FINAL PUBLISHABLE REPORT

Grant Agreement number: 266082

Project acronym: NOMANS2HIP

Project title: INOvative Energy MANagement System for Cargo SHIP

Funding Scheme: Collaborative project

Period covered: from 01/05/2011 to 30/11/2015

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I.1. Executive summary

The global optimization of energy systems aboard future and currently operating cargos is crucial to reduce greenhouse gas emission in a substantial and cost effective way. It is also of major economic interest in the merchant marine sector with volatile fuel markets.

A holistic approach, considering the overall production and management of energy aboard ships (including propulsion systems and energy output optimization), is the most promising approach to accelerate the adoption of low emission-higher energy efficiency cargo ships.

Taking this consideration into account and based on the array of innovative and renewable sources of energy, the INOMANS²HIP concept aims at proposing a break-through energy management system aboard ships based on an AC/DC network integrating all potential sources of energy. A Life-Cycle Analysis, risk assessment and cost study was be performed to provide an independent assessment of the impact of alternative energy sources being implemented on-board cargo ships. The proposed energy management system will gather data in real time and will be able to anticipate and optimize energy needs for each operational configuration of the ship considering risk levels while systematically favouring less polluting and cost effective sources of energy. The INOMANS²HIP project aimed to contribute to reducing greenhouse gas (GHG) emissions and pollution as a whole (SOx, NOx, and Noise). It fosters European competitiveness by providing innovative energy solutions to the global advantage to both European equipment manufacturers and shipyards.

I.2. Project context and objectives

The aim of the project was to gear towards optimised energy efficiency for ships in a context of greening maritime transport. The global optimization of energy systems aboard future and currently operating cargo vessels is crucial to reduce greenhouse gas emission in a substantial and cost effective way, taking into account its operation, maintenance and sustainability over time. It is also of major economic interest in the merchant marine sector as higher, ship efficiency means less fuel consumption and less pollution lowering the ship's operational cost.

Four complementary approaches will lead to this objective:

- Improve the efficiency of conventional sources of energy.
- Develop and implement novel and low carbon sources of energy
- Consider the overall energy production and its management system aboard ships and adopt an holistic approach
- Consider, as a general rule, that the operational life of the INOMANSHIP system's architecture will be studied and designed in accordance with the working life of cargoes.

Considering all aspects of the energy system promotes the integration of various sources of energy aboard ships whilst providing continuous propulsion and taking the human factors such as safety and comfort into account.

The energy management system will complement the concept of the All Electric Ship concept and foster its implementation, paving the way to an effective fleet management that takes into account a wide range of data including economic operating factors, energy efficiency and operating conditions.

There are presently no energy management systems mixing conventional, alternative and renewable energy sources in existence for cargo vessels. Taking this consideration into account and based on the array of innovative sources of energy, including recovery, renewable and storage that are now suitable to marine applications, the INOMANS²HIP (INnOvative Energy MANagement System for Cargo SHIP) concept aims at developing a new type of energy management system aboard ships integrating all potential sources of energy aboard ships.

The general objective of the INOMANS²HIP project is to contribute to the reduction of greenhouse gas (GHG) emissions and to the development of less polluting ships, by optimising the energy efficiency of existing and future cargo ships for given service and environmental conditions by optimizing ship design and operation for a variety of transport tasks.

The specific objectives of the project are to:

- Define the best strategies to integrate different sources of energy (conventional and renewable ones) aboard cargo ships. The aim is to analyse prime (environmental and operational) factors affecting energy consumption and develop strategies and tools to optimise energy consumption and minimise maintenance during service.
- Evaluate, through the use of new tools, new equipment to be installed on-board ships in order to assess the overall energy balance and to improve their overall efficiency.
- Define interfaces for all types of conventional and non-polluting/low carbon energy sources (including solar, wind, batteries, LNG, heat pumps) available that can be potentially integrated in the electric network of cargo ships.
- Define an energy management system to be installed on-board identified ship types (WP4).
- Define specific algorithms analysing in real-time the demand for energy under various operational configurations and providing the energy efficiency optimisation and minimise maintenance of existing and future ships.
- Design and develop a strategic software tool and virtual demonstrator through a specifically designed Human Machine Interface (HMI) suitable for different types of cargos and electrical networks (Alternative Current /Direct Current) providing advanced concepts for improved energy efficiency and reduced maintenance.
- Perform a safety, environmental and economic evaluation of the system to analyse operational maintainability and reliability, compliance with safety rules and economic factors.

To ensure the achievement of its ambitious goals, the INOMANS²HIP scientific approach relies on 4 steps:

- To prioritise among the various ship categories the two most suitable types of ship.
- To analyse the energy balance using a simulation based approach.

- To define suitable algorithms based on simulations prior to the development of the energy management system.
- To validate the system through an environment, economic, safety and risk analysis.

The work to analyse the conditions of integration of such technologies and proving possible energy efficiency gains, the technical feasibility of the INOMANS²HIP concept and its economic viability, but also its environmental and safety benefits for future or currently operating cargo ships.

As a main output of the project, a novel Human Machine Interface (HMI) implemented in a virtual demonstrator to include all aspects of power generation architectures and propulsion systems (mechanical or electric), as well as the integration of an array of renewable sources of energy and storage systems. The proposed simulator will allow end users to make a balanced judgement of the best configuration of power systems for a vessel based on its operational profile, making the INOMANS²HIP simulator the key project deliverable for the dissemination of results.

The project's goal was to combine unique sources of competences and experience in the field of energy system integration and optimization for a broad range of vessels (of differing size and type, possibly, LNG carriers). The INOMANS²HIP consortium will cover all marketing, engineering, R&D, safety, risk and environmental aspects of this complex subject following on from the European Power Optimized Ship for Environment with Electric Innovative Design On-board project so-called "POSEI²DON". This stems from the fact that the optimization of the energy efficiency for large vessels using innovative sources of energy is a necessary stage to the development of all electric ships. This project was a unique opportunity to share the INOMANS²HIP concept with research groups and companies involved in the development of future high efficiency-low greenhouse gas emission vessels.

I.3. Main S&T results/foregrounds

This sections presents the work and main finds of the INOMANS²HIP project.

The Market Study

Global shipping is estimated to contribute 4.5% to the annual global emissions of carbon dioxide (CO_2), 5-8% of sulphur emissions (SO_X) and up to 30% of nitrogen emissions (NO_X). It is also estimated that greenhouse gas (GHG) emissions from shipping will increase by two to three times of current levels by 2050 as the world shipping fleet grows to meet the increasing global demand for shipping resources and goods [IMO 2009].

Since the 1960's, the relationship between climate change and industrial emissions has become of growing concern to the world. Evidence has shown that GHG emissions, such as CO_2 NO_X and SO_X, lead to global warming, air acidification and air toxicity. Over the years individual nations and regions have banded together to improve air quality tackling air acidification and toxicity through the reduction or abatement of industrial emissions. The first major step in tackling this problem was the Kyoto agreement, an international agreement aimed at reducing overall CO_2 and other emissions of nation states to reduce global warming effects [Kyoto 1997]. The Kyoto agreements, which came into effect in 2005, committed nation states to reducing GHG emissions to 5.2% less than 1990 levels by 2012.

Major developments have been achieved in reducing emissions in a number of industrial sectors, through the application of evolved and emerging technologies in the motor, power and manufacturing industries. Although, shipping produces some of the lowest levels of emissions by sector (≈4.5% to global GHG emissions), further reductions are achievable. However, the marine industry has lagged behind in adopting fuel efficiency and emission reduction technologies or methodologies. To facilitate in the adoption of novel technologies and methodologies aimed at reducing emissions, the IMO introduced the MARPOL Annex VI legislation [IMO1983; IMO 2004]. In addition to this legislation, individual nation states and the European region have induced a number of regulations to reduce ship emissions in territorial waters and ports, helping to meet Kyoto commitments and improve overall air qualities [EU 2005; EU 2011].

The establishment of the Emission Control Areas (ECA) in the Baltic and North Sea, requiring the ship operators to limit SO_X and NO_X emissions from shipping in certain coastal and territorial waters. The regulations have various impacts depending on the operation and the type of ship. Using low sulphur fuels and the implementation of emission abatement technologies and methodologies can help in reducing emissions.

While traditionally, electric power generation on-board cargo ships is traditionally limited to using diesel gensets, the present trends show an increase of the electric demand leading to an increase of the installed power supply, as well as a need to be energy efficient to recovery as much as possible of the remaining energy losses. These trends bring more and more complexity in the energy design architecture with an optimisation of the operating profiles. The drivers of this evolution for more complex and powerful electric power generation systems are the following:

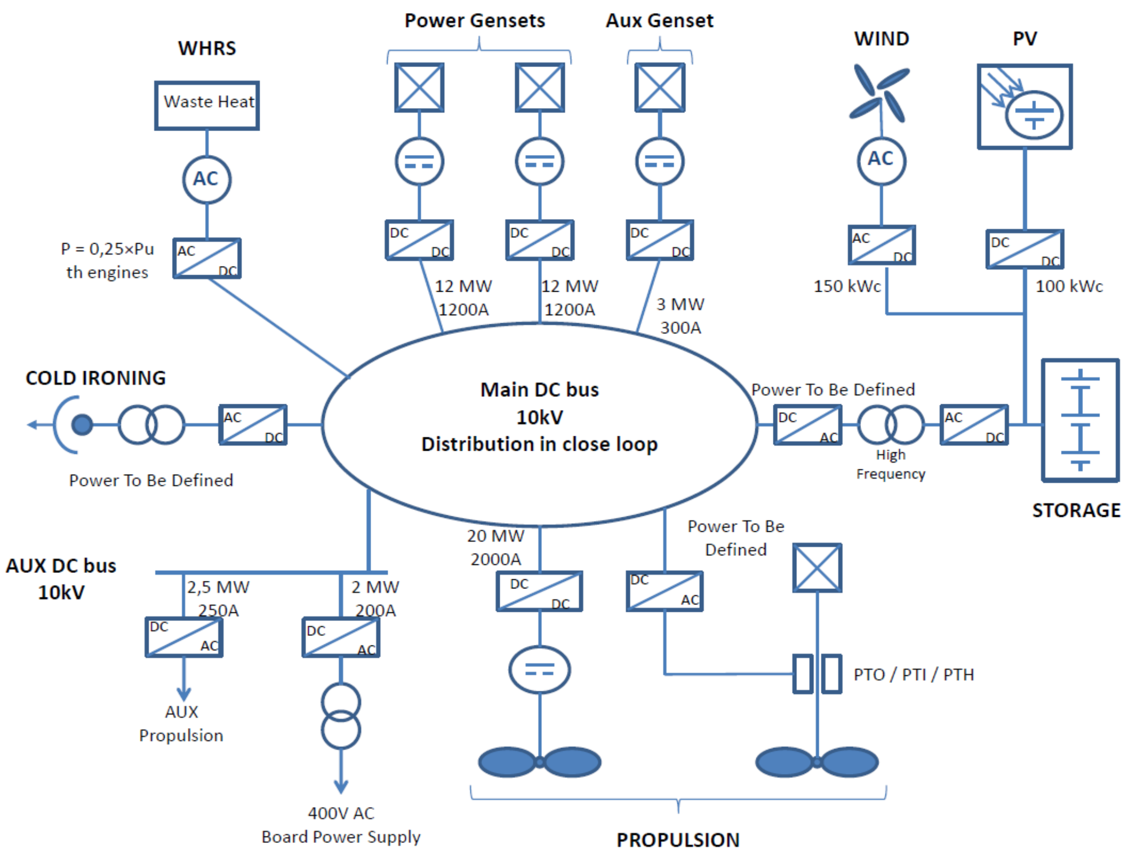
- Economic: - Installation costs can be inhibitive to wide sector uptake of advanced or alternative energy technologies. This is generally measured in the payback period to recover the initial costs of installation. However in a volatile fuel market, when fuel prices are high it encourages uptake of fuel reducing solutions, but when fuel prices are low this will discourage uptake of a solution.
- Technical: - The level of development can have a major influence on the acceptance and uptake of any new technological solution. New and immerging energy technologies take time to be developed to mature level and ensure efficient, hazard free implementation. Mature technologies with wide acceptance generally reducing capital costs, as most of the initial costs of any technology are up front in its development. However, mature established technologies may have limited development scope to improve efficiency.
- Regulation: - There are two aspects to the legislation that influence the uptake of technologies. The first is environmental legislation which limit the environmental impact of any industry or sector, forcing them to adopt better technology solutions. The other is the perceived associated risks, as new technology solutions can be perceived as less reliable and could be more hazardous than established mature technologies, such as diesel engines.

