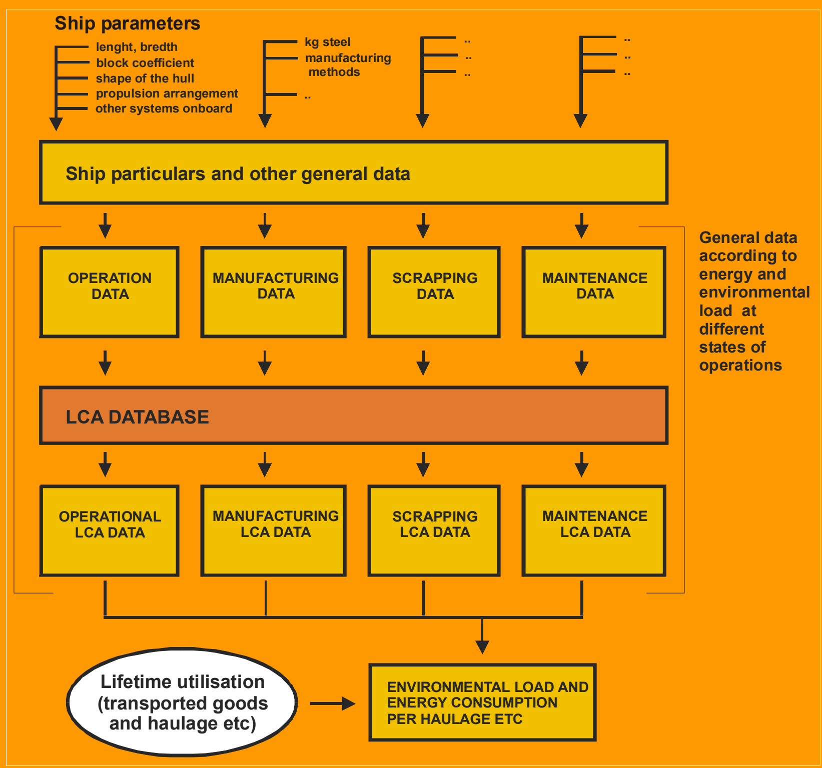
Computer application manual:

LCA-ship

A Life Cycle Analysis Tool for Ships

Prototype version 1.0

2004-08-30



SSPA **TEM** **MariTerm AB**

TABLE OF CONTENT

TABLE OF FIGURES

INTRODUCTION

This is the computer application manual for the *prototype application LCA-ship 1.0*.

The software tool/application *LCA-ship* is a result from the research project *Design tool for energy efficient ships* performed in 2002-2004. The project was sponsored by ***VINNOVA*** and ***The Swedish Energy Authorities*** together with industrial partners the projects. Industrial partners in the project have been:

- *The Swedish Ship Owners Association*
- *Ecoship Engineering AB*
- *Stena Rederi AB*
- *Wallenius Lines*
- *Munters Europe AB*
- *Gorthon Lines AB*

The scheme in **Figure 1** is based on the original work program overview taken from the first project description. The general idea of the project is to make it possible to estimate and compare environmental load from ship operations. The estimated environmental load can be seen as consumed energy or/and consumed/emitted resources/substances from all ship operations in a life cycle perspective. Thereafter these results can be analysed in respect to the vessels total life cycle, transported goods or haulage (functional unit). Also the estimated environmental load can be analysed with different characterisation and valuation tools.

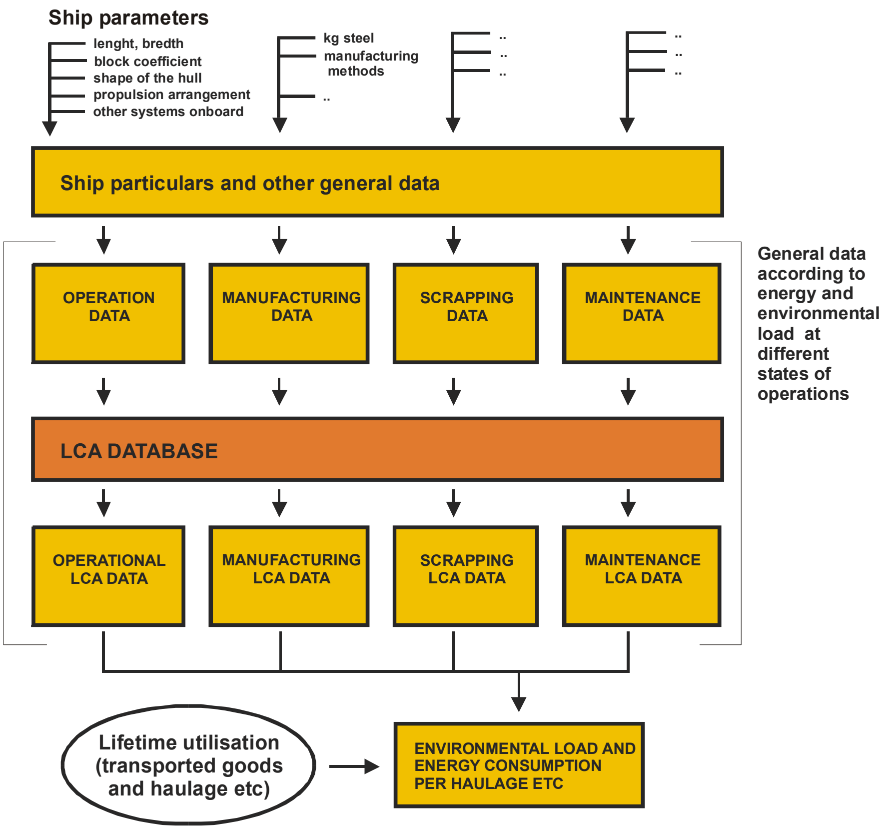


Figure 1 *Structure overview of the tool.*

There are some explicit conditions made in the original project description that have been important to include in the tool:

- In the project developed methods and the computer application should be based on a life cycle perspective
- It should be able to estimate energy consumption in the tool for a vessel based on given ship parameters and operational handling
- The tool should allow to relate the environmental load from the ship with the haulage or other benefits that the ship produces in a lifetime perspective

To fit to the budget of the project it was also stated in the original project description that the developed application should be a practicable working prototype. Some simplifications have therefore been made, that probably not could be accepted for commercial applications.

Some comments to the application

The users input to the application are the kind of information that is normally found in a shipping company concerning vessel data and the vessel movements. It all starts with defining the ship to be analysed and it follows by defining how the ship is used over the lifetime.

The application contains compiled and processed background information about specific materials and processes (LCA data) connected to shipping operations. The included LCA data makes it possible to calculate the environmental impact on the basis of the entered ship's data and ships' movement data. The LCA data is included in the tool in a processed form. LCA data for steel will for example include the environmental load from the production of steel, the process to build the steel structure of the ship and the scrapping and recycling phase. To be able to calculate the environmental load from the use of steel the amount of steel must also be known. The processed LCA data that the tool contains is the key factor to make it possible to perform life cycle analysis[1] of such complicated processes as a ship.

