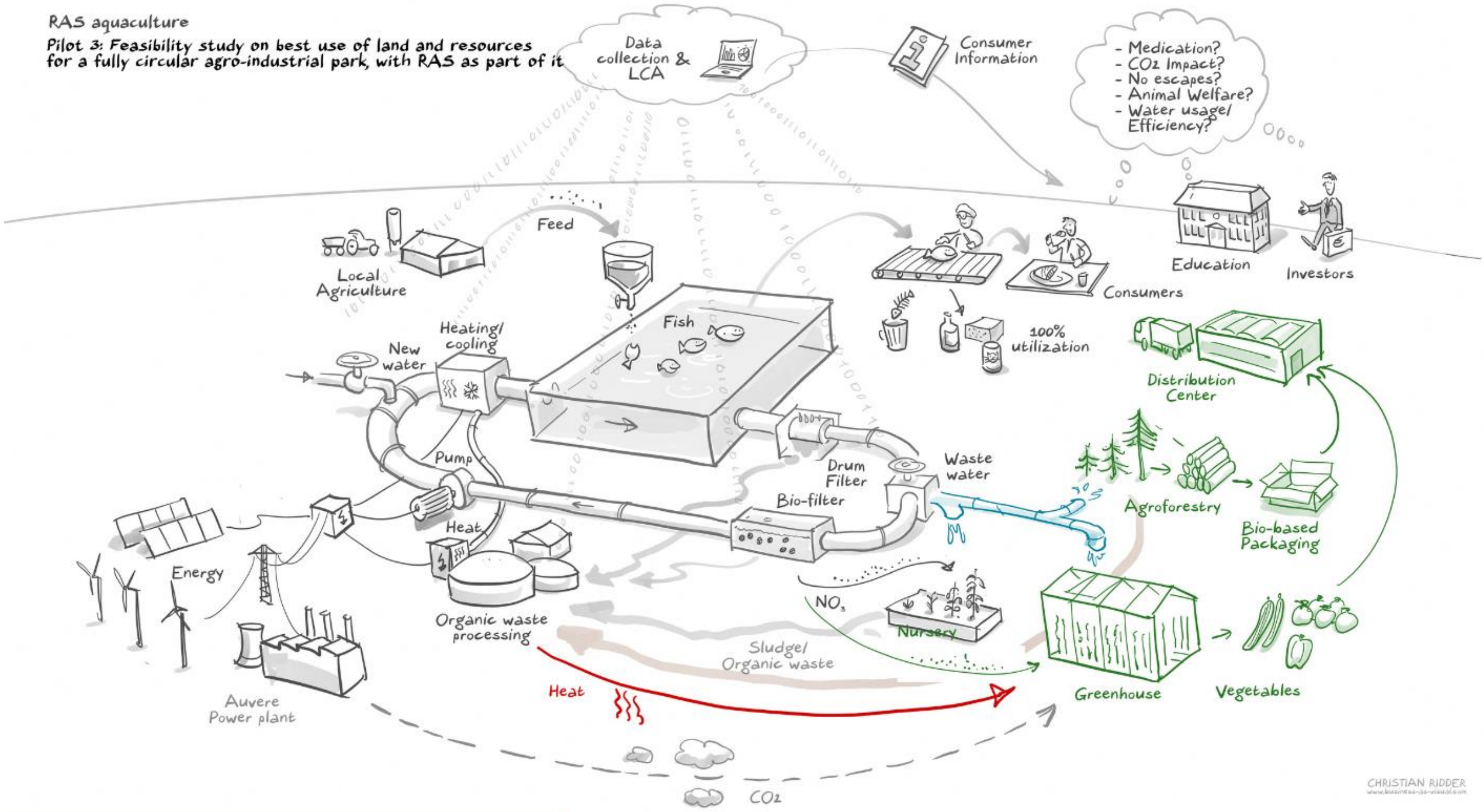

Chapter 3

Study on an Industrial Symbiosis Agro-park with a RAS farm

Business Model

Pilot Owner: IVIA EXPAND YOUR BUSINESS

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WATER-SMART SOCIETIES

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Summary

The Estonian Industrial Symbiosis Agropark (EISAP) was conceived as an innovative initiative to transform a degraded quarry in Ida-Viru County into a productive industrial ecosystem. It aims to integrate Recirculating Aquaculture Systems (RAS), greenhouse agriculture, and circular economy principles while leveraging waste heat, water, and CO_2 from nearby power plants. The project seeks to promote sustainable development, create local employment, and demonstrate the viability of industrial symbiosis. However, upon detailed analysis, significant challenges emerge, casting doubt on the project's feasibility and long-term viability.

The assessment conducted encompasses technical, economic, environmental, and social dimensions. It evaluates the macro-environmental landscape through PESTLE and SWOT analyses, site-specific conditions, resource availability, and technological requirements. The findings highlight numerous hurdles that question the practicality of implementing such an ambitious concept in the proposed location.

The foundation of EISAP's design is its dependence on waste outputs from the nearby Auvere power plant. This includes thermal energy, CO_2, and post-processed cooling water to support aquaculture and greenhouse systems. However, the long-term operational stability of the power plant is uncertain due to Estonia's commitment to reducing greenhouse gas emissions and phasing out oil shale energy production by 2030. While plans for biomass conversion exist, the technical feasibility of such a transition is unclear. Moreover, interruptions in energy production, whether due to maintenance or market conditions, could disrupt agropark operations. Such a critical reliance on a single, vulnerable input stream raises serious concerns about the project's resilience.

The physical characteristics of the site compound these challenges. The uneven terrain, characterized by steep slopes and ridges, is unsuitable for large-scale industrial infrastructure without extensive and costly modifications. Additionally, much of the area is forested, requiring significant clearing to make it viable for development. The landscape's instability, exacerbated by ongoing mining activities, further complicates the construction of RAS facilities, greenhouses, and transportation networks. In the longer term, cessation of mining operations would lead to rising water levels, fragmenting the area into isolated landmasses. The necessity to adapt to such hydrological changes introduces additional uncertainty and expense.

Resource availability poses another significant hurdle. Groundwater reserves in the region are limited and of varying chemical quality, possibly insufficient to meet the agropark's projected water needs. Surface water, primarily from the Narva River, is from fish farm perspective biologically polluted, heightening the risk of infections in aquaculture systems. While advanced RAS technologies could mitigate water usage, they demand substantial capital investment and operational expertise, which may not be readily available in this remote location.

Economic analysis highlights further vulnerabilities. The agropark's reliance on cheap inputs, such as waste heat and CO_2, assumes that these will be both available and economically advantageous compared to alternative sites. However, the power plant does not currently have the infrastructure to capture and supply CO_2, making it unlikely that EISAP would enjoy cost advantages over competitors. Additionally, the project's remote location increases transportation costs for both inputs and outputs, further eroding economic feasibility. The area's isolation also limits access to a skilled workforce, and while Ida-Viru County has high unemployment, the specific expertise required for such a complex operation may necessitate costly training programs or recruitment from other regions.

Environmental considerations amplify these issues. The proximity to Alutaguse National Park and Natura 2000 sites creates potential conflicts with conservation objectives. The presence of protected

species and high biodiversity in the vicinity could lead to regulatory opposition, delays, or even cancellation of parts of the project. Furthermore, mining activities and the associated dust, noise, and vibrations pose risks to sensitive aquaculture and greenhouse systems, potentially disrupting operations or lowering productivity. Integrating the agropark into such a challenging environment requires exceptional planning and mitigation measures, the costs and practicality of which remain unclear.

Technological integration, a cornerstone of the agropark concept, is another area of concern. While RAS and advanced greenhouse technologies are well-established, their application in this specific context involves untested interdependencies. The need for year-round waste heat, precise CO_2 utilization, and high-water quality demands cutting-edge solutions that may exceed current technological capabilities. Seasonal variations in heat demand between aquaculture and greenhouses further complicate resource distribution, requiring innovative but costly system designs.

From a regulatory perspective, navigating the legal landscape presents significant challenges. The need for multiple permits related to environmental impact, land use, water abstraction, and food production is compounded by the site's location in a defence zone and mining area. Coordination among various authorities, coupled with compliance with both EU and Estonian regulations, increases the risk of delays and unforeseen costs.

In conclusion, while the EISAP initiative aligns with global sustainability goals and seeks to revitalize a post-industrial region, its feasibility is undermined by critical vulnerabilities. Dependence on an unstable energy source, challenging terrain, limited resource availability, and unproven technological integration create a fragile foundation. Economic risks, environmental conflicts, and regulatory complexities further exacerbate these issues. Without substantial revisions to its design and guaranteed long-term support, the project is unlikely to achieve its ambitious objectives.

1. IDEA, VISION AND MISSION

Ida-Viru Investment Agency has initiated The Estonian Industrial Symbiosis Agropark, presenting opportunities for the implementation of industrial symbiosis, smart energy grids, and circular economy principles. This initiative has been facilitated in the framework of an Interreg BSR project Technology Transfer for Thriving Recirculating Aquaculture Systems in the Baltic Sea (TETRAS). The scope of the project is to work out, demonstrate and disseminate Recirculating Aquaculture Systems (RAS) in combination with other facilities in eco-industrial parks (Figure 1).

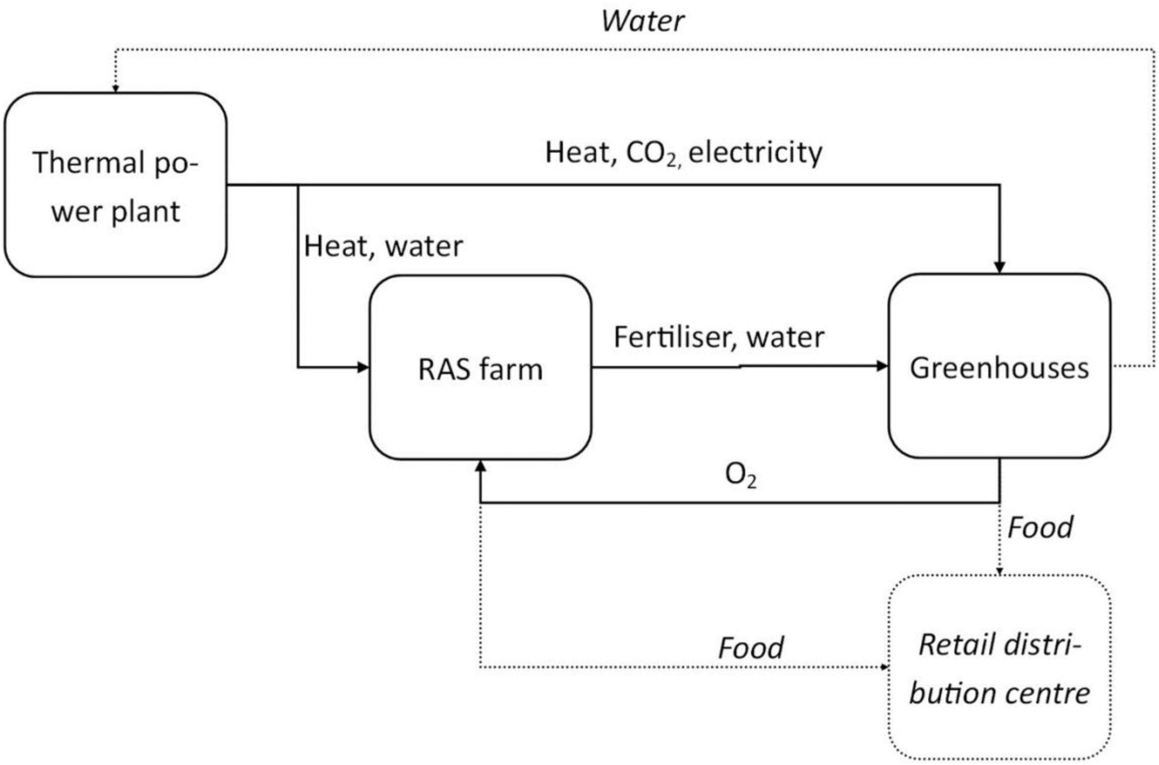

Figure 1. Conceptual position of RAS farm in EISAP (main material / product flows).

Vision. The project area today is a large excavated former quarry which is mostly covered by heaps of crushed stones, partly forested. The idea is to convert this land to a highly productive agri-industrial area, holding greenhouses, aquaculture and other facilities. The project should benefit from the existing thermal power plant as well as from low competition for the land resource.

Mission. The project should contribute to transformation from oil-shale based linear economy to sustainable circular solutions. EISAP should demonstrate a viable industrial symbiosis in bioeconomy. It should provide a significant number of work places for the people of Ida-Viru county, with minimised negative environmental impact.

Current document is a part of the initiation phase of the study. This phase kick-starts the business model innovation. Key activities include understanding the current business model and ecosystem, recognizing the need for innovation, and conducting stakeholder analysis to identify supporters and blockers.

2. MACRO-ENVIRONMENTAL FACTORS

2.1. Overview of Pestle analysis

A PESTLE analysis is a strategic framework used to understand and evaluate the external macro-environmental factors that impact the planned agropark. It stands for Political, Economic, Social, Technological, Legal, and Environmental factors. This analysis helps to identify opportunities and threats in EISAP development, supporting strategic planning and decision-making by providing a comprehensive view of the landscape it operates in.

The analysis involved:

- Political Factors: we evaluated the stability of the political climate, governmental support for industrial and eco-friendly projects, and identified key zoning and environmental regulations.
- Economic Factors: we reviewed local and national economic trends, funding availability for sustainable projects, and analysed the labour market's dynamics.
- Sociocultural Factors: we investigated public attitudes towards sustainability, assessing the impact of community engagement and potential local benefits.
- Technological Factors: we explored the presence of sustainable technologies and the need for infrastructure improvements to support industrial and agricultural innovation.
- Legal Factors: we examined compliance requirements with environmental laws and the process for obtaining necessary construction and operation permits.
- Environmental Factors: we assessed the potential environmental footprint of the eco-industrial park, focusing on resource use efficiency and waste management strategies.

Two types of solutions were analysed: (1) conventional solution with flowthrough fishponds, and (2) RAS, seeking aquaponic integration between fish farm and greenhouses (Figure 2). We found that political, environmental sociocultural factors favour EISAP very much. The bottleneck seems to be in technological issues. A key question is how to design such agropark in principle so that it will work.

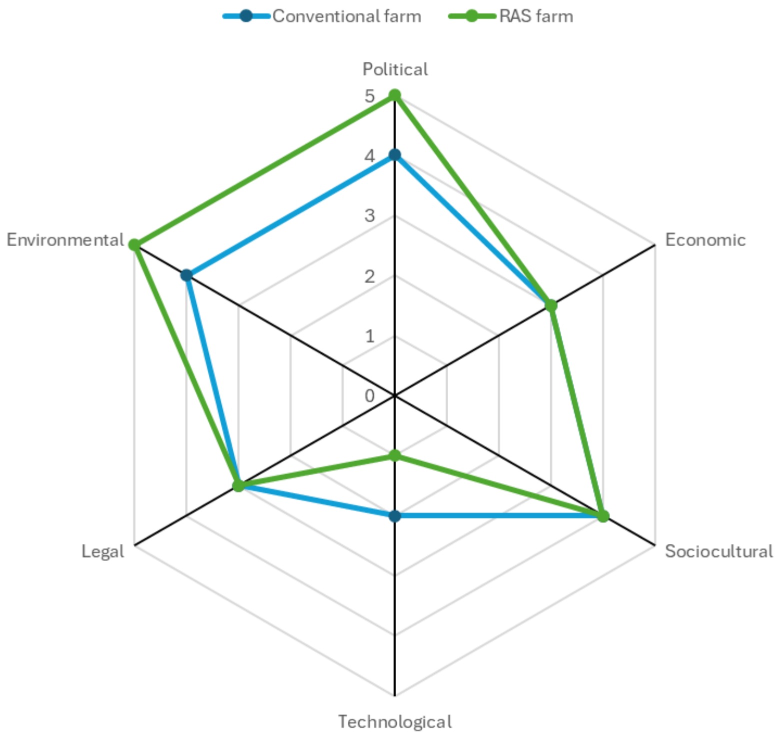

Figure 2. Political, economic, sociocultural, technological, legal and environmental factors of EISAP. 0 – hopeless. 5 – the best.

2.2. Overview of SWOT analysis

Table 1. Strengths, weaknesses, opportunities and threats of EISAP area

Strengths - Potentially cheap inputs: heat, water, electricity, CO2, land, labour - Supporting social conditions: industrially minded people, no residential houses - Favourable political environment: support to green transition, innovation, food security and industrial boost in Ida-Viru County - No conflict or competition with other initiatives in the area - Narva river is relatively little sensitive to water abstraction and wastewater discharge - Public funding incentives - The project area is under design and development	**Weaknesses** - No large city with potential workforce, suppliers and market nearby - Moderate transportation infrastructure - Changing environmental conditions due to mining activities and its inevitable closure in future - Weak potential for switching to sustainable (wind, solar) local energy supply - Unknown groundwater resources - Regulatory hurdles in Estonia
Opportunities - Large landmasses both inside and outside the EISAP area provide space for other large industrial and agricultural initiatives, complementing this symbiotic ecosystem. - Narva river provides sufficient water for other industrial and agricultural initiatives	**Threats** - Closure of the thermal power plant will stop the flow of heat, water, electricity and CO2 - External economic shocks may affect markets and suppliers in a small country - Political tensions with the Russian Federation affect especially eastern EU fringe. - Nature values may appear in the area, blocking the project development

2.3. Political factors

Supporting factors

Estonia, as a member state of the EU, adheres to the bloc's overarching environmental and energy policies, which are increasingly geared towards sustainability, carbon neutrality, and the promotion of circular economy models. **The European Green Deal** (Kazak, 2022), aiming to make Europe the first climate-neutral continent by 2050, supports initiatives that contribute to reducing carbon emissions, enhancing energy efficiency, and fostering sustainable economic growth. The agropark's design, which emphasizes the reuse of waste heat, water, and CO2 from an existing thermal power plant, directly contributes to these goals, potentially garnering support from both Estonian and EU funding mechanisms designed to encourage such innovative environmental projects.

Furthermore, the EU's **Common Agricultural Policy** (CAP, European Commission, 2023) and its frameworks for rural development provide financial and structural support for initiatives that enhance the sustainability and efficiency of agriculture, which the agropark concept is poised to do. By integrating Recirculating Aquaculture Systems (RAS) with greenhouse agriculture, the project can also align with the EU's strategies for sustainable aquaculture, a sector the EU aims to expand sustainably.

Estonia's political climate, especially regarding environmental sustainability and innovation, offers a strong foundation for development. Notably: (a) the government prioritizes industrial growth, and (b) the Just Transition initiative primarily targets the Ida-Virumaa region, where the phase-out of the oil shale sector has spurred political will to promote alternative, sustainable entrepreneurship. This favourable environment is shaped by key national priorities and policies that align with the agropark's goals, including energy efficiency, renewable energy development, sustainable agriculture, and technological innovation.

National Energy and Climate Plan (NECP, Ministry of Climate, 2019). Estonia's commitment to the EU's energy and climate targets is encapsulated in its National Energy and Climate Plan, which outlines strategies for reducing greenhouse gas emissions, increasing the share of renewable energy in its energy mix, and improving energy efficiency across all sectors of the economy. The agropark concept, with its emphasis on utilizing waste heat, water, and CO2 from an existing thermal power plant, directly contributes to these objectives by promoting energy efficiency and potentially reducing the carbon footprint of both agricultural and energy production processes.

Focus on technological innovation. Estonia is well-known for its digital innovation and technological advancements across various sectors (e-Estonia, 2021). The government's supportive stance on innovation extends to environmental and agricultural technologies, where there is a growing interest in projects that can demonstrate new ways of integrating technology with sustainable practices. The agropark project, with its potential for demonstrating innovative approaches to recycling and resource efficiency, is likely to find alignment with national priorities on technological innovation and sustainability.