Currently, there are a number of projects in Europe and around the rest of the world exploring different solutions for the marine industry to meet current and future legislative demands while remain cost effective, safe and competitive. The use of renewable energy sources, such as solar or wind power, is seen as one possible solution to more restrictive legislation and increasing fuel costs. Other solutions being investigated are the use of alternative fuels, electric ship concept, slow-speed shipping, energy recovery systems and emission abatement technologies.

The aim of the INOMANSHIP project was to explore the use of renewable energy production and energy recovery technologies with certain cargo ship's power plant architectures. To understand the current market opportunities and barriers, a review of the current and expected trends in ship power plant architecture was performed, analysing the reasons of the present architecture designs and give some possible trends of their evolution. An explanation of the different cargo ship categories and the main requirements for any on-board power system in relation to their operational profiles and legislative restraints was investigated.

The project explored the approach of the maritime transport industry to the challenges it faces as more restrictive emission legislation is implemented and fuel cost volatility. In particularly, fuel quality as used by ships was explored in relation to operating profiles. Part of the study focused on the LNG, whose use is emerging for some applications.

The use of renewable and energy recovery technologies, in conjunction with a suitable power management and distribution network, are seen as a solution to enable the marine industry to become more sustainable, reducing fuel consumption and emissions. A list of the possible energy sources was created, presenting the characteristics and constraints of each of the technologies and the possible integration on-board suitable cargo ships.



Concept of Multiple energy Source Integration and Managment

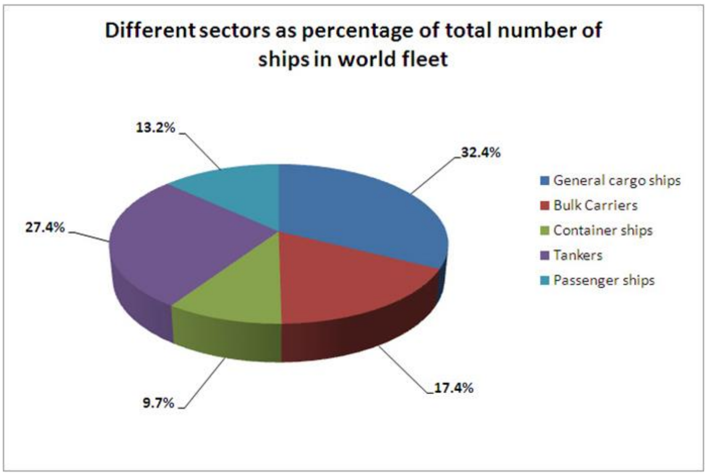
To enable the successful integration of the proposed technologies, the overall power distribution and management system needed to be reviewed. A review of the current possible solutions for the electric distribution architecture for various ship types was performed. An analysis of the possible architectures exploring the operation and integration of the different technology solutions, examining the market and legislative drivers influencing the final decision of the ship owners for the implementation of the proposed technologies. The areas of alternative energy solutions explored in the technology market review were as follows:

- WHR power generation, where the exhaust gas from the main engines of the ship are used to either drive directly a gas turbine or through the generation of steam, a steam turbine to generate electrical power.
- Flexible diesel engine generation, where generators of different sizes are installed to create a flexible power generation plant.
- Auxiliary power generation/propulsion, where an electrical alternator/motor is connected to the main propulsion engines to either generate electrical power or used to boost power to propellers, thus, maintaining the most optimal operating parameters for longer periods and reduces size engine required. Solutions include power-take-off (PTO - generation only), power-take-in (PTI – power generation and propulsion boost) and power-take-home (PTH – standalone self-start propulsion drive system).
- Renewable energy sources, the application of Photovoltaic (PV) systems or wind power generation to partially supply some of the power needs of the ship.
- Shore-to-Ship power supply, where the ship is connected to a local power supply while in harbour, reducing its need to run diesel generators during port stays.
- Energy storage, from mechanical systems, such as flywheels and compressed fluids, to electrochemical systems, such as batteries and fuel cells were explored for their practical applications on-board marine vessels.
- Alternative propulsion solutions, where the all-electric ship concept was explored, as well as wind power propulsion assistance, alternatively fuelled engines, diesel engine optimisation and improved propeller design.

Although, there are a number of solutions that appear to be available, some of which have matured in other industry sectors, a single solution for the marine industry has proven to be illusive. Finding a one size fits all solution has proven difficult as each ship is unique with its own power requirements. Even ships of a similar design can have very varied power needs depending on its operational profile.

The second part of the market study explored the marine shipping industry to identify a suitable ship type with a suitable operational profile that could be used as a reference to study the application of certain alternative energy technology solutions.

The cargo ship sector represents around 90% of the gross tonnage of the world's merchant fleet, consisting of around 38000 vessels at the end of 2010 (Ref. Marisec 2011). According to predictions, the world shipping fleet should increase by about 60% by 2020. The container, tanker and bulk carrier sectors will constitute the largest growth as the demand for transporting more resources and goods around the world is expected to double within the same period [Meech 2008].



Breakdown of World Merchant Fleet by Sector

The world cargo fleet statistics were categorise depending on the propulsion and the voltage level of the main electrical network. An analysis was made for the possible use of the Energy Efficiency Design Index (EEDI) guidelines developed for the largest and most energy intensive segments of the world merchant fleet. This covers 72% of emissions from new build ships, including the following ship types: oil tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo ships and combination carriers. So the selection of a reference ship considered as a suitable vessel to demonstrate the new energy approach and the possible integration of non-conventional energy sources was made based on certain criteria.

The potential ship market size for the implementation of certain renewable energy, energy recovery and storage technologies, as well as the power and sailing profiles of the ship need to be considered. For example, relatively long periods in port determines if shore-to-ship is suitable to implement, while sailing direction and operational area can determine the suitability and size of PV system that can be installed.

One important aspect to consider in the selection of a suitable reference ship, is the quality of information and data availability. Gathering suitably good quantity and quality data of the nature required to create a highly accurate model of the ship must be considered. The most suitable reference ship may not be possible to model accurately either due to the lack of recorded data or the parent company withholding data for commercial reasons. It was important to have a good relationship and understanding with the ship owners of the selected reference, in order to have sufficient data and information available to achieve the level of modelling for accurate and realistic simulations.

The ship categories were selected on the basis of certain criteria and suitability for the installation of the proposed energy generation and storage technologies. It was identified that ships whose working profile consisted of relatively short shipping times, frequent port visits and relatively long stays in port would benefit mostly from shore-to-ship and other energy source (wind turbines, energy storage devices and PV) technologies, when diesel generators would be preferred to run at a minimum. While, ships sailing east-to-west or visa-versa would always have one side of the ship facing the sun, increasing the possibility of PV energy generation. In addition, ships operating in ECAs would increase the commercial demand for renewable energy generation and recovery systems due to the increase legislation to reduce emissions. As well as these factors and the criteria stated above, a number of ship categories such as refers, shuttle tankers, coasters, short haul cargo ships and Ro/Ro freight ships were identified as being suitable to be studied.

Contact was established with a number of ship owners to see if they were willing and able to provide the information needed to create a suitable reference ship model. Although, a number of ship owners were interested and willing to assist in providing data, only one company could provide sufficient information and data to create a suitably accurate, realistic reference ship model in the time scale required by the project. It was, thus, decided to use a Ro/Ro freight ship sailing between ports in the Netherlands and UK as the reference ship.

Alternative Energy Technology Implementation and Network Design

The aim of this part of the project was to study the different energy sources, storage devices and principal consumers to determine the on-board energy needs of the reference vessel. The on-board systems of a ship were defined by the technical partners of the project as precisely as possible. The final goal was to determine the extent and mathematical models of the proposed on-board elements. The models allowed for the simulation to define the interaction of the different components and systems in order to develop the energy management requirements based on existing management laws.

General operational profiles for each of the proposed renewable and energy recovery technologies were discussed. Applying the real-time physical variable of the operational profiles gives a precise idea of the reaction of on-board power requirements for a trip of the vessel. The operational profiles of each technology were used as input variables to the mathematical model of the ship.

The INOMANS²HIP project explored many on-board ship's architectures and component solutions. The ship's propulsion system was also considered as this could be fully electric or include a connection from the main diesel propulsion engine to an alternator/motor for Power-Take-Off (PTO), Power-Take-In (PTI) or Power-Take-Home (PTH). A first global approach of the loads, sources and storage device was necessary to better understand the needs of the reference ship and match the technologies best suited to provide these needs. Once, the most suitable technologies were matched to the needs of the ship, network architecture designs were created for three new configurations of the ship, as follows.

1. A low cost retrofit configuration of ship, which realised that the cost of all the technologies could be inhibitive to implement and would take a cost effect approach. For this solution, being least intrusive to the original reference ship was key so only those technologies deemed cost effective to implement, but still providing a marginal fuel saving. A design was developed for the low cost retrofit ship which included a shore supply for port stays and the operation of a PTI/PTO power systems connected to the main propulsion engines.

2. A low emission retrofit solution of ship were cost of implementation was not a factor. The main aim being how to maximise fuel efficiency and thus, maximise the reduction in emissions. To achieve this all the alternative technologies identified as being practical would be implement in the original ship's network, to include solar PV units, WHR turbine generation, PTI, shore-based supply and battery energy storage.

3. A new network configuration of ship were the entire ship's power network would be redesigned to include the selected alternative energy technologies. The new network architecture was based on AC and DC ring network design to allow for easy implementation of and control of multiple energy sources, such as various sized diesel generators, solar PV units, WHR turbine generation, shore-based supply and battery energy storage. An all-electric propulsion system was implemented to optimise energy supply and user efficiency.

Stability and security of supply are of prime importance and the use of novel DC distribution networks brings about issues of small signal stability due to the need of multiple cascade power converters. A frequency domain methodology is presented, where by means of linearisation of subsystem models and Bode plots of supply and load impedances, interfacing capacitances and damping resistances can be chosen to ensure stability between the cascaded subsystems for the chosen power distribution network. This is then verified by means of comprehensive time domain simulations. The time domain study was subsequently used for a consideration of large signal events, where simulations have been performed to analyse the effect of fault clearance at various locations on the network with the use of solid state circuit breakers

Stability can be defined as the response of a system to a disturbance and the return to a stable operating point, not necessarily the same as the original one. With the cascaded DC system as proposed for the INOMANS²HIP project, two classes of stability can be identified, each with their own aspects and approaches to determining stability. The use of cascade converters and constant power loads presents a negative impedance characteristic which intuitively can lead to a destabilising effect on the distribution system. This can be designed for by means of impedance matching of the load subsystems and the distribution source, presenting a small-signal stability criterion. The second aspect of stability deals with large signal stability due to switching or faults. The system inductances and capacitances will lead to large transients and energy exchanges between the passive components, which must be analysed in order to prevent a cascade effect of the disturbance from affecting further branches of the system.

The use of DC as the distribution medium permits easier interfacing with power electronic loads and other generation sources, as there is only active power flow and no need of synchronisation as with AC systems. However, power electronics will be required for any power conversion stage since transformers are incompatible with DC systems. The simpler power flows also facilitate running generators at variable speeds such that better efficiency can be achieved by improving prime movers' operating points.

