EXECUTIVE SUMMARY

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Assessment and roadmap for the emissions reductions of machinery traffic at Vuosaari Harbour

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Report title

Assessment and roadmap for the emissions reductions of machinery traffic at Vuosaari Harbour

Client's name, contact person and contact information	**Client reference**
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Assessment and roadmap for the emissions reductions of machinery traffic at Vuosaari Harbour	

Summary

The purpose of this work was to produce an assessment and a roadmap for reducing the carbon dioxide emissions of Vuosaari Harbour by 60% by 2035, in comparison to the 2015 level.

This translated version is a summarised description of the assessment results and the roadmap.

During the work, key operators were interviewed: the Port of Helsinki Ltd, key harbour operators, machinery manufacturers and the Port of Gothenburg. During the work, a calculation model was developed to estimate the CO_2 emissions and total cost of ownership of the machinery. With the help of the calculation model, an estimate of the CO_2 emissions of different types of machinery was achieved. Based on the estimate, straddle carriers and terminal tractors account for over three quarters of all CO_2 emissions. Furthermore, the estimate shows that significant total savings could be achieved through use of electric battery-powered straddle carriers when compared to those that use fuel oil. If the objective of reducing CO_2 emissions by 2035 were implemented solely through use of renewable fuel oil, this would cost about one million euros per year, assuming that fuel consumption is at the same level in 2035 as in 2019.

A pivotal action proposed for achieving the emissions objectives is starting a pilot project. The main objective of the pilot project would be lowering the operators' threshold for moving to fully electric machinery and adopting renewable fuel oil, and, this way, them learning to use new technologies and developing operating models for these technologies. During the project, the operators would pilot a few electric battery-power machines, such as straddle carriers and terminal tractors, and demonstrate the use of renewable fuel oil in machinery of various ages. The Port of Helsinki Ltd would be in charge of coordinating the project. The Port would also be responsible for acquiring the machinery and charging systems selected for the pilot. The machinery acquired would be rented to the operators on 1-year or 2-year contracts through a separate tendering process. The quick charging and depot charging systems would travel with the machinery during the pilot. Other key incentives suggested for achieving the objective included partial or full compensation for the extra costs of renewable fuel, either directly or through the port charges. For fully electric machinery, a discount on the port charges is proposed, based on the proportion of tonnes transported on fully electric machinery out of total tonnes carried by the operator.

This assessment and roadmap were commissioned by the HNRY – Carbon Neutral and Resource-wise Industrial Areas project of 6Aika Six City Strategy, which is funded by the Helsinki-Uusimaa Regional Council with funding from the European Regional Development Fund (ERDF).

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Foreword

This assessment and roadmap were commissioned by the HNRY – Carbon Neutral and Resource-wise Industrial Areas project of 6Aika Six City Strategy, which is funded by the Helsinki-Uusimaa Regional Council with funding from the European Regional Development Fund (ERDF). The purpose of this work is to produce an assessment and a roadmap for reducing the carbon dioxide emissions of Vuosaari Harbour by 60% by 2035, in comparison to the 2015 level. During the commission, key operators at Vuosaari Harbour, as well as the Port of Gothenburg and machinery manufacturers, were interviewed. Within the commission, a calculation model was prepared for calculating the carbon dioxide emissions and total cost of ownership of the machinery. The calculation model will be published as a part of the results.

Espoo 1 March 2021

Authors

Vuosaari Harbour as an operating environment

- **It is estimated that cargo traffic in Vuosaari Harbour will grow substantially by 2030 because of the sea route reforms.**
    - Volumes brought on by the increase in cargo traffic must be taken into consideration in the port operations' development.
    - A final model has not yet been decided on, and no options have been excluded, either.
        - Distribution of shifts, automation, and moving to RTG cranes in the long run are all options.
- Considering the circumstances, the environment of Vuosaari Harbour has excellent conditions for using alternative driving power.
    - The electric infrastructure has been carefully designed at the construction stage, thanks to which there is extensive readiness for building charging stations and the capacity for electric supply is excellent.
        - Vuosaari Harbour has connections available for 10 MW charging, and with some extensions, the connections can be increased up to 17 MW. Additionally, the current maximum power of shore-side electricity transferred to ships, 2 MW, can be tripled when necessary.
    - An LNG fuelling station is available outside the Harbour. It is also likely that fuelling could be arranged in the harbour area.
- **Operators seem open to using new driving power, on the condition that the efficiency and cost structure of machinery operations remain the same.**
    - Operators seem to be well aware of the market situation, and alternative types of driving power have also been charted previously.
- **Customers' ability to influence environmental matters is low at the moment, which is why reforms of the port operations should pay attention to the impact of the costs and the profitability of the operations.**
- Types of machinery based on an electric powertrain and similar to those being used at Vuosaari Harbour are available, but their investment costs are higher than those of machinery using fuel powertrains, in addition to which machinery using fully electric powertrains also requires investments in the charging infrastructure.
- **For the operations of container ships, moving to portal cranes can be considered as they are easier to electrify.**
- **Reference case from the Port of Gothenburg: The operators in the Port of Gothenburg moved to renewable fuels independently during 2020. After renewable fuels, the next step is electrifying the machinery.**
    - The Port has ambitious goals. Operators need to accept a licence agreement tied to the environmental objectives to be able to operate in the area.
    - The Port's strategy is to continue operating using renewable fuel until the market for electric machinery has developed sufficiently. It is estimated that the transition period will be ongoing until 2030.
    - The Port of Gothenburg promotes more sustainable machinery operations together with its operators, and an environmental committee has been formed for this purpose. The committee meets every quarter.