Sustainable agriculture and food security. Estonia, like many countries, faces the challenge of ensuring food security while also moving towards more sustainable agricultural practices. The government has shown interest in projects that can contribute to local food production, reduce dependence on food imports, and ensure a stable supply of food products. By producing both fish and vegetables locally, the agropark could directly contribute to these goals, making it a potentially attractive project for national agricultural and food security strategies.

Blocking factors

While the Estonian political climate is broadly supportive, specific challenges related to regulatory frameworks, funding, and land use policies could impact the establishment of the agropark. Ensuring the project aligns with local planning regulations, secures necessary permits, and accesses available funding will be crucial steps in the project's development. **Regulatory hurdles** can be significant, as the project would need to navigate both Estonian and EU regulations concerning energy, waste management, and agriculture. Additionally, the project needs approvals from both different central government agencies as well as the local government (municipality), further complicating the execution and requiring additional coordination. The complexity of coordinating between different regulatory frameworks and securing permits for such a novel and integrated project can be time-consuming and costly.

Conclusion

In summary, the political and regulatory environment in Estonia and the EU, characterized by a strong commitment to environmental sustainability, renewable energy, and innovative agricultural practices, provides a fertile ground for the establishment of the agropark in Auvere village. The agropark represents a promising model for sustainable development, aligning with both national and EU priorities, and could serve as a blueprint for similar initiatives across Europe.

Given the supportive yet complex landscape of EU and Estonian political factors for an innovative and eco-friendly agropark in Auvere village, careful project design and implementation are paramount. The design should prioritize flexibility, environmental sustainability and alignment with local and EU regulations and policies.

RAS technology aligns with the EU's strategic priorities in sustainable aquaculture development, potentially attracting support and funding. However, the integration of the agricultural component should not be overlooked, as it complements the circular economy model.

2.4. Economic factors

Estonia's economy is characterized by high levels of innovation, a strong digital infrastructure, and a government supportive of entrepreneurial initiatives, particularly in sectors that promote sustainability and technological advancement. The nation has demonstrated resilience and adaptability in its economic policies, focusing on growth areas such as green technology, digital services, and sustainable agriculture. These priorities align well with the concept of an agropark that integrates recirculating aquaculture systems (RAS) and greenhouse agriculture, leveraging thermal energy and CO2 emissions from an existing power plant.

Supporting Factors

Funding availability and incentives. Estonia's incentive landscape, woven together with EU support measures, presents a robust framework for fostering sustainable development projects like the agropark. With specific emphasis on the Just Transition Fund (JTF) and the Estonian Environmental Investment Centre (KIK), alongside other financial instruments, the project stands to benefit from a multifaceted funding approach aimed at enhancing its implementation and long-term sustainability.

The JTF, targeting regions transitioning away from fossil fuel dependency, particularly Ida-Viru County, underscores the strategic alignment of the agropark with national and EU goals for a green transition. The fund's focus on renewable energy, energy efficiency, circular economy, and the digitalization of industries offers a direct incentive for the agropark, potentially easing the financial burden of initial setup and operational costs. The possibility of receiving up to €15 million, contingent upon project size and impact, emphasizes the fund's role in significantly lowering economic barriers to innovative agricultural and energy efficiency practices.

Simultaneously, KIK's role in financing environmental projects within Estonia supplements the JTF by offering a broad spectrum of support for environmental protection, renewable energy utilization, and sustainable natural resource use. This complementary funding avenue not only reinforces the project's economic viability but also its environmental and social value propositions. By facilitating investments in heat management, waste recycling, and habitat restoration, KIK enhances the project's alignment with sustainability criteria, potentially increasing its eligibility for further public and private investments.

Furthermore, the presence of other support mechanisms, such as the large investor support scheme by Enterprise Estonia and the Ida-Viru industrial investments support scheme by the State Shared Services Center, expands the financial landscape available to the agropark. These programs, tailored to stimulate industrial development and job creation in rural and transitioning areas, offer grants that can mitigate the cost of technological innovations and infrastructure development integral to the agropark's success.

This funding ecosystem not only underscores the financial feasibility of the agropark but also reflects a broader commitment by Estonian and EU entities to foster sustainable development, innovation, and regional economic diversification. The integration of Just Transition Support Measures and KIK, along with other financial instruments, provides a solid foundation for the project, enhancing its prospects for implementation and its potential as a model for sustainable industrial symbiosis.

Innovation-driven economy. Estonia's dedication to digital innovation and technology provides an excellent backdrop for the proposed agropark in Auvere village, enhancing operational efficiency and sustainability through e-governance and digital services (e-Estonia, 2021). Moreover, the vibrant startup ecosystem, supported by platforms like Startup Estonia, promises innovative solutions for agriculture and energy management (Startup Estonia, 2021). These elements collectively bolster the project's feasibility and alignment with Estonia's technological landscape.

Proximity of power plant. Local infrastructure plays a pivotal role in the design and implementation of the agropark. The proximity to the thermal power plant offers a direct connection to the power grid, ensuring cost-effective and efficient energy production.

In additon to the power plant, an **oil-shale processing plant** is being constructed today in Auvere. This pant will also provide heat which can be used by the agropark.

The **local transportation infrastructure** significantly influences the feasibility and operational efficiency of the Estonian Industrial Symbiosis Agro Park (EISAP) in Auvere village. The EISAP's masterplan highlights the importance of connectivity through road, rail, and potentially water, given its strategic location in Ida-Viru County, which is crucial for the movement of goods, services, and labour.

The project site's proximity to major roadways offers direct and efficient routes for transportation. The **road distance to Tallinn**, Estonia's capital, is approximately 209 km, which is about a 2h40min drive. This road connectivity is essential for accessing domestic markets, sourcing materials, and attracting a workforce.

The site benefits from direct **railway connections** to Narva, Tallinn, and Sillamäe. This rail infrastructure is a valuable asset for transporting bulk materials and products efficiently and sustainably, reducing the reliance on road transport and potentially lowering transportation costs. Rail connectivity enhances the site's appeal to investors and businesses looking for efficient logistics solutions.

The nearest **deep-water port** is in Sillamäe, located 32 km from the site, accessible by road or rail in approximately 40 minutes. This port access is crucial for importing raw materials and exporting products, especially for businesses within the agropark that engage in international trade. The port's facilities can accommodate large cargo ships, offering an important logistic advantage for the agropark.

The existing transportation infrastructure surrounding the EISAP site is a significant factor in its viability. Efficient transportation links are crucial for the operational success of the agropark, affecting everything from construction phase logistics to the daily operations of importing inputs and exporting produce. Additionally, the availability of multiple transportation modes can mitigate risks associated with disruptions in one mode, ensuring the continuous operation of the agropark's facilities.

In summary, the local transportation infrastructure plays a pivotal role in supporting the EISAP project. The available road, rail, and port facilities not only enhance the site's accessibility but also contribute to the economic feasibility and sustainability of the agropark. The strategic use of this infrastructure can reduce operational costs, improve supply chain efficiency, and ensure the project's long-term success.

Blocking Factors

Economic volatility and external shocks. Like many small, open economies, Estonia is susceptible to external economic shocks, which can impact funding availability and economic stability. Fluctuations in global markets, trade tensions, or geopolitical instabilities could influence the economic landscape, potentially affecting the agropark project's financing and profitability.

Regulatory and bureaucratic challenges. While Estonia is generally supportive of innovation and sustainable development, navigating the regulatory framework for a complex, multi-faceted project like the agropark could present challenges. Ensuring compliance with local and EU regulations related to land use, environmental protection, and agricultural practices might require significant time and resources, potentially delaying project implementation.

Future of Auvere power plant. In line with the need to reduce GHG emissions, Estonia is considering closure of power production from oil-shale already in 2030. This matter directly affects Auvere plant. However, the power plant, instead of closure, will probably switch fully from oil shale to biofuels. Around the future of the power plant several critical questions arise. If the power plant remains operational after 2030, will it work full-time or not? If the fuel is replaced, what will be the technical challenges for the agropark?

In conclusion, the economic conditions in Estonia, characterized by a supportive policy environment for innovation and sustainability, present a favourable backdrop for the establishment of an eco-friendly agropark in Auvere village. However, the project proponents must navigate economic volatility, regulatory complexities, and potential resource limitations. Strategic planning, leveraging available funding and incentives, and proactive engagement with regulatory bodies and the community will be crucial for overcoming these challenges and ensuring the agropark's success. It must be decided if the heat flow will come from the thermal power plant or from the oil shale processing plant.

2.5. Sociocultural factors

Labour

One of the goals of this project is to attract new industrial and logistics companies to the area, and through them create new workplaces. The envisaged creation of 600-1000 long-term jobs by EISAP indicates a substantial demand for labor.

The Estonian Industrial Symbiosis Agro Park (EISAP) in Auvere village, situated in Ida-Viru County, intersects with several critical aspects of Estonia's labour market, notably the availability and cost of skilled labour. Given the project's multifaceted nature, encompassing agriculture, energy efficiency, and technological innovation, a diverse skill set among the workforce is requisite.

Ida-Viru County, the project's location, historically faces higher unemployment rates compared to the national average, presenting both a challenge and an opportunity for EISAP. The local (north-east of Estonia) unemployment rate stands at 10,1%, significantly higher than Estonia's average (6,4%)[1]. This suggests a considerable pool of potential employees. However, the project’s success hinges on the availability of appropriately skilled labor within this pool (EISAP Concept Masterplan, 2021).

Demand for labor encompasses a broad spectrum of skills, from basic agricultural labor to highly specialized skills in managing sophisticated aquaculture systems, greenhouses, and the integration of renewable energy sources. So, there is a variety of positions and career paths for individuals with backgrounds in biology, environmental science, agriculture, business, and engineering, contributing

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[1] Statistics Estonia, 2024.

to the region's economic diversification and sustainability efforts. RAS farms and greenhouse agriculture may include roles in system design and engineering, water quality management, fish and plant cultivation, technical maintenance, research and development, marketing and sales, and administrative support. There will be additional roles, depending on the exact business model of the agropark.

Estonia has a skilled workforce with strong technical and scientific education systems. Given the technical complexity and innovative nature of the agropark, there's a pronounced need for specialized training and education to equip the local workforce with the necessary skills.

While Ida-Viru County may present a cost-effective labor market for the project, the need for specialized skills could drive demand for higher wages, especially for roles requiring significant technical expertise (EISAP Concept Masterplan, 2021). Average worker wage in Ida-Viru County is 1508 euro, at the same time average wage in Estonia is 1904 euro[2].

In summary, the EISAP's implementation context in Ida-Viru County presents a labour market characterized by high availability but with potential skill mismatches. Strategic initiatives, including targeted training programs and partnerships with educational institutions, could mitigate these challenges. Optimizing the local labour force's potential requires investment in skill development, aligning the workforce's capabilities with the project's innovative and technical demands.

Attitude towards such project

In Estonia, public trends towards sustainability and environmental issues are increasingly positive, reflecting a growing awareness and concern for climate change, renewable energy adoption, and sustainable living practices.

Trends in Ida-Virumaa towards sustainability and environmental issues are evolving, influenced by the region's transition from traditional, carbon-intensive industries to more sustainable practices. The shift is part of a broader acknowledgment of environmental concerns and the need for cleaner energy and industrial solutions. However, the pace and enthusiasm for these changes are affected by socio-economic factors, including employment concerns related to the decline of the oil shale industry and the integration of the local Russian-speaking minority.

Based on the data of 2021, total population of Ida-Virumaa is 132,741, from which 97 231 are Russians[3]. RAS farm development in Ida-Virumaa will include the integration of the Russian-speaking minority, which dominates the region, affecting workforce dynamics and community support[4].

On the other hand, one of Ida-Virumaa's most significant strengths, potentially bolstering knowledge transfer, is its robust and unique industrial tradition. This foundation can support the creation of innovative industries generating higher added value. The positive attitude of the Ida-Virumaa

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[2] Statistics Estonia, 2024.

[3] City Population, 2021. Available at: https://www.citypopulation.de/en/estonia/admin/0045__ida_viru/

[4] Belyi, A. V., 2020. A New Tale, Just Without Oil Shale: Climate Neutrality and the Future of Estonia’s Industrial North-East. International centre for defence and security. Available at: https://icds.ee/en/a-new-tale-just-without-oil-shale-climate-neutrality-and-the-future-of-estonias-industrial-north-east/

population towards industry, more so than in other Estonian regions, could further promote activities within its industrial sector[5].

In conclusion, the region's cultural adaptability and openness to innovation will be crucial in transitioning to and supporting new sustainable economic activities like aquaculture. Therefore, local attitudes towards sustainable practices and new industries, could influence local acceptance and enthusiasm for RAS project. It's plausible that in an industrial area like the project site, there might be less opposition to developments due to the lower population density and the area's industrial nature, potentially leading to fewer direct impacts on local residents' daily lives.

2.6. Technological factors

The technological feasibility of the Estonian Industrial Symbiosis Agro Park (EISAP) project in Ida-Viru County hinges on several key technologies, including waste heat utilization, CO2 capture and reuse, Recirculating Aquaculture Systems (RAS), and advanced greenhouse technologies. Assessing the availability and maturity of these technologies is crucial to determining the project's viability.

Waste heat utilization

The utilization of waste heat from industrial processes, such as that from the nearby Enefit power plant or oil shale processing plant, is a well-established practice with significant potential for energy savings and emission reduction (Liu, 2017), (Rakib et al., 2017). The feasibility of waste heat utilization within EISAP highlights the project's alignment with current technological capabilities and sustainability goals. However, directing post-use cooling water from thermal power plants or oil shale processing plant to fish farms requires careful consideration of the potential impacts on aquatic life due to chemical toxicity and other stressors. Cooling water discharge can have toxic effects on life (Kartasheva et al., 2008).

CO2 capture and reuse

CO2 capture and reuse involve capturing carbon dioxide from power plant emissions and using it to promote plant growth in greenhouses. The capture and reuse of CO2 from industrial emissions to enhance greenhouse crop productivity is technologically feasible, as evidenced by various studies. Ghiat et al. (2021) demonstrate how CO2 captured from an energy sub-system can be efficiently utilized to enhance food sub-systems, increasing yield while reducing crop water requirements. This indicates the project’s capacity for integrating CO2 capture and reuse within its operations. This technology not only helps reduce greenhouse gas emissions but also enhances agricultural productivity.

While the technology for CO2 capture is well-established, its integration with greenhouse operations for enhancing plant growth is still being refined. However, advancements in this area suggest that implementing this technology is within reach.

It should be ensured that captured CO2 is of sufficient purity while contaminants present in the CO_2 stream could be harmful to plants, humans working within the greenhouses as well as construction materials. The logistics of transporting CO_2 from the point of capture to the greenhouse facility must be considered, along with the need for storage solutions that maintain the CO_2 in a state suitable for use in enhancing plant growth. The costs associated with CO_2 capture, purification, transport, application, and possibly storage, must be offset by the increased yield from the greenhouse operation

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[5] Civitta, 2023. IDA-VIRUMAA TEADUS- JA ARENDUSTÖÖ TEENUSTELE JA TEADMUSSIIRDELE SUUNATUD OOTUSTE, SELLE MÕJU JA OLULISIMATE TEGEVUSTE ANALÜÜS. Available at: https://ivek.ee/wp-content/uploads/ida-virumaa-ta-analuus-logoga.pdf

to ensure economic viability. The construction materials should be chosen which properly resist acid environment and other challenges from CO_2 application. Compliance with local and international regulations regarding CO_2 capture and use, as well as the potential environmental impact of such operations, must be addressed.

Recirculating Aquaculture Systems (RAS)

RAS technology allows for the efficient and sustainable farming of aquatic organisms by recycling water within the system. This technology is crucial for minimizing water and energy use and environmental impact. RAS is a mature technology that has been successfully implemented in various parts of the world, indicating its feasibility for the EISAP project (Espinal & Matulić, 2019). The main challenges lie in scaling the technology and ensuring its integration with other agropark systems, such as using waste products as feedstock for aquaculture.

Sustainability and stability of the power plant

Heat flow and other flows from Auvere power plant are not fully stabile. The plant is sometimes stopped for maintenance works. Due to unfavourable market conditions (e.g. low electricity price), the power production may be temporarily stopped. RAS, greenhouses and other components of the agropark must have technical solutions to overcome such periods.

The long-term perspective beyond 2030 remains quite uncertain today. If the fuel is fully replaced with biomass, then it may need adjustments in the agropark technological solutions.

In addition to the thermal power plant, an oil shale processing plant will soon operate in the close vicinity. This facility may provide an alternative source of heat and other resources to the agropark.

Use of fish manure in greenhouses

Application of fish manure improves soil properties and enhances plant growth. Specifically, in a study on greenhouse cherry tomato production integrated with biofloc tilapia production, aquaculture effluent used in soilless culture was found to support plant growth effectively, suggesting potential for integration (Pickens et al., 2020). Integrating aquaculture with agriculture through the use of fish manure enables recycling of nutrients, effectively transforming waste into a valuable resource for plant growth. This method also mitigates environmental concerns associated with manure disposal (Wohlfarth & Schroeder, 1979).

However, there might be challenges. Such manure management may lead to other GHG - particularly methane and nitrous oxide - emissions which offset carbon benefits (Zhou et al., 2017). Excessive application of manures – a common mistake which can be avoided - can lead to nutrient leaching, soil acidification.

Different types of manure and treatment methods (e.g., composting, anaerobic digestion) can have distinct impacts on soil properties, plant growth, and environmental outcomes, making it critical to consider these factors in manure management strategies. It is quite likely that fish manure should be combined with inorganic fertilisers to ensure optimal effects. Regular monitoring of soil properties and careful management of manure applications are recommended to avoid overapplication and to tailor nutrient inputs to crop needs.

Advanced greenhouse technologies

Advanced greenhouse technologies, including automated climate control, hydroponic systems, and energy-efficient designs, are essential for the agropark's vision of sustainable agriculture. These technologies are well-developed and increasingly being adopted globally, suggesting their feasibility for the EISAP (Koukounaras, 2020). The challenge will be customizing these technologies to the specific needs of the project and ensuring their integration with the agropark's other sustainable practices.

Use of waste oxygen from greenhouses in RAS

Aeration enhances the oxygen levels in water, promoting healthier and more productive aquaculture environments (Ouellet-Plamondon et al., 2006). Utilizing waste O2 from greenhouses for aquaculture aeration represents a sustainable approach to managing greenhouse emissions, turning potential environmental pollutants into valuable resources for fish farming (Zhang et al., 2018). However, establishing a system that effectively captures and transports O2 from greenhouses to aquaculture systems requires significant technical and infrastructure development (Fang et al., 2017). Too much or too little oxygen can harm aquatic life, so careful monitoring and control systems are necessary to ensure optimal levels are maintained (Chowdhury et al., 2014). Failing to regularly check and maintain aeration equipment can lead to system failures, disrupting the oxygen supply to aquaculture systems (Jiang et al., 2015). Using sensors and control systems to monitor oxygen levels in real time allows for adjustments as needed to maintain optimal conditions for aquaculture (Ouellet-Plamondon et al., 2006).

Conclusion

Overall, the technological feasibility of the EISAP project is supported by the availability and maturity of key technologies. The project's success will depend on the effective integration of these technologies and overcoming challenges related to scaling and system integration. With Estonia's strong emphasis on digital innovation and sustainability, there is a solid foundation for addressing these challenges and realizing the vision of the EISAP.

2.7. Legal factors

There are legal procedures before and during construction and during operation. Compliance with Estonian environmental laws for RAS farms and greenhouses involves adhering to regulations that ensure the protection and sustainable use of natural resources. This includes managing water use efficiently, preventing pollution, and safeguarding biodiversity.