The proposed power distribution system illustrates the various subsystems to be included in the INOMANS²HIP distribution system. This illustrates the power generation sources, both conventional and the renewable sources such as PV and wind. The full advantages of DC systems, namely the ease of reconfiguration and control can be fully exploited by implementing a zonal distribution system. This approaches the division of the loads based on their physical on-board location and assigns zonal power centres to distribute power within zones. Buses on both sides of the vessel ensure redundancy and survivability in case of faults.

Energy Balance Analysis and Ship Simulations

This project aims to reduce the GHG by power management, so the electric installation of the ship is of high importance. Firstly, an existing cargo ship was chosen and used as a reference for the analyses. The main energy suppliers and consumers were modeled to create an INOMANS²HIP library in the General Energy Systems (GES) simulation tool.

To evaluate all the ship concepts in the project, a simulation environment, GES, was setup to model all the global energy systems on-board the reference ship. The tool simulated these global energy systems, read various operational profiles, and can compare the different ship configurations from pre-existing marine component libraries. The following ship systems were modelled;

- Main propulsion engines

- Diesel generators
- Fuel supply (HFO & MDO)
- Hull and wind resistance
- Hotel load
- Manoeuvring thrusters
- Main power buses (high & low)
- Controllable pitch propeller (CPP)
- Steering rudder
- Oil fired boilers

The tool was extended with new models of the alternative energy sources being investigated and used in the modelling of the new configurations of ship. This included models of the PTI alternator/motor, battery energy storage system, PV system, shore-to-ship power supply, WHR power generation, electrical protection systems and electric drives for propulsion.

One of the major advantages of the GES simulation environment is its ability to connect to other modelling tools, such as MatLab, to run real-time simulations. Because of the complexity of modelling some of the systems, namely the PV system, the bulk of this work was performed in MatLab and connected to provide a real-time energy inputs to the global ship models in GES. This was preferred as the PV model used seasonal weather data and shading effects throughout the day to determine the power output based on time of the year and day. In addition to the connection to other simulation tools, GES allows the input of the operational profiles of real ship data, enabling the calculation of the energy demand from the ship during each stage of its journey.

A realistic model of the reference ship was created. The ship's journey over a 24hr period, which enabled results for an outward and return journeys, were simulated from actual ship's sailing profile extrapolated from a month's worth of data. Results for the fuel, emissions and power profiles of the ship for each stage of its operation were produced. The operation of the ship was broken down into three stages;

1. Port stay – were only the diesel generators are run on MDO to provide the ship with all its harbour power needs of 650kW
2. Manoeuvring – were the ship sails at slower speed, the bow thrusters are engaged and the ships power is provided by the diesel engines running of MDO to provide 800kW of power
3. Transit – the ship sails at around 16knots for the outward journey from UK port-Dutch port and 14knots for the return journey, and running the diesel generators on HFO to provide 800kW of on-board power

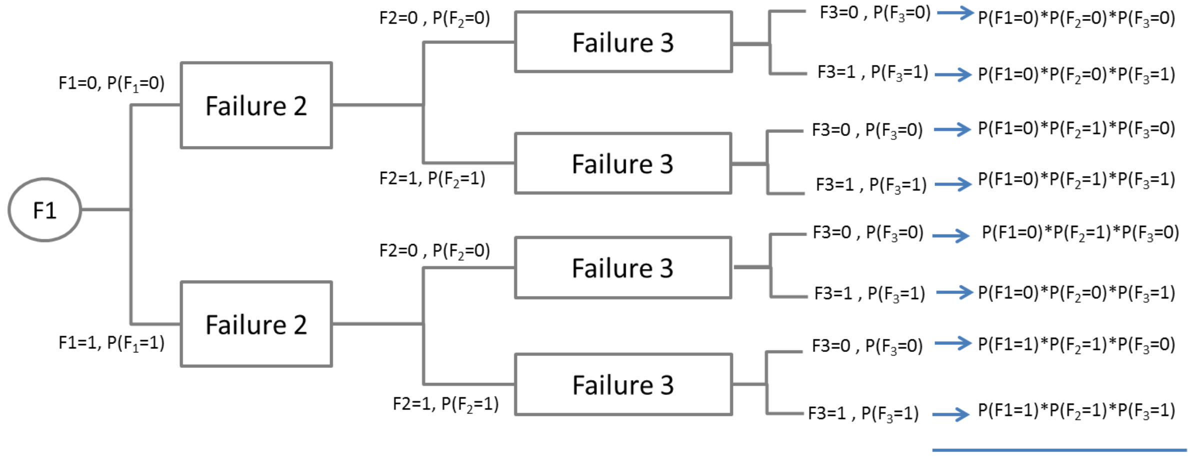
In addition to the reference ship the three new configurations of ship were modelled, i.e. low cost configuration, low emissions configuration and the new ring network configuration of ship. Running the same operational profile as in the case of the reference ship and comparing the results without optimisation. It was clear from the results that the new build ship gave a significant level of fuel saving compared to the other concepts being investigated.

For the low cost solution, a 2.4% fuel saving was observed mainly due to the ship getting its power while in port from a shore power supply. In the case of the low emissions solution, at this stage of the project a 2.7% fuel saving was made. Although, only marginally better than the low cost solution, it was noted that the systems complexity meant that without an optimisation algorithm some systems were not operating to their full capacity. For example, the batteries, which were mainly on charge, drawing power from the ship, and not discharging as much power. Over the project, the models and the component systems were continually reviewed and updated to improve their operation profile and be as realistic as possible.

Where the project saw a significant difference in fuel consumption with the reference ship was in the new ring network configuration of ship. Here, a 12.8% fuel saving was observed. This was largely put down to running the batteries in a better configuration and operational mode; the use of different sized diesel generators operating more efficiently at peak loads to provide power to the electric drives during transit; and similar benefits from other alternative energy sources.

At this initial modelling stage of the project, these would form the basis of modelling for the reference ship and the new configurations of energy efficient ships. The initial results without optimisation showed real promise of providing significant fuel savings. Throughout the project the models were continually reviewed and improved with regular updates, as more information and data was gathered for the individual system models and operational profiles, such as in the case of the WHR power generation system and combinatory curve for the propellers.

In addition to the advanced modelling of a ship using plug-in separate components, the GES modelling tool allowed for the exploration of risks associated with the implementation of the innovative energy technologies on-board the new configuration of low energy ships. For each system a pop-up window can be created were MTBF and MTTR data can be inputted. This will then calculate the probability of failure of the component and the amount of time that will elapse before the component is operational again. Using a fault tree analysis to combine the failure rates of the individual components, the associated risk of failure to a system, i.e. as propulsion (from fuel tank to propeller), or the global risk to the ship, i.e. total loss of power, was determined. This was used to verify and assess the associated risks determined for the individual systems and global ship configurations investigated in this project.



$$P(F_{global}) = \sum_{i=1}^{n_{branches}} P(F|F_i) \cdot P(F_i)$$

Fault Tree System Risk Assessment Method

PV Modelling:

The PV Module model produces good results compared with the sample cell from Solar Capture Technologies, and also replicates the performance of the IS-160 and CNPV-280P commercial modules. However, there are still areas where the model was improved over the final year of the INOMANS²HIP project. It is hoped that these advancements will ultimately ensure that ships with PV systems can accurately predict their energy demand for a particular route to within a reasonable level of accuracy.

Battery Storage Models

Using the power profile of the reference ship, a charging and discharging profile for the proposed battery storage system was created. Charging of the batteries will occur in port from shore power supply connected to the ship. When leaving and entering port, i.e. during manoeuvring, the ship uses this stored power to drive the thrusters and the shaft generators as motors (PTI) at low loads and speeds. During transit, the batteries will be recharged using power from the shaft generators (PTO), renewable energy from the PV modules and recovered energy from the WHR steam turbines. Using the battery storage system in this way will save fuel consumption, reducing the emissions leaving and approaching port, as the requirement for main engine switch-on for warming can be delayed until after the ship has left port.

Conclusion: WHRS

A full Ranking Cycle WHRS model has been designed and successfully applied for comparison with a Simplified Linear Estimation Model. Given the limited input required, the Simplified Linear Estimation WHR model correlates reasonably well with the fundamental Rankine Cycle model. The Simplified Linear WHR Estimation model shows acceptable results at the design point for operating at Generator Law condition. A 6% underestimate of WHR output power deviation is found in comparison with the full Rankine Cycle WHRS model. When taking into account off-design conditions, which will occur in-service, the accuracy is limited. At low loads an overestimated error of 73% for WHR output power was found. This may affect the overall WHRS concept performance at a commercial shipping level.

The Simplified model can be improved drastically by taking into account the influence of diesel engine speed, being of large influence. The Full Ranking Cycle WHR model is too slow to further exploit along a route in a Matlab-Simulink software environment.

Conclusion: PTO/PTI

When reducing the propeller pitch, Open Water propeller efficiencies are normally overestimated. The order of additional efficiency loss due to off-design pitch distribution lies in the order of 7%-10% when slowing down 50% from trail condition. This implies that the reference case with the use of PTO is probably too optimistic. Therefore, further development could be achieved to improve the CPP prediction model. The engine characteristics are also uncertain. In particular, data for reduced engine loads can be incorporated with our in-house data.

The PTO scenarios are limited to a configuration with four engines. Other combinator modes are to become included. Operating on three engines is favourable in view of service speeds and is recommended to be further evaluated.

Conclusion: Shore-To-Ship Power Supply

It is intended that for the two retrofit models (low cost and low emissions) that a shore-to-ship power supply should be implemented on-board the ship while in port. This would reduce emissions to zero from the ship as on-board generators would not be used in port.

For the low cost model, the load requirements for the ship is about 1.2MW while in port to run the ship systems, such as heating (if electrical boilers installed), lighting cargo equipment, pumps, cargo handling equipment, etc. However, when the low emissions retrofit and new build ship configurations are considered with an implemented battery storage system, then the load requirements of the ship increases to 1.85MW in the Netherlands and 1.62MW in the UK. The difference in charging is largely to relative time of stay in each port, with the UK port stay being longer, and to some extent, to the power left in the battery system before docking.

Another consideration in the use of the shore-to-ship power supply, is the infrastructure requirements both on the shore and ship sides, as this determines the type and quality of the supply. As the reference ship does not have a high-voltage circuit, unless electrical heating boilers and battery storage are installed as recommended in the retrofit and new build configurations, then a high voltage may not be required, unless transforms are installed to step-down the incoming power. New legislation being proposed for low voltage shore supply is being considered, which could have implications for implementation of a shore connection on-board the ship in terms of installation costs. However, it is clear that shore-to-ship power supply will reduce costs, as shore power is cheaper than running on-board generators, and emissions, as part of the shore supply will be zero, if renewables or nuclear power generation sources are used.

Conclusion: Auxiliaries Systems

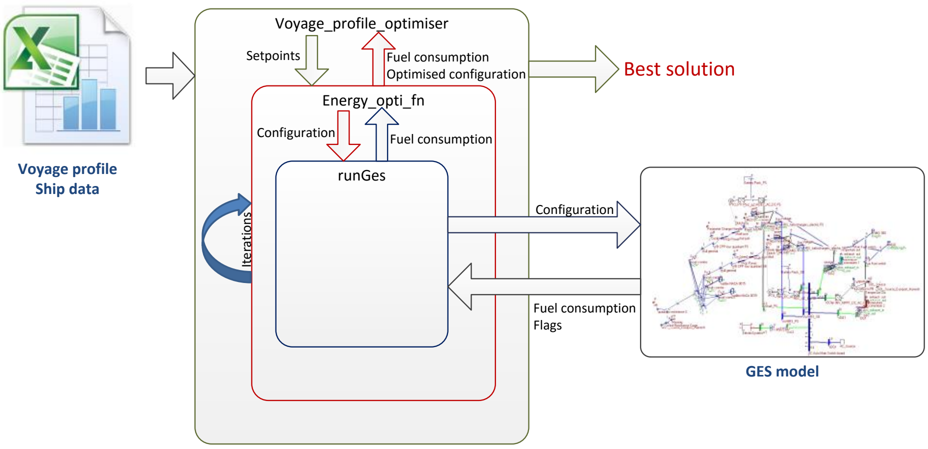
In principle is the internal auxiliary power profile of the cargo ship is simple. The total electric consumption of the auxiliary systems was estimated to be about 650 kW in harbour and 850 kW at sea. At sea, generator is run on HFO and in harbour the other generator is run exclusively on MDO to avoid fuel switching of the diesel generators.

