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Electric shipping in the city of Amsterdam

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Introduction

In November 2013, a policy paper for clean shipping has been adopted by the City Council of Amsterdam. This policy prescribes that every commercial ship needs to be zero-emission in 2020 or 2025, depending on its size, on the canals of Amsterdam.
In the context of the EFRO funded project “Operatie Boeggolf” Waternet, TNO and the Technical University of Delft worked together to test and evaluate various innovative powertrains for both the Waternet and the canal cruise fleet. Due to the adoption of the policy paper on clean shipping, the focus of the project shifted mainly towards battery electric and diesel-electric shipping. Additionally, TNO assessed the business cases for various types of battery electric canal cruise ships. This abstract describes an evaluated fully electric canal boat. The operational profile of the ship is examined. Also a comparison of the ship against a diesel fuelled ship was made with regard to the global warming and pollutant emissions. Finally, the business cases for various types of battery-electric canal cruise ships are shown.

Determination of an operational profile

For the development of a suitable electric powertrain configuration and sufficient energy storage capacity of a ship it is essential to determine the operational profile. An operational profile means that the required energy, on a timeline, for different types of daily operation and auxiliary functions are determined. The canal boat already has an electric powertrain, however, for the required propulsion energy the type of powertrain is not relevant.
The operational profile of the canal boat is divided into three operating areas:
1. sailing inside city canals
2. sailing outside city canals
3. manoeuvring, cornering, accelerating and slowing down

Table 1 and Figure 1 show the operational profile, the energy usage from on-board consumption is not taken into account. For every sailing hour 15.6 kWh is needed on average for propulsion. Measurements of the Technical University of Delft and Damen show approximately similar results [TU Delft]. Interesting to see is that manoeuvring, cornering etc. occurs quite often, this operation is responsible for 56% of the energy usage. Also the peaks are the results of manoeuvring, cornering, etc. The right side of Figure 1 shows that almost 30% of the time the ship propulsion needs to be between 10 and 12.5 kW, most likely this is sailing inside the canals at a constant speed of approximately 7 km/h.

However, also on-board equipment uses a lot of energy. Especially, the heating requires relatively much energy in the winter. It is estimated that on average 3 kWh per hour is needed for heating with a heat pump and 0.6 kWh for other on-board power consumption. For an electric boat the battery capacity needs to be larger due to driveline efficiency, battery discharge efficiency, converter efficiency and DoD (Depth of Discharge).

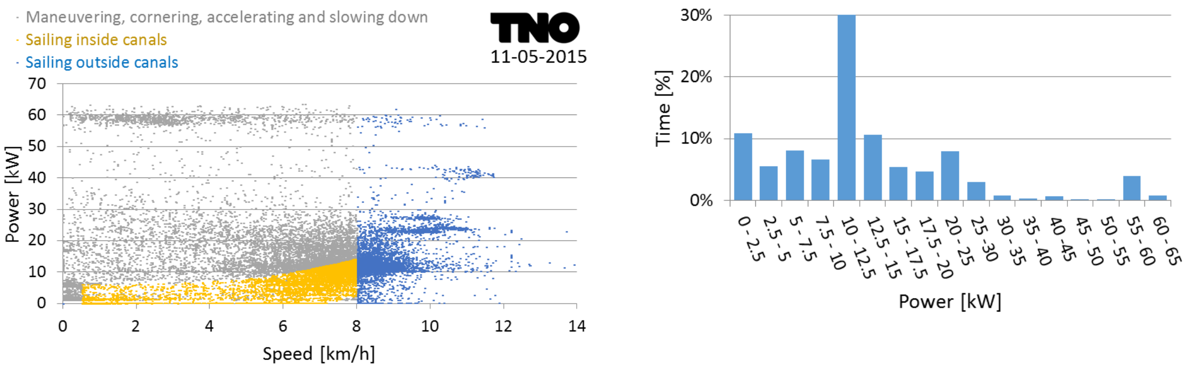

Figure 1: Operational profile of the canal boat

Table 1: Operational profile of the canal boat

	Time share [%]	Avg. Power [kW]	Energy share [%]	Average energy per hour during operation [kWh]
Manoeuvring, cornering, accelerating and slowing down	43%	20.4	56%	8.7
Sailing inside canals	32%	7.8	16%	2.5
Sailing outside canals	25%	17.1	28%	4.4
Total	100%		100%	15.6

Diesel versus alternative drivelines; a comparison of emissions

In this paragraph a comparison between CCRII diesel engines and alternative fuels and/or drivelines is made with regard to greenhouse gases (GHG) and pollutant emissions. The comparison is made for the canal boat and is based on the determined operational profile. The measured ship already has an electric powertrain, hence the cases are hypothetical.

