NO_x abatement and CO_2 reduction in asphalt pavement at the Port of Skagen

Carried out for The Port of Skagen by GEMBA Seafood Consulting A/S as a part of EU Interreg financed DUAL-Ports project

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PORT OF SKAGEN
MARITIME BUSINESS HUB OF SCANDINAVIA

GEMBA SEAFOOD CONSULTING

Indhold

1. Executive summary

This project is done as a part of the EU Interreg financed DUAL Ports project under the Interreg North Sea Region program. The analysis of the NO_x abatement and CO_2 reductions in relation to establishing a new road at the Port of Skagen has proven that small and medium sized ports also have opportunities to gain environmental achievements by choosing the most environmentally friendly pavement solution.

Planning, organization and taking environmental matters into force in port areas:

- In 2020, the Port of Skagen decided to find the most environmentally friendly pavement for a new road area as a part of the port's focus on sustainable development of the port.
- This solution was an asphalt pavement that has a reduced CO_2 footprint and at the same time is able to absorb NOx from the atmosphere.
- The new pavement shows that it is possible for an organization to make sustainable choices, also in construction of rather traditional infrastructure.

Carbon dioxide saving from the pavement solution:

- The Port of Skagen has chosen the most environmentally friendly pavement solution at a road with a surface area of 7,300 m^2.
- The road was paved with NCC Green Asphalt that saves approx. 25% CO_2 in the production phase through different energy reducing measures.
- The total outcome is a reduction of approx. 8.5 tonnes CO_2 compared to a traditional asphalt.

Extra environmental dimension in the pavement solution:

- As an additional component, a wear layer of NO_xOFF granulates were constructed on the new road area.
- The granulates is a stone mixture with titanium oxide that can extract NOx from the air and later is washed off as nitrate.
- The NOxOFF granulates secures an abatement between 100 and 146 kg NOx pr. year.

Central outcomes of the pavement:

- The investment in CO_2 reduced asphalt illustrates that by being alert and seeking opportunities for lowering emissions, it is possible even without high additional costs.
- The costs of the photocatalytic solution - NO_xOFF - may be paid back in terms of saved health expenditures over a period of 9 – 13 years and thereby well within the lifetime of the pavement.
- This payback time is seen as a saving of social costs while the actual investment is taken by the Port of Skagen that hence take a social responsibility from the NO_x emission that takes place at their areas.

2. Introduction and objectives

A seaport like the Port of Skagen is a generator of great value through its fish landing, seafood production, import/export activities and general service to the industry.

To ensure that such activities are handled efficiently, the port need to ensure appropriate and high-quality infrastructure that meet the demands from the port users.

On top of securing efficient infrastructure there is an increased focus on being sustainable in all its efforts. There are several ways to ensure and improve the sustainability of port operations and port infrastructure and it is the Port of Skagen’s position, that sustainability concerns should be included in all new infrastructure investments.

Investment in onshore power system for ships in the port is good examples of such investments or modern intelligent LED-light systems replacing old light systems in port areas.

One issues that hitherto has only received very little attention in studies and implementation of sustainable infrastructure – both in port areas and in other infrastructures is in relation to large, paved areas.

There are great CO_2 reductions to be achieved through a careful selection of the most environmentally friendly asphalt types, and new technology exists that can absorb and remove nitroxides (NO_x) and volatile organic compounds (VOCs) from the air.

With a desire to include sustainability concerns in all new investments and knowledge about technologies and materials that can achieve this, the Port of Skagen has in the DUAL-Ports project had a focus on selecting an innovative pavement solution that has a low CO_2 impact in relation to the life cycle of the asphalt and is able to absorb NO_x and VOCs from the ambient air.

3. The Port of Skagen

The Port of Skagen is the largest fishery port in Denmark and has a yearly landing of approx. 300,000 tonnes fish and is home port to the largest pelagic companies in Denmark. On top of the large fishing industry there is a great and developing activity from the cruise industry and various maritime service industry. All these activities require a large area and the Port of Skagen's land area stretches over 645,000 square meters and 6.1 km of quay. The Port of Skagen is a busy port with a great demand for transportation from lorries that bring fish and seafood products from the port, transport fish to the port for further production, internal transportation between the companies. Additional there is a heavy traffic in the port of fishing vessels that are landing their catch, bunker barges that serves the vessels off-Skaw with fuel, and cruise vessels that enters the port with tourists.

