LCA-ship

Design tool for energy efficient ships, A Life Cycle Analysis Program for Ships

Final report: 2004-08-27

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

Project: Konstruktionsverktyg för energieffektiva fartyg

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Authors: Karl Jivén, MariTerm AB, +46 31 12 20 30

Anders Sjöbris, MariTerm AB, +46 31 12 20 30

Maria Nilsson, TEM, +46 416 273 00

Joanne Ellis, SSPA Sweden AB , +46 31 772 90 00

Peter Trägårdh, SSPA Sweden AB, +46 31 772 90 00

Malin Nordström, SSPA Sweden AB , +46 31 772 90 00

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Front cover photographs by Karl Jivén from Port of Gothenburg and Alang Beach, India.

MariTerm AB, (visiting address: Banehagsgatan 15), P.O. Box 12 037, 402 41 Gothenburg, Sweden

TEM, Stiftelsen TEM vid Lunds universitet, Åsumsgatan 38, 275 37 Sjöbo, Sweden

SSPA Sweden AB, (visiting address: Chalmers Tvärgata 10), Box 24001, 400 22 Gothenburg, Sweden

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SUMMARY

In order to make it easier to include aspects during ship design that will improve environmental performance, general methods for life cycle calculations and a prototype tool for LCA calculations of ships and marine transportation have been developed. The base of the life cycle analyses is a comprehensive set of life cycle data that was collected for the materials and consumables used in ship construction and vessel operations. The computer tool developed makes it possible to quickly and simply specify (and calculate) the use of consumables over the vessel's life time cycle. Special effort has been made to allow the tool to be used for different types of vessels and sea transport.

The main result from the project is the computer tool *LCA ship,* which incorporates collected and developed life cycle data for some of the most important materials and consumables used in ships and their operation. The computer application also contains a module for propulsion power calculations and a module for defining and optimising the energy system onboard the vessel. The tool itself is described in more detail in the Computer application manual.

The input to the application should, as much as possible, be the kind of information that is normally found in a shipping company concerning vessel data and vessel movements. It all starts with defining the ship to be analysed and continues with defining how the ship is used over the lifetime.

The tool contains compiled and processed background information about specific materials and processes (LCA data) connected to shipping operations. 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 steel production, the process to build the steel structure of the ship, the scrapping and the recycling phase. To be able to calculate the environmental load from the use of steel the total amount of steel used over the life cycle of the ship is also needed. The processed LCA data in the tool contain the key factors to make it possible to perform life cycle analyses[1] of such a complex *"product"* as a ship and the sea transport activity performed by the ship.

The calculated environmental impact can also be analysed with respect to different operations, life cycle phases etc. To make comparisons easier between ship concepts etc., the calculated environmental impact can be evaluated with different categorisations and valuation models in an analyses module.

1 The LCA calculations will be valid for the specific cases that use the same base processes that were included in the LCA data that the program contains. Other cases could also be estimated with these data even if the base production processes vary from case to case. The user should keep in mind that if the base processes vary significantly the results should be considered an estimate only.

SVENSK SAMMANFATTNING

I syfte att göra det enklare att inkludera miljöaspekterna då fartyg designas har generella metoder för att genomföra livscykelanalyser (LCA) av fartyg utarbetats samt ett prototyp-verktyg för sådana analyser utvecklats. Basen i detta arbete har varit insamling och processande av livscykeldata för de material och processer som bedömts som viktigast när fartyg och sjötransporter skall analyseras i ett miljö- och energiperspektiv. Det datorbaserade LCA-verktyget som utvecklats, gör det möjligt att systematiskt och snabbt specificera (och beräkna) livscykelbelastningen för ett fartyg. Stor möda har lagts på att metoder och program skall kunna användas för olika typer av fartyg och transportupplägg.

Huvudresultatet från projektet är ett datorprogram *LCA-ship* som baseras på de metoder och modeller som utvecklats i projektet. Programmet innehåller en databas med livscykeldata för material och processer som samlats in och bearbetats under projektet. Programmet innehåller även moduler för att genomföra motståndsberäkningar av fartyg samt moduler för att specificera, beräkna och optimera energisystemet ombord. Till programmet hör även en manual.