Overall situation and development

EU regulation

- The European Union is committed to reducing greenhouse gas emissions by 40% by 2030. The Green Deal may make the objectives more ambitious (potentially -55%).
- The non-emissions-trading sector's (including traffic, for example) binding burden sharing (39% for Finland based on the current decisions) heavily steers the emissions reduction measures.
- The CO_2 emission limits for cars, vans and lorries are being made stricter in two stages, 2025 and 2030.
    - This, along with the directive on clean vehicles, also accelerate electrification.
- **The current EU regulations on machinery engines concern pollutant emissions, and not energy efficiency or CO_2 emissions, for the time being.**

National regulation

- **In Finland, the proportion drivable diesel machinery accounts for of all CO_2 emissions amounts to 4%**, while the proportion all traffic accounts for is 21%.
- **Finland has decided to reduce emissions from traffic by 50% by 2030** (the 2016 energy and climate strategy based on the burden sharing).
- The national climate and energy strategy is about to be updated, and it will involve preparations for the EU-level objectives becoming more ambitious.
- **In Finland, the use of biofuels has been considered a valuable measure in reducing the CO_2 emissions of traffic.**
    - In road traffic, the obligation to distribute biofuels has been in effect since 2008, and the target level for 2029 (and onwards) is 30%.
    - A distribution obligation has also been implemented for renewable fuel oil, which is 3% for 2021 and will be raised to 10% for 2030.
- The distribution obligation ensures a minimum level of biofuels at national level, but with the current structure, it does not allow for individual parties to truly increase the use of biofuels through their own actions.
- In the 'roadmap for fossil-free transport' report prepared on 27 October 2020 by a working group appointed by the Ministry of Transport and Communications, the following is stated regarding harbours, in particular: **"The programme's aim is for all new machinery and equipment to be compatible with alternative driving power from 2030 onwards."** In addition to this, the goal is to truly enable the use of shore-side electricity at large harbours.
- At the moment, the additional price of renewable diesel in road traffic use is about 25 cents per litre. For fuel oil, the difference will be about 25–40 cents per litre. Without the support of the distribution obligation, the price of renewable fuel oil would be about €1.70/l.

Ways of reducing the carbon dioxide emissions of machinery

- CO_2 emissions depend on performance, specific energy consumption and the carbon intensity of the energy used.
- **The emissions reduction measures can be divided into three main categories:**
    1. **measures applicable to the existing equipment**
    2. **measures that require new machinery**
    3. **measures that require both new machinery and new infrastructure.**
- The general rule of thumb is that the actual CO_2 emissions are determined by the energy used (fossil/renewable), not so much by the technology used in the machinery.
- **In balance calculations, the end use of biofuels, electricity and hydrogen is considered to be zero-emission.**
- **Renewable paraffinic diesel fuel (HVO) does not require changes to machinery or infrastructure, and it can be adopted 'overnight', in practice.**
- **However, the distribution obligation mechanism being used in Finland signifies that locally increased consumption of biofuel reduces the consumption elsewhere.**
- Overall, new machinery is more energy-efficient than old machinery thanks to better engines, steering systems and actuators.
- The development of engines alone cannot achieve significant emissions reductions; instead, the piece of machinery needs to be seen as an entity.
- **In a suitable application area, new hybrid machinery can reach as much as 50% savings in fuel consumption and an equal reduction in CO_2 emissions.**
- **Moving to actual electric machinery allows for significant improvements in energy efficiency and reductions in CO_2 emissions.**
- Regardless of the calculation method (zero-emission features in balance calculations; actual emissions using average Finnish electricity), using electricity reduces emissions, and since electricity is not governed by any obligations, moving to electricity truly increases the use of low-carbon energy.
- **However, moving to electricity requires that charging infrastructure be built, and electrification may not be suitable for all types of machinery due to technical, financial or operational limitations.**
- Reducing electricity consumption is possible through machinery that uses hybrid or battery electricity or shore-side electricity, but also, to some extent, by replacing old machinery with new machinery using combustion engines.
- By making the use of machinery more efficient (optimised performance, avoiding idling, future automation, etc.), both fuel consumption and emissions can be reduced. Renewable fuels are immediately available, while electrification requires new machinery and infrastructure. There are some types of electric machinery available, and lessons learned from city buses, for example, can be used for quick-charging. Fuel cell technology would also facilitate zero-emission operations and the reduction of energy consumption, but this technology has not yet reached commercial level in terms of harbour machinery.