In total this transport at the pavement and vessels in the port emits both Carbon dioxide (CO_2), nitrate oxide (NO_x) and Volatile Organic Compounds (VOC's) and the Port of Skagen wish to mitigate this emission by different means necessary.

Transportation at the roads and quay areas are substantial and upgrading and renewal of these areas is therefore an ongoing process and therefore possess some potential to improve the environmental footprint of the port, if met by requirements of being more sustainable than 'ordinary' and traditional pavement solutions.

Within the frames of the DUAL-Ports project, the Ports of Skagen wish to test:

- How much CO_2 can they save by choosing the most environmentally friendly asphalt?
- How much NO_x and VOC's are the new laid asphalt able to absorb based on the innovative technology?
- What is the cost/benefit ratio – *i.e.,* how much CO_2 is saved, NO_x and VOC's absorbed by this approach?
- Can the solutions be recommended to other ports and infrastructure projects?

In this project, the test area consists of a new pavement solution at a 700m road that stretches parallel with the entire port and creates the boarder to the rest of the Skagen town. In total the paved area makes up 7,300m^2.

While CO_2 is a global problem that leads to climate change, NO_x and VOCs are local pollutants that has a great impact on the local air quality in the town of Skagen.

4. Pavement solutions in port areas

The pavement approach is, in the case of Port of Skagen, divided into two sections.

1. The actual pavement with asphalt with a smaller OC_2 footprint compared to traditional asphalt.
2. An innovative approach with asphalt able to capture SO_x and NO_x from the ambient air.

In the following, the two approaches will be presented and discussed in relation to the case at the Port of Skagen.

4.1 Environmentally optimized asphalt

When asphalt is laid out there is a heavy use of energy (i.e., emission of CO_2) in the process. This means that if there are opportunities to decrease the CO_2 emission while laying the asphalt and at the same time to secure that the pavement will be of a great quality that lasts, there are some CO_2 gains to be won.

Asphalt is a 100% natural material and there is a great effort in securing full recycling of the stone material. This means that when roads are being renewed with a new layer of asphalt, the old and damaged layer is scratch of and reused in the asphalt industry.

When producing and laying asphalt, the stone material and bitumen (the black material that lies between the stones) a large amount of energy is used to heat the material. Recent developments in the production and laying out of asphalt has succeeded in bringing down the temperature with 20-30 degrees Celsius and thereby decreasing the energy, without decreasing the quality of the asphalt.

When asphalt can be reused and the production and laying temperature can be reduced, studies suggest that the CO_2 emission may be reduced by up to 30% compared to traditional process.

Asphalt production with a lower GHG emission has been developed in several asphalt companies based on both similar and different technologies and processes. One example comes from NCC.

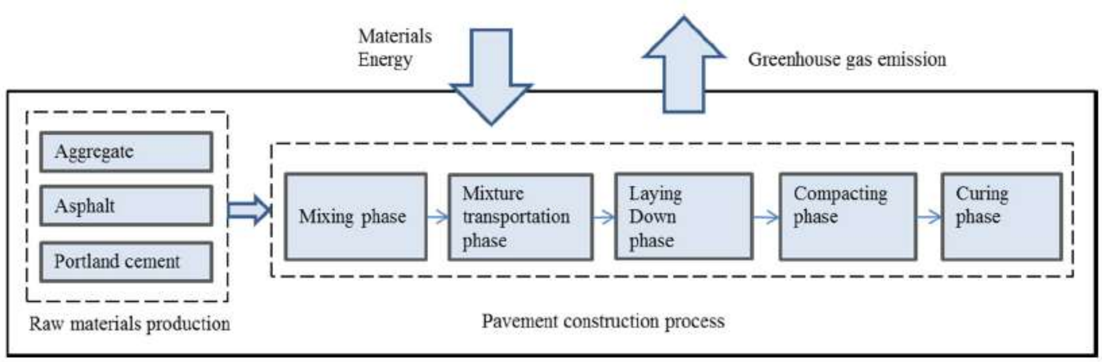
NCC is one of the leading construction companies in the Nordic region and has with several branches around Denmark. NCC has many and large contracts on road pavement solutions, large turnkey building contract etc. To ensure a green choice for its customers, NCC has developed an environmentally friendly asphalt solution called NCC Green Asphalt® that is an asphalt type that includes all possible means to reduce CO_2 emission. The asphalt emits approx. 25% less CO2 compared to traditional asphalt types. The asphalt is produced:

- With a low temperature foam that enables production at a much lower temperature
- All energy that is used in the production is based on green energy such as biogas.
- All resources are stored under a roof or covered meaning that e.g., stone materials are dry and do not need excessive heating to dry in the production.
- It is based on recycled material to the extent possible, i.e., surplus concrete, asphalt etc.