The calculated environmental impact can thereafter be analysed in respect to different operations, life cycle phases etc. To make simple comparisons between ship concepts etc., the calculated environmental impact can also be evaluated using different valuation models.

All calculations are made and stored under a ship name. Information is also entered and stored under the specific ship in the database, and it is not possible to use or access this when defining/calculating other ships. The reason for this is to prevent errors caused by non-consequent data (this is a prototype tool simplification that perhaps can be changed in a full version).

The computer tool *LCA-ship* has been developed using C# and Microsoft .NET technology. Ship data are stored on disc as xml file structures and can be exported to other computers assuming that the computer tools are of the same build version. The LCA files and Analysis methods are also stored as xml file structures, which can be replaced, removed or extended during runtime without any rebuilds.

[1] The LCA calculations will be valid for the specific cases on the base of the process that is used in LCA data enclosed in the tool. Other cases could yet be estimated with these data even if the base production processes will vary from case to case.

New LCA files can not be produced by the computer tool, but can be manufactured by hand or generated by other software, such as LCAIT and then converted to xml files.

No third party product has been used for the development of the computer tool, and is not required to run the application.

The tool comprise several parts: the executable application, dll component containing graphic controls (produced by SSPA Sweden AB) and functions to predict energy consumption (also produced by SSPA Sweden AB), xml files that store data for individual ships, xml files holding LCA data (produced by TEM and converted by SSPA Sweden AB), xml files holding Analysis methods (produced by TEM and converted by SSPA Sweden AB) and files holding default values.

The computer tool can be run on any Windows computer running the Microsoft .NET Framework 1.1. If the framework has not been installed, the framework can be downloaded and installed free of charge from Microsoft's website: https://www.microsoft.com.

More detailed information about theories behind the different modules, LCA data, categorisations- and valuation models in the application etc. can be found in the final report[2] of the research project.

[2] Jivén K., Sjöbris A., Nilsson M., Ellis J., Trägårdh P., Nordström M., 2004, *LCA SHIP, Design tool for energy efficient ships - A Life Cycle Analysis Program for Ships*, Final report: 2004-08-27, MariTerm AB et al, Gothenburg.

APPLICATION MENUS

Overview

The use of the application is straightforward and the application is structured quite the same way as the user would have worked without the application. The overall application overview can be seen in **Figure 2**. In the *Overview* menu, the user can see if data is missing or if enough data is entered to be able to perform the analysis. The sheet also contains compiled information about the vessel and operations that's going to be analysed.

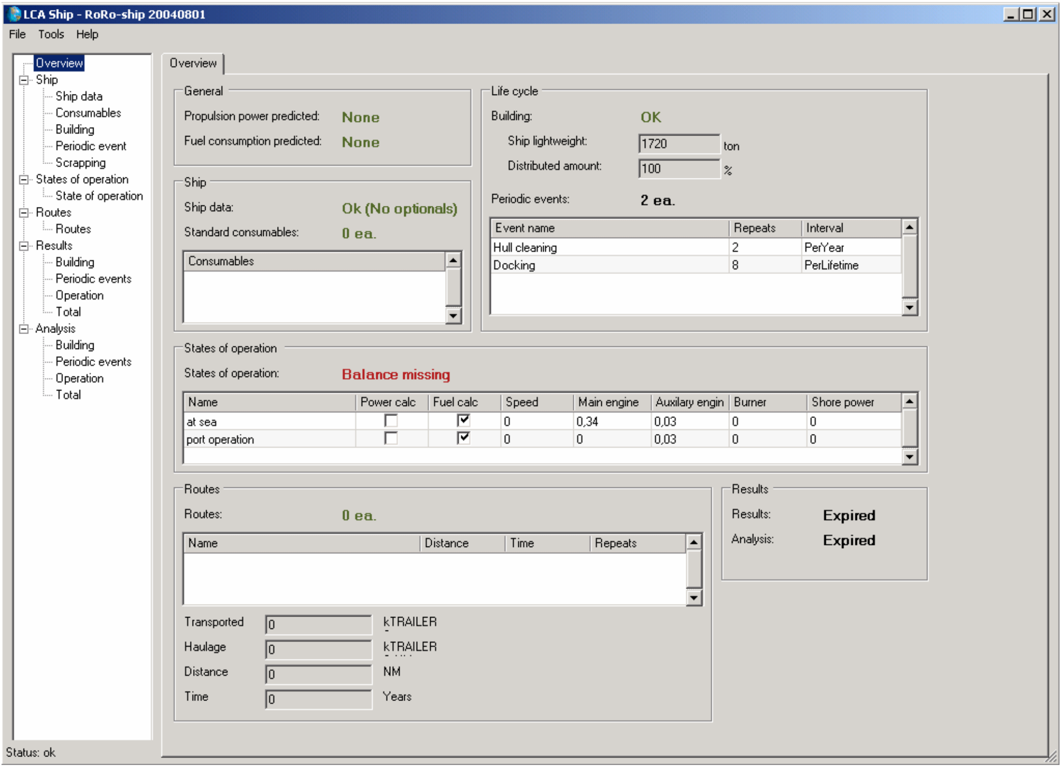


Figure 2 *The overview page contains compiled information regarding data entered into the application.*

To the left in **Figure 2** the application structure can be seen. Analyses of a ship concept start with the entering of ship data into the application in the *Ship* pages. Information to be entered is ship parameters as well as operational data for different kind of usage during the vessels active phase. The information will give the application such information so that environmental load from building, scrapping and periodic maintenance and finally the lifetime use/operation of the vessel can be calculated. The user of the application can use different application modules to estimate some parts of the required data. Examples of estimation modules are *required propulsion power module* at various operational conditions and *energy system planning modules* for energy use onboard.

The vessels performance can be entered for as many operational phases, so called *State of operation,* that are needed in order to specify the usage of the vessel in an accurate manner. An operation phase can describe the vessel entering the harbour, during loading operations or at sea under specific conditions etc.

A vessel's environmental load will vary with the use of the ship over the life cycle. These variations will be seen both in the vessel's total environmental load and per transported amount of goods. A defining of the vessel's use over the lifetime is therefore needed. The use of the ship over the life-time is specified with respect to travelled distance, the use over time, the ships different states of operation and the goods flow. The information regarding the use over the lifetime is entered in the module *Routes*.

After information about the ship and ship performance and the lifetime usage is entered, the total environmental load can be calculated. The calculated environmental load can be viewed in the module *Results*. Results can be viewed in respect to the whole lifecycle, a specific phase or specific *Route* etc per transported amount of cargo, per haulage or per travelled distance of the ship.