Ways of reducing the carbon dioxide emissions of harbour machinery

- The CO_2 emissions of harbour machinery can be reduced by making the use of existing machinery more efficient (including minimised idling), developing operating methods, adopting renewable fuels (diesel and CBG/LBG), moving to hybrid or battery-powered electric machinery, adopting new types of machinery (such as portal cranes), and gradually increasing the level of automation.
- **Potential key incentives of the Port of Helsinki for achieving the CO_2 emissions targets and accelerating the transition to new low-carbon technologies include:**
    - **partial or full compensation for the price difference between renewable fuels and fossil fuels; alternatively, granting discounts on the harbour charge for cargo traffic based on the CO_2 emissions reductions achieved through the use renewable fuels**
    - **encouraging the use of electric machinery by offering a discount on the harbour charge based on the usage level of electric machinery, measured in the amount of goods moved with electric machinery in proportion to the operator's total amounts, for example**
    - **regarding new technology, such as electric battery-powered machinery, investing in the battery-powered versions of the key types of machinery and leasing them to operators to gain user experiences during the pilot project**
    - ensuring that necessary infrastructure is available for the use of machinery technology that reduces CO_2 emissions, such as the charging infrastructure for electric machinery or LBG/CNG fuelling stations.
- **During the transition phase towards market-based low-carbon operations, the coverage of costs from the CO_2 reductions could be surveyed to develop new service models (such as carbon-compensated services) for passenger and cargo traffic, under the Port of Helsinki's leadership.**
- **At the moment, the Port of Helsinki does not see setting direct CO_2 reduction requirements for operators as feasible due to the Port's competitive situation and long lease periods. This alternative however could be considered in terms of new leases.**
- According to the objective, the absolute amount of CO_2 emissions from machinery at Vuosaari Harbour should be about 2,100 tCO_2 in 2035. In 2019, the amount of CO_2 emissions was 7,467 tCO_2. This means that, for the target level of 2035, CO_2 emissions should be reduced by 5,329 tonnes, which equals a reduction of 71%.
- **Using the fuel consumption of 2019 and the estimated additional price of renewable fuel oil (+0.4 cents/l), a CO_2 emissions reduction of 60% would cost c. €900,000 annually if the target were reached using renewable diesel only.**
- **If the calculation model created for this report and the initial data from the interviews are used, straddle carriers and terminal tractors seem to be the most significant source of CO_2 emissions: straddle carriers account for 70% and terminal tractors for 20% of the emissions:**
    - As such, it is key for the achievement of the objectives that the use of low-carbon driving power is promoted for straddle carriers and terminal tractors, in particular.
    - Conversely, reach stackers and forklift trucks have little significance regarding the achievement of the CO_2 target.
- **The electrical grid of the Vuosaari Harbour area (17 MW) has sufficient capacity for the load caused by the charging of straddle carriers (33 pcs) and terminal tractors (56 pcs).**
- Investing in fully electric machinery consuming high amounts of energy (such as straddle carriers and reach stackers), which involve a high annual number of operating hours, seems to enable a lower total cost of ownership (TCO) than diesel. Hybrid technology could also allow for lower total cost of ownership compared to diesel.
- **As for the machinery for which electrification or hybrid technology is not cost-effective or operationally feasible, the use of biomethane should be considered, for example for terminal tractors, in addition to renewable fuel oil. However, the limitations of the distribution obligation on the reduction of local CO_2 emissions should be noted.**
- Due to the variance in the operator-specific operating models and volumes, it is not possible to provide all-encompassing recommendations regarding the best possible driving power. Instead, matters should be reviewed separately for each operator and type of machinery.