Indata till livscykelanalysprogrammet är i första hand sådan information som normalt finns tillgänglig på ett rederikontor. Beräkningarna startar med att fartyget som skall analyseras beskrivs varefter fartygets användning under livscykeln specificeras.

Programmet innehåller insamlad och processad bakgrundsinformation kring de specifika material och processer som är kopplade till fartygsbyggnation och drift. LCA data som programmet innehåller innefattar processad information på så sätt att tex. data för konstruktionsstål inkluderar miljöbelastningen från stålets framställning till dess att det sitter monterat och ytbehandlat i strukturen samt miljöbelastningen från skrotningsfasen. För att kunna beräkna miljöbelastningen för stålet i fartyget behöver då programmet mängden stål som används under livscykeln. Den processade livscykeldata som programmet innehåller är nyckeln till att möjliggöra livscykelanalyser[2] av en så pass komplicerad produkt som ett fartyg.

Den livscykelbelastning som beräknats med hjälp av programmet kan analyseras i förhållande till olika faser av fartygets livscykel som byggnation/skrotning, operativ fas eller per periodiska underhåll etc. Resultaten kan fördelas per godsmängd som transporterats, per utfört transportarbete, per år eller per nautisk mil som fartyget utfört.

För att förenkla jämförelser mellan fartyg eller transportupplägg presenteras resultaten från beräkningarna även i kategoriserad och värderad form.

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[2] Livscykelanalyserna som utförs med hjälp av den LCA data som programmet innehåller är egentligen endast giltig för just de processer och material som programmet innehåller. Analyser kan naturligtvis ändå utföras på koncept som egentligen har annan miljöbelastning från insatsvarorna till fartyget/driften men man måste då vara medveten om att resultaten kan bli felaktiga.

BACKGROUND

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

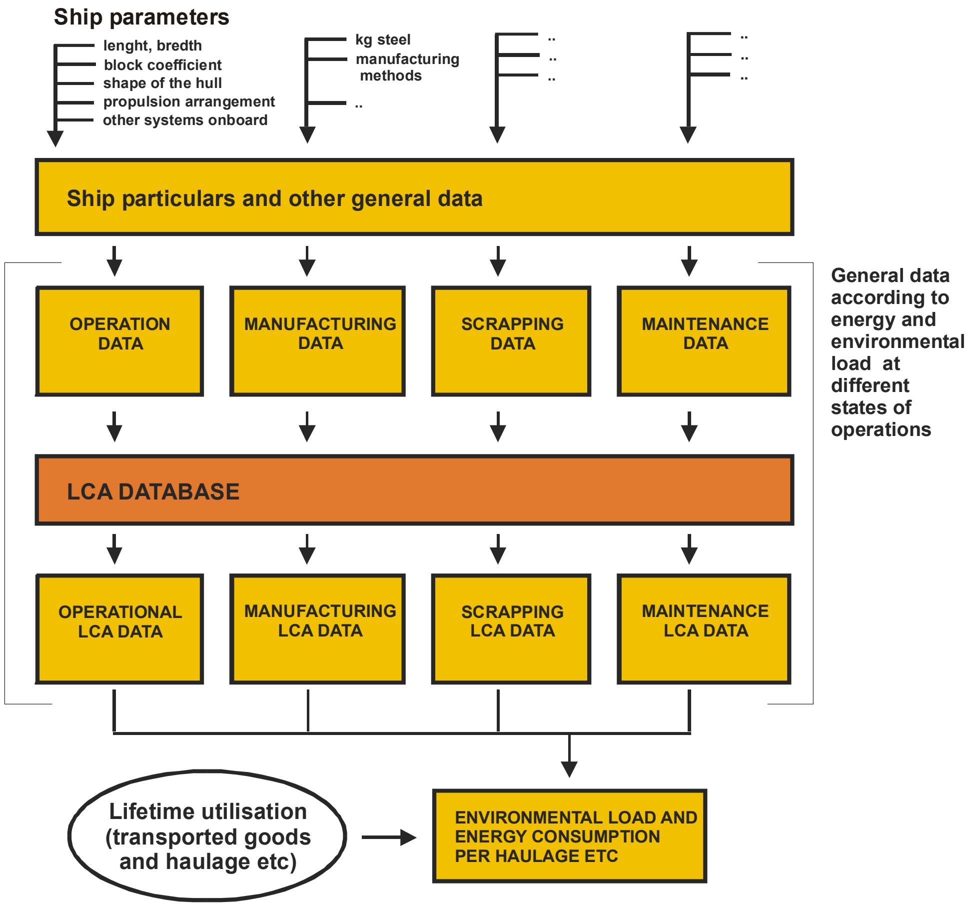

Figure 1 *Structure overview of the tool.*

There are some explicit statements made in the original project description that have been important to address in the project:

- The project and the developed methods should be based on a life cycle perspective
- It should be possible to estimate energy consumption in the application for a vessel based on given ship parameters and operational handling

- The application should make it possible to compare environmental load from the ship with the haulage or other benefits that the ship produces over a lifetime perspective
- A simplified form of Life Cycle Cost calculations (LCC) from a ship owner's perspective is to be developed

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

The relevancy of directing efforts and developing tools for optimising or analysing the energy use and environmental load from sea transports can be outlined if different sea transportation systems are studied. The energy use per transported unit/ton can vary greatly between different sea transport systems. The large differences in installed engine capacity per deadweight can be used as a measure of the energy used onboard per transported unit. The installed main engine power per total cargo carrying capacity (approximated with the deadweight[3]) for the vessels calling Sweden during a year can be seen in **Figure 2** - **Figure 4**. Normally the same share of the installed main engine capacity is used during operation at sea and the normal speed ranges for almost all ships vary between 15 to 25 knots. These figures give a hint of the large differences in energy use between different sea transport systems. As seen in the figures the energy use (shown as kW/dwt) may vary between 0.1 - 2.5 kW/dwt between the different systems. The variations between ships in the same category, size and design speed also differ a lot. The large spread of energy used per cargo capacity can be seen as an indication of the improvement potential. The sea transport system used for a specific cargo is often decided in the planning stage of the transport system. Improvements can be made using systems that consume less energy (either direct or indirect energy use), or by optimising within a certain system.

It is important to have accurate information about the energy consumption and environmental load during the planning phase of a sea transport project. The tool developed in this project estimates energy use and environmental loads from a life cycle perspective and is designed to be used in the early design process as well in analyses of existing ships.

3 Deadweight (dwt) is measured in ton and is a measure of the vessels total capability to carry cargo including bunker, provisions etc.

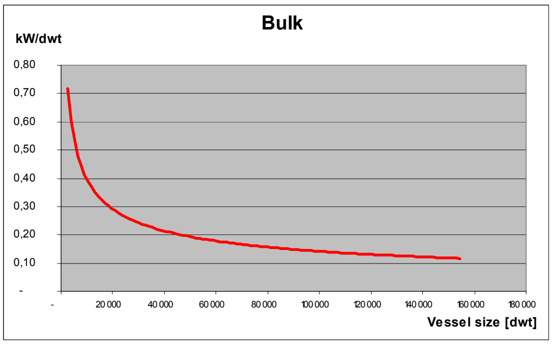

Figure 2 *Installed main engine power per ton deadweight for bulk ships by ship size.*

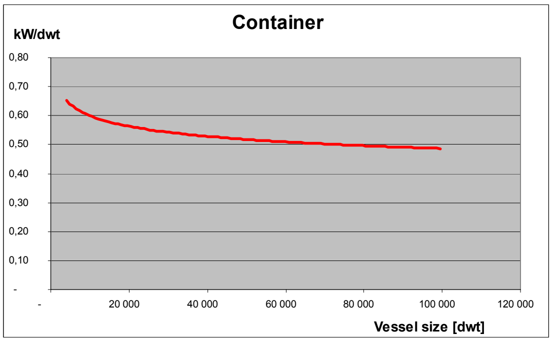

Figure 3 *Installed main engine power per ton deadweight for container ships by ship size*

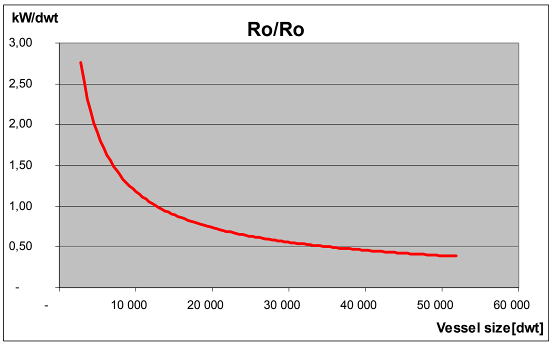

Figure 4 *Installed main engine power per ton deadweight for Ro/Ro ships by ship size*

THE PROJECT

The main purpose of the project has been to establish methods, tools and collect data in order to make it possible to perform Life Cycle Analyses of ship transport.