To provide heating on-board the reference ship, the internal energy profile derived from measurements and the operational profile of the ship. In harbour either one of the two boilers is used to provide the required 600kW of thermal energy. At sea, the required heating is produced using the two on-board economisers, which are connected to the exhaust pipes of the two central main engines. The internal energy profiles of these systems are the result of the associated simulations run in GES.

Operational Strategy and Optimisation

An overall energy power profile based on the operation of the diesel generators, propulsion engines and boilers has been created for each stage of the ships voyage. To enable the energy demands of the ship to be estimated, energy profiles of the proposed alternative energy systems (PV, PTO/PTI, WHRS, battery storage, etc.) were created before optimisation.

Two optimisation methods, Simplex method and Particle Swarm Optimisation (PSO) algorithms were explored to optimise the on-board power generation configuration based on the voyage conditions. The models developed in the previously were used as the optimisation functions, which in combination with the voyage profile data and the optimisation algorithms identify operating configurations, minimising the instantaneous fuel consumption of the system, thereby, implicitly minimising CO_2 emissions.



Representation of data flow for Optimisation

The Simplex method, which is available within the GES simulation tool and used to optimise the energy exchanges management system. In practice, a quite robust multidimensional optimisation method. The simplex method calculates likelihoods at simplex vertices. For an n-dimensional optimisation method, a geometric shape is set up with n+1 corners. The method moves towards a minimum and away from a maximum. For the INOMANS²HIP project, the results are also compared with the particle swarm optimisation (PSO) method to check the optimal results of both methods.

The simplex method needs a starting area for the parameters where a possible minimum solution exists. If the minimum solution is outside this area then the outcome is more random. So if the number of maximum iterations is reached a check has to be made. The flag principle that is used by the PSO method can also be used for checking the outcomes of the Simplex method.

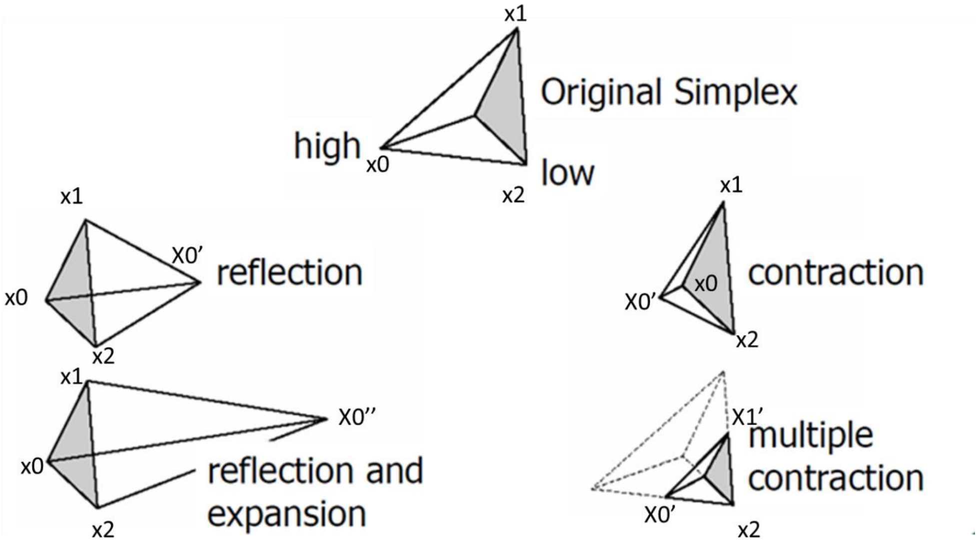


Illustration of Simplex Optimisation Method

Evolutionary algorithms are a type of computer algorithm, which use mechanisms from natural or biological processes as the underlying operating concept. One such method is Particle Swarm Optimisation (PSO), which is an optimisation/search algorithm, which takes inspiration from concepts of swarm intelligence. The fundamental concept is a computer algorithm that mimics the behaviour of a swarm of bees (or birds or any other swarming entity) as it searches for a global goal/s (such as finding food).

PSO was developed in the work of Kennedy and Eberhart [1], as a social interaction study. Its applicability was soon extended as a generic search algorithm, taking the concepts of swarm intelligence to a problem to be optimised. Swarm intelligence involves a number of agents that operate without any centralised control, but are able to share information between themselves. Each agent takes decisions based on this mutual information sharing, as well as information available to itself (its own memory) in order to change and search for a better location [2].

Optimisation involves minimising or maximising an objective based on the setting of a number of variables, subject to a number of constraints. An optimisation problem can, therefore, be described in two spaces – the search space and the solution space. In the search space, a solution is described by the particular combination of variables, while in the solution space, the solution is described by the value of the objective(s). Mapping between the two spaces is obtained by the objective function, which translates a particular set of variables to the corresponding objective value(s). This illustrates the various search spaces together with the fitness function/s mapping between the two. In this case, the search space consists of three variables, while the objective space is made up of two objectives. The number of fitness (objective) functions will be the same as the number of objectives.

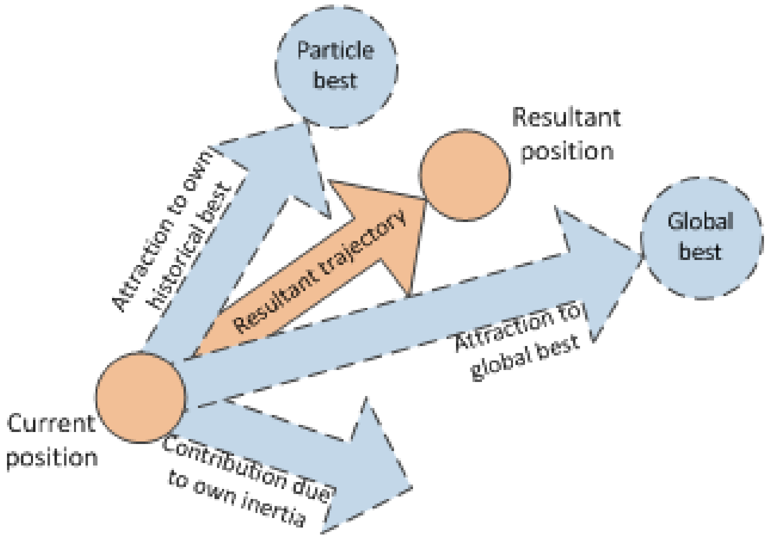


Illustration of Particle Swarm Optimisation Method

The optimisation of the on-board system is a highly nonlinear problem, which cannot be addressed easily by mathematical optimisation. The application of simulation based optimisation using a black box approach, whereby the information about the problem to be optimised is kept to a minimum, with the optimisation algorithm passing configuration data, and returning objective (fitness) values. For this project, the objective being considered is the minimisation of the fuel consumption, with the operational profile of the systems implement in the different configurations being the function to be optimised.

The motivation behind these types of algorithms is that they are highly generic and need minimal information about the problem at hand. This black box approach means that they can be applied to a wide range of problems with good results and without requiring complex reworking of the problem to suit the optimisation algorithm. Of course, there is no optimisation algorithm, which is best at everything, so this universality of evolutionary algorithms might come at the expense of performance (speed of solution).

Around 2% fuel reduction was achieved using the optimisation algorithms when applied to the references ship model. This simply represented operating the current installed propulsion engines, diesel generators and oil fired boilers in a slight more optimal operational manner with respect to the speed and energy needs of the ship.

Both methods of optimisation realise fuel savings of around 5% compared to the original case in the low cost configuration of ship model. The difference between the two methods is very small (of only around 1%) indicating that both are working successfully in locating optimal configurations. This compares to the 2.4% fuel saving observed before when the model was run without optimisation. It should be noted that the results of the Simplex method are of a single voyage and compared to the PSO baseline. As such they slightly differ from the results.

The results for the low emissions configurations are summarised and compared, which shows the time instants (rather than waypoints), since intermediate waypoints were introduced to give half hourly updates. It can be seen how the results with the PSO method both realise savings of around 11%, while the Simplex method reduces the fuel consumption by around 8%. It must be borne in mind, however, that in the Simplex implementation the batteries were not implemented. However, this does show that a significant improvement can be achieved by optimising the systems, not individually, but to achieve an overall optimisation goal.

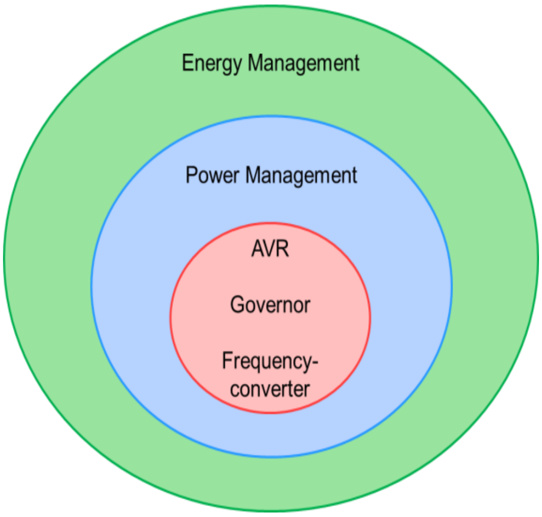
Being a stochastic optimisation technique, the global optimum cannot be guaranteed to be found, but PSO is seen to be an effective search technique that will locate solutions, which are at least close to the global optimum. This has been confirmed by repeated runs at specific set points, observing convergence to the same solutions. The PSO optimisation method takes about two minutes to finish 200 iterations. It is seen that most of the time is involved in overheads associated with the COM interface between Matlab and GES. The Simplex method, which is coded directly in GES is much more efficient and hence runs faster.

Results have shown how by use of an optimal control algorithm, fuel savings can be realised for the baseline case, while at the same time, the differences in results between the two optimisation methods is minimal. This confirms that the control schemes are working satisfactorily and locating similar results.

Development of Energy Management System (EMS) and Human Machine Interface (HMI)

The INOMANS²HIP project proposed to develop a new Energy Management System (EMS), as opposed to a more conventional power management system (PMS), for the purposes of the integration of different power sources for the chosen reference ship. Presently, ship's on-board electric management systems consist to optimise each power source independently without any consideration of the overall power needs. The energy management system aims to register the global energy needs on-board the ship and control the individual sources in order to select at any time the power issued from the most cost efficient or environmentally friendly sources in relation to the ship's operations.

An industry standard PMS system is usually referred to as the secondary control loop; controlling grid frequency and symmetric load division over available sources. This type of PMS system relies on primary control loops, such as generator voltage regulators (AVR) or diesel frequency regulators (Governor) in order to execute its task. The new to be developed PMS system or Energy Management System (EMS) is considered to be the tertiary control loop; acting on top of the industry standard PMS. This type of control system continuously optimizes energy supply to demand given a specific operational goal.



Representation of EMS

The Energy Management System should be based on the following functional requirements:

- The objective is to optimise energy generation; the level of consumed energy is considered to be a given fact
- The EMS system should primarily decide on how a certain load is distributed over various sources/storage devices given an optimizing goal.
- All combinations of source/storage devices should be possible.
- The EMS should be capable of coping with boundary conditions (e.g. monetary power limitations)
- The EMS should be capable of adapting to changing conditions of the power plant during the vessel life time (e.g. changing diesel generator performance; reduced battery capacity, etc.)
- It should be made clear to an operator how the total load is distributed over various sources
- It should be made clear to an operator on which basis the load is being divided such that the operator feels compelled to adjust its consumption pattern in order to match this basis.