To make comparisons between different phases of a vessel, between vessel concepts and different utilisation easier, the calculated results can also be evaluated and viewed in the *Analysis* module.

Ship

Ship data

Main ship parameters are entered under *Ship data*. These parameters are used or can be used in different modules as estimations of required propulsion power etc.

Information entered in the *Ship data* menu are first of all the *Ship name*, *Cargo unit* and the vessels *Cargo capacity*. If the power prediction module is to be used, mandatory respective voluntary power prediction data should also be entered. The *Ship data* menu can be seen in **Figure 3**.

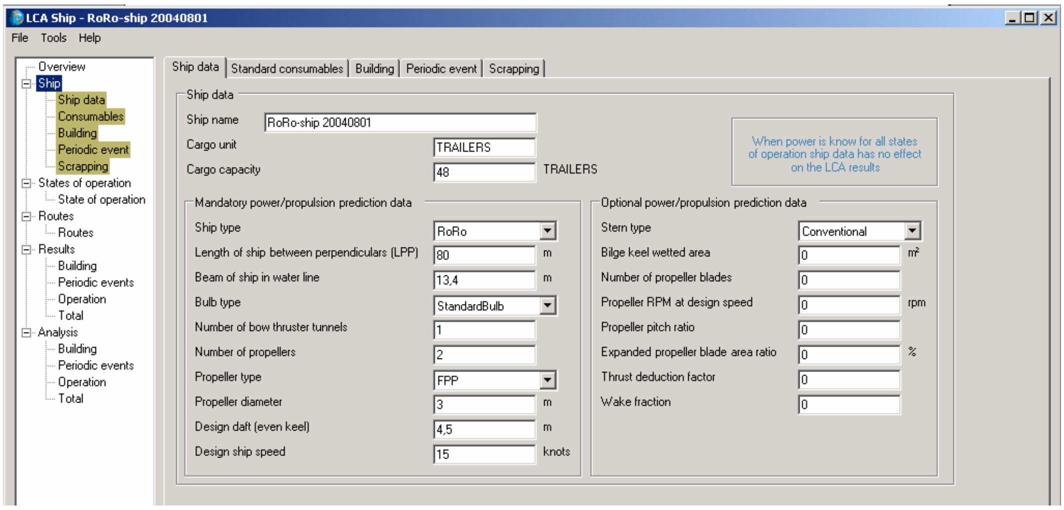


Figure 3 *Ship data menu under Ship.*

Consumables

In order to make the data entering faster it is possible to define some standard consumables used onboard in the menu *Standard consumables*, seen in **Figure 4**. These consumables will be default consumables in most of the menus and wizards where consumables are chosen and quantified.

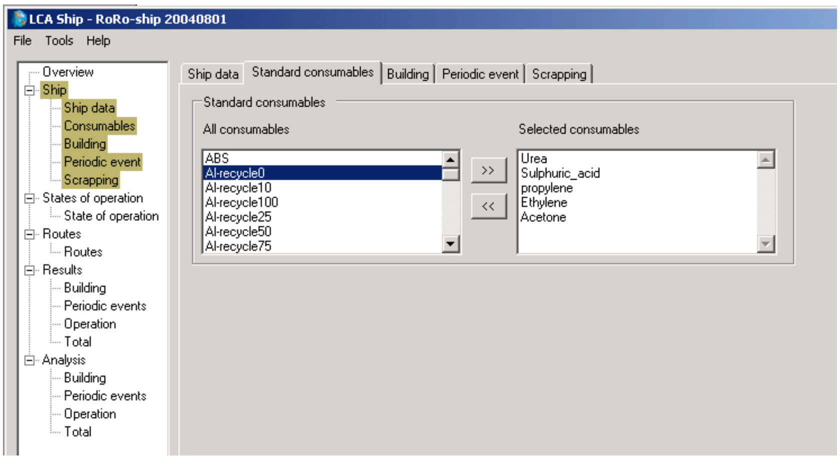


Figure 4 *Default consumables are defined under Ship, Standard consumables.*

Building and scrapping Page

The category *Lightweight components* are used to define the composition of the total lightweight of the ship in terms of different type of materials/components. This is done by entering a percentage of the total lightship weight for components in a fixed list. The list is fixed because the components in the list must have related life cycle data. The lightweight distribution is further used in calculations of environmental load in the building, maintenance and scrapping phase.

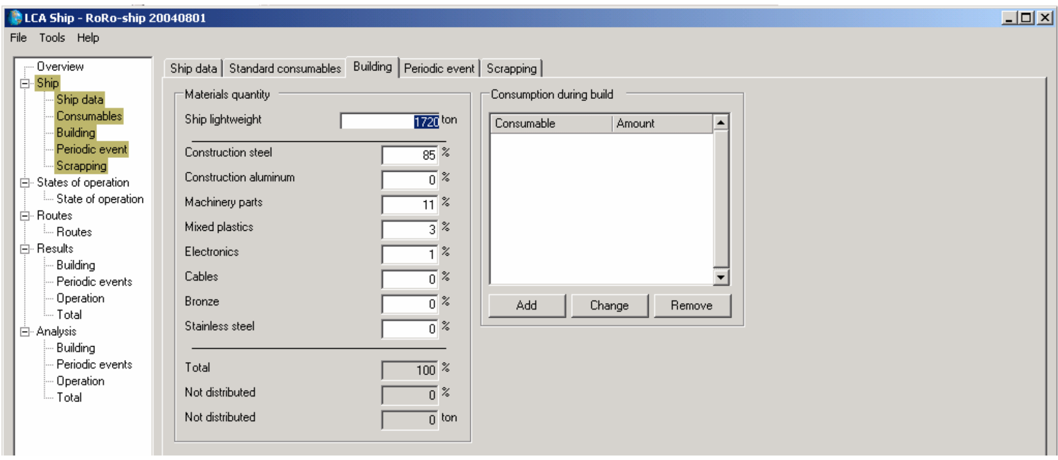


Figure 5 *Building makes it possible to specify the vessels lightweight and special consumption during the building phase.*