A diesel engine which complies with CCRII is used as baseline because CCRII is the current required emission limit for new engines. Below, the alternatives for CCRII diesel engines were determined. It should be noted, however, that since the policy paper for clean shipping in Amsterdam was published, conversion to electric or hybrid are currently the only options when sailing inside the Amsterdam city canals is the main operation.

- Diesel retrofit which result in comparable NOx and PM emissions as the Stage IIIb emission limits (the city of Amsterdam stimulates ship owners to comply with this standard).
- Natural gas engines which complies with the Stage IIIb emission limits
- Battery electric with a stage V generator as electric range extender, in this scenario the range extender provides on average 10% of the required energy.
- Fully battery electric with both the Dutch electricity mix emission factors as well as with 'green' renewable electricity. Renewable energy is obtained from wind, solar and hydro power.

Emission factors are used to calculate the NOx and PM emissions, these emission factors are combined with the operational profiles of the ships to calculate the emissions.

The CO2 emissions consist of well-to-tank (WTT) and tank-to-propeller (TTP). WTT CO_2 emissions are calculated based on

Table 2 [TNO 2015].

Table 2: WTT CO_2 emission factors

		Diesel	Gas	Dutch electricity mix	Green electricity mix
CO2 WTT	[g/MJ]	15	12.9	124.2	10

Figure 2 show the relative emissions for the canal boat. The stage IIIb level engines, both diesel and natural gas, show a NOx reduction of roughly 50% to 60% and a PM reduction of approximately 90%. The WTP (Well-To-Propeller) CO2 emissions of the gas engine are more or less comparable with the diesel engine. With the hybrid configuration, pollutant emissions are reduced by more than 80%. The conversion to an electric drivetrain is very suitable for the canal boat because the operational profile contains a lot of low-powered sailing. For the canal boat, the CO_2 emissions can be reduced by 55% with a hybrid configuration. With a fully battery electric driveline the CO2 emissions can even be reduced by 60% or more, depending on the type of electricity used (fossil or renewable).

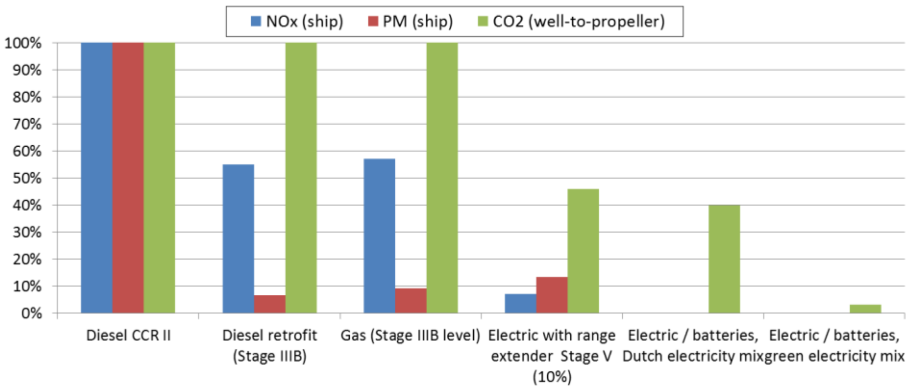

Figure 2: Relative emissions for diesel alternatives

Business case for electrification of a canal boat

The previous chapter showed that electrification of the driveline has a positive effect on emissions. However, for the canal boat entrepreneurs it also should have a reasonable business case. In this paragraph the business case for an electric canal boat is shown for various configurations for both the current situation and for the situation in the future.