As described in figure 1 the emission of CO_2 from pavement of roads takes place both in production, laying phase, compacting, and curing. While the main share of CO_2 emission comes from the production i.e., heating and mixing the materials at the plant, there are also emissions related to the transportations to where the asphalt will be used and to laying the asphalt that requires a great amount of heating and the compacting phase.

A generic overview of asphalt production and energy consumption from a typical pavement solution from production of asphalt to, transporting, laying, compacting, and curing can be seen in figure 1 below.

Figure 1: flow chart of materials and energy in the process of production to final pavement.



Source: Sha et al. (2016)

There are several variations to the energy consumption depending on the thickness of the layer of asphalt, used technology, distance the material and asphalt need to be transported to and from the production facilities etc.

The energy intensity and consequent CO_2 emission from these processes has been assessed in several countries around the world but it is important to use as local assumptions as possible because the different parameters are highly dependent on local situations such as use of stone material, degree of recycling, usage of energy for heating the materials (biogas, coal, natural gas. etc.) usage and import of bitumen etc.

In a study done by the Danish asphalt company Colas an assessment indicates the energy consumption and CO_2 equivalents from the different processes in the asphalt process.

The study takes point of departure in 'traditional' asphalt production that is produced at 180 degrees Celsius and under a set of assumptions that replicates the traditional Danish asphalt production and laying of asphalt.

The NCC Green Asphalt is produced at 25-30 degrees lower heat than traditional asphalt and leads to a decrease of approx. 30% in the production phase. The energy consumption for laying, transportation, aggregates, and binders is assessed to be the same.

Table 1 indicates the different energy levels and CO_2 equivalents of the various processes in asphalt pavement.

Table 1: Energy consumption and emission based on traditional asphalt pavement		
	Energy consumption (kwh per m2)	CO_2-equivalent emission (kg/m2)
Laying of the asphalt	1.0	0.3
Transportation from factory	0.4	0.1
Production	6.0	1.3
Transport to factory	1.5	0.4
Aggregates	1.1	0.2
Binder (e.g., bitumen)	6.7	2.0
Total	16.7	4.3
Source: Korsgaard (2010)		

As it can be seen from table 1, the largest energy consumption is in relation to the asphalt production and for heating and keeping bitumen hot. Table 1 illustrates that based on the assumptions laid out in the study, a total of 16.7 kWh/m2 is used for asphalt pavement which equals a CO_2e of 4.3 kg/m2.

While the numbers in table 1 is developed and identified by Korsgaard (2010), other asphalt producers calculate slightly different numbers. According to NCC their Green Asphalt has a reduction of 25% and a total of 8,524 kg CO_2e compared to traditional asphalt. This share is saved during the production of asphalt including the bitumen, while the transportation and other process are not included.

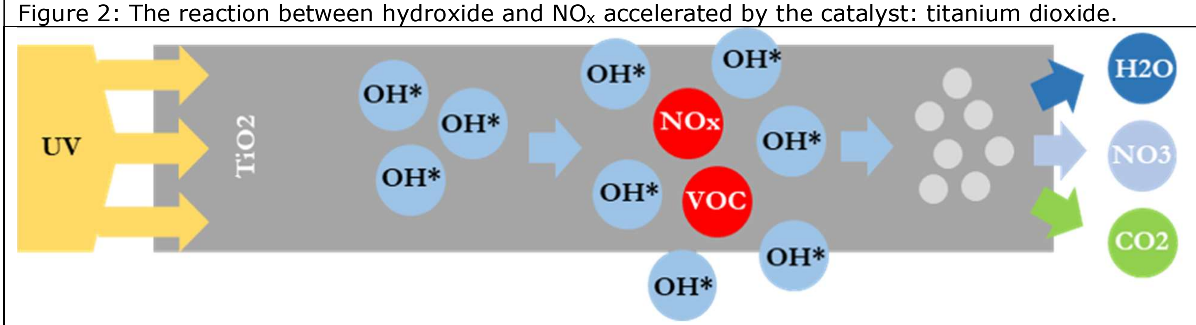
4.2 Photocatalytic asphalt

Photocatalysis is a process that through sunlight enables a catalyst to accelerate a reaction.