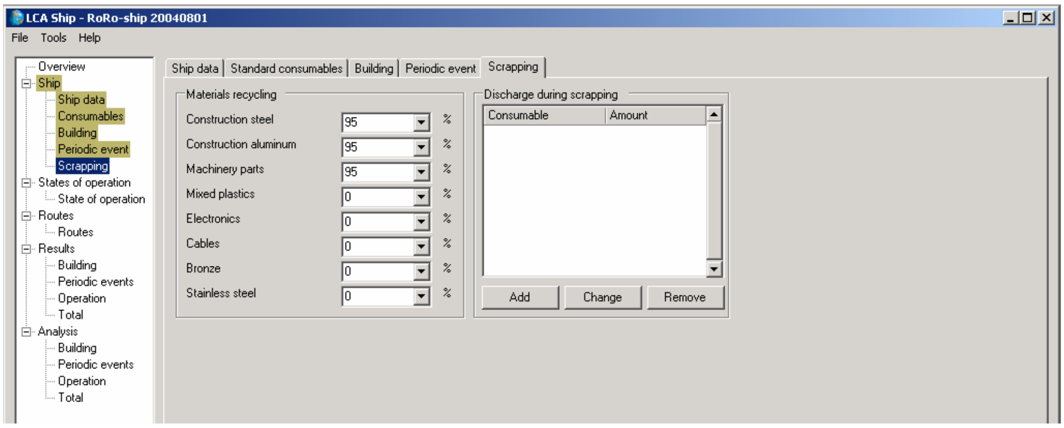


Figure 6 *The specification of information regarding Scrapping of the vessel.*

Periodic event

Different kind of periodic or constant consumption, maintenance and repairs, and the environmental load connected to these activities, can be entered in the menu *Periodic event*, see **Figure 7**. These occasions can be specified numbers of occasions per year or per lifetime. The environmental load connected to a *Periodic event* is given in respect to material that is substituted onboard and/or per consumables consumed.

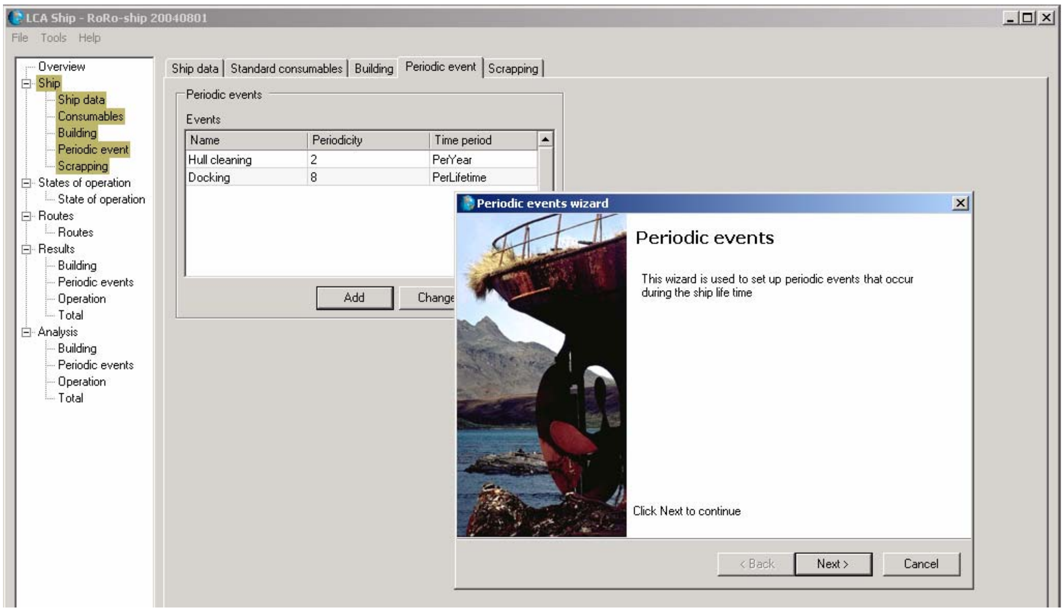


Figure 7 *Periodic events are specified in a wizard.*

States of operations

During a vessels active phase, the vessel will be used under continuous changing operational performance. The consumption of energy will vary with load conditions, speed, engine tuning etc. In the same way, other consumption and amounts of emitted substances will vary over time. To be able to model the environmental load from the vessel, per period, specific operation, or per the whole lifecycle, operational data for the usage of the vessel had to be entered.

The operational data is entered by the help of *States of operations*, operational data for different major operational conditions. The user of the application decides how many load conditions/ *state of operations* that is going to be entered, to make it possible to describe the vessels operational life accurate enough. This will vary with the kind of service, access to information, purpose of the analysis etc.

A State of operation consists of some specific data:

- Name of the State of operation and speed (at sea states)
- Type of energy consumed in the engines/consumed in the shore power system
- Amount of energy consumed in the Main engine, Auxiliary engines, Burners and Shore power system
- Emission factors for the engines at actual conditions (State of operation)

A *State of operation* can either be at sea or at the quay. A *State of operation* at sea must have a speed entered. A Ro/Ro service could be modelled with for example two states of operations in a simplified analyse. One *State of operation,* specifying the performance at sea at a specific speed and another *State of operation* covering port operations. The consumption of fuel/energy at sea respectively in port is given together with the defining of emission factors etc. The menu where *States of operations* are specified can be seen in **Figure 8**.

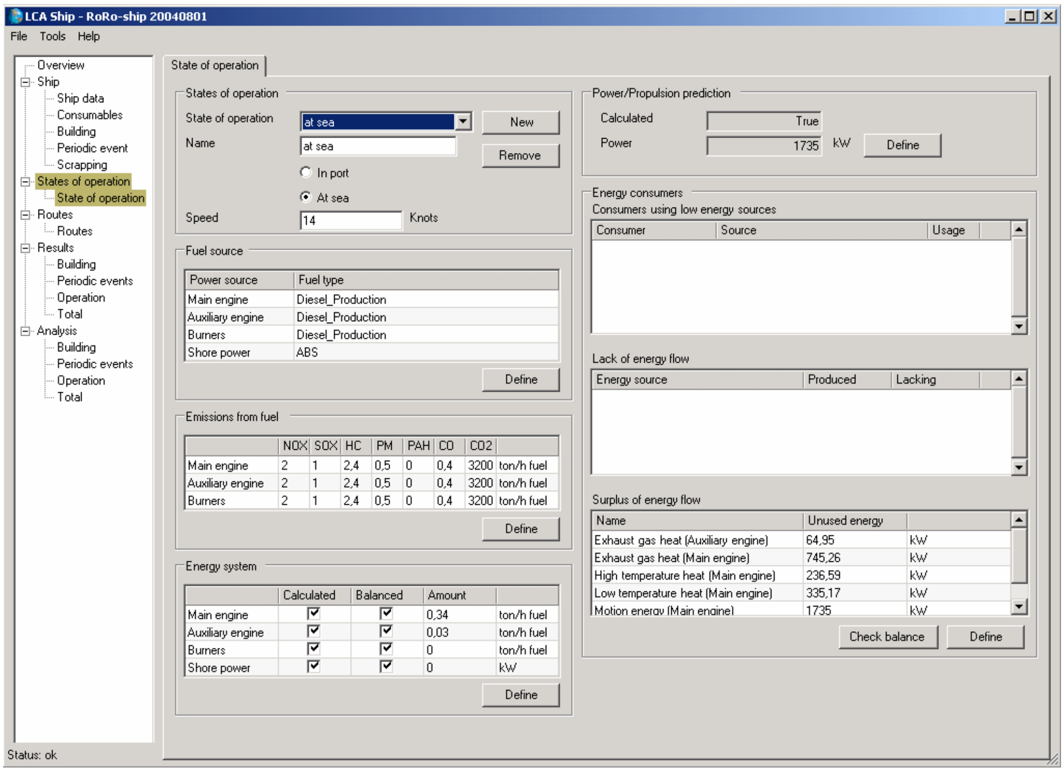


Figure 8 *State of operations menu.*

The specification of a *State of operation* starts with the choices of energy used in respectively engine and the specification of *Emissions from fuel* (emission factors) for each type of engine system (*Main Engines*, *Auxiliary Engines*, *Burners* respectively electrical mix in case of the use of shore to ship power connections). As the energy consumption could be known for a specific *State of operation* or had to be modelled, the process of data entering can differ slightly. The amount of energy used onboard can either be modelled/calculated or directly entered.