The project has also developed the software tool, *LCA-ship*. This research project was carried out from mid 2002 until mid 2004.

The project was sponsored by ***VINNOVA*** and ***The Swedish Energy Authorities*** together with industrial partners in the project.

Industrial partners in the project were:

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

The project was performed in cooperative comprising *MariTerm AB*, *SSPA Sweden*, *TEM* and the *Department of Marine Transportation at Chalmers University*. *MariTerm* was the project leader.

The reference group of the project consisted of *VINNOVA*, *The Swedish Energy Authorities*, industrial partners of the projects and the *Naval Department* at *Chalmers University of Technology*.

On behalf of Chalmers University of Technology, *Prof. Anders Ulfvarson* and *PhD Stud Hulda Winnes* have also contributed significantly to the project. *Chalmers* is involved in the project *INTERMODSHIP* where LCA analyses of designed RORO-vessels are to be performed with the developed LCA tool. *Joakim Gustafsson* participated in the *CTH*, *Naval department trainee program* where he worked with the project during his two months at *MariTerm AB*.

The project has also initiated a Master of Science thesis[4] that was performed at the naval department of Chalmers University of Technology in the field of systematic evaluations and selections of machinery components and their connections etc.

Support from the industry

The industrial support for the project has been substantial and important. In addition to all help in general discussions about the application, some areas can be identified where the support has been concentrated. These are:

- Compiled information of environmental aspects from ships and ship operation

[4] Ahuja (2003).

- Relations between ship handling and environmental performance
- Information and discussions about what demands the planned tool should fulfil
- Feedback of application proposals during the design process of the tool
- Information about what kind of information is available in different design phases when a new vessel is under discussion/construction.
- Knowledge about the design process. What does the decision making process look like?
- Life Cycle Data consumable etc and inquires about LCA data to suppliers.
- Information about engine room planning and state of the art knowledge about energy saving methods onboard ships.

The representatives from the industrial partners who have been most involved in the project as working members of the project group have been:

- *Bertil Arvidsson, The Swedish Ship Owners Association*
- *Björn Nyberg, Ecoship Engineering AB*
- *Harry Robertsson, Stena Rederi AB*
- *Per Wimby, Stena Rederi AB*
- *Johan Roos, Stena Line AB*
- *Sara Gorton, Wallenius Lines*
- *Christer André, Munters Europe AB*
- *Claes Fänge, Gorthon Lines AB*

The outline of the application has continuously been checked with the reference group and with the industrial partners in the project during the main project work phase. The viewpoints of the group have been necessary in order to create a tool/application that is easy to use and useful for the industry.

As the application has been developed and prepared for use, the testing and debugging have been important. The wider the circle of organisations that uses the tool, the more problems will probably be found and addressed. The project has also received assistance from the industrial partners in this area.

The developed application is considered to be a prototype~~,~~; the next project or phase of the development will most probably be additional development of the application to improve its user-friendliness and usefulness for anyone with insights into ship design, environmental issues related to shipping or shipping systems. To achieve this, feedback from all types of uses of the prototype tool is needed. This process will hopefully occur as a result of the dissemination phase of the project.

Project performance

The time table of the project work can be seen in **Figure 5**. The steps in the project are described more extensive below.

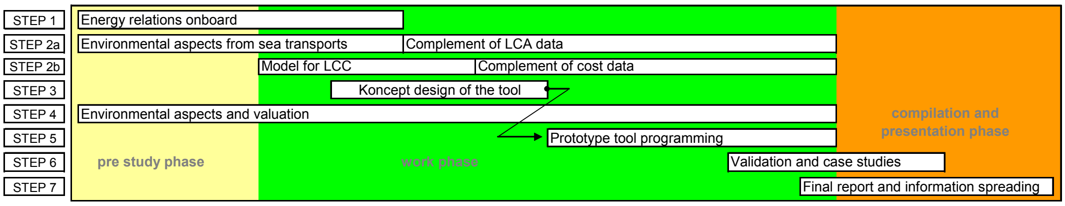

Figure 5 *Project planning from start to final reporting*

Step 1: Factors that have great impact on energy consumption and environmental load have been compiled and structured. The energy consumption relations to different factors as ship characteristics, length, breadth, speed hull form etc were compiled. The relations could be based on physical, statistical and rules of thumbs. (Responsible organisation for this step has been MariTerm AB).