Data used in the optimising EMS scheme and obtained yields should be recorded to be made present in a novel human machine interface (HMI). The HMI should be considered as a top layer HMI using input signals from different other control functions such as alarm monitoring system, power management system, battery management system and the propulsion control system. Whereas these control function only monitor and control sub systems and components, the EMS should monitor the total system performance. The conventional AMS HMI will still exist besides the EMS HMI to give more detailed information on component basis and is obligatory for the alarm functions.

Resulting from the requirements defined above, the EMS HMI should provide the following functions:

- The operator should be informed on the basis of current actual situation,
- The operator should be advised on actions to take with respect to energy consumption that line-up with EMS automated actions,
- The operator should be stimulated to follow given advice by means of for instance “serious gaming” strategies.

Information related to energy production and consumption should be presented in a supply and demand fashion. Instantaneous power information cannot be considered as relevant. Such information should be presented in a “trending” fashion, indicating past and future trends.

Finally, it should be indicated how well the EMS automation and operator are jointly performing with respect to the set optimising goal.

A ship is a complex system with many systems needed to be operated in order to provide the necessary power and propulsion for its successful operation. The systems can be consumers, in the case of pumping, lighting and heating systems, or supplies, in the case of the main propulsion engines, generators and boilers. All of these systems need to be monitored and controlled in order to ensure the efficient and safe operation of the ship.

In the case of the reference ship, a combination of classical workstations and digital human machine interfaces (HMI) centralised control stations are used. The classical workstations are used to monitor and control specific systems on-board the ship, such as the control pitch propeller (CPP), using traditional dials, monitoring rotary speed, propeller pitch, pump pressures, etc., and switches controlling speed, pitch and switching on/off pumps. In addition, the classical workstation has lamps and illuminated switches to indicate to the operator which system are engaged and to provide warning alarms in case of problems with specific machines and sub-systems.

In addition to the classical workstations, the engine room have a computerised digital HMI workstation monitoring and controlling complete systems, such as the entire power supplied from the generator to main switchboard, and propulsion systems, i.e. the main engines to propeller. To control these systems efficiently, an underlying PMS is employed at this level. The PMS monitors and controls the on-board power generation and propulsion systems, autonomously changing the operation of components/elements within the systems to best suit certain pre-programmed operating parameters and sailing requirements.

The equipment is a classical monitoring and control workstation with rotary dials and linear information for the operator of the control pitch propellers (CPP), associated systems and ultimately, the speed of the ship. In addition, speed/pitch control levers and chunky buttons allow the operator to turn-on or off individual systems and control the speed of the ship. Some of the buttons are illuminated or associated with an associated lamp to provide a visual indication to which systems are on or off and in case of problems with an individual system, an alarm.

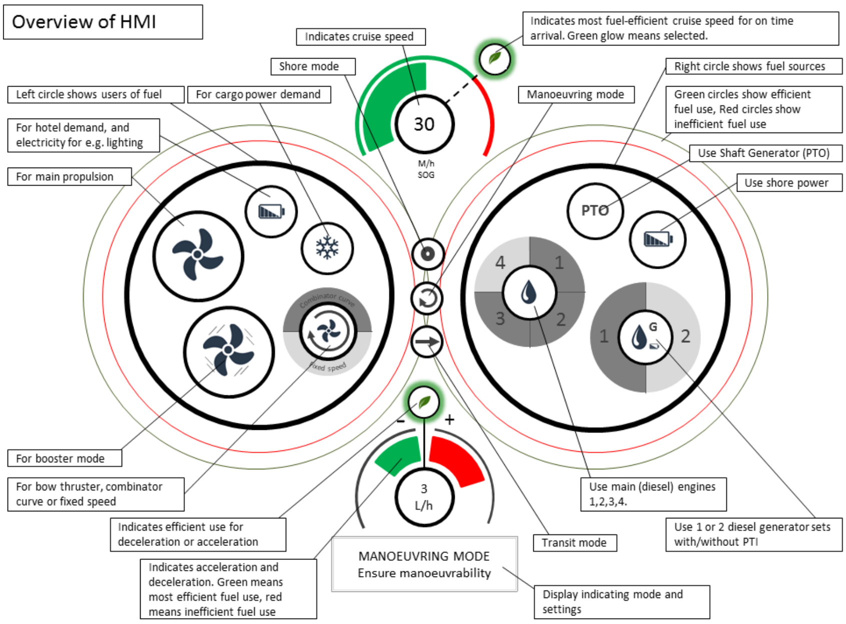
The proposed HMI described has three main functional properties.

(i) The first function is that the power management options are made conditional to the operational modes and, hence, to the operational goals.

(ii) The second function, is that it provides information of the power generation options, and that it gives information concerning the overall power demand of the cargo vessel.

(iii) The third function is to provide information and feedback concerning the influence the person responsible has on the power consumption. With the ‘person responsible’ we refer to the captain, helmsman or the bridge crew in general.

When designing a HMI concept, the first step is to develop the functional requirements and an interaction design profile. The second step is to translate that into a graphical design. An important element of a graphical design, besides executing the functional properties, is the way information is represented and the look-and-feel concept. The HMI is described using screenshots. Some elements are animated to aid visual recognition by the operator, and therefore, a ppsx file is available and posted on the project website, which can be run using Microsoft PowerPoint demonstrating the animation aspect of the HMI.



First Representation of the EMS HMI Concept

An energy exchange optimising algorithm or EMS is classified as a tertiary control loop with respect to (electrical) power generation on-board ships. Current industry standards revolve solely around a primary and secondary control loop.

The primary control loop controls voltage, speed and/or current in order to supply requested power per power source and keeps a more or less constant frequency and voltage. Such a control loop is usually based upon a droop power control scheme, whereby frequency and voltage dip slightly as the power request increases. This makes the power source inherently stable when running in parallel with a second power source. Another example of a primary control loop is the V/f control used in a frequency converter.

The secondary control loop is usually referred to as the power management system. The main goal of this control loop is to assure sufficient available power at all times, given an actual demand. Several functions within the power management system exist to support this goal.

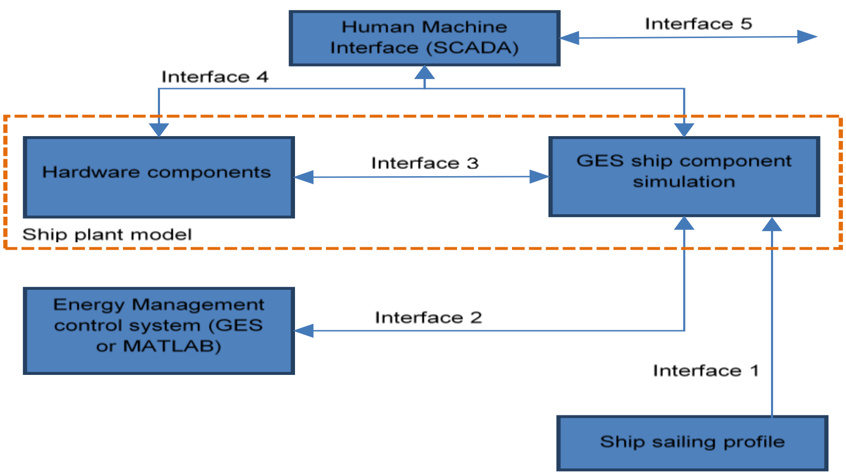
- Load shedding; non-essential loads are disconnected when all available power sources are fully loaded
- Load limiting; load is limited on the basis of the remaining available power (in case of a propulsion load the load limiting is executed by the propulsion control system.
- Fast load reduction; load is quickly reduced to a predefined value such that the power sources are not over-loaded after e.g. instantaneous loss of a power source.
- Load sharing; load is shared over various power sources such that no single power source will be over-loaded.

The optimising algorithm is introduced as a tertiary control loop or energy management system (EMS). The previous control loops are considered to be essential for ship operation, whereas this control loop is considered as non-essential. The optimising control loop functions in the domain of minutes, hours, days, months, etc. whereas the primary and power management control loops function in the domain of milliseconds and seconds.

Implementing a tertiary control loop on-board as defined requires a failsafe architecture, whereby the control output of the optimising algorithm does not compromises the safety of the ship. This is already partly achieved by cascading of the control loops. As such, control outputs of the optimising algorithm serve as inputs to the power management system, which is thereby, setup as the fall-back control loop. Equally the primary control serves as the fall-back for the power management system. Furthermore, the EMS optimised control set-points are validated with respect to guaranteeing power availability by the power management system.

Besides the fall-back and validation with respect to safety, one should also protect against instability. Based on this assessment and industrial expertise, a minimum time step of 1min with respect to control set-point updates was strived for. As such the optimising control actions won't interfere with the dynamics of the secondary and primary control loop. Furthermore, should such an optimising algorithm control power source set-points, minimum one power source should be left "un-controlled". The power sources that follow the optimising algorithm control set-points are not capable of delivering the dynamical power fluctuations anymore. As such power fluctuations will fluctuate with dynamics, e.g. < 1min, should be handled by a power source that doesn't follow the optimising algorithm control set-point. The choice of power source follows the dynamic power fluctuations that can be by itself again an output of the optimising algorithm.

To finally test and show the operation of the EMS, novel HMI and propulsion control HMI, two demonstrator were built. One by RH Marine (NL) for the EMS HMI monitoring and control system, the other by Wärtsilä (NL) for the novel propulsion HMI. The IMTECH demonstrator, using a mix of software and physical systems, ran the low emission ship model, the EMS optimisation and novel HMI to control all the power systems that included all energy systems represented in the low emission configuration ship model, such as diesel generators, battery storage, PV generation, etc. The propulsion demonstrator represented a novel monitoring and control workstation for the propulsion system implementing a power/speed matching combinator curve. The demonstrators were built and successfully run at two workshops held at the end of the project, and will be used for further development in novel HMI control systems.



Schematic of EMS HMI Demonstrator

Environment Impact and Associated Risk Assessment

Focussing on the marine power system, a study aimed to estimate the environmental impacts of the state-of-the-art technologies and efficiency techniques at various times throughout the life cycle of a seagoing vessel. The set objectives included identifying the Key Performance Indicators (KPIs), developing Life Cycle Inventories (LCI) and Life Cycle Assessment (LCA) models. The life cycle models are necessary for Life Cycle Impact Assessment (LCIA) – an essential step in LCA study which evaluates the potential environmental impacts of the product system, i.e. marine power plant in this case, during its life cycle using selected characterisation models. The relevant European and global regulations have been accounted for, while delivering work in this project, from designing, simulation, optimisation to environmental and risk assessments. The main questions asked are;

(i) How goal and scope are defined;

(ii) What characterisation models are applied;

(iii) How LCIs for individual technologies are built up;

(iv) And how LCA models for individual technologies are developed using the industry standard LCA software.

The discussion on LCIs is essential not only for meeting ISO requirements on transparency but also for allowing repetition of the technical work by a third party, should it be for future work or validation. A close link and intense dependency exist to drive the technical work. Altogether, 4 case studies were carried out, i.e. marine power plants on-board an existing cargo ship, retrofit designs with low capital cost, retrofit design with high potential of emission reduction, and full-electric design for new build ship. Background data from alternative sources was gathered, standardised and used for building up the LCIs. Data is the key requirement of this work. However, it presents an unavoidable issue in many cases due to inaccessibility. Assumptions are made where ever necessary to carry on the technical work. Such a process is commonly applied in an LCA study, which is, by nature, a study for estimating environmental impacts rather than determining the actual impacts. In this project, the development of LCA models take into account various life cycle phases, including energy and material acquisition, manufacturing, operation, maintenance and end of life, if data is sufficiently available.

Based on the Shipping KPI Standards, it was initially decided to include

(i) The release of substances,

(ii) Efficiency of emissions (i.e. CO_2, NOx and SOx) and,

(iii) Deficiency in relation to health and safety, critical equipment and system, and operation as the KPIs for this project.