Roadmap for reducing the carbon dioxide emissions from machinery at Vuosaari Harbour

Introduction to the roadmap presented

In the preparation of the roadmap for reducing the emissions from machinery at Vuosaari Harbour, the roadmap model presented by Robert Phaal from the University of Cambridge was originally applied[1]. The model has been used in many of VTT's projects and further developed by VTT[2]. The roadmap template allows for factors on various scales that affect the target or vision reviewed to be taken into consideration at various hierarchical levels (granularity). In the case of the machinery traffic at Vuosaari Harbour, the levels were defined as the following:

1. global trends and legislation
2. development in Finland and the City of Helsinki
3. technology, customers and harbour operators
4. measures.

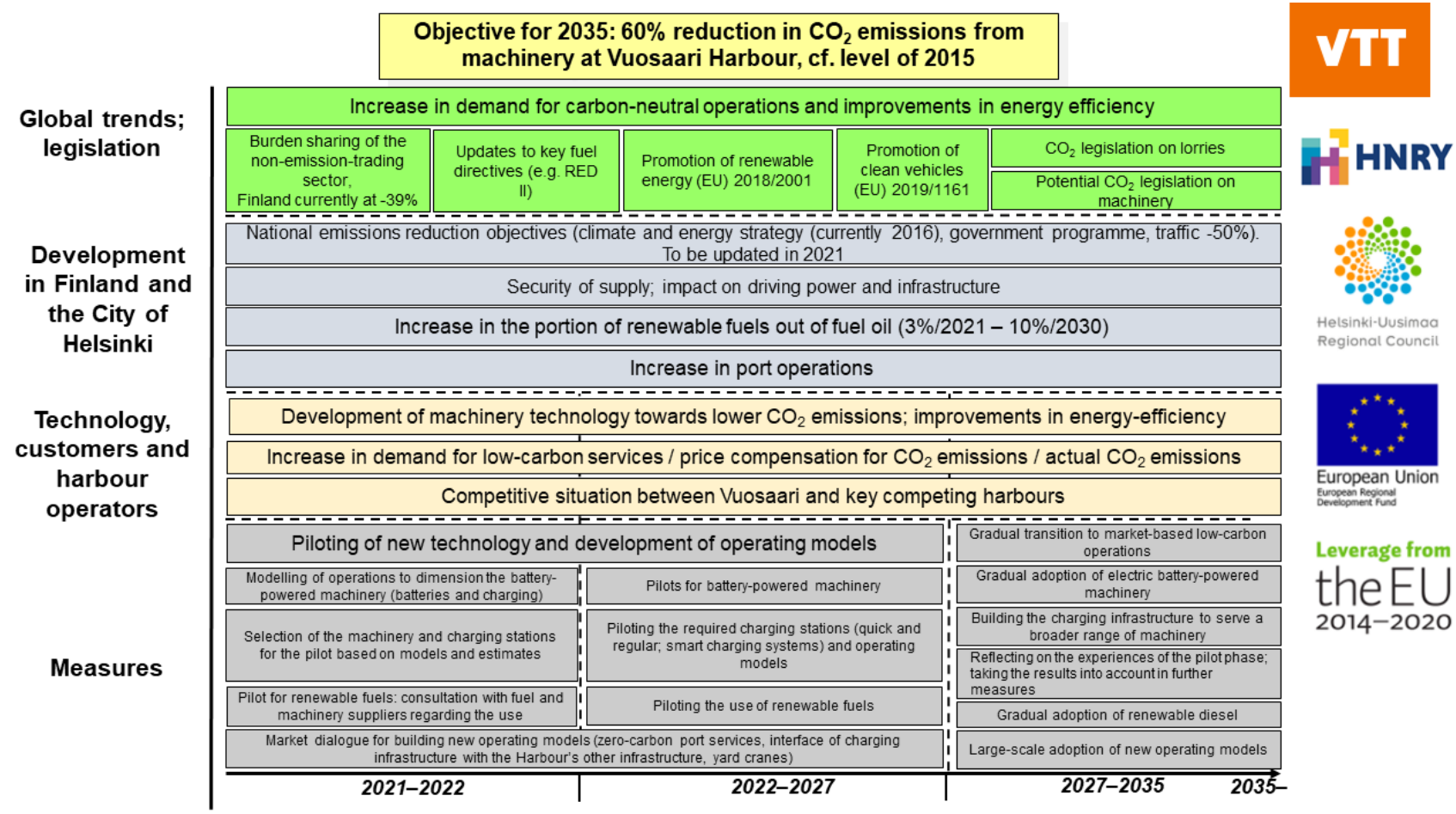
The timescale of the review was divided into three sections, from the present to the target year for the emissions reductions for machinery, 2035.