In the case that the energy consumption for the *State of operation* is known it is just entered. Use the *Define* button under *Energy systems* and choice *Fuel consumption known* in the wizard.

If the energy consumption is going to be estimated or optimised, the whole energy system onboard can be modelled.

To define consumption of energy and emission factors, the user could either enter known figures or take help of the application modules. There are modules for following energy calculations, specification and modelling:

- An energy system defining module (found under *Energy systems*)
- Propulsion power prediction module (Found under *Power/Propulsion prediction* respectively under *Energy consumers*)

Energy system modulation module

In order to module the energy consumption onboard, the specification of energy use in the Energy consumers will be coupled and matched to the energy “production” in engines, etc.

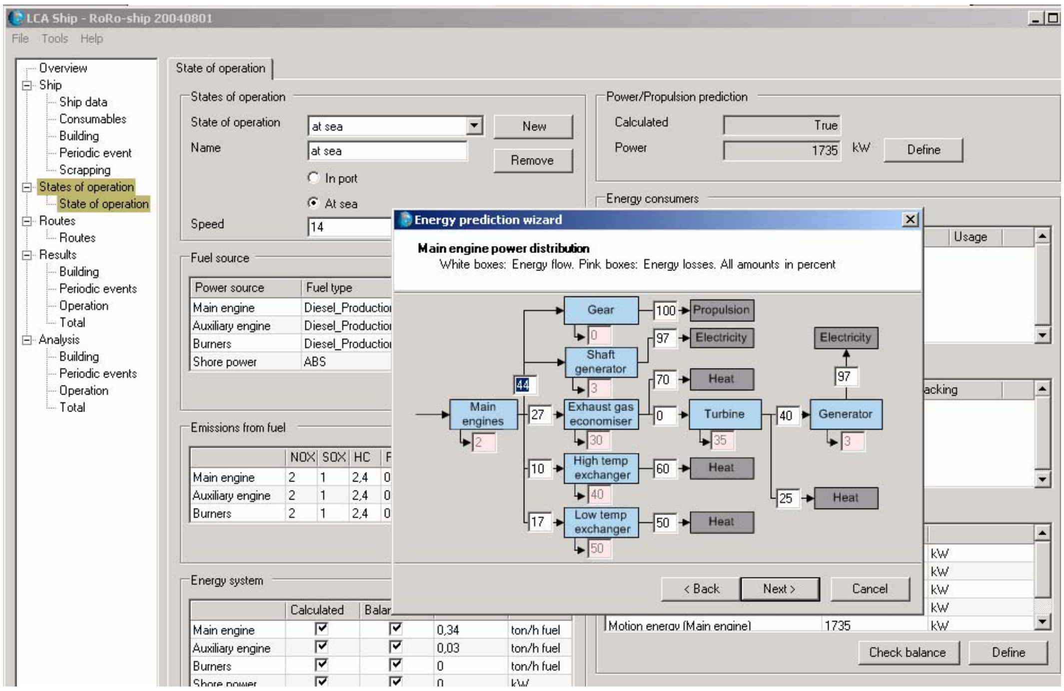


Figure 9 *The power distribution/efficiency of the energy production in Main engines onboard.*

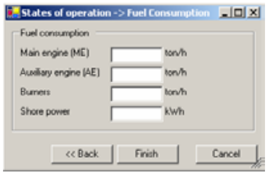


Figure 10 *Wizard for entering known energy consumption.*

Energy modelling and consumption calculations are based on:

1. A defining of energy consumers onboard
2. A defining of the energy flow and transformations
3. A balancing process where energy *"production"* and *"consumption"* is matched

As the machinery used onboard can vary with the use of the vessel all energy calculations and defining are made for a specific state of operation. For example will efficiency of engines vary with load factor and the uses of systems vary between sea and port state.

The energy system onboard a ship is a complex and well connected system. Some simplifications are therefore needed to be able to describe the energy use, the energy transformations and the energy flow between engines, technical components and energy consumers onboard. The idea of the module is to make it possible to optimise the energy system onboard regarding overall, low energy consumption. The application should make it possible to identify energy losses possible to reduce or re-use. The system components and their connections are defined in this module for each *States of operation* to be modelled.

A principal model of the energy flow trough the engine room has been developed. The idea is that all normal operational cases should be able to model in the system seen in **Figure 13**.

Energy flow into and out of a component can be of different form and quality. Despite this all energy flows will be calculated in kW in the model. The energy flow out from the components will often be of more than one type of energy. In reality, different form of energy will also enter some of the components; this will not be handled in this model. The modelling of the energy flow into and out of a component can be seen in **Figure 11**. Only *Energy consumers* can consume more than one energy type (see **Figure 14** for the defining of *Energy consumers*). For example, a main engine will have as outputs mechanical energy and various forms of heat. The mechanical energy can be used for the propulsion, direct or via a gear, and/or in a shaft generator. The various heat flows (exhausts, cooling systems, radiation etc) can either be used in heat exchangers etc. or direct for heating purposes. The main engine modelling can be seen in **Figure 12**. The energy flow goes from the left to the right in the figure. Oil etc is entering the Main engine and transformed into mechanical energy, exhaust heat and other heat flows. The transformation is steered by the user of the application. The distribution of the input flow to the defined possible output flows for the specific component. If the input flow is set to 100 % the sum of the defined output flow can never be over 100 %. If for example the shaft energy output is defined to 45 % of the input flow, the exhaust flow is set to 30 %, High temperature heat flow 20 % and Low temperature heat flow is set to 5 %. The defined output flow will then be 95 % of the input flow the rest will be undefined other losses from the components. If a specific flow into a *System component* (see **Figure 12**, **Figure 13** etc) does not exist or out of use at the specific *State of* *operation* the flow into the component is just set to 0 %. If the flow goes right through the component (as shaft power from the engine without a gear) the flow is set to 100 %.