A **detailed spatial plan** is developed for the project area, aiming to create a spatial comprehensive solution (Planning Act). If the plan involves significant environmental impact activities (such as deforestation of over 100 hectares), a mandatory **strategic environmental assessment (SEA)** is conducted (Environmental Impact Assessment and Environmental Management System Act), including **impact assessment on Natura sites**, if appropriate. To prevent significant environmental impacts, measures developed in the SEA are applied, including potentially mandated monitoring for environmental changes.

Construction principles are defined in the Building Code, detailing required procedures for building certain structures. After establishing a detailed plan, a construction project is developed, and a building permit is applied. After the construction is complete, an occupancy permit must be obtained. Buildings that are functionally co-dependent may be regulated by one common building/occupancy permit.

The obligation to obtain an **environmental permit** (General Part of the Environmental Code Act) may arise from water extraction, wastewater discharge into water bodies or soil, air pollution from emission sources, waste management, and mineral extraction. Greenhouses and RAS systems utilize water from the Narva River, with properly treated wastewater directed to the Auvere power plant's intake channel. Depending on the specific activities (activity's nature and threshold capacity), an **integrated environmental permit** may be required, especially for the food industry. Integrated environmental permit evaluates the environmental impact of emissions comprehensively and best available techniques, often detailed in EU level reference documents, must be applied. Also, it has to be noted, that all environmental permits requiring further **monitoring and reporting**.

The project area includes no **land improvement systems**. Requirements related to constructing these systems are governed by the Land Improvement Act.

The project area is situated on the Narva quarry mining claim. Additional **permit or reporting obligations** may arise in connection with **construction activities in the mining claim** (Earth's Crust Act).

The project area is located within a **defence facility restriction zone** (Sirgala training area and its prospective expansion), where construction is only possible with approval from the Ministry of Defence or an authorized government body. Various constructions, including simpler structures, can impact the operational capability of a defence facility. Additionally, the project area is within Estonian **border zone**. Activities in the border zone and border waters that could hinder border surveillance or disturb border peace must be reported to the Police and Border Guard Board, possibly necessitating additional approvals for development.

Requirements related to **food production, processing, and transportation** must be adhered to. Companies dealing with food must either apply for an **activity license or notify** the Agricultural and Food Board of their operations. General food safety standards must be met during production, processing and transportation, with additional specific requirements apply for certain food groups, packaging, materials, and labelling etc.

2.8. Environmental factors

EISAP area experiences a climate that is characterized as humid continental. This means the region has significant seasonal temperature variations, with relatively warm summers and cold, snowy winters.

According to the masterplan, there is a desire to create industrial symbiosis in the agropark. This is a concept in which wastes or by-products of industrial processes are used as a feedstock for other industrial processes.

The circular agro-industry produces food and materials while delivering organic waste to the organic waste processing plant. Aquaculture industry will produce water and fertilizer for the agro-industry while producing food for the food market.

The energy generation industry provides all the local entities with affordable electricity. Furthermore, it delivers CO2 to the greenhouses. The energy generation industry offers low- and high-grade heat or steam to the circular agro-industry or aquaculture industry depending on the heat energy needs of these industries local product creation and processing.

Supporting factors

Use of waste heat: RAS systems need to maintain consistent water temperatures year-round, which can be energy intensive. Greenhouse agriculture, with year-round production or extended growing seasons, has higher heating demands. The Enefit Power AS power station is currently equipped to deliver waste heat to the site. This can significantly benefit the environment by reducing energy consumption from other sources and minimizing greenhouse gas emissions.

Use of captured and purified CO2: Implementing carbon capture technologies to the power plant with an additional carbon scrubber allows it to provide captured and purified CO2 to the nearby greenhouses, where CO2 is used as a feedstock for crops. This lowers the carbon footprint of the power plant and creates a local circular carbon flow.

Use of treated wastewater for the aquaculture system from thermal power plant can significantly reduce the freshwater footprint of the operation.

Use of technogenic land: The area of EISAP is 1507 ha. The project site currently sits on a former oil-shale surface mine, largely overgrown with young pine trees. It has poor quality of soil (crushed shale rock), so project aims to increase biodiversity in local and regional scale (large ecological corridors and other natural elements, and integration with the surrounding ecosystem).

Proximity of Narva river: Agropark and greenhouses can significantly benefit from its close proximity to the Narva River. The river can provide a reliable water source essential for irrigation, enhancing the sustainability and efficiency of agricultural practices. This geographical advantage supports the development of a vibrant agricultural ecosystem, promoting the growth of diverse crops and facilitating aquaculture initiatives within the agropark.

Blocking factors

Existing natural values on site or nearby (for example protected species) - currently, little is known about the natural values of the area, as the entire territory has been closed off due to mining. Consequently, there are no data from incidental observations, and no inventories or monitoring have been conducted. Some data has been collected in the initial stages of the agropark development[6] and it has shown that despite intense human impact, there might be natural values in such areas. For example, studies have shown that former mining areas can be unexpectedly rich in biodiversity, including dragonflies (Bobrek, 2020) and butterflies (Beneš *et al*., 2003). Further studies will take place, to specify the area's natural values, which may influence the development in this area (especially its extent).

To the south of the project area lies Alutaguse National Park, part of the Natura 2000 network as nature and bird area. Nearby habitats host protected species. Close to the project area is Narva River, which serves as a habitat for protected fish species. The detailed planning process will assess potential environmental impacts from the proposed activities, considering the project's proximity to these significant conservation areas and protected species.

2.9. General feasibility

Cheap input

The main selling point for EISAP is cheap energy from the thermal power plant. While energy constitutes a significant proportion of the costs of greenhouses and aquaculture, a cheap source of heat and electricity may pull the business model to economically feasible side. In addition, the power plant may potentially provide cheap water and CO2 to boost plant growth. Such approach is promising in the context of circular economy, energy saving and innovation policy in Estonia. However, successful exploitation of the above-mentioned resources remains challenging. A major question is long-term operation of the power plant which requires oil-shale. An idea to shift it completely to biomass fuel may technically fail. At the same time, EISAP can hardly shift to own solar or wind power source because such installations are banned there for military reasons. Thus, sustainability of energy supply for EISAP is actually under question.

There are other technical challenges. Efficient capture and transportation of waste heat, CO2, water and electricity from power plant to EISAP need to be solved.

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[6] MTÜ Puhmaskulmik, 2023. Ekspertiis Auvere agropargi planeeringualal kaitsealuste liblikate ja kiilide leidumise kohta.

Both aquaculture and greenhouses require heating but probability in different ways. Greenhouses need hot air while aquaculture needs rather hot water. During summertime, aquaculture may need efficient cooling instead of heating. There are other seasonal specifics too. Mostly, heating, cooling and heat maintenance issues must be solved creatively as we lack similar existing large-scale business solutions.

Land for the EISAP is cheap and available. However, land surface is extremely sloppy. The area consists mostly of large furrows and ridges, more than 10 m high. Moreover, it is mostly covered with forest. Clearing and smoothing such land may appear very costly while adjusting the facilities (greenhouses, fishponds etc) between such ridges seems questionable.

Aquaculture may work either as a flow-through or circular system. A flow-through solution is feasible in case of abundant water availability. This is the case for surface water which can be sufficiently extracted either from power plant outflow of from a river. However, these waters are probably biologically polluted. Use of such surface waters may bring disastrous infections to fish farm. This could be avoided by the use of groundwater instead. Nevertheless, such resource is much more limited. Both quantity and quality of groundwater for aquaculture in EISAP area are critical but unknown.

In case of moderate groundwater availability (ca 100 – 1000 m3/hr), aquaculture could be potentially designed as RAS. Such solution requires more advanced filtration, pumping, aeration and other systems to control the environment. Hence, it is quite a capital-intensive and questionable option.

The idea to employ waste CO2 from the power plant in greenhouses is rather theoretical. Today, the power plant does not plan to capture, purify and sell CO2. We must conclude, that giving CO2 to these greenhouses need not be cheaper than in other locations.

Remote place

An asset of the area might be its remoteness. Nobody lives there to oppose the project as local inhabitants in SEA and EIA processes. Other business actors – dealing with mining, forestry, energy and oil production – are well consolidated, enabling easy negotiations. However, such remoteness has disadvantages too. Transportation of materials and products may appear expensive, potentially requiring costly investments to additional infrastructure. While nobody lives there, all workforces must travel there from quite far. It remains unclear if such workers with proper qualification and motivation are available.

Changing environment

Today, oil shale mining industry keeps the area dry by water pumping. The end date of the mining is unknown today. However, if pumping stops then water level in EISAP area will rise several meters. Transportation corridors – trenches – which today are in use by oil shale lorries, will be submerged. Hence, the EISAP area will roughly fragment to three peninsulas, isolated by water channels. Therefore, the project must account for significant environmental changes, even though the timeline for these changes remains uncertain.

Coexistence with mining

Currently, to generate heat for EISAP, the thermal power plant must burn oil shale, which is transported from a quarry by trucks passing through the EISAP area. This transportation causes significant dust emissions from the roads, potentially settling on greenhouses and obstructing sunlight. Mining activities include explosions which may affect fish farms with noise and vibration. Such disturbances also originate from a military training area in the vicinity. Hence, the development of EISAP must consider, solve and adapt with such problems.

3. ENVIRONMENTAL CONDITIONS

3.1. Land resources

3.1.1. Landscape analysis

Land surface

The land surface of the project area is very uneven (Figure 3). The area consists mostly of large furrows and ridges, more than 10 m high. The average slope is 13,1%.

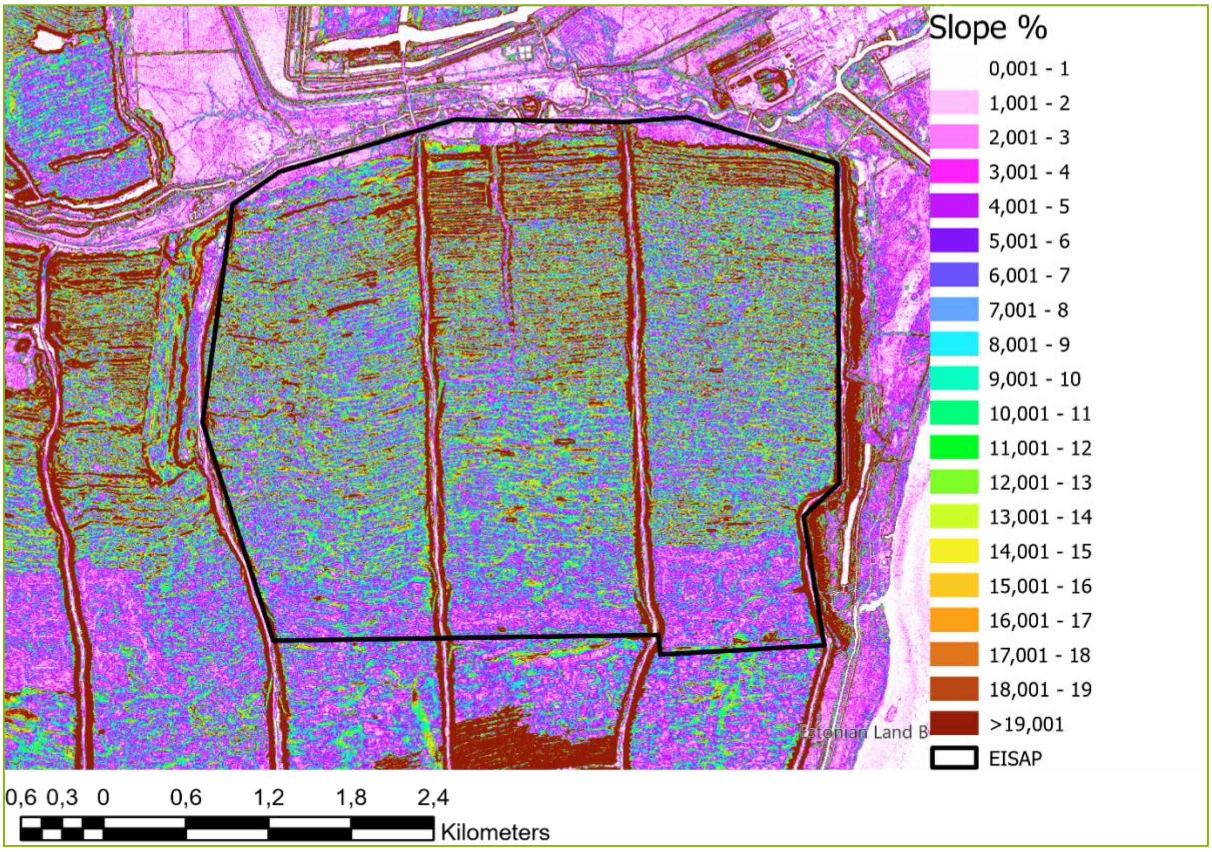

Figure 3. Slope inside and outside the project area.

Slopes of the northern part are steeper while southern part is a bit flatter. In South-East end, the average slope within 100 m radius is less than 6% (Figure 4). This area covers ca 30 ha.

Land cover

Most of the area is forested (Figure 5). As oil-shale mining have advanced from north to south, the latter end is quite bare. The trees are either missing or young.

Probably the most suitable type of landscape for EISAP infrastructure is bare and flat. Such type, having less than 6% slope and vegetation lower than 5 m, covers ca 30 ha in the south-east corner of EISAP area.

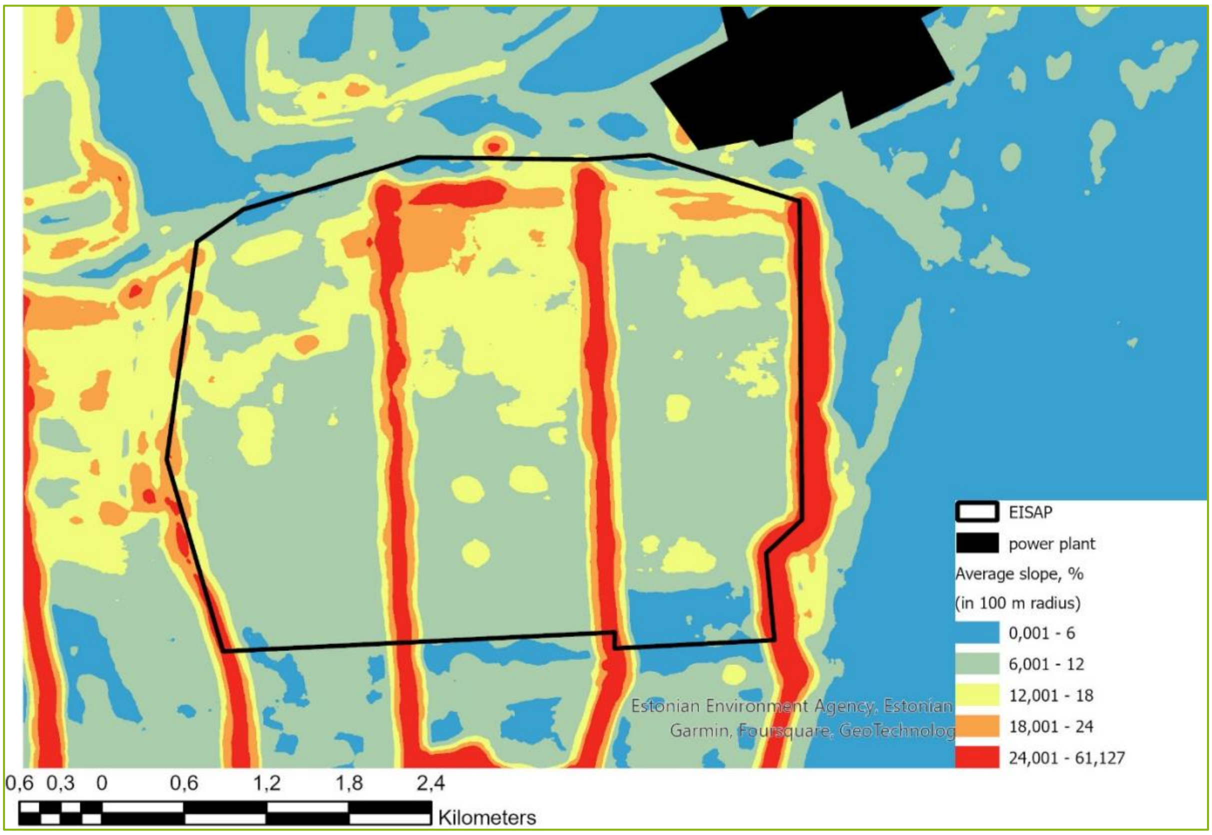

Figure 4. Average slope in 100 m radius inside and outside the project area.

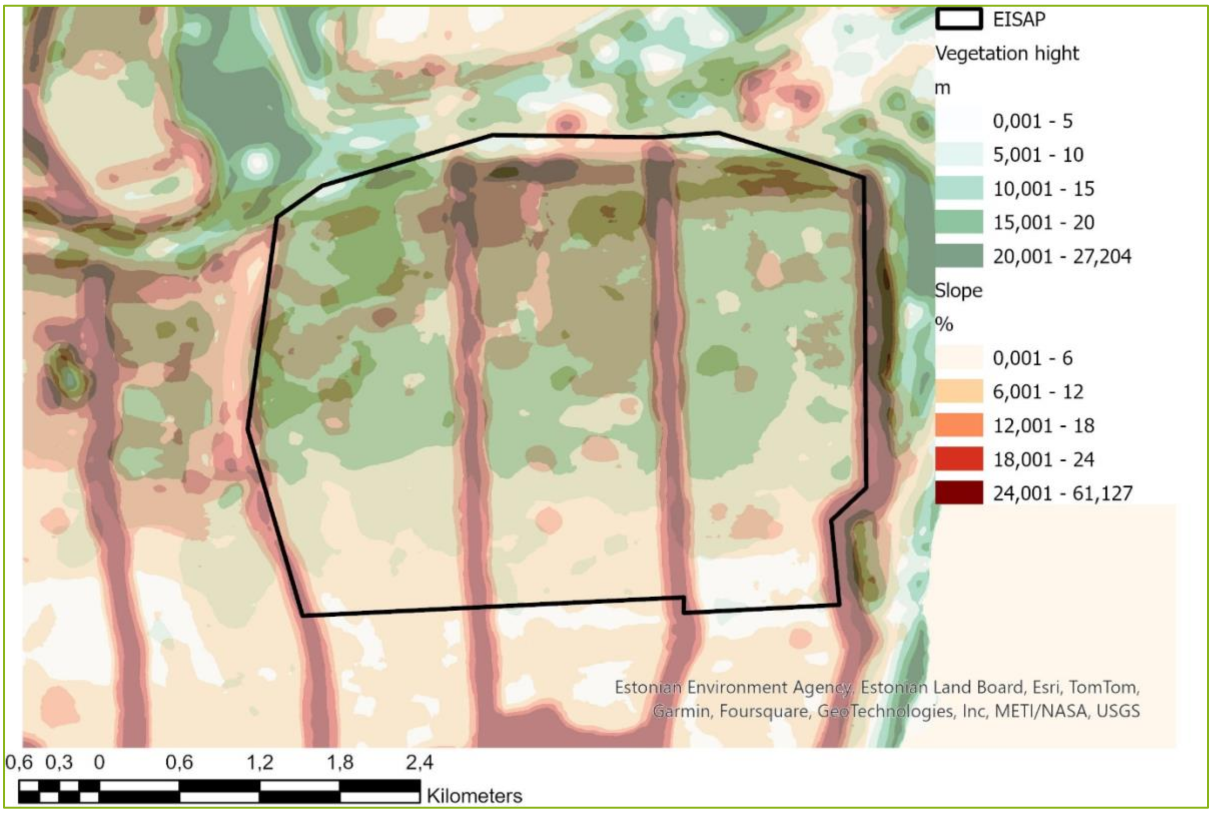

Figure 5. Vegetation hight and slope in EISAP area. Note a bare and flat zone (white color) in south-east corner.