For the business case an operational profile is very important to determine the size of the battery package, which has a large effect on the business case. The operational profile showed that the measured canal boat needs 19.2 kWh per hour. Due to driveline efficiency, battery discharge efficiency (depends on battery type), converter efficiencies etc. more battery capacity is needed than the required energy. It also is important that the battery package is not discharged too deep, otherwise the lifetime is influenced in a negative way, often DoD (Depth of Discharge) of 80% is maintained.

Table 3 shows the needed battery capacities, this is without the 80% DoD. For the business case options which charge only overnight it is chosen that battery package needs to be sufficient for approximately 10 operating hours. Furthermore, the trip length is determined at 80 minutes. In between trips, 15 minutes are available for charging, this means that option 3 needs fast charging, for this reason the more expensive lithium-titanate batteries are chosen. A safety margin of 10% of the capacity is maintained for option 3. The difference between option 1 and 4 is the battery type, Li-ion batteries have a higher discharge efficiency.

Table 3: Required battery capacity per option

Option	Size battery package
1. Lithium-ion battery package with overnight charging	211 kWh
2. Lithium-ion battery package with overnight charging + charging after each trip	119 kWh
3. Lithium-titanate battery packages with fast charging after each trip	35 kWh
4. Lead-acid battery package with overnight charging	243 kWh

Figure 3 show the results of the business case calculations, with 2014 as the year were the investment was done. A fully electric driveline has considerably higher investment costs than a conventional driveline for this segment, mainly due to the costs of the batteries. Energy usage costs are, however, lower. Currently, the option with lead-acid batteries shows with 12 years the shortest return on investment, due to the relatively low battery price. The Li-ion option which charge overnight and after each trip show currently a positive business case after 14 years due to relatively small battery package. The other options show a return on investment of more than 16 years.

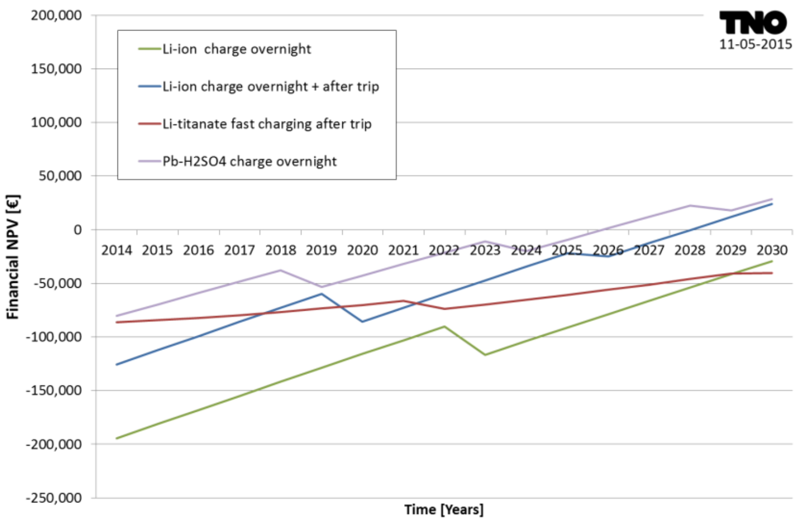

Figure 3: Financial Business Cases, relative to a new diesel engine, investment in 2014

Li-ion options becoming more interesting with an investment in the near future. With an expected price reduction of Li-ion batteries, the pay back time is expected to go down to about 6 years for new installations in 2024. For lead-acid batteries it is expected that the battery prices are more or less stable, hence the return on investments stays approximately 12 years.

Conclusions

The operational profile of canal boat is characterized by a very low average power. Due to this there is a large saving potential of energy consumption, CO2 and air pollutant emissions, compared to a conventional combustion engine operation.

With a fully electric driveline for the canal cruise boat, the CO2 emissions can even be reduced by 60% to 95% depending on the type of electricity used (Dutch production mix or fully renewable electricity).

A fully electric driveline has considerably higher investment costs than a conventional driveline for this segment, mainly due to the costs of the batteries. Energy usage costs are however lower. Payback periods were calculated as a function of battery price and size (which is also dependent on charging frequency). With current battery prices, the payback times are expected to be about 12 years or longer. With an expected price reduction of Li-ion batteries, the pay back time is expected to go down to about 6 years for new installations in 2024.

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