However, the KPI Standards only measures the amount of emissions without assessing the impact of shipping activities on the environment. The omission of assessing the environmental impact from the Shipping KPI Standard has indeed presented a drawback.

From an environmental perspective, Life Cycle Assessment (LCA) is a recognised tool with the capacity to assess a range of environmental impacts. It was found that LCA has been applied by research community to identify KPIs of the system under study. Taking the above reasons into consideration, LCA was chosen to define KPIs for INOMANS²HIP project. Based on the LCIA results, the phases, technologies and components which show the most significant impact were identified for each impact category.

At each life cycle phrase, a certain amount of inputs (i.e. energy and materials) and outputs (i.e. emission, waste, energy etc.) are likely to be extracted from or released to the earth, which results in some impacts on its surrounding. In this context, ISO 14044 has implicitly distinguished natural environment, resources and human health as the Areas of Protection (AoPs), representing the areas in which the society seeks to protect. In addition, LCA is recommended as a tool to assess the environmental impacts which can be classified into a range of impact categories. Some common examples of impact categories include climate change ozone depletion, acidification, eutrophication, toxicity, photochemical oxidant formation, particulate matter formation, etc. The fundamental principles of LCA are defined by ISO 14040 and 14044, covering goal and scope definition, LCI analysis, LCIA and life cycle interpretation.

The LCI and LCIA results indicated that emission, fuel and/or water consumption were the KPIs for most technologies. The LCIA results indicated that the implementation of marine power plant with low-cost configuration design would result in a reduction for most environmental issues. As evidenced by the LCIA results. Further reduction would be possible in the case of implementing low-emission configuration design. As the benefits of implementing an advance technology or system will always come along with certain burdens, an overall assessment taking into account environmental, economic and risk aspects is necessary.

The implementation of integrated alternative energy sources on-board, together with the dedicated intelligent EMS that activates the best suited energy source at the moment enables an optimised, more efficient operation with a lower environmental impact due to reduced greenhouse gas emissions. The design and operation of the ship with its retrofitted or new energy system with aid of the EMS shall be such that, compared with the reference ship design as built today, no unacceptable risks are introduced. This implies that the influence of design modifications, additional components and subsystems shall be such, that the risk level is comparable (equivalent) to, or even lower than the reference design.

The risk of an undesired event is a combination of the probability of occurrence of the event and the expected consequences. The consequences of an energy system failure are considered equivalent between all designs. Of course this assumption is valid only under the premise that the design and construction of the systems follows the relevant standards and rules applicable as to the time of design and construction, e.g. battery or PV modules require special care in terms of installation, monitoring, firefighting, etc. A more dedicated review of the risks with respect to PV systems was presented.

The other parameter influencing risks, the probability of occurrence, was assessed by systematically estimating the Mean Time Between Failure (MTBF) of all relevant components, as well as their Mean Time To Repair (MTTR) during the workshops. Dedicated system models, were developed and the system availability of the reference, of the two retrofit designs and of the new design have been estimated.

Two software tools were applied for this: a fault tree analysis tool run in GES and the fault tree analysis tool Hip-HOPS, a specialist system risk assessment tool. The approaches led to slightly different configurations used, components being present and even some implicit properties per component. Because the goal of the research was a comparative assessment of the different designs and not the comparison of two programs, this was accepted. As such, the different approaches can be seen as a sensitivity check, showing the robustness of the results in terms of the overall conclusion.

The analyses results show that the retrofit designs have in general a comparable, slightly better availability than the reference ship configuration, but the new design has a much higher availability due to the inherent redundancy seen in a ring network distribution system. However, at the same time, the more supplies are connected to a distribution line, the more sources of failure, e.g. through short circuit, is expected. This effect can be seen in the port mode, where the reference system performs better than the retrofit, although the retrofit systems have “extra” supply possibilities like the shore connection. This result assumes that the shore connection is not only another source of power, but, at the same time an additional source of failure. If, however, after a failure the connection to shore is kept open (disconnected), then the performance of the retrofit designs is similar to the one of the reference design. For the new build design a similar effect was identified. There are several potential power supplies to the hotel load, but every one brings its potential failures. For that reason, a redundant connection to the hotel load supply is required, which enables a much higher availability.

The overall trends and conclusions for both modelling approaches are the same. Overall, the risk contribution from system failures of the retrofit and new build designs can be considered to be at least of the same magnitude, if not lower, than the reference design. The new build design shows a higher availability when compared to the retrofit and reference designs

Economic analysis is commonly used to support decision-making in relation to the design and development of products, processes, and activities. In principle, it covers the complete life span of the product systems under study and takes into account of all processes involved and costs incurred throughout the entire life cycle. Cost can be classified as tangible and intangible. Tangible costs include initial capital and running costs. Materials, construction and installation costs incurred at the beginning of the lifespan of the product system are typical examples of initial capital cost. Other expenses such as fuel, insurances, financing and interest rates, maintenance, alternation, replacement, disposal etc. that occur throughout the lifespan of the product system are examples of running cost. Meanwhile, any loss of business and disruption cost during installation or renovation are identified as intangible costs. Although intangible costs add additional expenses to the overall performance, both tangible and intangible costs shall be considered separately [9]. In gathering data required for an economic analysis, some general aspects are considered, as follows [9]:

- Source, reliability and age of the data
- Conversion of the data into a meaningful structured format
- Performance of the product system and availability of its performance data, e.g. activity, electricity, gas, water, oil etc.
- Maintenance type, frequency and cost
- Time differences

A number of appraisal techniques can be applied in economic analysis, for example, Payback, Net Present Value (NPV) and Internal Rate of Return (IRR). Payback is a simple method, which measures the time required to return an investment by outflowing all cash flows. Although the method is straightforward, it only considers cash flows within the payback period and does not make proper allowance of the time value of money.

This was followed by an overall assessment on the implementation of existing plant on-board the reference ship, low-cost, low-emission retrofit and new-build configurations where environmental, risk and economic assessments were all taken into account. The LCA results show that the environmental flows can be reduced, in ascending order, by low-cost, low-emission and new-build configurations. As a reduction in all impact categories is not possible in reality, it is reasonable to find no improvement and even more an increment in only a few impact categories for these configurations. Among all, the new-build configuration, i.e. full-electric power plant is preferable due to its superiority in improving the environmental friendliness of marine power plants. To differentiate, the implementation of existing plant and low-cost configuration are unfavourable when compared to low-emission and new-build configurations, which are perceived as acceptable and favourable respectively.

The risk contribution from system failures of the retrofit and new build designs can be considered to be at least of the same magnitude, if not lower, than the reference design. The new build design shows a higher availability when compared to the retrofit and reference designs. The analysis was performed based on the assumption that the consequences of energy system failure of all designs are equivalent, which is only valid under the premise that the design and construction of the systems have followed relevant standards and rules.

From an economic point of view, the new build configuration is perceived as preferable compared to low-cost and low-emission configurations. This is true, in particular, when the oil price is high at a low interest rate. Among all, the new build configuration is identified as the option with the lowest environmental burdens, acceptable risk which requires the lowest investment and life cycle cost. Thus, the implementation of low-cost, low-emission and new-build configurations (with the incorporation of a selection of energy conversion technologies and energy use techniques at various life cycle phases) was certified and justified. It is concluded that while all configurations can be safely implemented, both low-emission and new-build configurations have shown environmental benefits while the latter has demonstrated the potential of cost saving, if compared to existing plant on-board the reference ship.

	Environmental concern	Reliability	Investment and life cycle cost	Total weighting score
Existing plant	Unfavourable (0.1)	Acceptable (0.3)	Acceptable (0.3)	0.009
Low-cost	Unfavourable (0.1)	Acceptable (0.3)	Acceptable (0.3)	0.009
Low-emission (with single-array PV systems)	Acceptable (0.3)	Acceptable (0.3)	Unfavourable (0.1)	0.009
Low-emission (with four-array PV systems)	Acceptable (0.3)	Acceptable (0.3)	Unfavourable (0.1)	0.009
New-build (with 1196 PV modules)	Preferable (0.6)	Acceptable (0.3)	Preferable (0.6)	0.108
New-build (with 1204 PV modules)	Preferable (0.6)	Acceptable (0.3)	Preferable (0.6)	0.108

Table of Final Assessment Conclusions for PV Installation Case Study

I.4. Potential impact and main dissemination activities and exploitation of results

Potential Impact of the Project Results

The use of different energy sources on a vessel represents a difficulty in the energy distribution design which is solved often by the creation of separate networks. Presently, a system which can merge the management of these sources does not exist. The management system, which was created by the project permits the integration of several energy sources together on the same network.

This system will contribute to the greening of the maritime transport and to the reduction of gas emissions particularly in sensitive areas where the management system could select the energy production in priority from green energy sources without stopping the other sources for safety reasons.

The project concentrates on cargo vessels with special emphasis on cost effective energy system optimisation. Through this technology, the project will ensure environmentally friendly maritime transport activities through the greening of ships and maritime operations. It explored innovative solutions and technologies for pollution reduction (greenhouse gases, SO_X, NO_X, particulates, noise), by the rationalisation of energy use and ease of electric ship deployment.

The expected impacts of the project are to:

- Contribute to CO_2 reduction emissions from maritime transport operations aligned with new policy targets, by giving the opportunities to efficiently manage and optimise energy.
- Reduce exhaust and local emissions to reach near-zero-emission levels through the widening of energy sources managed on-board ships.
- Ease the increased share of bio-fuels and alternative hydrocarbon fuels in maritime transport applications, by providing tools for an efficient energy management using different sources of energy.
- Facilitate the introduction of renewable energy sources including hydrogen and fuel cell technology in maritime transport applications by 2020 as an economic, safe and reliable alternative to conventional engines.
- Have a neutral impact on climate change.
- Optimise the energy efficiency of cargo ships for given service and environmental conditions.

Environmental Impact and energy efficiency

The Waterborne sector is the second contributor of the share of the Green House Gas (GHG) emission at European level. In addition, based on EC figures (EU energy and transport in figures – Statistical Pocketbook 2009), a comparison of the GHG emission in tonnes CO_2 equivalent by transport mode with the performance of freight transport mode in tonnes-kilometres clearly indicates that the tendency of the environmental performance of waterborne sector has been increasing with time, unlike most other modes of transport (see figure below). The tendency shows that GHG emissions are rising faster than the activity itself.

The trend for maritime transport increasing its share of GHG emissions is confirmed at global level by a study of International Maritime Organisation (IMO) which states that “by 2050 ship emissions may grow by 150% to 250% compared to the emissions in 2007 (Second IMO GHG study 2009). The primary gateway to reduction of CO_2 emissions is increased energy efficiency; with reduction potential being applicable to all emissions of exhaust gases from ships. Effective integration of different energy sources, including renewable energy sources, will clearly benefit the reduction of GHG emissions produced by maritime transport.

The project aimed to develop a management system to be installed on-board new or existing cargo ships. This management system will contribute to the development of innovative new ships and to refit some vessels with hybrid or full electric propulsion increasing the greening aspect of the maritime transport.

The strategic management of multi energy sources, fuel cells, advanced batteries and green shore power supply "cold ironing" combined to PTO, PTI, PTH systems allows less polluting and lower consumption solutions to be favoured whilst improving the level of safety in various operational conditions and harsh environments. The management system permits the maintenance of all energy sources in service for safety reasons while, for example, only the green sources will be really active thus reducing overall GHG emissions and pollutants such as SO_X , NO_X and particulates.

The deployment of the management system was critical for a complete integration of unconventional sources of energy and will thus increase the share of non-polluting sources of energy on ships. The project gave a clear understanding of the possibilities of greening maritime cargo transport at short and medium terms, and pave the way to good investments in this technology area, giving a technological advantage to European naval equipment industry.

Technology Innovation impacts

Short term scientific impact:
The optimization of various sources of energy aboard ships using different electric networks (AC/DC) and electrical characteristics present the challenge of providing an efficient energy distribution in a safe and reliable way.