In the case of photocatalytic impact on pavement, such as asphalt, the reactant is titanium dioxide (TiO_2) that creates a reaction between sunlight, hydroxide, and NO_x to create water, CO_2, and nitrate, that all are harmless compounds in the scale that they are produced in, in this reaction. Apart from the reduction of NO_x to harmless compounds the technology also degrades Volatile Organic compounds (VOC's) in a similar process.

Figure 2 below illustrates this reaction.

Figure 2: The reaction between hydroxide and NO_x accelerated by the catalyst: titanium dioxide.



Source: Photocat

Stones used in the top layer may be treated with titanium dioxide and hence create a surface that receives sunlight on the top of the pavement. After laying the asphalt, this stone compound treated with titanium dioxide creates an absorbent that can remove NO_x from the ambient environment.

The degree to which NO_x is removed from the air is based on several factors of which the most important are:

1. The actual presence of NO_x in the air
2. Inflow of sun at the pavement
3. Humidity in the air just above the pavement

If the road is in an environment with very little NO_x pollution, e.g., in a rural area with very little traffic, and very little sun light, perhaps forested areas and a high humidity, there is a very little abatement of NO_x. Also, there are different technologies to coating and integrate TiO_2 into the materials that leads to different results. Different studies suggest different degrees of NO_x removal from the air, see e.g., (Atzl 2018).

Under Danish circumstances the company Photocat has made several tests and assess that a photocatalytic coated asphalt will abate approx. 13.8 g/m2 pavement at a specific test site in Roskilde and up to 24.4 g/m2 pavement under optimal conditions (Jensen and Pedersen 2021).

There are a few companies that sells TiO_2 treated stone material such as concrete tiles, granulate for asphalt pavement, or roofing felt that can extract NO_x from the ambient air. Common for the companies are that the TiO_2 is either mixed in the stone material or the stone material is coated with TiO_2 afterwards. One company that has had success with TiO_2 materials is Photocat.

PHOTOCAT

Photocat is a Danish green tech company founded in 2009. Photocat produce photocatalytic technology for various building materials and among others stone material used in pavement.
Photocat has several different products that are based on the catalytical benefits of TiO_2 and one of these are stone material that are used as the top layer in in asphalt pavements and hence gets exhibited for sunlight every day all year round. The product from Photocat is called NO_xOFF and is mainly highlighted for its ability to extract NO_x from the air, but also include several other beneficial air-quality improving properties.

The NOxOff treated stones are able to extract approx. 20g of NOx per square meter pavement.

One of the materials from Photocat is a concrete granulate containing TiO_2 that can be applied as the final wear layer on an asphalt road. The granulate will continue to extract NOx from the ambient air for many years. Some companies selling TiO_2 concrete stones promise 25 years warranty and argues that the effect of the stones will remain high though out is lifetime.

The picture in figure 3 shows a wheelbarrow with TiO_2 NOxOFF granulate from Photocat that is ready to be compacted into a layer of asphalt.

Figure 3: TiO_2 concrete stone material ready to be compacted into a asphalt pavement.

4.3 NOx and health costs

Nitrogen dioxide is a gas that at high concentrations causes inflammation of the human airways. Nitrogen is released during fuel combustion and forms in combination with oxygen create Nitric oxide (NO) and nitrogen dioxide (NO_2). NO is not considered to be hazardous to health at typical ambient concentrations, but nitrogen dioxide can be. Together NO and NOx are referred to as NOx.

NOx gasses react to form smog and acid rain and is one of the central parts in formation of fine particulate matter (PM).

The pollution and potential health issues can be assessed in monetary terms as externality costs. This means that a price has been put on the cost of polluting with e.g., on kg. of NOx translated into health costs that local health sector may face from dealing with consequences of NOx.

The externality costs may vary depending on the population density and whether the pollution is taking place in areas with high buildings where the pollution, when moved with the wind, moves to other populated areas and areas with lower buildings and less densely populated.