The roadmap template created was filled in by VTT experts using the combined effect of the calculated analyses presented above, stakeholder interviews, expert assessments and other matters presented in this report. The roadmap produced with this method was first reviewed and edited by VTT's internal working group. The engagement of various stakeholders and inclusion of their views, which are a typical part of roadmap processes, were implemented as a part of the programme at a virtual event held for the project on 17 February 2021. Representatives of the City of Helsinki, the Port of Helsinki and the harbour operators were invited to this event.

[1] Phaal, R. & Muller, G. (2009). An architectural framework for roadmapping: Towards visual strategy. Technological Forecasting & Social Change 76 (2009) 39–49.

[2] Ahlqvist, T. & Myllyoja J. (2011). Part II. Ch 3.: Roadmapping – Multilateral Support of the Strategic Work. In: M&A as a Strategic Option – From Opportunities to New Business Creation. Edited by Raukko, Räikkönen & Rantala. Technology Industries of Finland. Teknologiainfo Teknova Oy.

The roadmap with review periods included



Assessment of measures selected

The measures included in the roadmap presented above are divided into three time periods. The first period covers 2021–2022, the second covers 2022–2027, and the third covers 2027–2035. VTT suggests that the measures include detailed planning of the pilot programme during the first period. During the second period, the pilot programme would be implemented, and during the third period, operators would gradually move towards market-based operations, with the aim of a 60% reduction in CO_2 emissions by 2035 compared to 2015.

The main objective of the measures selected is to develop the operations and their environment so that the emissions reductions objective could be achieved on market terms. As such, the objective is to create a path towards market-based use of low-carbon fuel and energy.

For electric machinery, in particular, the supply and costs of purchase, as well as the technology itself, will very likely develop in a positive direction during this decade. One of the most significant driving forces is the legislation on heavy road vehicles, as a result of which electric powertrains will be increasingly available for lorries. Through this, electric powertrains and the development of their technology are very likely to spread to machinery, with a brief delay.

Measures selected and reasons for the selection

Electric machinery is still a brand new kind of technology, and it is not yet being used extensively. Because of this, users do not necessarily have much practical experience of operating such machinery and its effects on operations. This matter was also brought up in the interviews with the harbour operators. In addition to this, there is a need to acquire user experiences of the charging systems of electric machinery before large-scale investments are made in them. Based on the interviews, uncertainties regarding renewable fuels mainly involved their suitability for older machinery.

HSL's ePELI pilot project has been a significant influence on electric buses becoming more common in HSL's transport operations. Following this excellent example, a pilot project was also seen as an important tool for learning about the technology and new operating models at Vuosaari Harbour.

Planning initiative for the pilot project

Based on the above, VTT is proposing that a planning initiative be undertaken in 2021–2022 regarding the pilot project. During the planning initiative, the following actions would be taken:

- Modelling the operation of electric machinery to dimension the necessary battery capacity and charging systems.
- Through the modelling and calculations, information about the machinery and charging systems selected will be produced.
- Discussing and agreeing on the demonstration of operations with companies supplying renewable fuel oil.
- Extensive charting of the future prospects of renewable fuels, cf. technology and fuel options used in lorries, such as CNG/LNG and ethanol diesel ED95.
- Starting market dialogue to form new operating models (compensation for the costs of reducing the carbon footprint, charging infrastructure interfacing with other infrastructure in the Harbour, portal cranes).

At the end of the planning initiative, a clear plan of the machinery and charging infrastructure should be available. Section **Virhe. Viitteen lähdettä ei löytynyt.** features an example of the battery capacity and operating cycle required for a container straddle carrier. To be able to select the most suitable type of machinery (in terms of model, battery capacity, etc.) and know the requirements of the charging infrastructure, operating options to be tested during the pilot phase should be created based on the usage needs and modelling. The objectives should also include a plan for the piloting of renewable fuel oil in machinery of various ages and in various operating conditions. Furthermore, the charting should provide a more extensive view of which technologies using renewable fuels could be available for harbour machinery in the future. The point of reference is the technology used in lorries.

The Port of Helsinki Ltd would be responsible for procuring the electric machinery and charging stations selected for the pilot project proper. Leasing of electric machinery to operators could be implemented through tendering as described in section 4.2.1. Regarding the charging infrastructure in the pilot phase, moving the quick-charging stations to the operators' operating areas should be considered for the period when the operators are using electric machinery requiring quick-charging. Similarly, the lower-power charging stations should be located close to the operator whose turn it is during the pilot phase. In the pilot phase, the operators would not pay rent for the charging station, only the costs of the electric energy they have consumed.