3.1.2. Infrastructure

EISAP area has very good connection with power grid and railways (Figure 6). Railway connection is towards west, to Jõhvi and Kohtla-Järve as well as to a large Sillamäe port. At the same time, the road connectivity is limited, primarily linking to the town of Narva. Most roads are unpaved, resulting in significant dust and mud. There is also a notable lack of roads heading south. Power grids surround the area with 330 kV air lines. They are equipped with several substations.

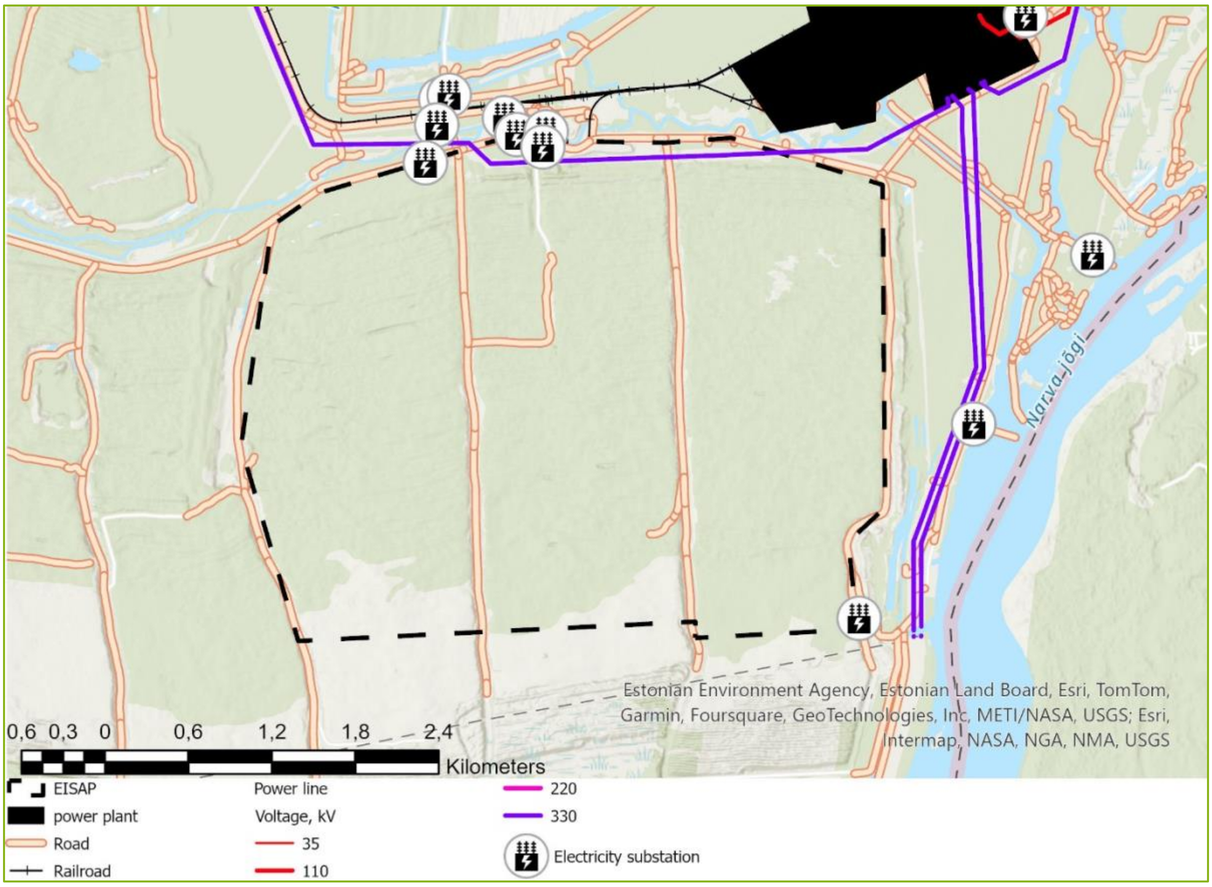

Figure 6. Infrastructure inside and around EISAP area.

3.1.3. Land purpose

EISAP area and its surroundings are mostly on cultivated land for forest management (Figure 7). All these lands have good perspective for industrialisation. For instance, large forest management areas are just North-East from EISAP area.

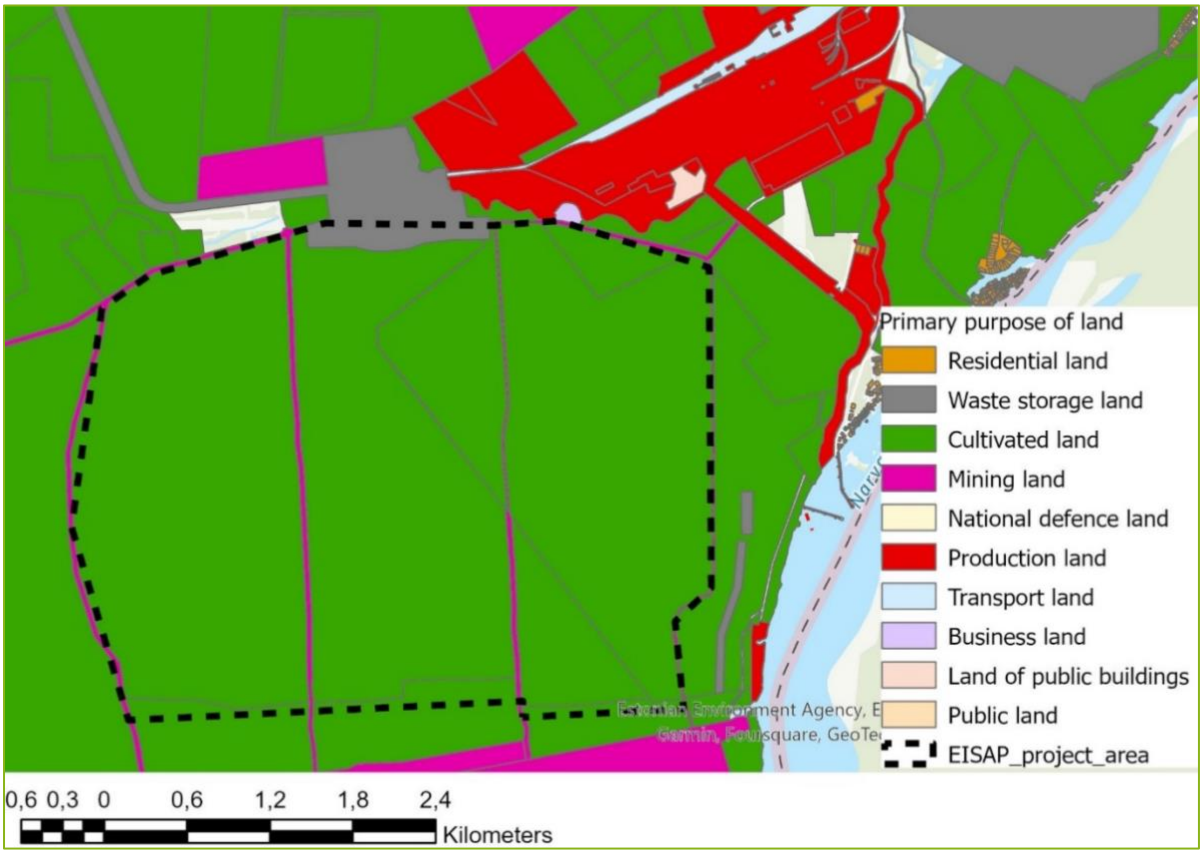

Figure 7. Land purpose in EISAP area.

3.1.4. Land ownership

EISAP is fully on state lands (Figure 8). State land also surround it in most directions. In combination with homogeneous land purpose (cultivated land), it should be quite easy to make rental agreements inside EISAP and also to extend the agropark area to neighbouring lands if necessary.

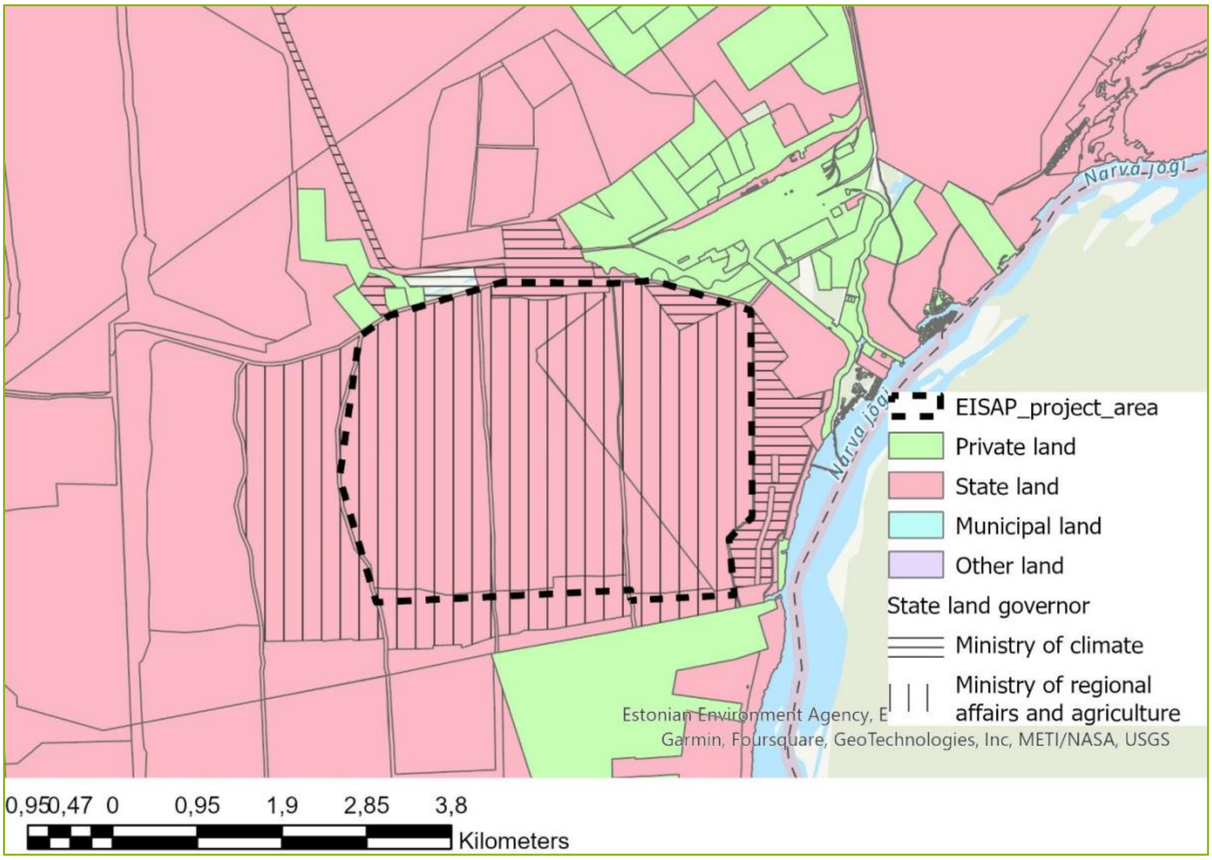

Figure 8. Land ownership in EISAP area.

3.2. Natural water resources

EISAP area is surrounded by rivers in north and east side (Figure 9). These rivers may provide surface water for irrigation, fishponds and other purposes.

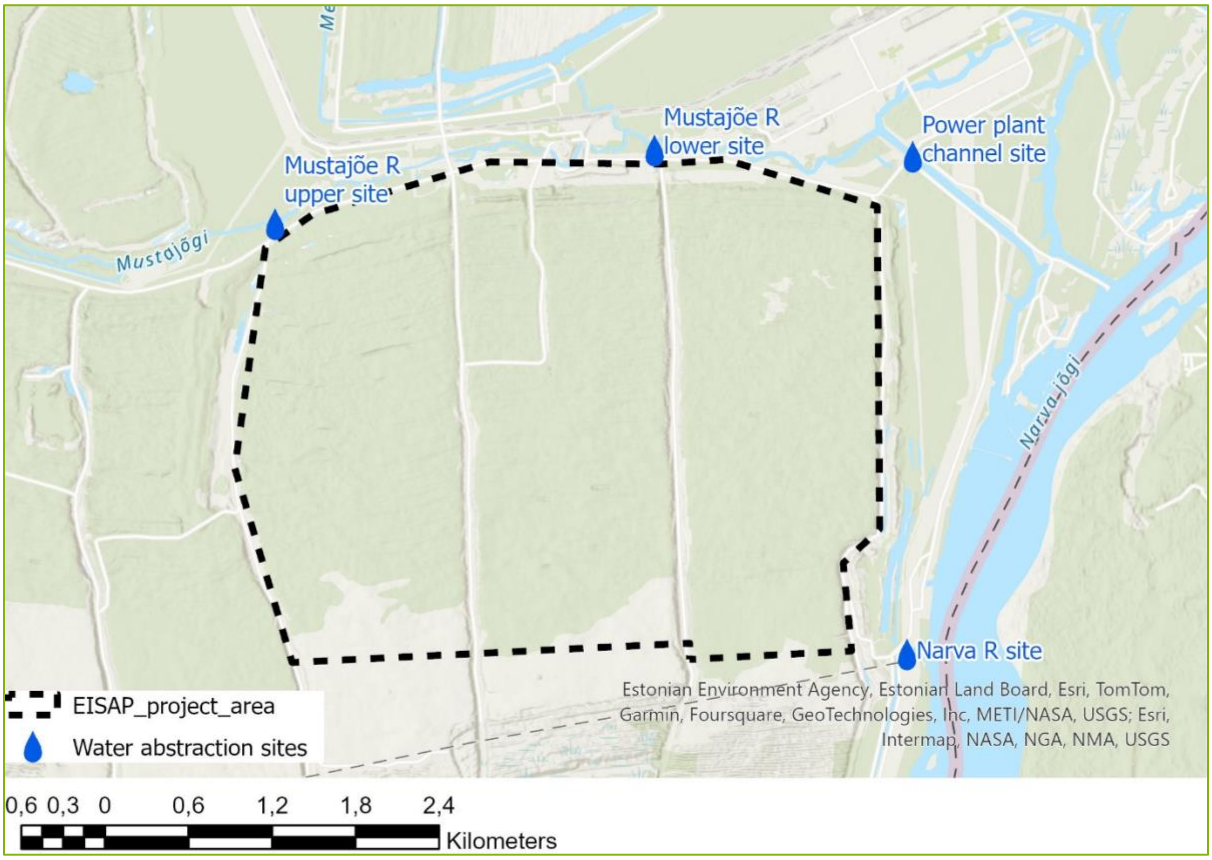

Figure 9. Possible surface water abstraction sites for EISAP area during oil shale mining period.

3.2.1. Narva river

The average water runoff of Narva River is 400 m^3/s. This is sufficient to provide EISAP with surface water without significantly compromising the hydrological status of the river. At the same time, the river carries much biological pollution (infectious diseases) which may harm aquaculture.

Ecological status. The ecological state of River Narva near EISAP is moderate while chemical state bad (Kliimaministeerium, 2024). The main reasons are high Hg concentration in fish and fish migration barriers. Nutrient status is very good.

EISAP impacts. The main pollution risks from bioeconomy are related to the load of nutrients, especially nitrogen (N) and phosphorus (P). Nutrient status in Narva River is very good, affording such additional load (Table 2). Some additional load cannot make significant harm.

Table 2. Assessment of River Narva water quality in relation to EISAP (KESE, 2024).

Quality parameter	Good status thresholds	Measured concentration, long-term average (2019 – 2023)	Status evaluation
Ptot (mg/l)	0,041–0,060	0,034	Very good status. Affords additional load.
Ntot (mg/l)	1,6 – 3,0	0,61	Very good status. Affords additional load.

Conclusion. While most Estonian rivers suffer from nutrient pollution and limited water runoff, the Narva River stands out as an exception. As the largest river in Estonia, it maintains a low nutrient content, making it an attractive option for further agricultural and industrial use. These unique characteristic positions the Narva River as a valuable resource for sustainable exploitation.

3.2.2. Mustajõe river

EISAP locates at the mouth of River Mustajõgi, with catchment area ca 400 km^2. Minimum monthly load in the river between 2004 and 2008 was 0,4 m^3/s (July 2006) which is 1440 m^3/h (Keskkonnaportaal, 2024). This is sufficient to irrigate greenhouses while such abstraction may significantly reduce the runoff in the river. For aquaculture, such runoff rate may appear a bit too low. However, for a RAS it should be sufficient.

Nutrient status of Mustajõgi River is very good (Kliimaministeerium, 2024). Hence, it affords some additional load of nutrients. Similarly to River Narva, Mustajõgi River may potentially bring harmful biological pollution to aquaculture.

3.2.3. Groundwater

Due to extensive mining activities, the chemical composition of groundwater in large areas of Ida-Viru County has changed, leading to issues with the supply of drinking water to the population. For the EISAP project, which involves water-consuming production, the quantity and chemical quality of available water are crucial. Therefore, it is essential to analyse the availability of groundwater resources needed for production within the EISAP area.

The following groundwater bodies are present in the EISAP area (Figure 10):

- **Ordovician Ida-Viru Oil Shale Basin Groundwater Body** (S-O): Overall status poor (2020). The poor status is due to both quantitative and chemical issues.
- **Ordovician-Cambrian Virumaa Groundwater Body in the East Estonia Basin** (O-Cm): Overall status good (2020).
- **Cambrian-Vendian Voronka Groundwater Body** (Cm-V2vr): Overall status poor (2020). The poor status is due to poor chemical conditions (chlorides).

Additionally, a very small area in the south and east of the EISAP site contains **the Middle-Upper Devonian Groundwater Body in the East Estonia Basin (D2-1)**, which has a good overall status (2020).