Step 2a: The relationships between energy consumption and other environmental aspects identified in step 1 have been analysed in a life cycle perspective in Step 2a. The operational phases were identified to be most important over the life cycle, and therefore most efforts were placed on the vessel’s operational phases. Categorisations and valuation of the environmental aspects are mostly based on existing reports, methods and earlier projects. (Responsible organisation for this step has been TEM).

Step 2b: A model for Life Cycle Cost (LCC) calculations has been discussed and outlined. The economic effects of an activity that affects energy use or environmental impact can be analysed from a life cycle perspective. The proposed model is not included in the prototype tool but it is possible to implement this in the next generation of the tool.

Step 3: Concept design and development of the application. The tool was based on the information that was processed during step 1 and 2. (Responsible organisation for this step has been MariTerm AB).

Step 4: The life cycle data for materials, processes and products that were considered to be important from a life cycle perspective have been processed parallel to all other work during the whole project. (Responsible organisation for this step has been TEM).

Step 5: Programming of the prototype tool according to the concept design in step 3. (Responsible organisation for this step has been SSPA).

Step 6: Validations and demonstration of the tool in close cooperation with the industrial partners in the project. (Responsible organisation for this step has been SSPA).

Step 7: Reporting and final step of the project. (Responsible organisation for this step has been MariTerm AB).

Main work areas for the project organisations

MariTerm AB has been project coordinator for the project with special responsibilities for creating the module of onboard energy systems and the specification of the application.

SSPA Sweden has been responsible for developing the propulsion prediction module and producing the programming tool.

TEM has been responsible for the collection and processing of life cycle data and for categorisation and valuation methods used in the project.

The Department of Marine Transportation at Chalmers University has been a resource and discussion partner throughout the project.

LIFE CYCLE ANALYSIS (LCA)

Methodology

The increased awareness of the importance of environmental protection and the possible impacts associated with products manufactured and consumed, has led to a demand for the development of methods to better comprehend and understand how to reduce these impacts. One of the techniques developed in response to this demand is Life Cycle Assessment, LCA.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:

- Compiling an inventory of relevant inputs and outputs of a system.
- Evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA facilitates the study of the environmental aspects and potential impacts throughout a product's life from raw material acquisition through production, use and disposal.

LCA can assist in:

- Identifying opportunities to improve the environmental aspects of products at various points in their life cycle.
- Decision making (e.g. strategic planning, priority setting, product or process, design or redesign).
- Selection of relevant indicators of environmental performance.

LCA is one of several environmental management techniques and may not be the most appropriate technique to use in all situations. Generally the information developed in an LCA study should be used as part of a much more comprehensive decision process or used to understand the broad of general trade-offs. Comparing results of different LCA studies is only possible if the assumption and context of each study are the same. In the application developed in this project the assumptions and context are the same which allows the user to compare different alternatives before a decision is made.

This study only considers selected components of a ship, and only data considered to be of major importance have been emphasised.

The framework

This section gives a brief presentation of the LCA framework and terminology, based primarily on ISO 14040[5]. **Figure 6** illustrates the framework and also some applications of LCA, which are outside the LCA framework.