To compensate for the carbon footprint of port operations, it should be analysed if a service model for passenger and cargo traffic could be brought to market to fund the CO_2 emissions reductions.

In the planning initiative, the Port of Helsinki Ltd as the initiative owner would have a central role. The operators at Vuosaari Harbour would also play a key role. For them, this would mean close collaboration in the planning and operational development of the pilot project proper, as well as participation in the discussions with machinery manufacturers and fuel suppliers. In addition to this, the operators would play a key role in the development of the service model for compensating for the costs of reducing the carbon footprint.

Pilot project proper

VTT is proposing a pilot project for 2022–2027. The Port of Helsinki would assume the main responsibility as the owner and leader of the project. The purpose of the project would be increasing knowledge and understanding of using new types of driving power and their impact on operations. The content would include the following actions, among others:

- piloting of electric and hybrid machinery by various operators
- piloting of quick and ordinary charging stations (practical experiences of the power requirements, type and location)
- testing and developing various operating models for electric machinery
- piloting the use of renewable fuels
- using existing machinery more efficiently
- piloting new operating models (such as a service compensating for the costs of reducing the carbon footprint).

At the end of the pilot project in 2027, the operators should have significant knowledge of operating electric machinery and using and dimensioning the charging infrastructure required, as well as its optimal placement. In practice, this means that the operators and the Port of Helsinki would have clear views on the charging infrastructure required and the usage model for it, as well as the requirements for the optimal operation of electric machinery in the harbour area. Based on this knowledge, the Port of Helsinki, together with the operators, could develop the quick-charging infrastructure and plan an operating model for the new charging stations to be invested in. In other words, will the Port of Helsinki invest in quick-charging stations itself, or would it be more feasible to purchase everything as a service from

the charging operator. In the first option, the Port of Helsinki would be an investor in the charging system and assume responsibility for its functionality. The Port of Helsinki would charge the operators a utilisation fee for the use of the charging station. For renewable HVO-based diesel fuels, obstacles to their use should be removed through demonstrations, i.e. the suitability and functionality of HVO-type diesel fuels for machinery of various ages should be verified. During the pilot phase, measures that make the operating of the existing machinery more efficient should also be considered. The financial and technical feasibility of biomethane should be studied in select machinery, such as terminal tractors.

Depending on market developments, adopting a service model for compensating for the costs of carbon footprint reductions should be considered during the pilot project.

After the pilot project, operators should be more aware of the ways through which the reduction of carbon dioxide emissions by 60% would be possible by 2035.

If market-driven demand does not arise for low-carbon harbour services and/or the total cost of ownership of electric machinery does not allow operators to invest in it despite the incentives described in section 4.2.1 Virhe. Viitteen lähdettä ei löytynyt.**, the Port of Helsinki should start compensating for the extra costs of renewable fuels as necessary as a fallback plan. However, it should be noted that, as described in section 0, local use of renewable diesel does not truly enable the reduction of carbon dioxide emissions at a national level due to current legislation (the distribution obligation).** In addition to this, the Port of Helsinki should also consider the opportunities for adding requirements following the emissions objectives in new leases in the harbour area.

Overall, the main objective of the pilot phase should be the development of Vuosaari Harbour's operations towards a 60% reduction in carbon dioxide emissions from 2015, through market-based measures.

Summary and conclusions

The purpose of this assessment and work on the roadmap was to present concrete and timed measures through which the carbon dioxide emissions from the machinery at Vuosaari Harbour could be reduced by 60% by 2035 from the 2015 level. As a part of the work, key operators were interviewed, including companies operating at Vuosaari Harbour, the Port of Helsinki, the Port of Gothenburg and machinery manufacturers.

According to the objective, the absolute amount of CO_2 emissions from machinery at Vuosaari Harbour should be about 2,100 tCO_2 in 2035. In 2019, the amount of CO_2 emissions was 7,467 tCO_2. This means that, for the target level of 2035, CO_2 emissions should be reduced by 5,329 tonnes, which equals a reduction of 71%. **If this emissions reduction was achieved through the use of renewable fuel oil, the cost of achieving the target would be about one million euros annually, calculated using the fuel consumption level of 2019 and the estimated extra costs of renewable fuel oil (+0.4 cents per litre).**

A calculation model was built for estimating the emissions reduction and cost impact of different types of machinery. Based on the estimates and information gained from the interviews, an estimate of the CO_2 emissions of various machinery types was calculated. **The results of the calculations clearly suggest that the most substantial measures for reducing carbon dioxide emissions should be directed at straddle carriers and terminal tractors. The CO_2 emissions of these two types of machinery are clearly the highest: straddle carriers account for 70% and terminal tractors account for 20% of the total emissions.** Conversely, the significance of reach stackers and forklift trucks in terms of achieving the CO_2 targets is small, as they only account for 10% of the emissions. The sections described above are estimates based on the data used (estimates and information received), and they should only be seen as approximate.