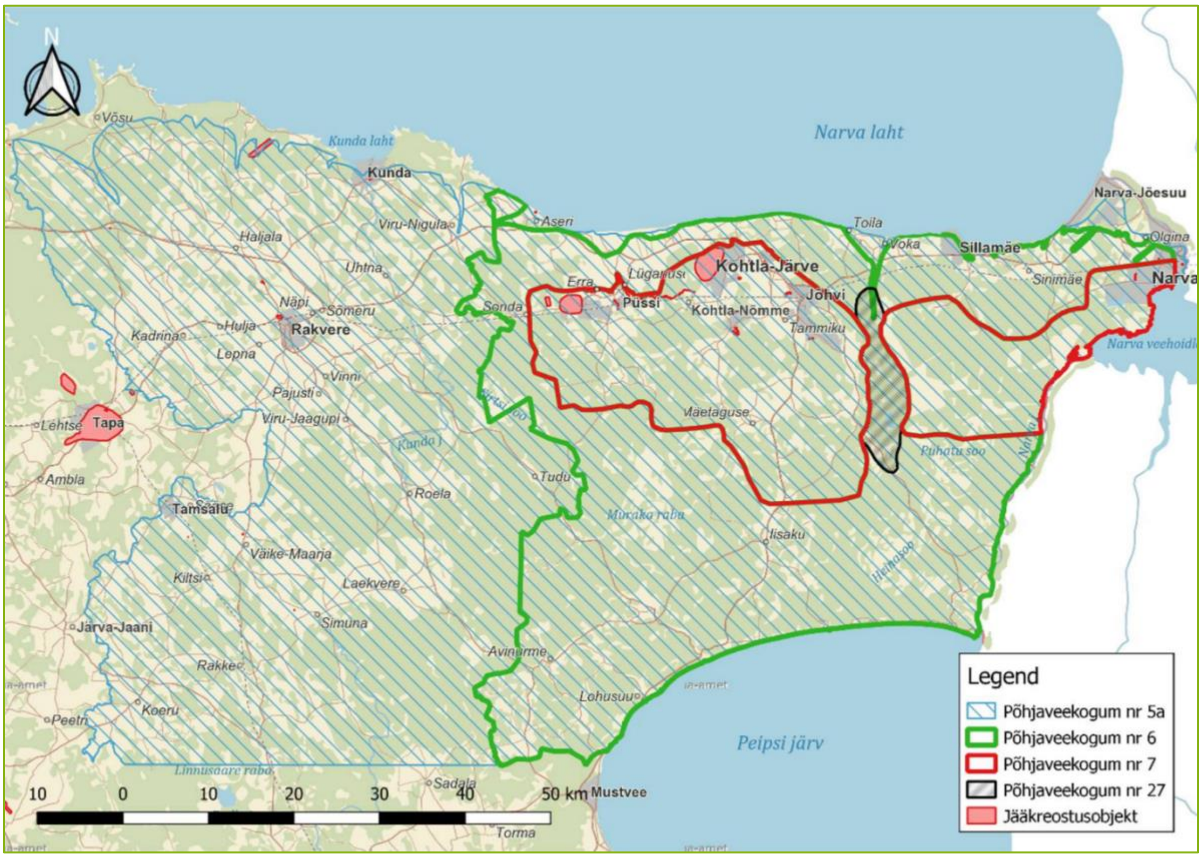

Figure 10. Groundwater bodies, where 5a: Ordovician-Cambrian Virumaa Groundwater Body in the East Estonia Basin; No. 6: Ordovician Ida-Viru Groundwater Body (not present in EISAP area); No. 7: Ordovician Ida-Viru Oil Shale Basin Groundwater Body[7].

Currently, there are no established groundwater reserves[8] or boreholes in the EISAP area. The nearest boreholes are located northward in the Narva quarry industrial area (boreholes PRK0003434 and PRK0003416), where water is extracted from the Voronka aquifer (depths of boreholes are 180 m and 190 m, respectively[9]). The groundwater is primarily used for domestic purposes (cafeteria, showers, etc.)[10]. The established groundwater reserve in the Narva quarry industrial area (Cambrian-Vendian Voronka groundwater body) is 180 m^3/day, valid for the period 2021-2045[11]. Actual water extraction from boreholes in the Narva quarry did not exceed 70 m^3/day between 2008-2019.

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[7] Raidla, V., Truu, M., Tarros, S., 2023. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi hüdrogeoloogilised uuringud. Eesti Geoloogiateenistus, Rakvere.

[8] Groundwater reserve is the calculated amount of groundwater that can be extracted for water services or personal use, ensuring that its extraction does not cause significant depletion or deterioration of the groundwater status in the designated area.

[9] EELIS, vaadatud 17.07.2024

[10] Grigorjeva, I., Metsur, M. 2021. Narva karjääri ja Estonia kaevanduse põhjaveevarude ümberhindamine.

[11] The groundwater reserve was re-evaluated in 2021, resulting in a reduction of the established groundwater reserve by 120 m^3/day (shared extraction for the Narva quarry and the Estonian Power Plant) due to significantly lower actual water usage. The previously established groundwater reserve was 300 m^3/day, of which 256 m^3/day remained unused. Grigorjeva, I., Metsur, M. 2021. Narva karjääri ja Estonia kaevanduse põhjaveevarude ümberhindamine.

The production activity planned in the EISAP area will require a significantly larger water resource (estimated at 100 – 1000 m^3/h), making the existing groundwater reserve of 180 m^3/day (from the Cambrian-Vendian Voronka groundwater body) insufficient for EISAP production needs. For groundwater extraction exceeding 500 m^3/day, prior studies are required to determine the groundwater reserve. The feasibility of using existing groundwater reserves will depend on the confirmed reserves, the amount of water reserved by environmental permits, and the condition of the groundwater body. According to 2020 estimates, only the Ordovician-Cambrian Virumaa groundwater body in the East Estonia Basin (O-Cm) is in good condition[12].

Groundwater Bodies Analysis:

Ordovician Ida-Viru Oil Shale Basin Groundwater Body: The poor status in 2020 was attributed to both quantitative and chemical issues. Groundwater extraction from oil shale mines exceeds the natural groundwater resources, affecting nearby surface water bodies dependent on groundwater. The poor chemical status is due to exceeding threshold values for hazardous substances (SO4, NH4, total phenols, chemical oxygen demand (COD), and Ba)[13]. Additional data on chemical and quantitative indicators of this groundwater body were collected as part of the LIFE IP CleanEST project[14].

Ordovician-Cambrian Virumaa Groundwater Body in the East Estonia Basin: This body is in good chemical and quantitative condition (2020 estimate). The greatest risk to groundwater quality comes from polluted water from upper layers (including mines) infiltrating through damaged borehole casings and seals. Insufficient water yield may be a problem for industrial needs[15].

Cambrian-Vendian Voronka Aquifer: This water is predominantly Na-Cl-HCO3 type, mostly meeting drinking water quality standards except for naturally high total iron content. Long-term monitoring has occasionally detected sodium levels exceeding the limit (200 mg/l). The status is threatened by mixing with saltier water layers, leading to increased chloride concentrations. The poor overall status was due to high chloride levels[16]. However, chloride monitoring data[17] suggests no salinization of the Voronka aquifer at the Narva quarry and no expected deterioration of groundwater quality during the new water usage period (up to 2045).

In conclusion, the latest data indicates that groundwater suitable for drinking is present in the groundwater body No. 7 (Ordovician Ida-Viru Oil Shale Basin Groundwater Body), but likely only sufficient for individual households. Regional hydrogeological and geochemical peculiarities (e.g., high iron content) must be considered. Large-scale groundwater extraction must account for damaged

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[12] Marandi, A., Karro, E., Osjamets, M., Polikarpus, M., Hunt, M. 2020. Eesti põhjaveekogumite seisund perioodil 2014-2019. EGF 9416. Eesti Geoloogiateenistus, Rakvere.

[13] Marandi, A., Karro, E., Osjamets, M., Polikarpus, M., Hunt, M. 2020. Eesti põhjaveekogumite seisund perioodil 2014-2019. EGF 9416. Eesti Geoloogiateenistus, Rakvere.

[14] Raidla, V., Truu, M., Tarros, S., 2023. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi hüdrogeoloogilised uuringud. Eesti Geoloogiateenistus, Rakvere.

[15] Raidla, V., Truu, M., Tarros, S., 2023. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi hüdrogeoloogilised uuringud. Eesti Geoloogiateenistus, Rakvere.

[16] Marandi, A., Karro, E., Osjamets, M., Polikarpus, M., Hunt, M. 2020. Eesti põhjaveekogumite seisund perioodil 2014-2019. EGF 9416. Eesti Geoloogiateenistus, Rakvere.

[17] Grigorjeva, I., Metsur, M. 2021. Narva karjääri ja Estonia kaevanduse põhjaveevarude ümberhindamine.

groundwater layers and boreholes, which could cause unpredictable changes in the chemical composition of the extracted water[18].

For the other groundwater bodies in the area – Cambrian-Vendian Voronka and Ordovician-Cambrian Virumaa (No. 5a) – while their water quality generally meets drinking water standards, their water yield is insufficient to meet the needs of the Ida-Viru County population and industry [19]. The sufficient water reserve for the EISAP project is not yet known.

An alternative solution could be the use of freshwater reservoirs, though organic pollution may present significant challenges[20].

3.2.4. Precipitations

EISAP area is well fed with precipitation. The long-term annual average precipitation in Jõhvi (ca 26 km from EISAP) in 1991 – 2020 was 717 mm (Keskkonnagentuur, 2024). This amount divided quite evenly between all 12 months, from 34 (April) to 93 mm (August). Sometimes, a month may pass without any significant rain or snow. Between 2013 and 2023 in Narva station (18 km from EISAP) less than 7 mm precipitated in Jan 2017, May 2018 and March 2022.

During winter months, December – February, most of the precipitation comes as **snow**. EISAP area has normally much snow. Snow cover lasts there relatively long, in average 125 days annually (Estonian average 90 – 110 days). The maximum monthly snow cover in Jõhvi in 2010 was 78 cm. An estimated maximum snow pressure in EISAP is 1,6 kN/m^2.

3.2.5. Future waterbodies

Today, oil shale mining industry keeps the area dry by water pumping. The end date of the mining is unknown today. However, if pumping stops then water level in EISAP area will rise several meters (Figure 11). Transportation corridors – trenches – which today are in use by oil shale lorries, will be submerged. Hence, the EISAP area will roughly fragment to three peninsulas, isolated by water channels. Water depth will be more than 2 m in most parts. The only remaining road in the area is located in the north side of EISAP area. In order to maintain connectivity in the area, new roads are necessary, accompanying with dams or bridges.

An option may emerge to use these new waters as transportation channels. However, these channels will not automatically connect EISAP with any existing port.

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[18] Raidla, V., Truu, M., Tarros, S., 2023. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi hüdrogeoloogilised uuringud. Eesti Geoloogiateenistus, Rakvere.

[19] Raidla, V., Truu, M., Tarros, S., 2023. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi hüdrogeoloogilised uuringud. Eesti Geoloogiateenistus, Rakvere.

[20] Raidla, V., Truu, M., Tarros, S., 2023. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi hüdrogeoloogilised uuringud. Eesti Geoloogiateenistus, Rakvere.

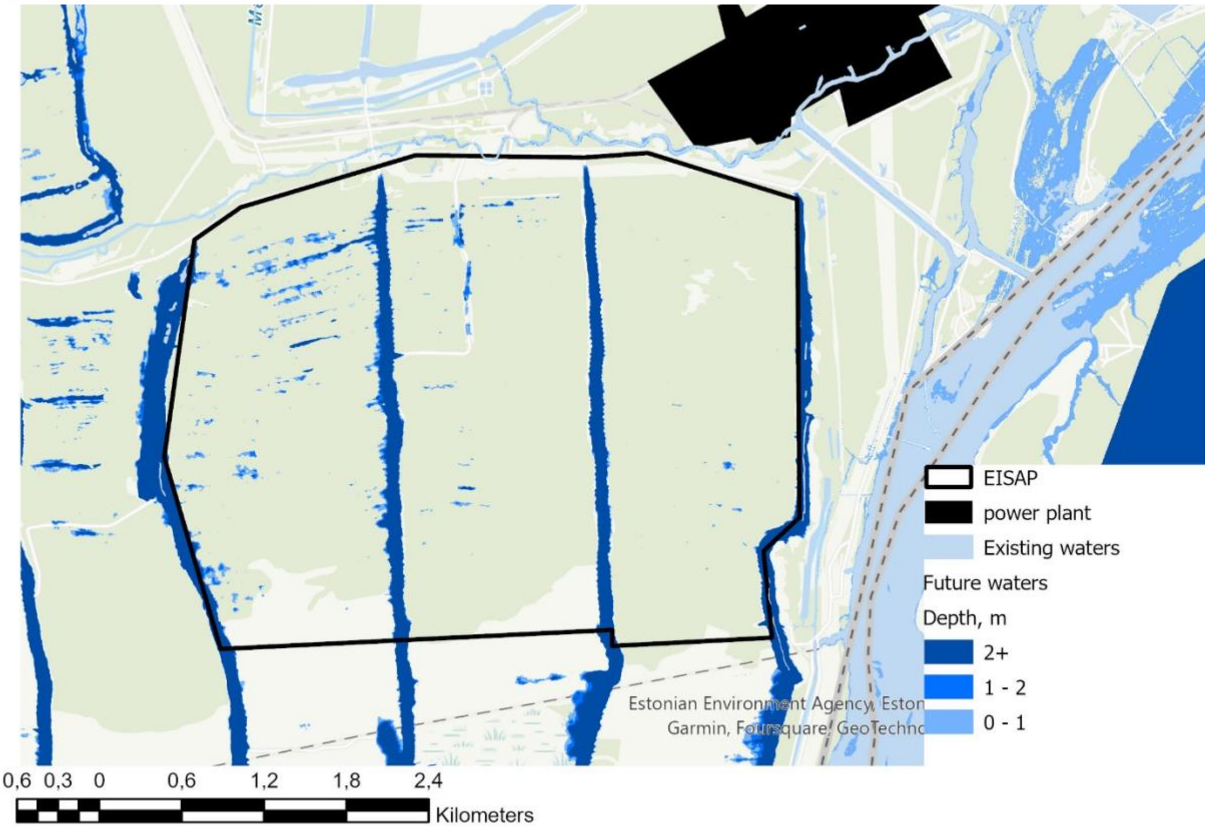

Figure 11. Expected future water in EISAP area, after the end of mining and related pumping activities

3.3. Important neighbourhood aspects

3.3.1. Connections

The **local transportation infrastructure** significantly influences the feasibility and operational efficiency of EISAP. The EISAP's masterplan highlights the importance of connectivity through road, rail, and potentially water, given its strategic location in Ida-Viru County, which is crucial for the movement of goods, services and labour.

The project site's proximity to major roadways offers direct and efficient routes for transportation. The **road distance to Tallinn**, Estonia's capital, is approximately 209 km, which is about a 2 h 40 min drive. This road connectivity is essential for accessing domestic markets, sourcing materials and attracting a workforce.

The site benefits from direct **railway connections** to Narva, Tallinn and Sillamäe (Figure 12). This rail infrastructure is a valuable asset for transporting bulk materials and products efficiently and sustainably, reducing the reliance on road transport and potentially lowering transportation costs. Rail connectivity enhances the site's appeal to investors and businesses looking for efficient logistics solutions.

The nearest **deep-water port** is in Sillamäe, located 32 km from the site, accessible by road or rail in approximately 40 minutes. This port access is crucial for importing raw materials and exporting products, especially for businesses within the agropark that engage in international trade. The port's facilities can accommodate large cargo ships, offering an important logistic advantage for the agropark.

The existing transportation infrastructure surrounding the EISAP site is a significant factor in its viability. Efficient transportation links are crucial for the operational success of the agropark, affecting everything from construction phase logistics to the daily operations of importing inputs and exporting produce. Additionally, the availability of multiple transportation modes can mitigate risks associated with disruptions in one mode, ensuring the continuous operation of the agropark's facilities.

In summary, the local transportation infrastructure plays a pivotal role in supporting the EISAP project. The available road, rail and port facilities not only enhance the site's accessibility but also contribute to the economic feasibility and sustainability of the agropark. The strategic use of this infrastructure can reduce operational costs, improve supply chain efficiency and ensure the project's long-term success.

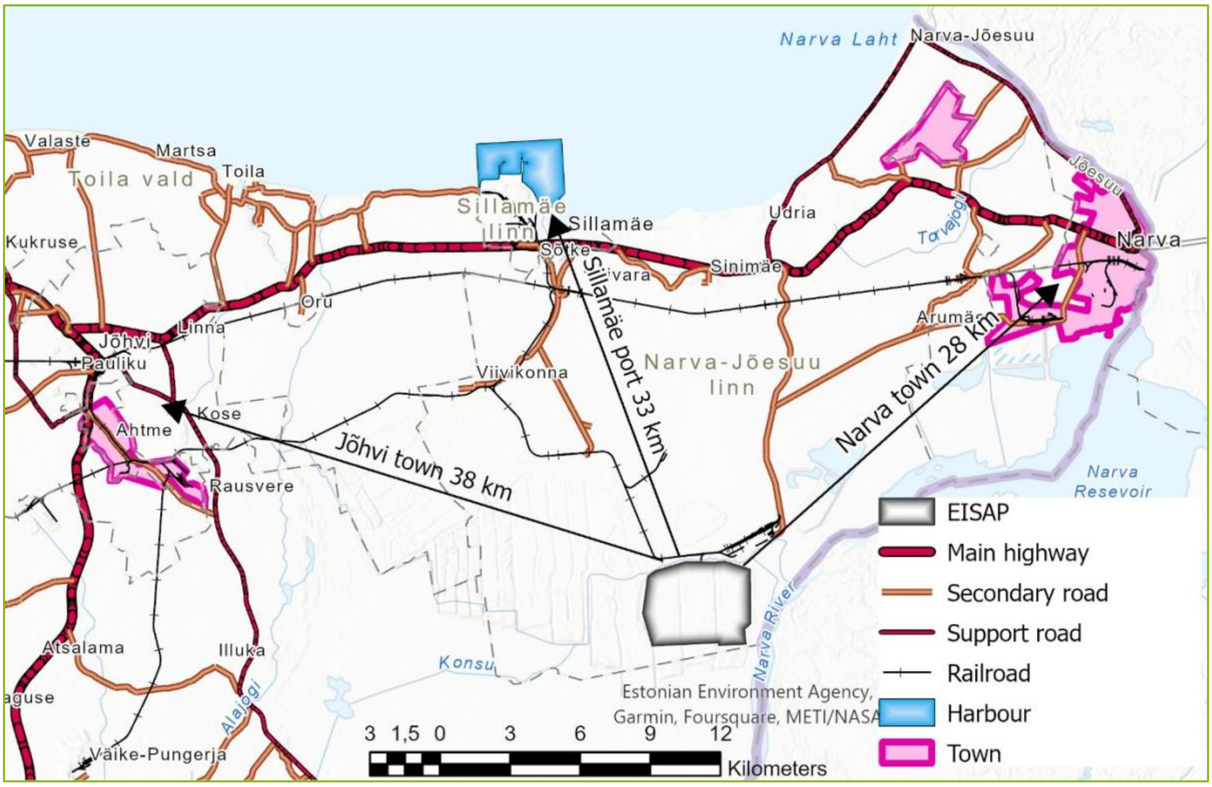

Figure 12. EISAP vicinity to towns and Sillamäe harbour. Indicated distances follow roads.

3.3.2. Military training field in Sirgala

The project area is situated within a restricted defence facility zone, specifically the Sirgala training area and its proposed expansion. The perimeter of the Sirgala training area is approximately 600 meters from the northwestern corner of the EISAP area. The training ground may impact the EISAP area primarily through disturbances such as noise and vibration.

The currently used portion of the training ground covers an area of 2,834 hectares. In 2023, planning began for the expansion of the Sirgala training area, aiming to increase its size by an additional 4,968.7 hectares. This expansion will extend northwest, into the closed areas of the Viivikonna oil shale quarry and will not encroach upon the EISAP project area. Also, further expansion towards the EISAP area is unlikely due to potential negative impacts on the Puhatu Natura 2000 bird area.

Environmental noise calculations at the Sirgala training area indicate that the use of most shooting ranges and training areas has not resulted in high environmental noise levels near noise-sensitive buildings. The equivalent noise level remains below 50 dB, and the permitted noise levels have not been exceeded in the Sirgala settlement (approximately 1 km from the training ground boundary) or in Viivikonna village (approximately 4 km away)[21]. These distances are comparable to the distance between the EISAP production buildings (not expected to be noise-sensitive) and the training ground. Therefore, noise from Sirgala training area will unlikely significantly impact EISAP activities.

However, the potential impact of vibration must be taken into account. Activities currently conducted at the Sirgala training area cause vibrations, but their extent is considered minor due to the geological structure of the ground being disrupted by mining[22]. At the same time, short-term disturbances from vibrations cannot be ruled out[23]. Seismic vibrations from trial blasts were measured at distances ranging from 0.35 to 7.8 km from the blast site[24]. The outer boundary of the EISAP area is approximately 0.6 km from the Sirgala training ground's boundary, making vibration occurrence within the EISAP area possible.