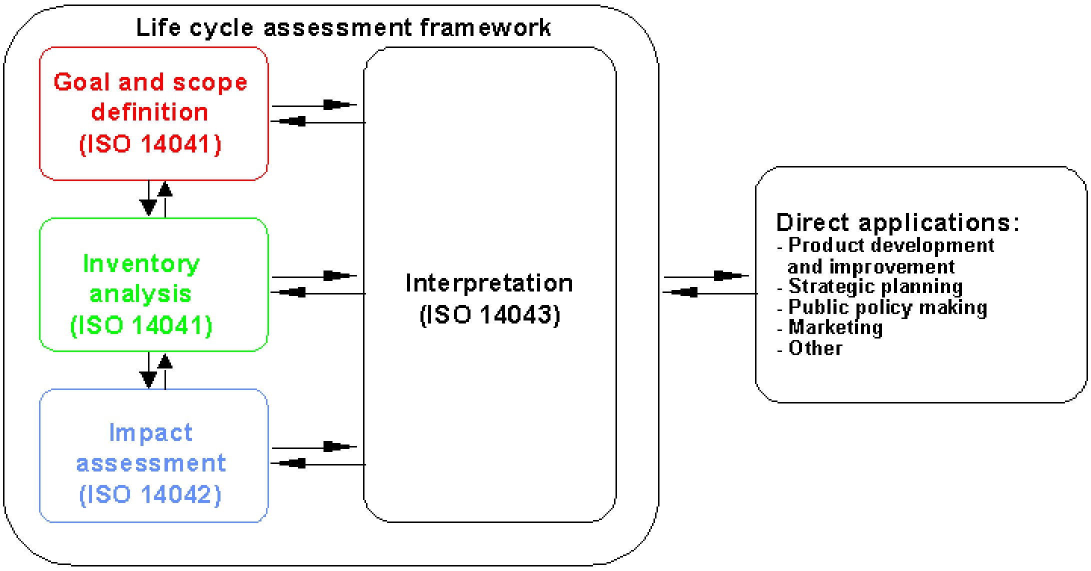

Figure 6 *Phases of an LCA* [5]

A life-cycle assessment includes four phases: [5]

1. Goal and scope definition.

2. Inventory analysis, involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle. The inventory analysis results in a large table of all inputs to the system (resources, etc.) and all outputs from the system (emissions, etc).

3. Life-cycle impact assessment, aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system[5]. This phase may include elements such as:

   3.1. Classification (in which different inputs and outputs are assigned to different impact categories based on the expected types of impacts to the environment).

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5 ISO (1997a)

3.2. Characterisation (relative contributions of each input and output to its assigned impact categories are assessed and the contributions are aggregated within the impact categories).

3.3. Valuation (weighting across impact categories).

4. Interpretation, in which the findings of either the inventory analysis or the impact assessment, or both, are combined in line with the defined goal and scope.

One of the goals of this project has been to demonstrate and confirm that the LCA-method is applicable for environmental life cycle evaluation for ship transportation. One other goal has been to make it easier for ship owners to compare different ship systems from an environmental view.

An important feature of the ISO framework is the interpretation phase where overall conclusions from the study are to be drawn. These conclusions should be based on information from all other phases and elements of the LCA. This implies that the results from the valuation element will not necessarily be identical to the conclusions drawn in the interpretation. Using a valuation method is thus something different from drawing conclusions. To use a valuation method can be a way of analysing the results. Results from the valuation can be conditional: if a certain valuation method with a certain set of values is used then a certain result is obtained. By using several valuation methods and sets of values, several results can be obtained, which can be used when conclusions are to be drawn and recommendations are to be made in the interpretation phase.

Classification and Characterisation

The classification section should describe which flows 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

ACIDIFICATION

Natural rain is slightly acidic due to the presence of various acids in the air that are washed out by rain. However, a number of man-made emissions are either acid or they are converted to acid by processes in the air. Examples of such emissions are SO_2, (which becomes sulphuric acid) and NO_X, (which becomes nitric acid) NH_3 and HCl.

As a result, the acidity of rain can be substantially increased. In a number of areas (such as large areas of Sweden), the soil and water have a limited capacity to neutralise these added acids. If water becomes too acid, an increasing number of aquatic species are harmed. If the soil becomes too acid, the ability of plants to grow and thrive is harmed.

This impact category treats those matters that contribute to acidification of land and sea. The characterisation factor that has been chosen is the fractional of released protons calculated from ability of one gram of the matter in question to release hydrogen ions in comparison to ability of releasing hydrogen ions from one gram of SO_2.

To interpret the acidification indicator, it is important to realise that the site where an emission takes place relative to a sensitive area is important. Also, acid falling into the sea is easily neutralised.

Eutrophication

Aquatic plants and algae gradually fill in freshwater lakes and estuaries over time in a natural process called eutrophication. This process is controlled by low concentrations of certain nutrients (like phosphate and nitrogen) that the plants and algae require to grow.