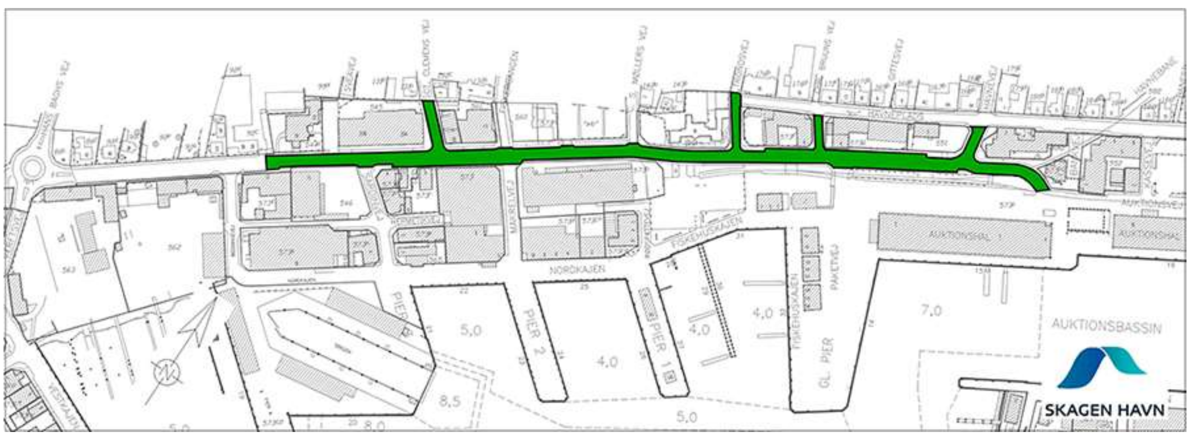
In Denmark, the externality cost has been assessed by the Danish Centre for Environment and Energy (DCE) with a 'base level' of 34€ per kg NOx emitted (Jensen and Pedersen (2019). On top of these 34€ an additional local cost between 10 to 47€ depending on the local build environment and population density. For the Port of Skagen with rather little high buildings and low population density, the additional local costs are assessed to 10€, meaning that the total costs would be 44€ per kg. NOx that is extracted from the air.

5. Case results – Port of Skagen

In the case of the Port of Skagen there has been used a combination of the green asphalt solution from NCC and NOxOFF granulate for the top layer. A combination of these two technologies gives an optimal solution to bringing down the CO_2 and NOx in asphalt paved areas an infrastructure that is necessary for the port to remain efficient.

In total an area of 7,300 m2 was paved with asphalt. The road stretch is depicted in figure 4.

Figure 4: The 7,300 m2 road that is paved with NCC Green Asphalt and covered with NOxOFF granulate.



Benefits of green asphalt solution

The road that was paved at the Port of Skagen was an existing road that needed a new asphalt layer which means that the underlying carrying structure was remained. A total of approx. 600 tonnes asphalt was spread over the 7,300 m3 at a thickness of 4 cm. In the case of Skagen they have used the asphalt type SMA 8 that was produced by NCC using the concept of NCC Green Asphalt.

Based on the calculations from NCC the Green Asphalt has saved 8,524 kg CO_2 compared to traditional asphalt. This means that according to NCC's calculations a traditional asphalt production for 7,300 m^2 emits four times 8,524 kg CO_2, i.e., 34.096 kg CO_2 while the NCC Green Asphalt emits 25.572 kg CO_2e.

The saving of 8,524 kg CO2 includes the asphalt production including binder, *i.e.,* bitumen and means that a total of 8.5 tonnes of CO_2e has been saved from the pavement solution that has been selected by the Port of Skagen.

Figure 5 show the laying of asphalt at the Port of Skagen.

Figure 5: Roadwork at the Port of Skagen September 2020.

Costs of green asphalt solution

The asphalt including laying, costs approx. 12€ pr m^2 and hence has a total cost of approx. 86,000€.

