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1.1.1.1.1 Annex A: Public summary

NAVAIS Project Task 4.2 involved selecting a set of suitable abatement options to apply to the designs of workboats and ferries performed in WP2 and WP3. As a lot of these abatement options influence or even interfere with each other, it was decided that it is much more relevant to design an optimisation tool, which can help select relevant abatement options from a long list. In this way several advantages have been achieved:

- The results are not limited to NAVAIS ships, but can be used for any available vessel type
- The long list can be updated and extended during the NAVAIS project and thereafter
- The designers can experiment with requirements and profiles to better discuss the impact of a choice with the client.

A tool was created for these 3 objectives to allow for easy adaptation. First the capabilities of the selection tool were defined. The emissions considered in the selection tool are various exhaust emissions (NOx, SOx, PM, VOC and CO2) and relevant discharges to sea are also taken into account. Both upstream (WTT) exhaust emissions for producing fuels and operational (TTP) exhaust emissions on board are considered. The emissions regulations and limits depend on the vessel characteristics, operational profile/area and energy systems. Energy systems such as diesel engines can be selected as the benchmark. The selection tool must found an optimal combination suitable for new-build vessel from a dataset with different fuel concepts and technical abatement options. So operational measures and retrofit abatement options are not considered. The feasible abatement options must be compatible with different ship design aspects such as the vessel type and energy systems. The emission regulations may require abatement options that may have conflicting effects, such abatement options may reduce specific emissions but can increase the fuel consumption and/or increase other types of emissions. Therefore in addition to the strict emission regulations, use can be made of the external costs of emissions to facilitate the trade-off between additional emission reductions.
A suitable concept of the selection tool including a selection procedure was then defined. This is further advanced into a coupled selection tool including datasets, a user-interface and a decision making technique. The design space of possible combinations can be significant, due to the many abatement options in the dataset. This design space is reduced by imposing the emission criteria and compatibility criteria, but the space is still substantial and therefore various decision-making techniques were explored. In this thesis, the internal (operational + investment) costs and emissions are analysed for one year, so investment costs of abatement options that may have unequal lifetime are evaluated on annual basis. Furthermore, a basic cost-valuation approach is used to provide a neutral view and to reduce influential parameters such as a discount factor and the analysis period. The evaluation of the environmental (WTT+TTP) performance is based on the operational profile and on the predefined emission factors in the dataset. The reduction effects of abatement options are assumed to be constant (design condition) and their reduction effects (relative to the reference fuels) are evaluated over the quantified benchmark emissions.
The identified decision factors were integrated into a optimisation problem.

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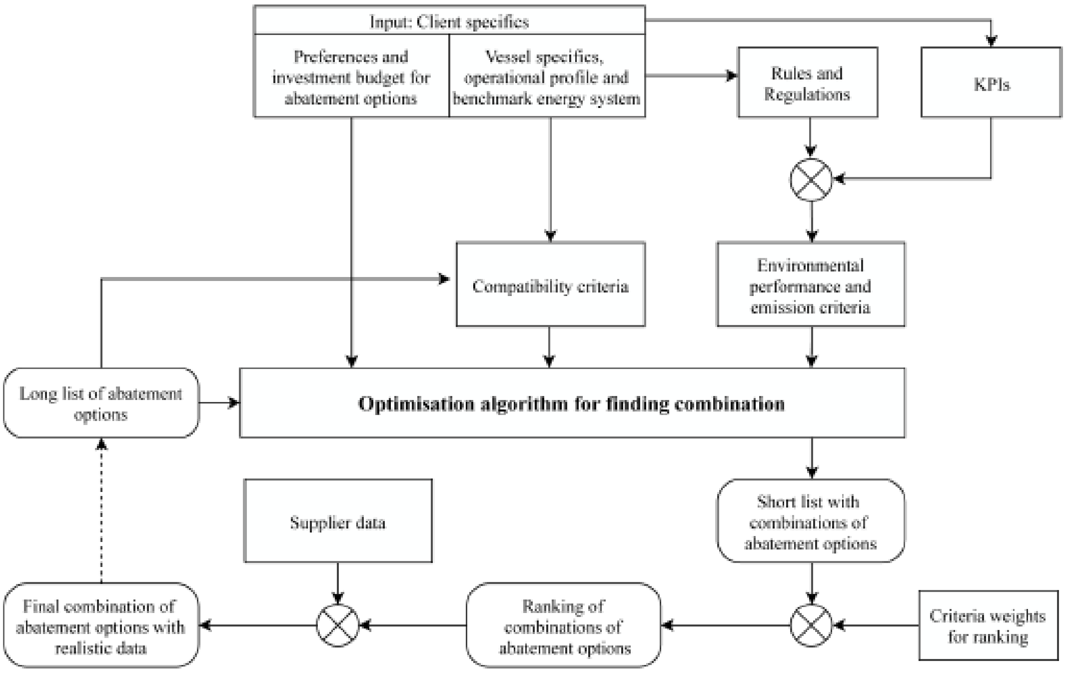
Therefore different formulations of objectives and constraints were explored and the formulation suitable for this thesis has been defined. This optimisation problem is mathematically formulated as multi-objective optimisation problem by two objectives. A common desire of the decision makers is to minimise the internal costs and the second preference is to reduce emissions in order to meet the emission regulations. In this thesis, the second preference is formulated more seriously by the objective of minimising external costs, as this can stimulate decisions to reduce the overall environmental impact. The mathematical formulated optimisation problem includes various constraints such as the emission constraints and compatibility constraints. The total effect of multiple abatement options on the benchmark emission factor or fuel consumption can be calculated through recurrence relations. The type of optimisation algorithm depends on the characteristics of the optimisation problem, therefore the optimisation problem is further classified. So the optimisation problem can be classified as a constrained combinatorial optimisation problem, where the decision variable is a binary. Furthermore, the problem is non-linear, because of the recurrence relations used and the product of the total emission-reduction effect with the total energy efficiency effect which are both dependent on the decision variable.