Vibrations from blasts or large-calibre weapon fire do not travel to distant buildings through the ground; instead, the vibrations are caused by the sound wave energy impacting the ground and buildings (known as shock waves). Most building vibrations arise from the pressure of sound waves on exterior surfaces and windows, which is the primary source of structural damage risk[25]. At the same time, a study conducted in 2022 found that the weapons used at the Sirgala training ground do not pose a risk of structural damage (including window cracking) to nearby noise-sensitive objects (the closest buildings are at least 160 m from the training ground). However, when using large-calibre weapons, window vibrations and associated sounds ("rattling") cannot be ruled out. Therefore, building designs within the EISAP area must consider the potential impact of vibrations from training ground activities. Glass is particularly sensitive to vibrations, and measures to mitigate vibrations may be necessary.

Additionally, the potential impact of vibrations on living organisms in the RAS system should be considered.

3.3.3. Operational factors of Mining

When planning and implementing the EISAP project, it is necessary to consider certain impacts and conditions that may be caused by activities in the active quarry area. These may include:

Environmental factors, such as:

- Water Pollution: Contamination of groundwater and surface water due to runoff from mining sites, leaching of heavy metals, and use of chemicals.
- Air Quality: Dust and emissions from mining operations, transportation, and machinery can degrade air quality and contribute to respiratory problems, as well as dust from the mine and roads may settle on buildings, including greenhouses.
- Soil Erosion: Mining activities can lead to soil erosion, affecting land stability and leading to sedimentation in nearby water bodies.

Noise and Vibration, such as:

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[21] AS Maves. 2019. Sirgala harjutusvälja keskkonnakorralduskava.

[22] Hendrikson&Ko. 2023. Sirgala harjutusvälja ehitusprojekti keskkonnamõju hindamine.

[23] AS Maves. 2019. Sirgala harjutusvälja keskkonnakorralduskava.

[24] Hendrikson&Ko. 2023. Sirgala harjutusvälja ehitusprojekti keskkonnamõju hindamine.

[25] Akukon Eesti OÜ. Sirgala harjutusvälja mürauuring. Tallinn 2022.

- Noise Pollution: Continuous noise from mining equipment, blasting, and transportation can be disturbing to workers in EISAP.
- Vibration: Blasting and heavy machinery can cause vibrations that may affect nearby structures, causing potential damage or discomfort and cause negative impact on living organisms.

Safety and Health, such as:

- Occupational Hazards: Mining is inherently dangerous, with risks including cave-ins, explosions, and exposure to hazardous substances.

Infrastructure and Transportation, such as:

- Road Damage: Heavy machinery and increased traffic can damage local infrastructure, including roads and bridges.
- Traffic Congestion: Increased transportation needs for moving mined materials can lead to traffic congestion and accidents.

4. Auvere energy complex

EISAP area borders with an energy complex of two thermal power plants: Eesti and Auvere power plant (Figure 13). Their capacities are 866 and 272 MW. There is also an oil plant with electric power production capacity of 12 MW. Eesti power plant works on oil shale while Auvere plant uses a mix of oil shale, biomass and ewe gas. While Eesti power plant is very old, Auvere plant is new. Technically, the latter may operate still several decades. However, political and economic perspectives are different.

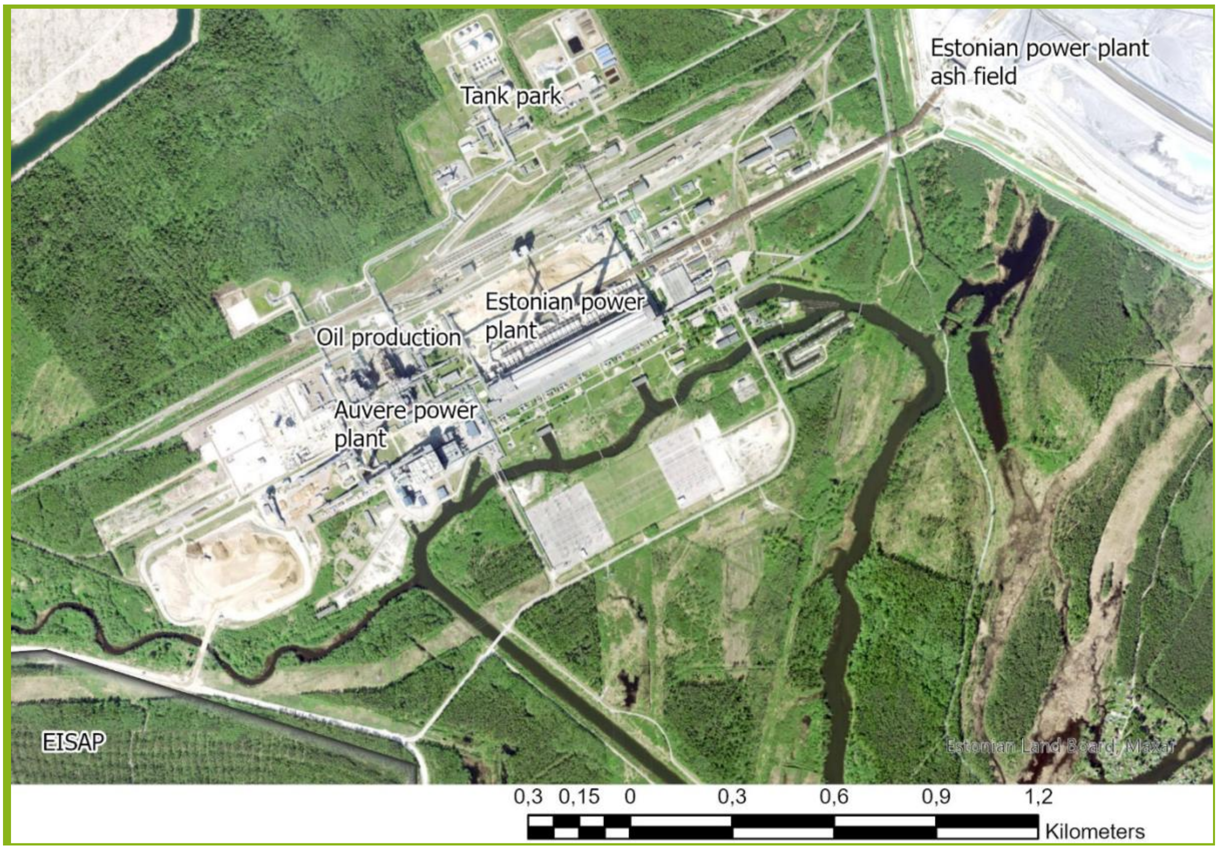

Figure 13. Auvere energy complex

Today these power plants provide two main functions: profit for the owner (Estonian government) and electricity supply for Estonia. Due to rising GHG emission price in the EU market and increasing supply of climate neutral electricity, Auvere energy complex may lose its economic feasibility very soon (Riigikontroll, 2023; Elering, 2022). Technologically, these power plants cannot switch fully to biomass while Estonian government has banned the use of wood as fuel there. After 2026 Estonian government may decide not to support the operation of this complex anymore.

Auvere power plant

The main activity of the Auvere Electric Power Plant is the production of electricity.

One oil shale circulating fluidized bed (CFB) boiler (input power according to fuel 680 MWth) and one turbogenerator with auxiliary equipment have been installed at the Auvere Power Plant. Up to 2,200,000 tons of oil shale, biomass - wood chips and waste wood are used as fuel, in total up to 1,500,000 tons per year and 120,000 thousand m^3 of flue gas per year. The use of peat up to 520,000 tons per year is still allowed as an alternative fuel.

Up to 7,000 tons of oil shale oil is used to heat up the shore (heating is done together with oil shale, a maximum of 36.1 t/h of oil and up to 70.6 t/h of oil shale is used).

The maximum annual net electricity production of Auvere Power Plant is 2.6 TWh.

Eesti power plant

In the facility, electricity is produced mainly from oil shale, other solid fuels, including biomass and off-gas (i.e. semi-coke gas or oil shale gas). It is theoretically possible to replace up to 5% of the used oil shale with coal in the energy blocks of Eesti Elektrijaam.

Ashes are generated as a waste of electricity production, which are deposited in a landfill that is part of the facility.

It is a facility with a very long history. The first power unit of Eesti Elektrijaam was put into operation in 1969, the design capacity of 1610 MW was achieved in 1973. Due to stricter future environmental requirements, the 8th energy block was renovated in 2001-2004.

The usable capacity of non-renovated blocks is lower than the installed capacity, because steam parameters (pressure, temperature) are limited due to intensive contamination of the heating surfaces of the boiler.

The installed heat production capacity of Eesti Elektrijaam is 84 MWh.

The maximum annual net electricity production of Eesti Elektrijaam is 7.6 TWh. The actual production volume depends directly on consumption and the emerging electricity market and is therefore difficult to predict.

Oil production plants

Auvere energy complex hosts a few units of shale oil production plants: Enefit140, Enefit280 and Enefit280-2.

Enefit140. The nominal cost of oil shale (i.e. raw material) of the Enefit140 ewe unit is 140 t/h: working time up to 8000 h/a. At nominal load, one ewe unit produces oil shale oil approx. 17.5 t/h and exhaust gas approx. 5050 Nm^3/h. Ewe gas with a high calorific value is burned in the boilers of Eesti Elektrijaam.

Enefit280. Nominal cost of dry oil shale (i.e. raw material) is 280 t/h and working time up to 8100 h/a. At nominal load, one ewe unit produces oil shale oil approx. 40 t/h and flue gas approx. 12000 Nm3/h. Uttegas is burned in the boilers of Eesti Elektrijaam.

Enefit280-2 is under construction today. Its oil shale nominal cost will be 280 t/h, up to 2014888 t are used annually; oil production up to 267,980 t/a, flue gases up to 68.5 million m^3/a, up to 203 GWh/a of electricity is produced from the residual heat of the device. The calculated annual operating time of the Enefit280-2 device at nominal load is 7200 hours, real operating time at least 75% load is 7450 hours, with warm-up-stop periods up to 8200 hours. Taking into account the maintenance and repair work and the operation of the infrastructure, the facility operates year-round, i.e. 8,760 h/a.

The planned activity is part of the Auvere energy complex, the infrastructure of which will be used by the Enefit280-2 device (the use of the infrastructure is regulated by other complex permits).

The technical lifetime of Enefit280-2 is at least 35 years (from EIA report), until ca 2060. The economic payback time is less than 10 years.

Cooling system and water heating

In **Auvere power plant**, the annual amount of cooling water which is used is 520 M m^3. Water is taken from surface water intakes from the Eesti EJ inflow channel (Mustajõe canal) and Mustajõe. The technological and rainwater used in production is discharged to Mustajõgi river. Two parallel 80 m long cooling water channels with a diameter of 2x2.2 m with cleaning gratings, gratings and butterfly valves and cooling water pumps with a maximum productivity of 13.5 m^3/s per energy block have been built for the intake of cooling water. The temperature of the cooling water in the power plant rises ca 7 – 11 degrees. According to the valid complex permit, the permissible temperature range of the cooling water fed into the river through the cooling water outlet is 0–33°C.

After commissioning the **Enefit280-2** device, the maximum cooling water requirement of the oil industry is up to 15,000 m^3/h (4.16 m^3/s), or up to 100 million m^3 per year. The real need is somewhat lower, considering the amount of cooling water used so far (expected to be up to 85 million m^3/a). The total cooling water requirement of two Enefit280 devices is 7.5% of the designed capacity of the Eesti Elektrijaam system (the actual share may be slightly higher, as sediment accumulates in the channels and the actual capacity of the system is lower before cleaning).

Provision of electricity

According to the Estonian Electricity Market Act, a direct power line can be built from the power plant up to a distance of 6 km to an electrical installation. In such case, the user need not pay network charges. This makes possible for EISAP to potentially get relatively cheap electricity from Auvere energy complex.

5. Technical solution for EISAP

5.1. Existing systems and solutions in RAS, aquaponics and greenhouses

5.1.1. Greenhouses

General idea

A greenhouse is a special structure that is designed to regulate the temperature and humidity of the environment inside. There are different types of greenhouses, but they all have large areas covered with transparent materials that let sunlight pass and block it as heat. The most common materials used in modern greenhouses for walls and roofs are rigid plastic made of polycarbonate, plastic film made of polyethylene, or glass panes. When the inside of a greenhouse is exposed to sunlight, the temperature increases, providing a sheltered environment for plants to grow even in cold weather.

Commercial greenhouses predominantly use soilless systems, particularly **hydroponics**, rather than traditional soil substrates. Hydroponics is widely used in commercial greenhouse operations due to its efficiency in resource use and control over plant growth conditions. This system allows for precise control of water, nutrients, and environmental factors, leading to higher yields and better-quality produce. Common substrates used in hydroponic systems include rockwool, perlite, coconut coir, and other inert materials.

Commercial greenhouses are now frequently **located near appropriate industrial facilities** for mutual benefit. For example, Cornerways Nursery in the UK is strategically placed near a major sugar refinery, consuming both waste heat and CO2 from the refinery which would otherwise be vented to atmosphere. The refinery reduces its carbon emissions, whilst the nursery enjoys boosted tomato yields and does not need to provide its own greenhouse heating.

Today’s economic map of the world is characterised by **clusters**: critical masses in one place of linked industries and institutions, from suppliers to universities to government agencies, that enjoy unusual competitive success in a particular field (choomans & Ravensbergen, 2022). Such a tendency clearly characterises horticulture in today’s Europe. The strongest cluster has its roots in the Netherlands, evolving into an increasingly international network.

Scale

Companies in the **Dutch** Controlled Environment Agriculture (CEA) cluster contribute €21.1 billion directly and indirectly to the Dutch economy (Schoomans & Ravensbergen, 2022). The CEA cluster, which consists of private and public entities in the value chain of vegetables, fruit, ornamentals, seeds and other plant propagation materials and technology, accounts for 3.4 per cent of total national employment, providing approximately 300,000 jobs (254,000 FTE). The vegetable production area in 2018 was 4970 ha (51 jobs per ha). The yield was 1,77 M tons[26]. The largest complex in the Netherlands is Noordvliet greenhouse, 97 ha, operated by CombiVliet in Middenmeer. **In Canada**, vegetable greenhouses employed in 2023 in total 14,1 thousand workers on 200 ha (7 workers per ha)[27].

In **Estonia**, greenhouse vegetables were grown in 2023 on 83 ha, producing 5309 t (64 t/ha). AS GrüneFee, the Estonian largest greenhouse vegetable operator, employees 102 workers (including part-time) on 6 ha of greenhouses (17 jobs per ha, 2023). The company sold vegetables for 11,4 M €. One job produced 3,7 t of vegetables.

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[26] https://opendata.cbs.nl/

[27] www150.statcan.gc.ca

Based on these proportions, the scale for EISAP greenhouses might be 100 direct and indirect FTE jobs. If each job produces in average 7 t of vegetables – as in the Netherlands – they will produce 700 t/yr. In contemporary Estonian greenhouse conditions such yield requires **11 ha of greenhouse area**. If each ton contributes to economy 11 864 € - as in Netherlands – it makes 8,3 M €/yr.

Lighting

The extent to which natural and artificial light is used in greenhouses is largely determined by the latitude, the time of year, and the specific crops being cultivated. Natural light plays a significant role in greenhouse operations during the summer months in Nordic countries. During this period, regions such as southern Norway, Sweden, Denmark, and Finland experience long days with extended daylight hours. During these months, commercial greenhouses can rely predominantly on natural light, which is abundant and of high quality for photosynthesis. This extended daylight allows for efficient plant growth with minimal need for artificial lighting, reducing energy costs and the carbon footprint of greenhouse operations. The reliance on natural light during summer enables growers to cultivate a wide variety of crops, including vegetables, herbs, and flowers, with high productivity.

In contrast, the winter months in the Nordic countries are characterized by short days and long nights, with some regions experiencing polar night, where the sun does not rise above the horizon for an extended period. This lack of natural light necessitates the use of artificial lighting to sustain plant growth in commercial greenhouses. Artificial lighting, primarily in the form of high-intensity discharge (HID) lamps, light-emitting diodes (LEDs), and sometimes fluorescent lights, is extensively used during the winter to supplement the limited natural light. These lighting systems are designed to provide the specific light spectra needed for photosynthesis, ensuring that plants receive adequate light to grow despite the low levels of natural sunlight.

The reliance on artificial lighting in winter poses significant energy demands, making it a major operational cost for greenhouse businesses in the Nordic region. However, the adoption of energy-efficient LED lighting has been increasing, as LEDs offer lower energy consumption, longer lifespan, and the ability to fine-tune light spectra to meet the specific needs of different crops.

New solutions

Vertical farming

Vertical farming is an indoor greenhouse solution which normally does not use sunlight. Such system is very land-effective in urban areas. In EISAP, as land is cheap, vertical farming seems not feasible.

Solar greenhouses

A solar energy greenhouse is a structure that has solar panels installed. They collect the light from the sun and transform it into heat. It provides the right environment for the growth of plants even in unfavourable climatic conditions. A new kind of solar film makes it possible for farmers to generate energy with their greenhouses while still allowing enough light to reach their plants for photosynthesis. Light travels at different wavelengths, and the film uses spectral filtering to allow certain wavelengths of light to pass through to the plants while absorbing other wavelengths to use to produce energy. Thin solar panels can be quickly and safely integrated into the glass cover of new construction projects. Nowadays such systems are widely spread all over the world, as a roofed solar power plant also perform the function of a durable, long lasting glass greenhouse roof.

Sonneveld et al. (2010a, b) described a new prototype greenhouse that they have developed, which combines reflection of near infrared radiation (NIR) with electrical power generation by means of hybrid PV cell/thermal-collector modules. In addition to the generation of electrical and thermal energy, the reflection of the NIR results in improved climatic conditions in the greenhouse.

Walipini (Pit) Greenhouse

A walipini style greenhouse is essentially a pit greenhouse, or a hole dug in the ground with glazing laid over it. The pit style greenhouse works quite well near the equator at high altitudes in mostly dry climates. In these areas, neither one of the walls will cast a deep shadow into the growing space and the roof water runoff will not damage the walls of the excavated pit. If walipini needs to be built in the northern latitudes, one can build an earth berm on the northern side of the greenhouse to create a steeper roof slope. As of now, there aren't any widely recognized large farming companies that use Walipini-type greenhouses on a massive commercial scale.

In EISAP area, Walipini style might be supported by very ridged landscape. Ridges may serve as natural backwalls for the greenhouses, providing insulation (Figure 14).