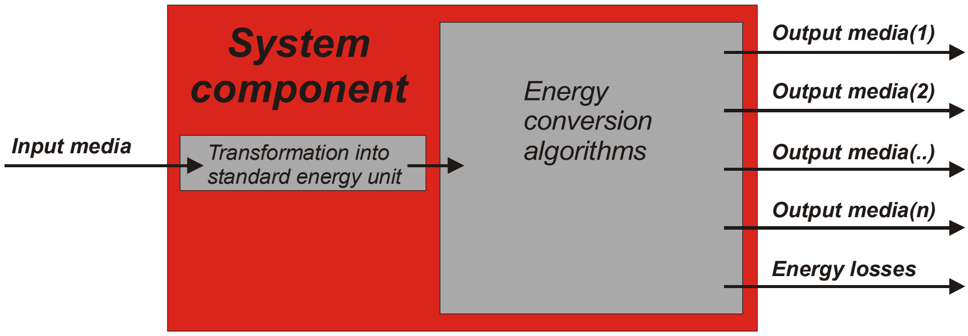


***Figure 11** An engine or machinery component is defined by input and output flow of energy and algorithms for the transformation*

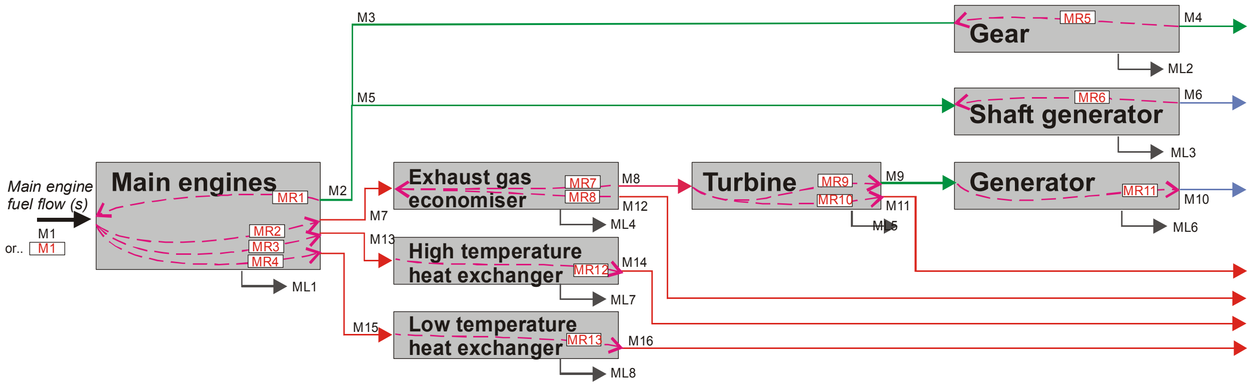


***Figure 12** An example how engines and components can be connected to each other through input and output of energy between the components.*

The optimisation process with the help of the engine defining model is very much a trial and error with components onboard. Examples of questions that can be tried with the model are:

- What happens if an exhaust gas economiser is installed?
- Could the exhaust energy flow be possible to use in an exhaust gas turbine for electricity production?
- Is the energy production and consumption possible to balance?
- How will the total environmental load be affected if the vessel is connected to shore power in ports?
- How will efficiency of different components affect the total energy consumption and the total environmental load from the ship operations?

An example of the energy flow between energy system components onboard can be seen in **Figure 12**. The primary energy flow into the system onboard must be in already defined forms with related life cycle data such as Heavy Fuel Oil (HFO) etc. Output of the energy system onboard will normally be energy in a form not possible to use further (heat, friction between hull and water or wave resistance etc).

The range of possibilities to define the energy system onboard is very wide. A vessels energy system could for example be defined very complex or just very simple of:

1. One System Component run by oil, producing mechanical energy for the propulsion (Main engine)
2. One System Component run by oil producing electricity (Auxiliary engines)

These two components could be enough to define the energy consumption for different *States of operation* (at sea, loading, idle etc.) for a ship in operation.

Note that the user of *Energy system modulation module* must know the basic principles of energy transformation and engine systems. For example will the quality of the heat energy flow steer the possibilities to make something good out of the energy. Hot water of 20°C will be very expensive to transform into electricity and the efficiency will be extremely low. A steam flow at high pressure and temperature will on the other hand be more useful onboard for many functions.

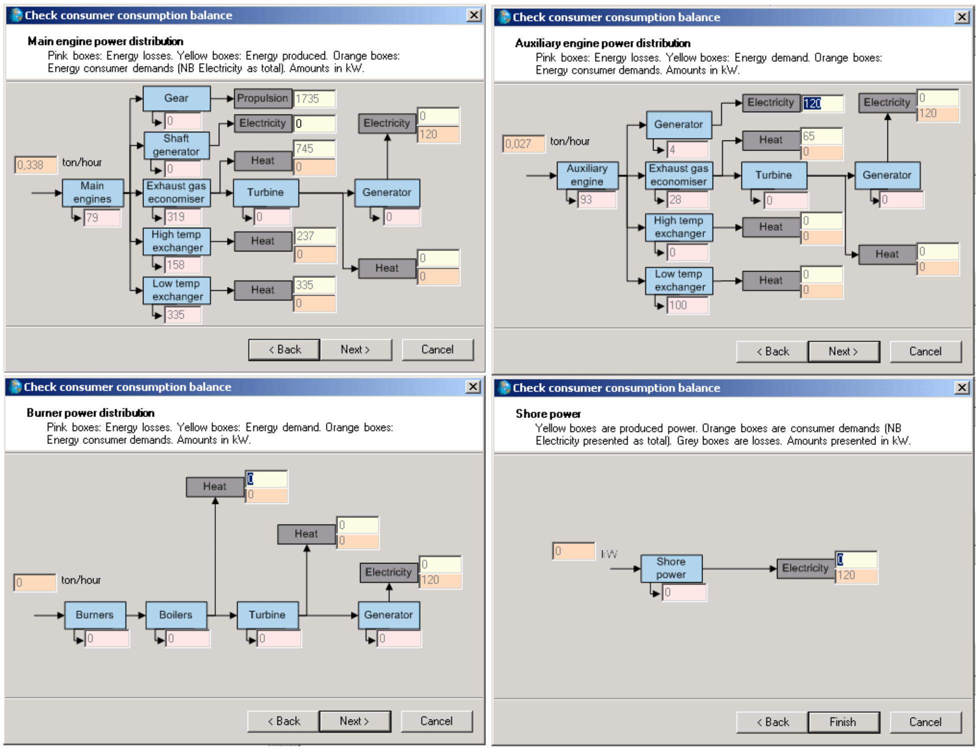


Figure 13 *The total energy "production" system is built on the Main Engine-, Auxiliary Engine-, Burner- and Shore power systems.*

After the energy production system onboard is defined for the specific *State of operation* the energy consumption should be entered. Energy consumption is entered for one ore several *Energy consumers*. It is possible to define all consumption onboard for the *State of operation* in one *Energy consumer*. Each process that is running at the *State of operation* could also be defined by under it's own *Energy consumption* name (propulsion, fans, accommodation heating etc.). The consumption for an *Energy consumer* is defined by a sum of each available energy flow (shaft energy, electricity, low/high temperature flows from main engines, auxiliary engines, boilers and burners etc). Available energy types depends on the defining of the energy "production" system onboard. The defining of an *Energy consumer* can be seen in **Figure 14**.