The INOMANS²HIP project contributed to provide a better understanding regarding the feasibility to optimise the management of these sources in a single electrical network, to provide a better control of the behaviour, applicability and real-time monitoring, and strategic management of various types of innovative equipment for different types of ships, beyond cargo ships, operating in different environments:

- Various Energy Sources: Solar cells, Wind Turbines, shore-to-ship, diesel engines
- Various Energy Recovery Systems; PTO/PTI/PTH, WHR electrical generation
- Various Storage Systems: Advanced Batteries

The project contributes to demonstrate real advantages of DC grids for marine applications in terms of technical practicality implementation and stability of multi energy source management compared to conventional AC network configured ships.

New tools for Life Cycle Assessment, risk assessment and cost analysis were applied during the evaluation process which can be applied to the maritime sector or in other sectors. A library of new energy components models were developed and made available to be used for innovative ship design.

Long term scientific impact:

This project provides a range of opportunities for a wide variety of electric energy sources including energy recovery, renewable energy and energy storage systems which aim to increase the energy efficiency for both new and existing ships. The relevant technology were a key asset for the optimization of the electric interfaces and global energy efficiency aboard all electric ships.

Contribution to the topics of the WATERBORNE Strategic Research Agenda:

The long-term and short-term scientific outcomes of the INOMANS²HIP project will contribute to the implementation of the WATERBORNE Strategic Research Agenda (WSRA). They fit directly or indirectly to research topic identified in the WSRA Implementation Route Map.

In particular they are in line with the following research topics:

- Next Generation Power and Propulsion Concepts in which the following tools, concepts and processes are awaited:
    - Intelligent electrical power management systems
    - Full electric propulsion
    - Availability, Reliability and Maintainability models
    - Risk analysis and redundancy optimisation
    - Life Cycle Cost (LCC) modelling
- Electric Power & Propulsion Component Design which looks for "new concepts to enable the maximum benefits of electric propulsion, control, manoeuvrability and low noise"2.2.1.2 BESST: Breakthrough in European Shipping & Shipbuilding Technology for Cruise & RoPax which seeks for "increased energy efficiency (hull form, propulsion chain, auxiliary engines)"
- Life Cycle Philosophy which calls for "new tools to allow the analysis of the environmental and economic impact of vessels"
- State of the Art Design and Analysis Tools which requires "development of systems for simulation and modelling of ship operational life cycle costs"

Industrial and Economic Impacts

Ship builders and operators ask increasingly demanding higher efficiency, less polluting electrical systems and safer solutions. Furthermore, we observe from customers' requests, research and development press releases and conferences in this field, a general trend toward the "all electric ship" including electrical auxiliaries, electric propulsion systems and powered actuators and more recently the possibility to integrate all possible green sources of energy to replace current mechanical, pneumatic or hydraulic systems, steering gears, bow thrusters, stabilisers, miscellaneous deck equipment and Waste Heat Recovery Systems (WHRS). This trend calls for a modern, intelligent, unified and computerised control system. The aspect related to optimisation of energy aboard merchant ships calls for a strategic control and management system for the various sources of energy including renewable energy.

The FP7 IP project POSE²IDON demonstrates, in its market study, a growing interest for the electric ship concept in the world fleet. The sector has a growing demand to implement and utilise new energy sources on board of the ships and/or to manage them in an environmental friendly manner. Europe is the world leader in the field of electric propulsion for ships. The use of advanced, greener safer and more efficient sources of energy managed in a strategic way further supports its position as a world leader in this sector. The project will benefit to European equipment suppliers, ship operators, and the renewable industry by generalising the implementation of advanced energy technologies to a broad range of marine and offshore applications, improving commercial competitiveness a global industry and securing jobs within the industries affected.

A study on Competitiveness of the European Shipbuilding Industry issued on 8th October 2009 for the Directorate-General Enterprise & Industry of the European Commission (pp 174 – 175; Authors: ECORYS, Teknologisk Institut, Cambridge econometrics, CES ifo, idea consult) shows that:

- European shipyards follow a specialisation strategy where innovation and new product development are more important than low cost strategies.

- European marine equipment suppliers try to adopt a strategy of continuous innovation and R&D to keep ahead of competition.

INOMANS²HIP will provide results to support and strengthen with the competitive strategy and effectiveness of European ship builders and European marine equipment suppliers by providing innovative outcomes. System management is the crucial part of energy production, distribution and consumption. It is therefore essential to develop innovation and knowledge in this direction to maintain a competitive electric industry and particularly in the maritime transport where Europe is recognised as the leader of electric propulsion. The proposed management system will support and encourage this leadership position. In addition, in comparison with conventional propulsion and energy generation, it is envisaged that electric propulsion leads to advantages in terms of comfort, power needs, fuel consumption, emissions, maintenance and life-cycle costs. More efficient ships will be built through European-led technology and this will give a competitive advantage to European industry.

Since the INOMANS²HIP consortium proposes to develop an easier integration of several energy sources, the project could benefit to industry outside the waterborne sector such as the European renewable energy sector by facilitating integration of different sources and therefore their implementation at a large scale.

<u>Relevance to Policies</u>

The outcomes of the **INOMANS²HIP** will contribute to the EU's maritime transport policy (Communication from the Commission to The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions Strategic goals and recommendations for the EU's maritime transport policy until 2018, COM(2009) 8 final, dated 21/01/2009), since it is relevant to:

- Ensuring steady progress towards a coherent and comprehensive approach to reduce greenhouse gas emissions (GHG) from international shipping, combining technical, operational and market-based measures.

- Overseeing the smooth implementation of the amendments adopted by the IMO in October 2008 to MARPOL Annex VI to reduce sulphur oxides and nitrogen oxides emissions from ships. This includes assessing which European sea areas qualify as Emission Control Areas, the availability of the adequate fuels and the impacts on short-sea shipping. The Commission's proposals should ensure that modal 'back-shift' from short-sea shipping to road is avoided.

- Promoting a European Environmental Management System for Maritime Transport (EMS-MT), targeting the continuous improvement of the environmental performance of shipping; consider modulation of registration fees, port dues and other charges, with a view to rewarding efforts towards greener shipping.

<u>Contribution to standards</u>

GICAN will have the scientific role to propose modifications of some electric maritime and naval standards according to the performances obtained by the management system. Contributions will be sent to OMI, AFNOR, ISO in order to standardise electric interface guidelines.

The proposed technology will have an application on-board a large range of ships – new and existing – allowing an immediate energy saving. This may also be linked to the definition of new electrical interface standards allowing an easy connection of different energy sources without being obliged to redesign totally the energy distribution system on-board.

Main Dissemination Activities

INOMANS²HIP project corresponds to a R&D development "close to market", a situation which explains why the majority of deliverables – and the most important – are classified "Confidential". In such cases only the authors of the corresponding deliverables are authorised to disclose the information contained in the documents.

This situation limits considerably the dissemination activities to specific information when "important milestones will be achieved" as mentioned in the DoW. The disclosure of material took the following forms:

- Development and update of the website with an alert to a dedicated audience
- Press releases on partner's initiative
- Individual participation to conferences or exhibitions
- Edition of posters, flyers or short newsletters to be distributed during these conferences or exhibitions.
- Sharing information with other similar projects and interested organisations
- Journal articles and papers
- Organising workshops and IAB meetings

The dissemination agenda depended, also on the results and their possible content able to be disseminated. In previous periods no real valuable information was available for dissemination because the project was suspended and restarted with the market study being completed at the end of Period 2 (M36) and all previous deliverable reports being resubmitted. In this period, which covered 18 months of the project (M37-M55), all of the technical objectives of the project were completed. Since all the objectives of the project were met during this period dissemination of results could proceed, subject to individual partner's agreement, the consortium agreement and EU project regulation. Not all results could be full disseminated due to confidentiality of some commercial sensitive information. However, as much as possible of the project's work and results was disseminated as possible in the time remaining of the project.

The targeted audience may be composed of:

- Potential users of the project results: Ship-owners and Shipyards
- Promoters of other projects linked to the current project and its goals under the form of cross-fertilization
- Researchers and other "experts" working in the same field and more specifically in the field of energy management

- Maritime equipment industry acting on the power generation domain: electrical equipment (converters), Diesel generators with low emissions, fuel cells, photovoltaic technologies, renewable energies in general
- Agents and political institutions linked to the project's goals and subject
- Ministries of Transport, Education and Research
- National and European maritime clusters such as Waterborne Technology Platform, SEA EUROPE – Community of European Shipyards' and Marine Equipment' Manufactures' Association, ECSA - European Community of Ship-owners, EWEA – European Wind Energy association)
- EU DG Research, DG Transport and European Maritime Security agency EMSA
- International Energy Agency
- The wider maritime industry
- An interested members of the general public

At the beginning of the project a competition was held at a design college in Paris to design a project logo. The following design won the competition

INOMANS²HIP Logo

Industrial Advisory Board Meetings

Three IAB meetings are were organised to harbour an external point of view on the project orientations and on the pertinence of some development. Prior to the meeting a theme and subsequently a list of questions were thought of by the partners in close relation with the present situation of the project. For this reason the IAB calendar was directly influenced by the project development, the value of its results and the problem linked to the research confidentiality.

- IAB No. 1, Amsterdam 24th June 2014; Topics for discussion were;
    - Advanced operational control systems
    - Impact future on marine markets, legislation & costs
    - Main electrical novel grid architecture (AC vs DC)
    - Numerical simulation process
- IAB No.3, Amsterdam 25th June 2015; Topics for discussion were;

  - Advanced operational control systems
  - Impact future on marine markets, legislation & costs
  - Main electrical novel grid architecture (AC vs DC)
  - Numerical simulation process
- IAB No.4, Rotterdam 4th November 2015; Topics for discussion were;
  - Advanced operational control systems
  - Impact on future marine markets, legislation and costs
  - Main electrical novel grid architecture (AC vs DC)

In addition, three workshops were organised of marine experts to demonstrate the EMS and HMI control systems, as well as disseminate results and gauge expert opinion. Two workshops were organised to coincide with some of the IAB meetings to maximise participation and minimise costs.

- HAZID workshop, Amsterdam 24th June 2014
- Propulsion HMI workshop, Waalwijk 10th September 2015
- EMS & HMI demonstration workshop, Rotterdam 4th November 2015

Website and Other Internet Activities

The Website is available at the following address: www.inomanship-ip.eu

Throughout the project the website has maintained by adding new and updating older webpages to provide information about the project to the public. This included a project blog, videoed interviews of consortium members, photographs, public reports, synopsis of confidential reports, etc. Below are just some of the screenshots of the INOMANS²HIP website.

The website had 4,761 visits over the period from October 2013 to February 2016, with a peak of 444 hits in March 2014 and average of 164 visits/month..

In addition to the website, extra online dissemination activities were carried-out and managed by NAREC included:

- LinkedIn group on the following site: https://www.linkedin.com/groups with 118 members
- YouTube videos with a total of 119 views over the past few months
  a. LCA study interview: - https://www.youtube.com/watch?v=vVNwgc0QGRo with 28 views over two months
  b. INOMANS2HIP demonstrator facility: - https://www.youtube.com/watch?v=XZitMHoPoyA with 21 views over three months

  c. INOMANS2HIP interview with Edward Sciberras: - https://www.youtube.com/watch?v=eJu7wVZe8v8 with 70 views over six months

- Twitter account: https://twitter.com/inomans2hip with 72 followers, 123 tweets and 251 following

In addition to the INOMANS²HIP website and social media activities, the project has a presence on a number of marine related websites and social media sites. This includes individual partners have posted a description of the project on their company websites, as well as commercial directories and information sites.

Publishable Articles and Journal Papers

During this period of the project, a number of partners have been involved or are still involved in preparing papers and articles for publication. This includes journal and conference papers, as well as three postgraduate dissertations/Thesis. A list of some of the highlights of the papers being published are shown below.