To achieve the reduction target for carbon dioxide emissions, starting a pilot project for new technology is seen as a key measure. The pilot project proper would be preceded by a pre-planning initiative of one or two years. During this initiative, the most suitable machinery and its qualities (equipment size, battery size, etc.), as well as the quick-charging and depot charging stations, to be selected would be defined based on modelling and estimates built on the operators' data.

Through the pilot project proper, the operators and the Port of Helsinki would gain a clear understanding of what it means to operate electric battery-powered machinery and what requirements this sets for the operations and charging infrastructure. At the same time, they would gain knowledge of how the quick-charging stations should be located, and how many operators one station can serve. During the pilot project proper, the use of renewable fuel would also be piloted. This means that renewable fuel oil, at the minimum, would be used in a demonstrative manner in machinery of all ages for several years.

At the end of the pilot project, the operators would have a much better understanding of what it means to operate electric battery-powered machinery and how the operating models should be potentially developed for the operation of battery-powered machinery to be as extensively feasible as possible. In addition to this, the Port of Helsinki would have a much better understanding of the quick-charging infrastructure required, the placement of the charging stations and the most functional operating model, i.e. how the operating costs charged to the operators would be allocated fairly.

Based on the preliminary calculations, the most feasible option seems to be investing in fully electric machinery consuming high amounts of energy (such as straddle carriers and reach stackers), which see a high annual number of operating hours. This would also enable a lower total cost of ownership (TCO) than that of diesel. Hybrid technology could also allow for lower total cost of ownership compared to diesel. However, more detailed estimates must be

calculated for each operator, based on the operator's own data on consumption and operating hours.

Primarily, replacing straddle carriers and terminal tractors with electric battery-powered ones should be considered if otherwise feasible in terms of operating the machinery. As for the machinery for which electrification or hybrid technology is not a cost-effective option or current types of operations would not be anywhere near possible, the use of biomethane should be considered, in addition to renewable fuel oil. These types of machinery include terminal tractors. **However, it is important to note that, in terms of renewable fuel oil, local reduction of CO_2 emissions is possible, but due to the current distribution obligation, individual operators using renewable fuels will not reduce CO_2 emissions at national level.**

Potential key incentives of the Port of Helsinki for achieving the CO_2 emissions targets and accelerating the transition to new low-carbon technologies include:

- **Compensating for the costs of reducing carbon dioxide emissions**
  Partial or full compensation for the price difference between renewable fuels and fossil fuels. Alternatively, granting discounts on the harbour charge for cargo traffic based on the CO_2 emissions reductions achieved through the use of renewable fuels.
- **Encouraging the use of electric machinery by offering a discount on the harbour charge based on the usage level of electric machinery, measured in the amount of goods moved with electric machinery in proportion to the operator's total amounts.**
- **Pilot projects for electric battery-powered machinery**
  Regarding new technology, such as electric battery-powered machinery, investing in the battery-powered versions of the key types of machinery and leasing it to operators to gain user experiences during the pilot project. This reduces the operators' risk in terms of the greater investment costs of electric battery-powered machinery compared to conventional machinery. The specific types and amount of machinery must be defined together with the operators so that the pilots meet their needs as well as possible.
- **Updating the energy infrastructure**
  Ensuring that necessary infrastructure is available for the use of machinery technology that reduces CO_2 emissions, such as the charging infrastructure for electric machinery or LNG/CNG fuelling stations. **Based on the preliminary calculations, operating 33 electric battery-powered straddle carriers at the same time would require nine 600-kW quick-charging stations. In this case, the power required would be 5.4 MW. If, in addition to this, all terminal tractors were electric battery-powered and charged through depot charging systems of various power levels, the power required would be 7.7 MW. The total peak power required of the electric grid would be about 13 MW.** It is possible to expand the power of the harbour area's electric grid from 10 MW up to 17 MW. As such, the capacity of the electric grid seems to be sufficient for operating battery-powered straddle carriers and terminal tractors.

Based on current information, the investment cost for the estimated nine 600-kW quick-charging stations would be to the order of 3–5 million euros.