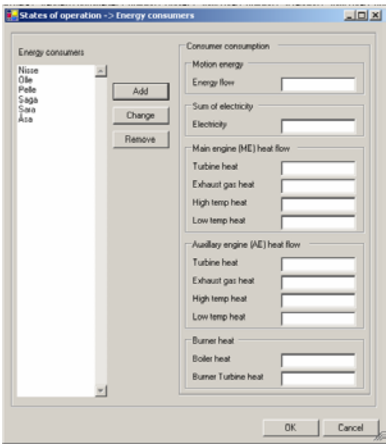


Figure 14 *Wizard for the defining of Energy consumers.*

All the defined *Energy consumers* at the *State of operation* will be summed by energy type. Electricity consumed in *Energy consumers* will for example be summed as consumed electricity at the *State of operation*. In the same way will consumed *Shaft energy* or *Main engine high temperature heat* be summed type by type.

When energy consumption has to be modelled/calculated, energy consumption for propulsion respectively other consumers are entered under *Power/Propulsion prediction* respectively under *Define – Energy consumers*. The amount of energy calculated or predicted under *Power/propulsion prediction* will automatically be added as the amount of *Propulsion energy* output from the *Main Engine*.

The result of the calculation from *Power/Propulsion prediction* is primarily the delivered power to the propeller, but the actual propeller rpm that sometimes may be required for calculation of fuel consumption is also provided.

Some types of energy consumption entered in the Energy consumers will automatically be balanced by the system on the production side. When the shaft energy consumption is summed, the system knows how much shaft energy that has to come out from the shaft energy production (P). If there is no gear the shaft energy production out of the main engine has to be the same as the shaft energy consumption. In our further example the shaft energy output was set to 45 % of the energy input into the system. The energy input into the main engine will then be P/45%≅2.2*P. With the energy content for the chosen fuel the oil consumption into the main engine could also be calculated. As the relation between the energy inflow into the main engine and the other outputs (exhausts, low/high temperature flows) these flows can also be calculated. The reason behind this calculation method is to copy the process onboard when the energy system is planned. The Main engine will be run to produce shaft energy (and or electrical energy in a shaft generator), the other energy flows as exhaust heat etc. will just follow.

After the specification of the energy system and the consumers are maid, the system has to be checked for balance. The application will inform the user about consumers using energy sources with lack of energy and lack of energy in the specific energy flows. The application will also tell the user which of the energy flows in the system that still has a surplus of energy flow that might be available.

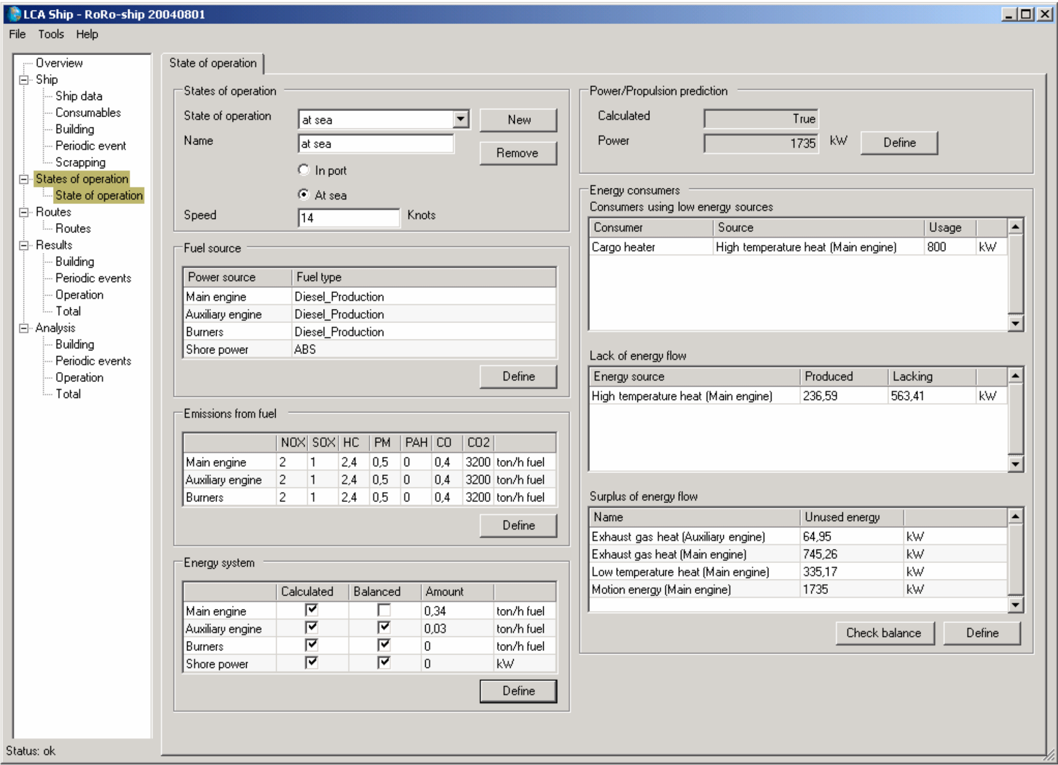


***Figure 15** The Energy consumer, Cargo heater is specified to use 800 kW of High temperature heat from the Main engine. Only 257 kW is producer so lack the of energy will be highlighted by the application.*

Routes

The module is used to define how the vessel is used during its productive lifetime. The definitions and statements in the module should make it possible for the application to calculate the amount of the most important parts of the vessel's environmental load and produced haulage during the active life cycle, see **Figure 16**. Each route will consist of a series of port calls etc. connected with sea transports defined with one or several *"State of operation"* and distance for each *"State of operation"* between ports. Several routes for a ship can be defined and each route will cover a certain time. The vessel lifetime utilisation is then summarised from the defined routes.