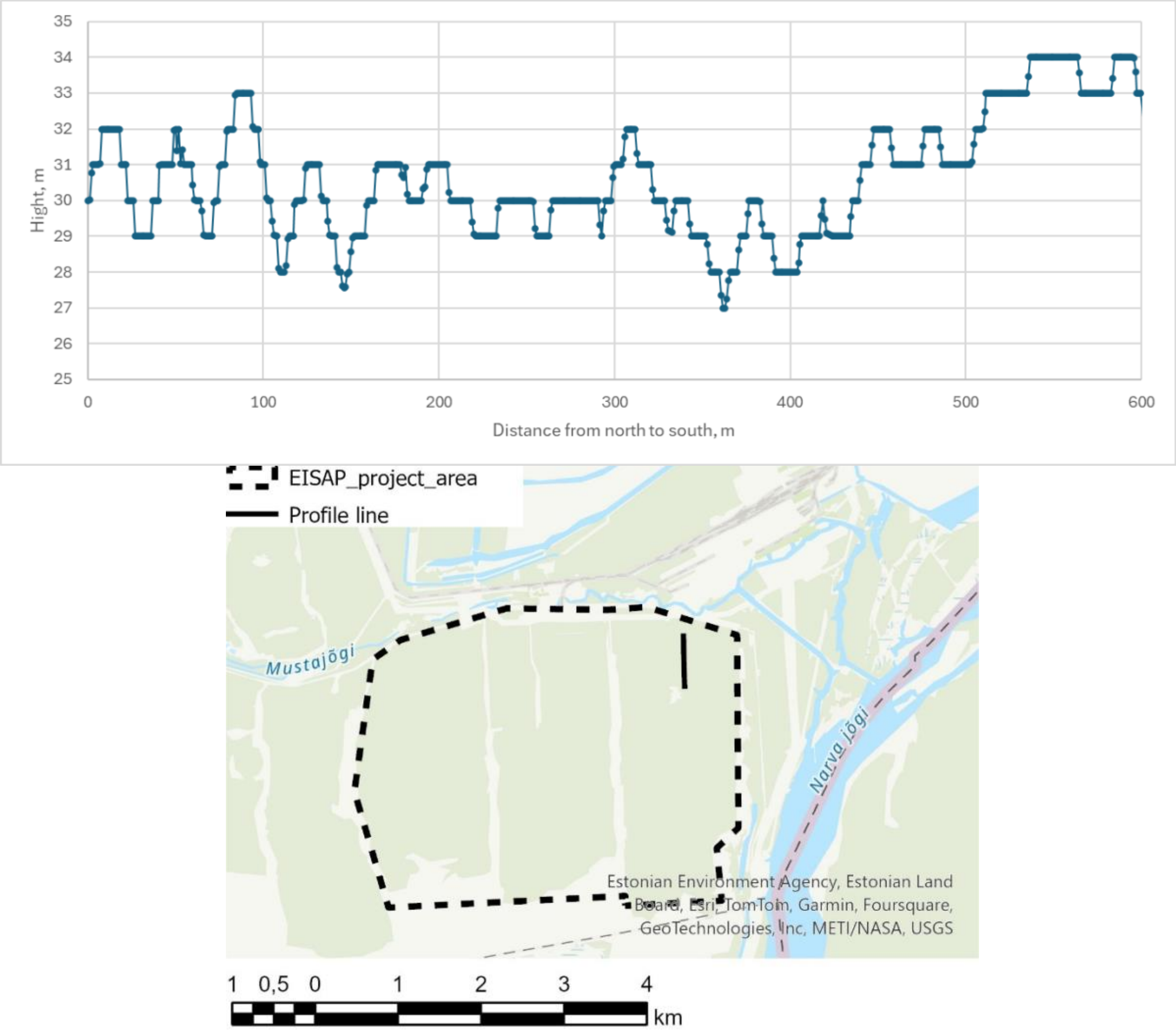

Figure 14. Elevation profile of the north-east corner of EISAP area from north to south. Within first 400 m we see 6 ridges with at least 3 m relative height.

5.1.2. Aquaponic systems

General idea

Aquaponics is an integrated farming concept that combines fish, hydroponic plant production, and nitrifying bacteria in a symbiotic environment. The most common form is the integration of hydroponic beds in the water circuit of a recirculating aquaculture system (RAS) (Delaide et al., 2015; Rakocy, 2012). This integration aims to convert the normally wasted nutrients excreted by fish into valuable plant biomass. This allows for lower water exchange and spillage which should significantly reduce the environmental impact of fish and hydroponic plant production.

There are nice examples of commercial aquaponic farms. ECF Farm Berlin works since 2015 in 1800 m^2, producing basil and cichlid.

In contrast with conventional soil-based systems, hydroponic beds are able to consume nutrients from a very diluted solution. The main idea is that fish and plants live in roughly the same environment. There are several challenges, however. Nitrogen concentration tends to rise too high and toxic for fish. Phosphorus, in turn, tends to settle, leaving plants to P deficit.

Generally, aquaponics systems are classified into three types, namely media-based bed, floating raft, and nutrient film technique. Among them, the media-based system is believed to be more efficient in the utilization of nitrogen since it provides more volume-to-surface area ratio for the microbes than the other two types.

Business perspective of aquaponics

General feasibility. Compared to conventional agriculture, the main advantages of aquaponics are land and water saving (Turnshek *et al.*, 2019). However, it may require more energy, capital and work input. Love *et al.* (2015) found that in Florida (US) the size of aquaponics producers is significantly smaller than hydroponic production and is to a large extent still more of a hobby activity than successful commercial enterprises. Only 31% of these farmers reported profit. Only 10% of the farms received more than $50 000 annually. Turnshek *et al.* (2019) concluded that aquaponics mostly relies on volunteer work. Full market potential analysis and well-founded cost-effectiveness assessments for European conditions are not known at the present time.

European perspective. The experimental and pioneering status of commercial aquaponics is one reason why the financing of larger commercial-scale projects can be a challenge (Morgenstern's *et al.*, 2017). Most aquaponic systems in Europe have been financed through research grants or through aquaponics enthusiasts. Personal communication with German banks that are traditionally strong in financing agricultural investments and that are therefore familiar with the intricacies of crop production and animal rearing revealed that they would not finance an aquaponics project due to lack of a proven and established business model.

Morgenstern's et al. (2017) modelled profitability of aquaponics in University of Applied Sciences of South Westphalia (Germany). An analysis of the cost structure of the modelled production-sized aquaculture system shows that labour, fish feed and juveniles and energy are the main cost drivers, contributing roughly one third of the main costs each.

Economic evaluations of aquaponic systems are still a very complex and difficult task at present. Although aquaponics is sometimes presented as an economically superior method of food production, there is no evidence for such generalised statements. Up to now, there is hardly any reliable data available for a comprehensive economic evaluation of aquaponics. Aquaponics constitutes a major communication challenge as a rather unknown food production system with high innovation levels and in most cases with high technological inputs.

EISAP perspective. Location decisions for aquaponics farming are a key determinant of economic viability as many production factors related to aquaponics production are not flexible in terms of space. This relates particularly to land. Aquaponics as a land-efficient production system can only count on this advantage in land-scarce regions. Comparatively, rural areas with relatively low land prices therefore cannot generally generate sufficient incentives. Hence, EISAP area seems unsuitable for aquaponics. Such conclusion could be reversed only by very significant other site-specific advantages, for example, waste energy and CO_2 supply from Auvere energy complex.

5.1.3. Fish farming

5.1.3.1. POND FARMING

General idea

Pond farming, also known as pond aquaculture, is a conventional method of raising fish in man-made or natural ponds. It is one of the most common forms of aquaculture, particularly for freshwater species. Ponds are typically constructed by digging a depression in the ground and using the excavated soil to build embankments around the pond. Ponds are usually designed with inlet and outlet structures to control water levels and allow for drainage.

Freshwater fish farming in the EU, particularly in countries like Hungary and Romania, has shown potential when combining traditional pond farming with intensive cage culture. This combination allows for increased production capacity and species diversification while also improving nutrient recycling. However, despite these advancements, the overall growth in freshwater aquaculture has been stagnating since the 1990s. This stagnation contrasts sharply with the significant technological advancements and economic rationalization observed in marine cage culture, which has become the dominant form of aquaculture in Europe (Gál et al., 2011).

Challenges

Freshwater fish farming in the European Union (EU) presents a complex but potentially rewarding business opportunity. While it holds promise for meeting local demand for fish, increasing rural employment, and contributing to the sustainability of food systems, several challenges must be carefully navigated to ensure profitability and minimize risks.

Profitability in freshwater fish farming largely depends on the ability to manage costs effectively and meet consumer expectations. European consumers are increasingly concerned with food quality, safety, and environmental impact, which places pressure on the aquaculture sector to adopt sustainable practices. The farming of alien species in European inland waters, while accounting for a significant portion of production, poses environmental risks that could affect profitability. Indigenous species, although commanding higher market prices, make up less than a third of the production, highlighting a potential area for growth if managed sustainably (Turchini & Silva, 2008).

Current trends in freshwater fish farming reveal a focus on improving operational efficiency and sustainability. A study analysing the efficiency of aquaculture production across EU Member States showed that freshwater finfish aquaculture efficiency can be improved, particularly in reducing feed, energy, and livestock costs (Gutiérrez et al., 2020). Furthermore, climate change poses additional challenges by affecting water quality and temperature, which in turn impacts fish health, growth performance, and feed conversion. These factors are critical in determining future production costs and returns, making them key considerations for the long-term profitability of freshwater fish farming in the EU (Kreiss et al., 2020).

Risk management is a crucial aspect of ensuring the sustainability and profitability of freshwater fish farming in the EU. The industry faces significant risks from environmental factors, such as the threat of viral diseases, which can lead to substantial economic losses. The spread of diseases, particularly those not currently notifiable, remains a significant concern for the industry, highlighting the need for effective disease management and biosecurity measures (Haenen et al., 2018).

In addition to environmental and health risks, the economic viability of freshwater fish farming is influenced by market dynamics. The EU's strategy for ensuring fish supply relies heavily on imports and fisheries agreements with third countries. This dependency on external sources could pose a risk to local production if global market conditions shift or if there are disruptions in trade agreements (Mulazzani & Malorgio, 2015).

In conclusion, while freshwater fish farming in the EU presents several opportunities, particularly in diversifying species and increasing production efficiency, it also faces significant challenges. Profitability is contingent upon managing production costs, meeting consumer demands for sustainable practices, and navigating environmental and market risks. To ensure long-term viability, the industry must continue to innovate and adopt practices that balance economic, environmental, and social considerations.

Feasibility in EISAP

EISAP area enjoys high volumes of flowing surface water from Narva and Mustajõgi rivers. Hence, a fish farm need not suffer from water deficit. These rivers may afford some pressure from fish farm wastewater, without significantly compromising high water quality downstream. Rough surface of the EISAP area may provide some pre-established pits for the fishponds. However, these few advantages hardly suffice for an attractive business idea. Additional assets are probably needed.

5.1.3.2. Cage farming

General idea

Cage system freshwater fish farming in Europe presents both promising opportunities and significant challenges. The method, which involves raising fish in cages submerged in freshwater bodies, has seen varying levels of adoption across the continent.

While cage farming is the leading method for marine aquaculture, its use in freshwater environments is less widespread in Europe. It is employed in specific regions and conditions but does not contribute as significantly to the overall production volume compared to pond farming.

Freshwater cage farming is often employed in large lakes, reservoirs, and rivers where water flow and depth are sufficient to support cages. These environments provide the necessary water exchange to maintain water quality and ensure the health of the fish. For instance, cage fish farms are in some Bulgarian reservoirs.

Challenges

One of the critical factors influencing the profitability of freshwater cage farming is the management of **water quality**. Poor water quality can lead to increased mortality rates and reduced growth performance, directly impacting economic returns. For instance, the success of cage farming operations depends heavily on maintaining optimal levels of dissolved oxygen, which can be challenging in environments with fluctuating temperatures or high organic loadings. The need for continuous monitoring and management of water quality parameters, such as pH, temperature, and oxygen levels, adds to the operational costs and complexity of cage farming (Devi et al., 2017).

Environmental risks associated with cage system freshwater fish farming are significant and must be carefully managed to ensure long-term sustainability. One of the primary concerns is the accumulation of waste products, such as uneaten feed and fish excreta, which can lead to localized pollution and eutrophication of the surrounding water body. This accumulation can alter the benthic environment, reducing biodiversity and affecting the overall health of the ecosystem. For example, studies have shown that cage farming can lead to increased levels of heavy metals in sediments and changes in the composition of benthic communities, which can have long-term ecological consequences (Xie et al., 2020).

Current trends in freshwater cage farming in Europe indicate a growing emphasis on sustainability and environmental stewardship. The integration of cage farming with other aquaculture methods, such as pond farming, can help mitigate some of the environmental impacts by enhancing nutrient recycling and reducing the discharge of pollutants into the environment (Blancheton, 2000).

In conclusion, the feasibility of cage system freshwater fish farming in Europe is multifaceted, with significant potential for profitability if managed effectively. However, this potential is tempered by the need for substantial investment in water quality management and the mitigation of environmental risks. As the European aquaculture sector continues to evolve, the adoption of sustainable practices and the integration of innovative technologies will be crucial for ensuring the long-term viability of freshwater cage farming.

Feasibility in EISAP

EISAP area does not contain any suitable waterbody for cage farming. In the vicinity, there is Narva River which can perhaps host such cages. The Estonian side of the river near EISAP area is up to 400m wide, affording some space.

However, Estonian environmental policy generally opposes cage farms, submerged into natural water bodies. Such facilities are too polluting. In case of Narva River, cross-border issues may appear.

5.1.3.3. RECIRCULATING AQUATIC SYSTEMS (RAS)

General idea

Recirculating aquaculture systems (RAS) are land-based aquaculture facilities – either open air or indoors – that minimise water consumption by filtering, adjusting, and reusing the water (Fig 15). Compared to traditional pond or open water aquaculture, the water recirculation process in RAS makes it possible to control the culture conditions and collect waste. In addition, land-based aquaculture avoids escapees and limits external transmission of diseases and parasites. RAS gives promise of more sustainable food production with healthier fish and lower consumption of fresh water. RAS technology allows for the efficient and sustainable farming of aquatic organisms by recycling water within the system. This technology is crucial for minimizing water and energy use and environmental impact.

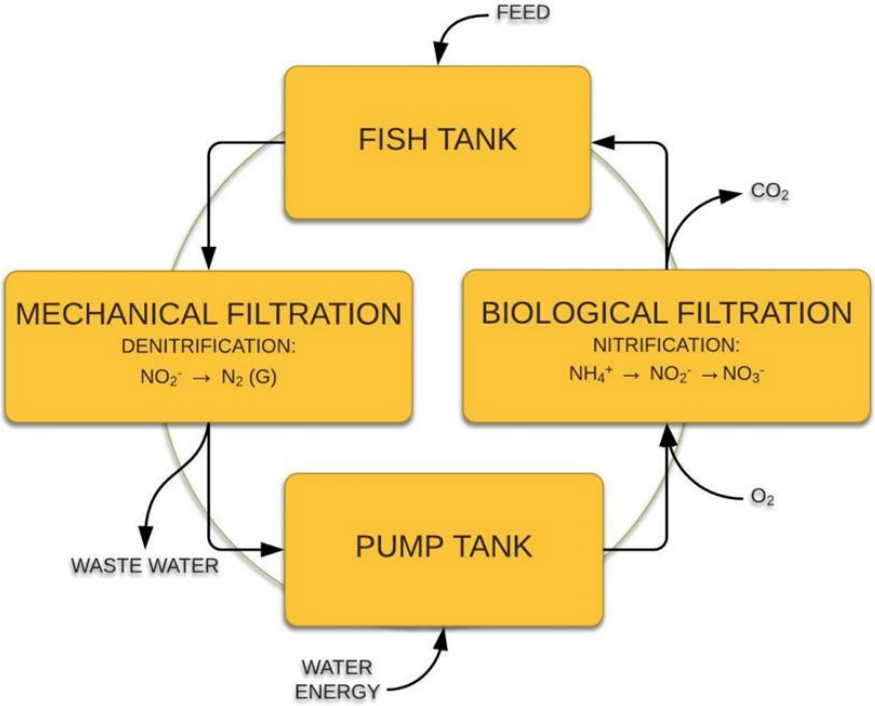

Figure 15. Major flows in recirculating aquaculture system.

On the other hand, a RAS facility tends to be quite expensive. Investment costs are high, and the recirculation technology consumes vast amounts of energy and requires to be controlled and managed by a skilled workforce. Furthermore, the technology remains to prove its viability on large-scale production. Fish welfare is not necessarily ensured in RAS, and several projects have experienced mass mortality, due to design errors or technical difficulties of the water recirculation. Lastly, without the correct management, fish grown in RAS can have a muddy or earthy off-flavour.

RAS is a mature technology that has been successfully implemented in various parts of the world, indicating its feasibility for the EISAP project (Espinal & Matulić, 2019). The main challenges lie in scaling the technology and ensuring its integration with other agropark systems, such as using waste products as feedstock for aquaculture.

EU perspective

In 2018, imports made up 73% of total EU finfish supply (AIPCE, 2019). Thus, to avoid reducing the self-sufficiency rate, which was estimated at 43,4% in 2017 (EUMOFA, 2019; all fishery and aquaculture products for human consumption), the European seafood production – primarily aquaculture – should aim to develop along with the growing global demand.

EU generally supports blue economy initiatives, fish farming and innovation. The main obstacles are access to feed supply, time consuming and costly bureaucracy and access to funding (EUMOFA, 2020).

Risks

RAS production is technologically complex compared to traditional production methods. RAS have a long history in freshwater environment (e.g. portion trout, eel and smolt), but are immature in terms of commercialised large-scale production of market-sized fish in saline water environment. Despite technological developments in recent years, there are still many risks associated with RAS operations. The risks can be classified in four main categories: operational risks, financial risks, market risks and social and regulatory licenses (Rabobank, 2019).

Operational risks are related to the functioning of the system. The equipment and technology must be managed correctly to replicate the optimal environment and water quality for the fish, and to ensure optimal animal welfare and growth. If the equipment or technology (filtering systems, pumps, etc) malfunctions, either due to errors, ineffective design/assembly or poor management, the accumulation of toxic gases (e.g. carbon dioxide, ammonia and hydrogenic sulphide) will negatively affect the health, welfare and growth performance of the fish, and can quickly even have fatal consequences. Sub-optimal rearing conditions can also reduce the quality of the product in terms of colour, texture and taste.

With all the technology and management of the different variables, a skilled workforce is essential for a RAS facility to operate successfully. **Competence** is needed with the reared species, water quality, the technological installations, and in general management. Often, the competence should be specific to the farm/technology that is managed, and education within general aquaculture might not be enough. Despite the high impact of workforce skills on the farming performance in RAS, availability of competence seems to be one of the main bottlenecks in these systems. In order to increase the availability of skilled workforce, it could be wise to locate RAS facilities close to areas where research and education activities take place.

Financial risks. One of the toughest challenges for RAS operations is to be found in the amount of capital expenditure (capex) that is required upfront. Building and constructing RAS facilities account for most of the development capex. However, uncertainty regarding future costs of production, including biological risks, and the long time period between the initial investment and the revenue from RAS production increases the need for financial flexibility. There is also uncertainty regarding the expected return on investments due to market risks.

Operating costs (OPEX) are generally considered higher in RAS compared to traditional farming methods. This is mainly due to the energy-demanding process of treating and transporting the water. The highest costs connected to water treatment are related to pumping and lifting of water, CO_2 removal, temperature control and oxygenation. Naturally, the costs will be reduced if the inlet water can flow into the facility (reduced need for pumps), and if it has high quality and the right temperature (reduced need for filtering and treatment). In all aquaculture production, feed is one of the major operating costs and even more so in RAS if the facility uses specialised RAS-feed. Sludge (fish manure) may serve as a valuable resource for other facilities, but it may appear as a challenge either.

Market risks. RAS cannot be labelled as organic and there are no RAS-specific labels or certifications. Although RAS may work as a sustainable solution, customers need not pay any price premium.

Social and regulatory risks. As with traditional aquaculture, production permits are necessary to establish a RAS facility. In addition, licenses are required for the intake and discharge of water. The interactions between local, regional, national and EU legal requirements can often make the licensing process unpredictable and protracted.

Feasibility in EISAP

RAS may work as a feasible solution especially if there is water deficit in EISAP area, preventing flowthrough fish farming. Although there’s sufficient water amount in Narva and Mustajõgi rivers, these sources may poorly suit for fish farming, especially due to infection risks. Groundwater quantity, in turn, may be limited, requiring RAS.

5.1.4. INTERLINKAGES

5.1.4.1. Flows of material

General idea

Horticulture (greenhouses) and aquaculture (a fish farm) may form industrial symbiosis. In principle, fish fulfil a heterotrophic while vegetable plants an autotrophic function in such mutualistic relationship (Fig 16). Heterotrophic fish, as all the other animal, feed on organic carbon and consume molecular oxygen (O_2) for respiration. These are produced by all plants which emit them as life byproducts. At the same time, plants feed on mineral carbon (CO_2 gas or dissolved HCO_3^-) and other mineral nutrients – phosphate, ammonium etc. - which are dissolved in water. All these compounds are excreted by fish as byproducts of respiration and other metabolism. Applying such approach, a well-balanced ideal industrial ecosystem might theoretically minimise its waste flows.