In the transition towards market-based low-carbon operations, it would be expedient to aim to cover the costs of the carbon dioxide reductions through new service models (such as carbon-compensated services), in addition to the actual incentives. The service models could be applied to passenger and cargo traffic, from which funds would be collected for the progress towards the harbour's carbon dioxide reduction targets.

In the section on the Harbour's key operators and stakeholders, it was mentioned that the cargo traffic at Vuosaari Harbour is predicted to grow significantly by 2030 because of the changes to sea routes and the decisions made by the City of Helsinki and the Port of Helsinki Ltd. The pressure from increasing cargo traffic will be discharged in various ways, which have not yet been decided. **There are plenty of options, and none of them should be excluded at this time. These options include the distribution of shifts and automation, and in the long run, potentially moving to RTG cranes.** Considering the circumstances, the environment of Vuosaari Harbour has excellent conditions for using alternative driving powers. The electric infrastructure has been carefully designed at the construction stage, thanks to which there is extensive readiness for building charging stations and the capacity for electric supply is excellent. For the potential use of biomethane, there is a LNG station outside the Harbour, which makes it likely that fuelling could be arranged in the harbour area. The Vuosaari power plant will also have a natural gas line connected to the national network.

Operators seem open to using new forms of driving power, on the condition that the efficiency, ease of operation and cost structure of machinery operations remain the same. Based on feedback from the harbour operators, the influence of customers' demands and goals on environmental matters is low at the moment, which is why reforms of the port operations should pay attention to the impact of the costs and the profitability of the operations. However, it was still recognised that awareness of environmental factors and values is rapidly increasing all the time. This will most likely impact the operations in the next few years.

As a point of comparison for the situation of Vuosaari Harbour, an interview with the Port of Gothenburg was also carried out. There, the operators moved to renewable fuels independently during 2020. After renewable fuels, the next step is electrifying the machinery directly. A rapid transition to renewable fuels has been supported by the favourable competition situation between the Port operators, notable industry in the Port's vicinity, and the environmental awareness and desire to use low-carbon logistics services of the companies that use port services. The Port of Gothenburg promotes more sustainable machinery operations together with its operators, and an environmental committee has been formed for this purpose. The committee meets every quarter.

In connection with the interviews, it was brought up that the competition situation between the operators at Vuosaari Harbour is challenging, and that the operators have signed long-term leases with the Port of Helsinki. Due to this, it is difficult to implement the actual requirements for achieving the objective, and they may not be sustainable in terms of the port operations. Because of this situation, incentives set by the Port of Helsinki would be a sustainable and better solution for achieving the objective.

A CO_2 emissions reduction objective has been defined for lorries and cars for two stages: from 2025 onwards, and from 2030 onwards. However, the current EU regulations on machinery engines only concern ordinary air pollutants, and not energy efficiency or CO_2 emissions, for the time being. The CO_2 emissions reduction objective for lorries heavily directs the sector towards low-emission and zero-emission solutions. **It is very likely that the development of lorry technology will also advance the transition of machinery towards low-emission or zero-emission technology.**

At the moment, the type approval system for vehicles and engines defines carbon dioxide emissions using a tailpipe principle, or a Tank-to-Wheel principle. The most objective way of viewing various solutions would be taking the entire fuel chain (Well-to-Wheel) into account, in which case the low-carbon qualities of renewable fuels would be considered when calculating the emissions.

In the road traffic in Finland, the obligation to distribute biofuels has been in effect since 2008, and the target level for 2029 is 30%. Similarly, the distribution obligation for light fuel oil used

in machinery entered into force in 2020. **The obligation increases the portion of bioliquid of fuel oil in Finland gradually up to 10% by 2030.**

The CO_2 emissions of machinery depend on performance, specific energy consumption and the carbon intensity of the energy used. Thus, the emissions reduction measures can be divided into three main categories:

- measures applicable to the existing equipment
- measures that require new machinery
- measures that require both new machinery and new infrastructure.

Renewable paraffinic diesel fuel (HVO) does not require changes to machinery or infrastructure, and it can be adopted 'overnight', in practice. New powertrains are energy-efficient. In a suitable application, new hybrid machinery can fuel consumption savings of as much as 50% and an equal reduction in CO_2 emissions. Moving to actual electric machinery allows for significant improvements in energy efficiency and reductions in CO_2 emissions. However, moving to electricity requires that charging infrastructure be built, and electrification may not be suitable for all types of machinery due to technical or financial limitations. The operating capacity of machinery is an essential part of the whole, which is why the new technology must offer equal or nearly equal performance to conventional machinery so that the use of new technology can be increased significantly.