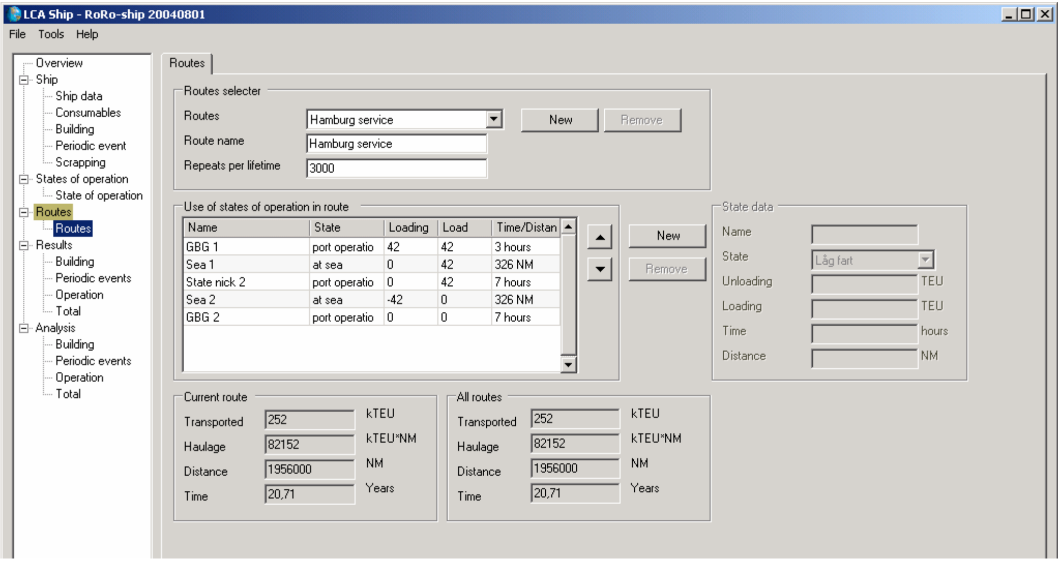


***Figure 16** Routes menu.*

Input data to the module are the *Routes* that the user specify based on already entered *States of operations*. Output from the module are the amount of hours the ship is used in the different "*States of operations*" defined under *"Ship data"* with associated information about transported goods, which is used in the result calculations.

Result

The result menu present calculated LCA data for the vessel according to entered ship and vessel performance data. The inventory analysis results in a large table of all inputs to the system (re-sources, etc.) and all outputs from the system (emissions, etc), see **Figure 17**.

The results can be viewed in respect to:

- Total lifecycle
- Periodic events
- Operational phases
- Building and scrapping phase

The functional unit that the results are shown for could be:

- Total performance
- Transported goods (Ton, TEU etc.)
- Haulage (Ton*km, TEU*km etc.)
- Vessel operational year
- Steamed distance (NM)

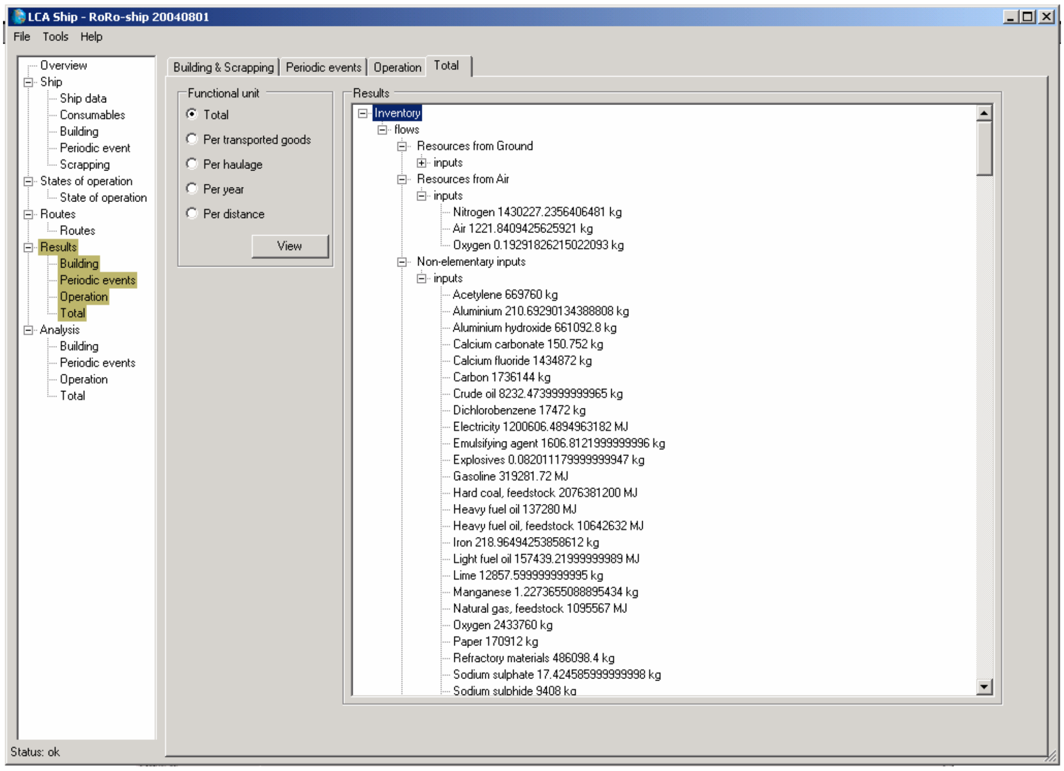


Figure 17 *Results menu.*

The results presented follow the ISO-standard on LCA 14041 where all input and outputs for the process are calculated. Inventories analysis cover

- Resources from ground (inputs)
- Resources from air (inputs)
- Non-elementary inputs (inputs)
- Emissions to air (outputs)
- Emissions to water (outputs)
- Elementary waste (Outputs)
- Non-elementary outputs: Waste (outputs)
- Non-elementary outputs: Co-products (outputs)
- Non-elementary outputs: Products (outputs)
- Other inputs (inputs)
- Other outputs (outputs)
- Resources from water (inputs)

Analysis module

To make comparisons easier between ship concepts etc., the calculated environmental impact, presented in *Results*, can be evaluated with different categorisations and valuation models in an analyses module.

The classification should describe which flows that contribute to each impact category. In the characterisation step, the contributions of the different flows to each impact category are aggregated. This aggregation is based on a traditional scientific analysis of the relevant environmental processes. In this project the following characterisation categories have been chosen

It is generally recognised that the valuation element requires political, ideological and/or ethical values and these are influenced by perceptions and worldviews. Not only the valuation weighting factors, but also the choice of valuation methodology, and the choice of using a valuation method at all, are influenced by ethical and ideological valuations

Since there is presently no societal consensus on some of these fundamental values, there is presently no reason to expect consensus either on valuation weighting factors, or on the valuation method, or even on the choice of using a valuation method at all.

If no valuation method is used at all, comparisons are made category by category, and not on an aggregated level. Even if the preceding phases and elements are mainly based natural sciences, this should not be interpreted as if they are totally free from value choices. Hence they are not questioned and debated as various valuation (weighting) methods.

In the valuation step, different impact categories are compared with each other. This can be done either qualitatively or quantitatively. If it is done quantitatively it will result in the only figure that will describe the environmental impact of the product. In the valuation, different types of environmental impacts will be compared with each other, for example a potential impact on people's health would be weighed against the impact on biological variety, or consumption of finite resources. This can not be done simply based on traditional scientific methods. In addition, valuations of a political and/or moral nature must be introduced.