After the optimisation problem was mathematically formulated, various optimisation algorithms were explored that can solve the optimisation problem in reasonable computation time and can be integrated in the selection tool. A suitable optimisation solver is the NGPM [59] solver which is an implementation of the Non-dominated Sorting Genetic Algorithm II (NSGA-II) [80]. The multi-objective formulated optimisation problem can be solved by the (NSGA) genetic algorithm, it also gives the opportunity to simultaneously search through different regions of the solution space and at the same time find a diverse set of optimal solutions. The constraints of the defined optimisation problem are translated into constraint violations, which are used for the ranking of the individuals (combination of abatement options). The initial population size (number of individuals) and number of generations are determined case-specific by 'trial and error'. The multi-objective optimisation problem gives a Pareto front with non-dominated solutions. Therefore a ranking of solutions (combinations) can be found by attaching criteria weights to the objective functions.

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The selection tool was tested by case studies to evaluate the performance of the developed methodology. This thesis project is in collaboration with the project New, Advanced and Value Added-Innovative Ships (NAVAIS) and the case studies are done for the road ferry and the workboat. The considered (double-ended) road ferry mainly uses the battery-electric mode and it is assumed to operate in Northern Europe (Baltic Sea). Since there are no operational emissions, only 9 fuel consumption reduction options are relevant for the analysis. The first case study for the road ferry was conducted with a population size of 80 and 20 generations. The output of the case study shows a Pareto front. The considered (aquaculture) workboat is a diesel-based configuration and the workboat is assumed to operate in the North Sea. In the case of the workboat, a larger number of abatement options is applicable due to the existence of operational exhaust emissions. This case study was carried out with a population size of 200 and 40 generations. The output shows more clearly a Pareto front, there is more variability in the solutions and the ranking differs for the different ranking scenarios. In order to comply with the strict NOx emission regulations, the Selective Catalytic Reduction (SCR) is implemented in each scenario. In the ranking scenario in which external costs are given a high weight, it can be seen that abatement options that reduce PM emissions are more present in the solutions. In addition, the fuel consumption can be increased as a result of the implementation of emission-reducing options.

With deliverable D4.2 a model to automatically select the best combination of abatement options has been delivered. Although the model selects the optimal combination, the output is sensitive to the entered values and weighing factors used. It should not be seen as one ideal combination to be selected, but rather as a tool to learn about useful abatement option combinations and limitations to their use and applications. In other words, if circumstances change a different option may be more suitable. Knowing when to switch between options is very important. It will help in discussions between yard and ship owners on which equipment to select.

The main recommendation for NAVAIS is to keep updating the long list of abatement options with every new element discovered over the duration of the project and thereafter. This will make the tool better over time and will decrease the effort each time it is used.

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