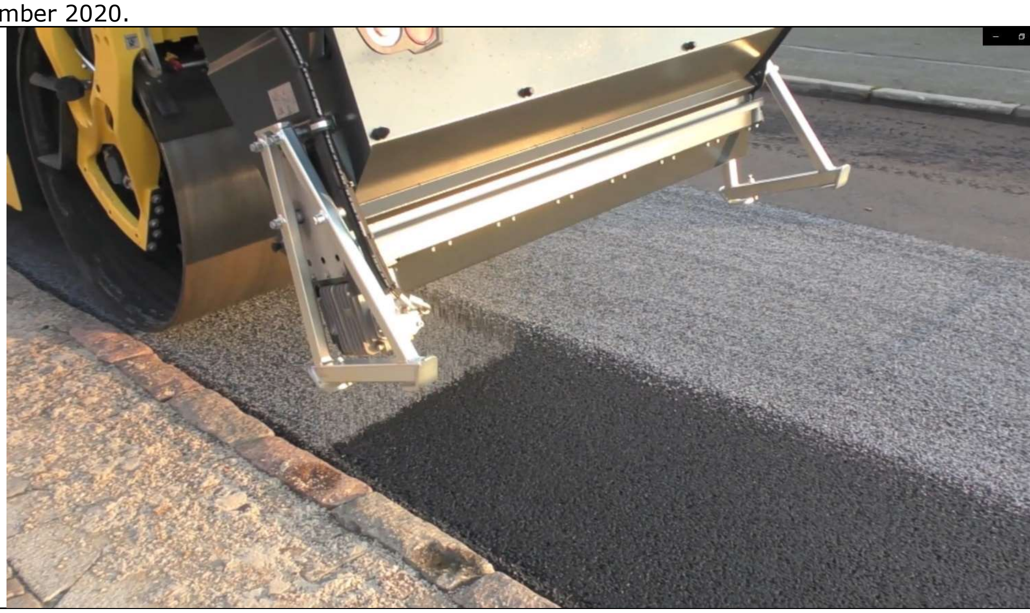
A traditional asphalt pavement of 7,300m^2 would cost approx. 10% less i.e., 77,400€ and the green asphalt solution has therefore had an extra cost of 8,600€.

With the saving of 8.5 tonnes of CO_2 in the asphalt pavement process it means that 1 kg of CO_2 savings have a cost of approx. 1 €.

Benefits from photocatalytic asphalt solution

The 7.300m^2 road at the Port of Skagen has been topped with a layer of photocatalytic NOxOFF granulate that is able to absorb and remove NOx and VOCs from the air. The picture in figure 6 shows the laying out of the granulate and a road roller that compress the stones into the pavement at the Port of Skagen, September 2020.

Figure 6: Road roller that spread and compress the granulate into the pavement. Port of Skagen, September 2020.



The supplier of the TiO_2 granulates, the company Photocat, has in a similar study measured the abatement to 13.8 grams NOx removed pr. m^2 (Photocat 2018). However, the granulate used in the Port of Skagen is based on a different technology and may absorb as much as 20 grams NOx pr. m2. This means that the 7,300 m2 pavement removes between 100 and 146 kg NOx each year.

As it was established above, the health costs associated with pollution of one kg NOx in the case of the Port of Skagen is assessed to 44€ per kg NOx extracted from the air. By removing between 100 and 146 kg NOx pr. year, the theoretically health costs may be reduced by between 4,400€ - 6,424€ per year.

Costs from photocatalytic asphalt solution

The NOxOFF granulate including laying out of the stone costs approx. 8.25€ per m2 and hence has a total cost of approx. 60.000€

The NOxOFF granulate has a one-time cost but will continue to generate a cost reduction in national and local health spending for many years. Based on the reduced health costs to the municipality a payback time may be assessed.

The costs of the photocatalytic solution may be paid back in terms of saved health expenditures over a period of 9 – 13 years and thereby well within the lifetime of the pavement.

This payback time is seen as a saving of social costs while the actual investment is taken by the Port of Skagen that hence take a social responsibility from the NOx emission that takes place at their areas.

6. Perspectives and conclusions

The Surface Pilot at the Port of Skagen has illustrated that there are good opportunities and reasons to utilize novel approaches to greening of paved areas at small and medium sized ports.

The Port of Skagen has in this way both illustrated a way of bringing down CO_2 emissions from asphalt pavement and absorption of NOx and VOC's from the air reducing health cost in the surrounding society.

The investment in especially CO_2 reduced asphalt illustrates that by being alert and seeking opportunities for lowering emissions, it is possible even without high additional costs as part of the normal modernization in a port.

There are several low-hanging fruits that may contribute in the movement towards a greener infrastructure in port areas, the investment done by the Port of Skagen illustrates that there are opportunities in many infrastructure investments that need to be investigated in all aspects when being constructed. This insight documented by this project can pave the way for many other small and medium sized ports in the future.

7. Bibliography

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