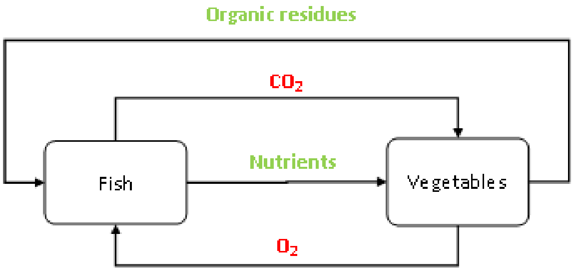

Figure 16. Possible symbiotic relations between vegetable and fish production. Red colour indicates flows which cannot be applied in industry. Green colour shows flows which can be feasibly applied.

Organic residues

In the context of European aquaculture, plant residues are increasingly being utilized as a sustainable alternative to traditional fish feeds, particularly in light of environmental concerns and the need to reduce reliance on marine-derived fishmeal. Various plant residues, such as wheat straw, rice husk, and corn straw, have been explored for their potential as feed ingredients in European fish farms. These lignocellulosic materials, although low in protein and high in fibre, can be processed and combined with other feed components to enhance their nutritional value and suitability for fish diets.

For instance, research has shown that wheat and corn by-products, when treated appropriately through processes such as fermentation or enzymatic hydrolysis, can be effectively used in fish feeds. These treatments help to break down the fibrous content and increase the digestibility and nutrient availability of the residues. Additionally, certain agricultural by-products, like oilseed cakes (e.g., rapeseed and sunflower), have been found to be valuable due to their higher protein content, making them suitable supplements in aquaculture feeds (Cherubin et al., 2018).

In European aquaculture systems, the use of horticultural residues, such as those from tomatoes, has been explored as a sustainable alternative to conventional feed ingredients. Tomato residues, including skins, seeds, and pulp, are by-products of tomato processing and are generated in large quantities. These residues are increasingly being investigated for their potential as feed components in fish farming, primarily due to their nutritional content and availability.

One approach to utilizing tomato residues in aquaculture is through their incorporation into fish feed. A study by Hoffman et al. (1997) explored the partial replacement of fish meal with tomato meal in the diets of African sharptooth catfish (*Clarias gariepinus*). The results indicated that fish fed with a diet including tomato meal showed relatively strong growth, suggesting that tomato residues can be an effective alternative protein source in aquaculture feeds. This is particularly relevant as the high cost of fish meal drives the search for alternative, cost-effective protein sources that are not suitable for human consumption.

One of the promising strategies involves the use of horticultural residues, such as vegetable and fruit waste, to cultivate **invertebrates** like insects and worms (Fig 17). These invertebrates can efficiently convert low-value organic residues into high-quality protein, which can be harvested and processed into fish feed. The potential of using insects like black soldier fly larvae (*Hermetia illucens*) and mealworms (*Tenebrio molitor*) has been extensively studied. These insects can thrive on a diet composed of plant residues, converting them into biomass rich in proteins and fats that are suitable for aquaculture feed (Makkar *et al*., 2007).

Figure 17. Possible fish feed production chain in EISAP.

The use of these plant residues in fish farms across Europe not only supports the circular economy by repurposing agricultural waste but also contributes to the sustainability of aquaculture practices. However, challenges remain, particularly concerning the variability in the nutritional content of these residues and the presence of anti-nutritional factors that could affect fish health and growth. Therefore, ongoing research and development are crucial to optimizing the use of plant residues in fish feeds, ensuring they meet the specific dietary requirements of different fish species and adhere to stringent food safety standards (Pleissner & Rumpold, 2018).

CO_2

In greenhouse agriculture, CO2 enrichment is a common practice to enhance plant growth, particularly for crops like tomatoes, cucumbers, and peppers. This process involves increasing the concentration of CO2 within the greenhouse to levels higher than those found naturally in the atmosphere, typically around 800 to 1,000 ppm, to boost photosynthesis and improve crop yields.

Normally, such CO_2 cannot be economically captured from fish farm. However, fish farm manure (sludge) can feed biogas station. While the primary biogas product is methane (CH4), its purification process may generate CO_2 which can serve as fertiliser for greenhouses.

Usually, biogas stations can be economically feasible if the daily load of manure exceeds at least 10 t. This is by far too much for a fish farm. Hence, a fish farm can only contribute to a biogas plant which gets its major biomass from other sources.

Other plant nutrients

A fish farm may work as an important source for greenhouse plant nutrients.

Phosphorus is excreted by fish mostly in solid form as manure. The collected slurry is often too solid or dense to be directly used in hydroponic greenhouse systems. To make it usable, the slurry is usually mixed with water to create a nutrient-rich solution. This can be done by agitating or aerating the slurry in a tank to keep the solids suspended in the water. In some systems, the slurry is further processed to break down solid particles, often through mechanical stirring or the use of a pump that recirculates the slurry to keep it well-mixed. This creates a nutrient solution that is more homogeneous and easier to distribute through the hydroponic system. Before the slurry is introduced to the hydroponic plants, it is typically passed through a series of filters to remove any large, undissolved particles that could clog the hydroponic system. This filtration ensures that the solution is fine enough to flow smoothly through the irrigation system used for the plants. The filtered nutrient solution, rich in dissolved nutrients, is then cycled into the hydroponic growing beds. The plants take up these nutrients through their roots as the water flows through the system. The nutrient-rich water is delivered to the plant roots through various hydroponic methods such as Nutrient Film Technique (NFT), Deep Water Culture (DWC), or drip irrigation systems. The roots of the plants are submerged in or exposed to the nutrient solution, allowing them to absorb the necessary nutrients directly from the water.

Nitrogen. Fish excrete nitrogen primarily in the form of solved liquid ammonia (NH3), which is a byproduct of protein metabolism. This can be nitrified. Nitrification is a two-step process where ammonia is first converted into nitrite (NO2-) by bacteria of the genus Nitrosomonas. Subsequently, another group of bacteria, Nitrobacter, oxidizes nitrite into nitrate (NO3-), which is the preferred form of nitrogen for plant uptake.

Once the ammonia has been converted into nitrate, the nutrient-rich water can be circulated through the hydroponic system, where it is delivered to the plant roots. The plants absorb the nitrate from the water, which serves as a vital nutrient for their growth. Nitrogen, in the form of nitrate, is a fundamental building block of amino acids, proteins, and chlorophyll, all of which are critical for the development and health of the plants.

The above-described approach is practiced in aquaponic systems. In case of conventional aquaculture and horticulture, nitrogen should probably be concentrated before the transport to the greenhouse. Such concentration may be too costly, economically unfeasible.

O_2

The concept of capturing oxygen or oxygen-rich air from greenhouses to aerate fish farms is intriguing and theoretically possible. It aligns well with the principles of integrated agriculture, where different components of a farming system support each other. However, the feasibility of such an approach depends on several technical, economic, and biological factors. The practicality of this approach, considering contemporary technologies, remains very questionable.

Conclusion

Use of horticultural organic residues for aquaculture is both economically and technically feasible. Use of fish farm manure as phosphorus fertiliser source for greenhouses is also feasible. Exchange of nitrogen, CO_2 and O_2 between these systems is feasible only if they are integrated to a single aquaponic system.

5.1.4.2. Flows of water

Water exchange between aquaculture and horticulture

Aquaculture wastewater has high content of nutrients, including nitrogen and possibly carbon in the form of HCO_3^-. In the treatment process, among other steps, such water could be directed through the greenhouses (Fig 18). This would sustainably substitute the use of natural water with post-consumer water. At the same time, such water would be potentially better for horticulture than pure natural water. However, risks should be considered and managed. For instance, if fish are treated with antibiotics, these may contaminate greenhouse crops.

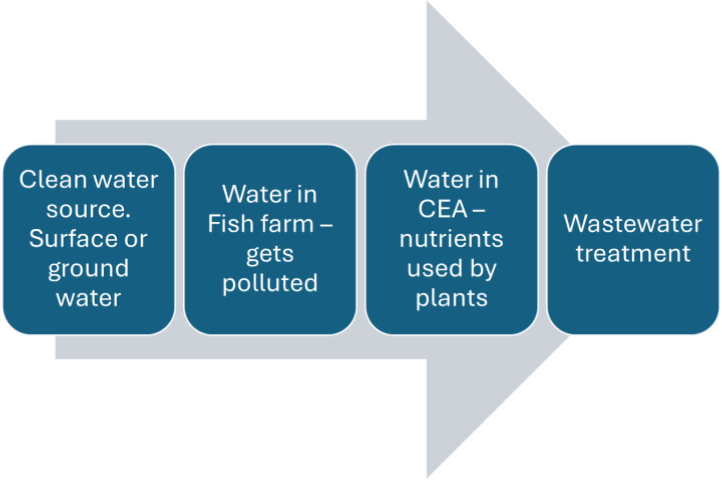

Figure 18. Proposed major water flows in EISAP.

It must be noted that although greenhouse plants consume nutrients from aquaculture their effluent water will still contain high levels of nutrients. Before discharging such water to the environment, it requires specific treatment.

Water temperature

Optimum temperature for fish farm

Different fish species have different optimal temperatures for growth. Fish living in temperate climates, such as trout and salmon, have optimal growth rates at around 15 to 20 °C (Fig 19) whereas fish living in tropical areas, such as tilapia and African catfish, have their optimal growth rates at around 30 °C. Fish also have upper and lower lethal temperature limits, and the farmer must be sure to keep the farmed fish within these limits or the fish will die. For instance, trout suffers from severe stress above 23 °C.

Natural water temperature

Water temperature in Narva and Mustajõgi rivers fluctuate annually roughly between 0 – 4 ^{0}C in January and 15 – 25 ^{0}C in July. The temperature of the cooling water in the Auvere energy complex my rise by an average of 7-8 °C when passing through the complex (Tuvikene, 2007). Hence, temperature of fresh effluent water fluctuates between 7 – 12 ^{0}C in January and 22 – 33 ^{0}C in July.

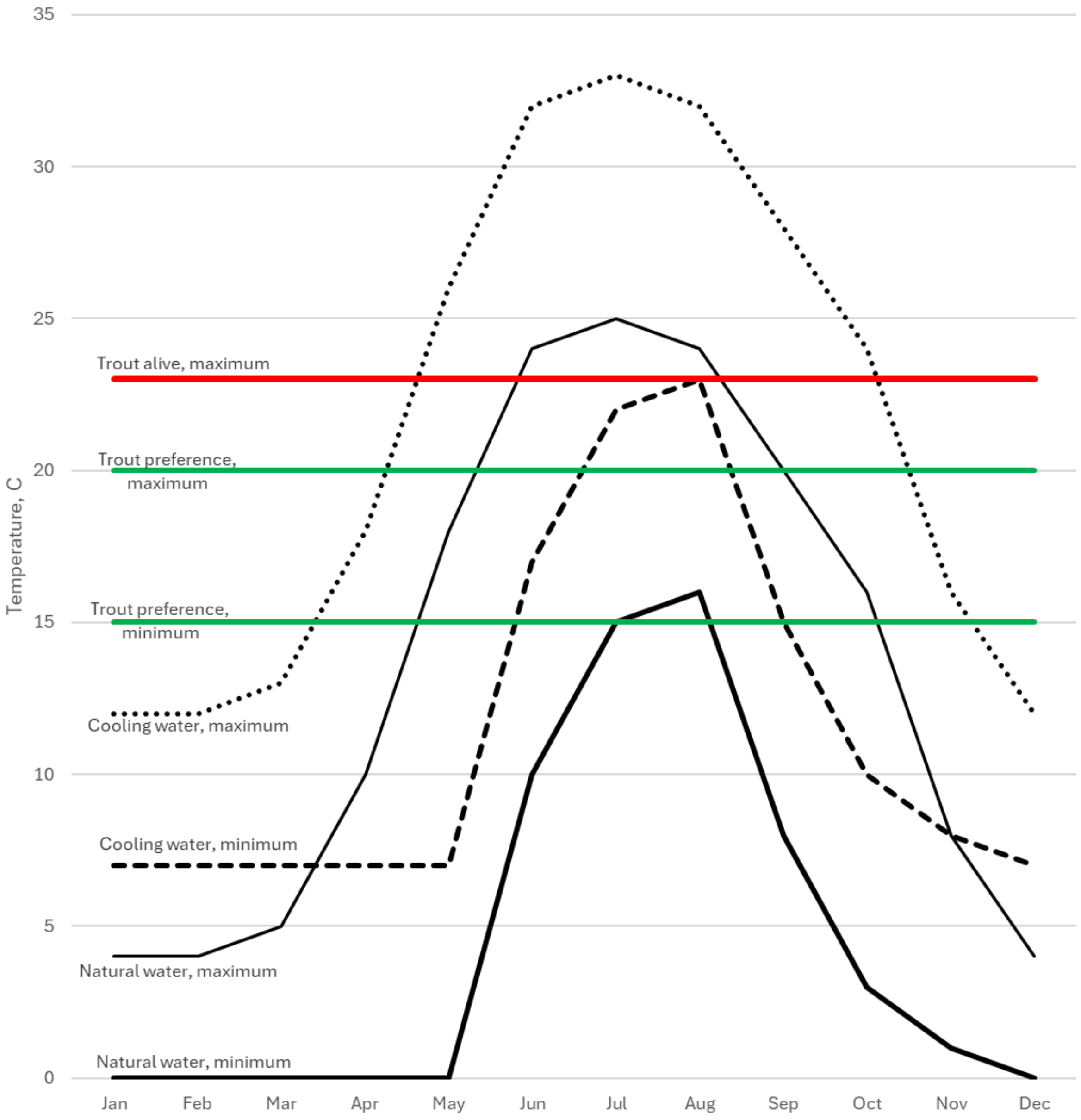

Figure 19. Temperature of water and RAS requirements, an example.

Temperature fit for RAS

During wintertime, from December to March, cooling water temperature in the above given preconditions is sufficient for trout survival but below optimum. Although pumps, lamps and other devices may provide some excess heat to the system, the optimal growth likely requires additionally water heating. Such heating, however, is energy intensive. Producing 500 t/yr fish to heat 1700 m3/hr water from 10 to 15 degrees, ca 10 MW of power in needed.

During spring and autumn time (April, May, October, November), depending on the conditions, either cooling water or natural water will likely provide quite optimal growth. The system should adaptively switch from cooling water to natural water. Such natural water should probably be taken from Mustajõgi river which supplies sufficient flow even during low water period (Enefit Energiatootmine AS, 2019).

During summertime, while extreme weather, even natural water, exceeding 24 degrees, may appear lethally hot for trout. For comparison, a sturgeon farm was held in these cooling water until 2020. Although sturgeon tolerates warmer temperatures than trout, the fish massively died in summers of 2003 and 2010 (Enefit Energiatootmine AS, 2019). Water temperature rose to ca 30 degrees in these days. Hence, during such hot periods, cooling is required to maintain and optimise the aquaculture. Producing 500 t/yr fish, to cool 1700 m3/hr water from 25 to 20 degrees, ca 2,5 MW of power in needed.

Conclusion. Heated cooling water from energy complex is a valuable resource for RAS but insufficient. Such cooling water is useful during most of the year. However, to achieve optimal temperature, all the following three more facilities are necessary: (1) unheated cool natural water, for instance from Mustajõgi river for survival, (2) additional water heating during winter time for optimal growth, and (3) water cooling during hot summers for survival.

Chemical description and pollution concern

Cooling waters

Cooling water of the energy complex is not polluted with any chemicals (Eesti Energia, 2007). Neither will be the oil factory cooling water polluted (Enefit Energiatootmine AS, 2019).

RAS wastewater

Nutrients. Fish faeces are rich in nutrients which work as pollutants in surface waters. A trout farm produces most of the nitrogen in dissolved form while phosphorus in particles (Table 3, Bregnballe, 2022). If water runoff from RAS is 3400 m3/h, the average added concentrations in unpurified wastewater will be 1,66 mg/l of N and 0,2 mg/l of P. For comparison, the average content of total N in Narva River between 2014 and 2019 was 0,58 mg/l while total P was 0,026 mg/l. If Narva River serves as the water source, RAS may thus multiply N content 3 times and P content 8 times.

Table 3. Waste products of a trout farm, with 1000 t/yr fish production (from Bregnballe, 2002).

	N, kg/yr	**N, mg/l**	**P, kg/ye**	**P, mg/l**
In particles	6593	0,22	4066	0,14
Dissolved	42 857	1,44	1978	0,07
Total	**49 451**	**1,66**	**6044**	**0,2**

Antibiotics. For bacterial infections, such as *furunculosis, vibriosis* or BKD, the use of antibiotics is the only way to cure the fish (Bregnballe, 2022). In some cases, fish can become infected with parasites living inside the fish, the way to remove these is also with antibiotics. The residues of these antibiotics in water may theoretically harm biological wastewater treatment. Also, there is a concern if such water is suitable for greenhouse irrigation. Bregnballe (2022) has found that such effects are low. However, he recommends careful monitoring of water quality parameters and proper system adjustments.

Greenhouse nutrient needs

Fertiliser amount. Greenhouses may annually consume, in case of very intensive management, up to 300 kg/ha N and 60 kg/ha P. If the operational area of the greenhouses is 276,5 ha, they will consume up to 83 t N and 17 t P. RAS in our example can supply more than half of the nitrogen and over a third of the phosphorus demand. However, the flows from the fish farm – 49 t N and 6 t P – may, depending on the management decisions, serve as sufficient to cover 100% of the N and P need of the greenhouses.

While fish excrete faeces annually in a quite stabile rate, greenhouse plants and soils may perform significant seasonal dynamics. In such case, a technical solution might be needed to store a significant extent of the nutrients.

Fertiliser content in water. In a conventional greenhouse system, as discussed above, the greenhouses in our model scale need only 7% of the RAS water while 100% of the RAS nutrients. Water Over flushing of the plant substrate should be avoided. Compared to RAS wastewater, conventional greenhouses receive nutrients in much more concentrated form. For instance, in soilless rockwool system, a recommended concentration is 210 mg/l N and 39 mg/l P (Kläring, 2001). Quite similarly, in the standard recipe of Hoagland solution for hydroponic system, there is 210 mg/l N and 31 mg/l P. Hence, the original RAS wastewater should be concentrated ca 100 times, i.e. 99% of water should be removed. This is possible for P but infeasible for N.

Today, recommended N content in aquaponic is low and depends on both plant and fish species it is combines. It is normally approximately 5 (1 – 10) mg total N/l for tomato (Hu et al, 2015; Wongkiew et al., 2017).

Greenhouse purification effect

A hydroponic greenhouse normally removes ca 40% of the irrigated N and 75% of P from irrigation water (Grewal et al., 2011). Hence, ca 60% of N and 25% of P will be drained off. In some systems, water is reused. However, greenhouse wastewater has very high nutrient content which needs treatment for discharge or reuse. Compared to RAS wastewater, greenhouse wastewater has much higher nutrient content, hence, more suitable and efficient for treatment and reuse.

Purification

Extraction of nutrients from RAS wastewater

Normally, fish farms successfully manage to remove P to sludge with high efficiency. However, removal of N remains challenging. Fish faeces contain very little N. Instead, fish excrete N mostly via gills in dissolved form. For instance, in case with just a settlement pond as the only treatment facility, 500 t of trout production generates 20 t of annual N discharge. Removal of N from fish farm wastewater is normally facilitated through denitrification. As the product volatilizes in the form of molecular nitrogen to atmosphere, it cannot be used in greenhouses. Hence, transfer of N from RAS to greenhouses remains challenging.

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