- Energy Management: "adapt your engine to every mission", - A. Breijs (IMTECH) ; Published in Engineering the triple A navy: Active, Adaptive and Affordable (2016)
- LCA – Assessment of the Conventional Marine Power System On-board a Ro/Ro Cargo Ship - Janie Ling Chin and Anthony P. Roskilly (UNEW), Published in The International Journal of Life-Cycle Assessment (2016)
- Investigating a conventional and retrofit power plant on-board a Roll-on/Roll-off cargo ship from a sustainability perspective - a life cycle assessment case study - Janie Ling-Chin and A.P. Roskilly (UNEW), Published in Energy Conversion and Management (2016)
- Advanced Real-time Ship Modelling for the Control & Optimisation of Multiple Alternative Energy Sources On-Board a Ro/Ro Cargo Ship - Hans van Vugt (TNO), Jonathan Heslop (UNEW), Edward Sciberras (UNEW) & Leo de Vries (WARTSILA), Presented at COMPIT 2016 Conference (May 2016)
- Feasibility Study of Ship Integrated Photovoltaic Systems - Matthew Thomas Pitt (UNEW), MSc Dissertation (2012)
- Study in Advanced Marine Electrical and Power Systems - Edward A. Sciberras (UNEW), PhD. Thesis (March 2016)
- Life Cycle Assessment (LCA) of marine power technologies - Janie Ling Chin (UNEW), PhD. Thesis (2016)

Conferences and Events

During the last Maritime Industry Brokerage Event (MIBE) in November 27th, GICAN participant, Pierre Marchal, explained the INOMANS²HIP objectives to his contacts individually.

Pierre Marchal and Jacques Peyron of GICAN participated on April 14th and 15th to the TRA2014 conference by presenting a poster explaining the aim of the project. Approximately 100 leaflets have been distributed, giving more detailed information. Members of GICAN also attended the EURONAVAL exhibition held in Paris in October 2014, were they handed out leaflets about the project as well as general discussions with marine industry representatives. In February 2015, they also attended the EUROMARITIME exhibition in Paris representing the project with a poster display and talking generally to the wider marine industry.

In addition to attending conferences, Pierre Marchal of GICAN also presented the ideas and concepts developed in this project at the French Maritime RDI committee in Paris and at the SEA European RDI committee in Brussels. This work is ongoing and will continue to raise the concepts and ideas developed in this project for possible future areas of research.

A number of partners will participate to the "Electrical and Hybrid Maritime Propulsion" conference in Amsterdam on June 24th to 26th as speakers on following topics:

- "Method of implementing hybrid propulsion with LNG power generation" by:
    - Jonathan Heslop, research assistant, Newcastle University, Swan Centre, UK
    - Leo de Vries, senior manager propulsion systems, Wärtsilä Netherlands BV, Netherlands
- "Improved vessel performance by smart energy management: a joint effort between the owner and system supplier" by:
    - James Anderson, senior technical manager, Caledonian Maritime Assets Ltd, UK
    - Alexander Breijs, consultant, Imtech Marine, Netherlands
    - Walter van der Pennen, consultant, Imtech Marine, Netherlands

IMTECH also represented the project at the Electric and Hybrid Maritime Conference 2015, in Amsterdam from 25th – 26th June 2015.A poster was created for INOMANS²HIP project in December 2014 presenting objectives, methodology, results and green ship solutions. The poster is currently on display in the 2nd Floor of Stephenson Building in Newcastle University, which is accessible to all academics, students and visitors who walk pass there. In addition, it was exhibited at the following events organised by Newcastle University:

- A one-day visit of The UK's Engineering and Physical Sciences Research Council (EPSRC), which is one of the key funding bodies for research in engineering and the physical sciences. The meeting took place on the 10th December 2014. More than 90 academic and researchers based in Newcastle University attended the event for presentation and poster exhibition;
- The 3rd Sustainable Thermal Energy Management International Conference (SusTEM2015), which took place in Newcastle on the 7th and the 8th of July 2015. There were more than 110 delegates attending the conference where posters were displayed throughout the event.
- Industrial Forum on Thermal Energy Management in Newcastle on the 9th of July 2015. The one-day forum was attended by 42 delegates, mainly from industries across the UK as well as a few from Europe and the USA.
- Networking Meeting of a national industrial academic research partnership network named Sustainable Innovation in Refrigeration Air Conditioning and Heat (SIRACH), 5th February 2015. The one-day event focused on opportunities, challenges and new solutions for heating and cooling.

In addition to these events and conferences that have been identified as partners directly discussing the work of the INOMANS²HIP project, partners attended other conferences and events were this project and its related concepts were indirectly discussed.

I.5. The address of the project public website and relevant contact details

http://inomanship.eu

II. Use and dissemination of foreground

Dissemination Activities of Foreground Results

template A2: list of dissemination activities

NO.	Type of activities[1]	Main leader	Title	Date/Period	Place	Type of audience[2]	Size of audience	Countries addressed	ECAS
1	Presentation	P. Marchal / GICAN	Maritime Industry Brokerage Event (MIBE)	27-29/11/2013	Santiago de Compostela (Spain)	Scientific Community (higher education, Research), Industry	200	Europe	ok
2	Poster, leaflets and interviews	P. Marchal - J. Peyron / GICAN	TRA2014 conference	14-15/04/2014	Paris	Scientific Community (higher education, Research), Industry	50	Europe	ok
3	Conference	J. Heslop / UNEW W. ven der Pennen / IMTECH	Electrical and Hybrid Maritime Propulsion" conference	24-26/06/2014	Amsterdam	Scientific Community (higher education, Research), Industry	50	International	ok
4	Leaflets and interviews	P. Marchal - J. Peyron / GICAN	Exhibition EURONAVAL	27-30/10/2014	Paris	Naval and maritime communities	100	International	ok
5	Leaflets and interviews	P. Marchal - J. Peyron / GICAN	Exhibition EUROMARITIME	3-5/02/2015	Paris	French maritime communities	50	France	ok
6	Contribution	P. Marchal / GICAN	Proposal for topic for EU call: DC distribution on board and Energy management	18/06/2014	Brussels	SEA Europe RDI committee		Europe	no
7	News	P. Marchal / GICAN	GICAN Newsletter: "Zoom sur le projet européen INOMANS²HIP"	01/10/2015	Paris	French maritime communities	200	France	ok
8	Conference	All partners/WARTSILA	Inomans²hip conference	04/11/2015	Rotterdam	Experts, Deft University and invited personalities	200	Netherlands	ok
9	Presentation	P. Marchal / GICAN	INOMANS²HIP project conclusions	on-going	Paris	French maritime RDI committee - Ministery		France	NO
10	Presentation	P. Marchal / GICAN	INOMANS²HIP project conclusions	on-going	Brussels	SEA Europe RDI committee		Europe	NO
4	Thesis	Janie Ling Chin/UNEW	Life Cycle Assessment (LCA) of marine power technologies	on-going	Newcastle	Scientific Community (higher education, Research)		International if the thesis is made available online	NO
5	Video/interview	Janie Ling Chin, interviewed by Tom Bradley/UNEW	Life Cycle Assessment (LCA) for environmental studies	30/11/2015 onwards	Inomaship website (http://inomanship.eu/video s/)	Public		International	ok
11	conference/oral	Janie Ling Chin	The UK's Engineering and Physical Sciences Research Council (EPSRC)	10/12/2014	Newcasle uk	Scientific Community (higher education, Research)	90	UK	OK
12	conference/poster	Janie Ling Chin	The 3rd Sustainable Thermal Energy Management International Conference (SusTEM2015),	07/07/2015	Newcasle uk	Scientific Community (higher education, Research)	110	UK	OK
13	poster	Janie Ling Chin	Industrial Forum on Thermal Energy Management	09/07/2015	Newcasle uk	industry, researchers	42	UK, europe, usa	OK
14	poster	Janie Ling Chin	Sustainable Innovation in Refrigeration Air Conditioning and Heat (SIRACH)	05/02/2015	Newcasle uk	industry, researchers		uk	OK
15	Company internal article	Erich Rüde / DNV GL		16/12/2015 onwards	DNV GL intranet	industry, researchers	5000+	International	ok
16	Web	T. Bradley / NAREC	www.inomanship.eu	24/07/2013	Inomaship website (http://inomanship.eu/video s/)	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	4401	International	no
17	Video	T. Bradley / NAREC	Peter Rampen - INOMANS2HIP Demonstrator	01/10/2015	Inomaship website (http://inomanship.eu/video s/)	Scientific Community (higher education, Research), Industry, Civil Society, Medias	62	International	ok
18	Video	T. Bradley / NAREC	Edward Sciberras - Particle Swarm Optimisation	01/11/2015	Inomaship website (http://inomanship.eu/video s/)	Scientific Community (higher education, Research), Industry, Civil Society, Medias	14	International	ok

19	Video	T. Bradley / NAREC	Tony Roskilly - INOMANS2HIP project	01/11/2015	Inomaship website (http://inomanship.eu/videos/)	Scientific Community (higher education, Research), Industry, Civil Society, Medias		International	ok
20	Web	T. Bradley / NAREC	INOMANS2HIP twitter	01/10/2013	Inomaship website (http://inomanship.eu/videos/)	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	71	International	
21	Web	T. Bradley / NAREC	INOMANS2HIP LinkedIn Group	01/05/2014	Inomaship website (http://inomanship.eu/videos/)	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	120	International	
Future participation									
22	Conference Compit 2016	Hans van Vugt	A Power System Modelling Approach to Investigate On-board Configurations for Alternative Energy Generation Technologie	9-11 May 2016	Lecce / Italy	Public		Internatinal	

Published Articles and Papers

template A1: list of scientific (per reviewed) publications, starting with the most important ones										
NO.	Title	Main author	Title of the periodical or the series	doi	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[1] (if available)	Is/Will open access[2] provided to this publication?
1	Energy Management: "adapt your engine to every mission"	A. Breijs (IMTECH)	Engineering the triple A navy: Active, Adaptive and Affordable	2016	INEC 2016 http://www.inec.org.uk/	UK	2016	paper / 4000 words	TBC	yes
2	Life cycle assessment (LCA) - From analysing methodology development to introducing an LCA framework for marine photovoltaic (PV) systems	Janie Ling-Chin, Anthony P Roskilly (UNEW)	Renewable & Sustainable Energy Reviews	doi:10.1016/j.rser.2015.12.058	Elsevier Limited	International	2016	tbc	TBC	yes
3	LCA – Assessment of the Conventional Marine Power System On-board a Ro/Ro Cargo Ship	Janie Ling-Chin, Anthony P Roskilly (UNEW)	The International Journal of Life-Cycle Assessment	on-going	Springer	International	2016	tbc	TBC	Yes
4	Investigating a conventional and retrofit power plant on-board a Roll-on/Roll-off cargo ship from a sustainability perspective - a life cycle assessment case study	Janie Ling-Chin, Anthony P Roskilly (UNEW)	Energy Conversion and Management	on-going	Elsevier Limited	International	2016	tbc	TBC	yes
5	A Power System Modelling Approach to Investigate On-board Configurations for Alternative Energy Generation Technologie	Hans van Vugt (TNO), Jonathan Heslop (UNEW), Edward Sciberras (UNEW) & Leo de Vries (WARTSILA)	Conference Compit 2016	9-11 May 2016	Lecce / Italy	Public	2016	tbc	TBC	yes
6	Feasibility Study of Ship Integrated Photovoltaic Systems	Matthew Thomas Pitt (UNEW)	MSc Dissertation	Aug-12	UNEW	UK	2012	100	TBC	yes
7	Study in Advanced Marine Electrical Systems	Edward A. Sciberras (UNEW)	Ph.D Thesis	Sep-15	UNEW	UK	2015	200	TBC	yes
8	Life Cycle Assessment (LCA) of marine power technologies	Janie Ling Chin (UNEW)	Ph.D Thesis	on-going	UNEW	UK	2016	200	TBC	yes