When the nutritional balance is disturbed so that the amount of nutrients increases it is called eutrophication. In aquatic systems this leads to increased production of biomass which can cause lack of oxygen and bottom death. In terrestrial systems deposition of nitrogen-containing matter leads to changing of species differentiation.

An eutrophication indictor is derived by converting the different chemical forms of phosphorus and nitrogen into a common or equivalent form. Then, the proportion normally found in aquatic algae is used to weight the phosphorus and nitrogen. These values are added into an overall indicator. The potential contribution to eutrophication will be expressed here as NO_X-equivalents, which is the ability of one gram of the emission in question to help growing the biomass in comparison to the ability of one gram of nitrate. The use of nitrogen instead of phosphorous is made because, usually, phosphorus is the limiting nutrient in freshwater and nitrogen in estuaries and salt water.

Global Warming

The earth's climate is driven by the balance of energy or heat added by the sun and lost by the earth. The primary energy is lost through heat radiation. Several gases in the atmosphere, called greenhouse gases, can reflect some of this heat back to the earth. This effectively warms the earth and may alter the climate over time as these gases increase in concentration.

The Global Warming Potential, GWPs describe the contribution to radiative forcing, taking into consideration the atmospheric lifetimes and absorption properties of different gases. These properties are then compared to the properties of CO_2 and converted into CO_2 equivalents.

OZONE DEPLETION

High in the earth's stratosphere, chemical processes maintain a balanced concentration of ozone. This protects the earth by absorbing much of the harmful ultraviolet radiation from the sun.

If a gas can stay in the atmosphere long enough to reach the stratosphere, and if the gas carries bromine or chlorine atoms, the ozone balance may be threatened as free bromine and chlorine can accelerate the breakdown of ozone.

ODP, ozone depletion potential, are dependant on the atmospheric lifetime of various compounds, the release of reactive chlorine or bromine from the compounds and the corresponding ozone destruction within the stratosphere. The properties of each gas are then compared to the properties of CFC-11 and converted into CFC-11 equivalents. Then the individual equivalents are added together for the overall ozone depletion indicator score, which represents the total quantity of ozone depleting gases released.

PHOTO-OXIDANT FORMATION, PHOTOCHEMICAL OZONE PRODUCTION

Formation of ozone and other oxidants near the ground have increased during the last century. These have toxic effects on human and plants. Creation of high concentration of oxidants and ozone in the troposphere is coupled to emission of hydrocarbons, and presence of sunlight and NO_X. The potential contribution to oxidant formation here is expressed in POCP-equivalents, which is a measure of the ability of the emission of question to create oxidants in comparison to the same ability of ethene.

Valuation

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.

The following valuation methods have been chosen for the project.

ECOINDICATOR 99

The Eco-indicator 99[6] is a state of the art, "damage oriented" impact assessment method for LCA . The indicator models damage on human health expressed in DALY (disability adjusted life years) within global warming, ozone depletion, respiratory health effects and carcinogenic effects.

Ecoindicator 99 also models resource depletion effects for fossil energy, metal resources and land use. Normalisation is made for Europe, and valuation (weighting) is dealt with in an expert panel judgement drawing on cultural theory.

EDIP

The Environmental Design of Industrial Products (EDIP) method is to apply weighting factors on the basis of political environmental targets set by the Danish Government or by various international protocols and was developed by Wenzel et al[7, 8]. International and national agreements give reduction targets for many pollutants that it is felt required reduction due to the contribution to global and regional environmental damage to ecosystems. The EDIP method for environmental impact is based upon scientific, technical and political considerations.

On weighting, the relative seriousness of each individual type of resource consumption, environmental impact and impact on the working environment (relative to other types within the same category) is expressed in a weighting factor.

The criteria in assessment of the seriousness of an impact address the consequence of that impact category on the safeguard objects, i.e. the elements which the user of life cycle assessment aims to protect. The safeguard objects normally comprise human health, ecosystems health and resource basis.

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6 Goedkoop M & Spriensma R (1999)
7 Wenzel, H; Hauschild, M and Alting, L (1997)
8 Wenzel, H; Hauschild, M and Alting, L (1998)

EPS 2000 AND EPS MONEY

Environmental Priority Strategies in product design The EPS system[9] is mainly aimed to be a tool for a company's internal product development process.

The EPS 2000 default method is an update of the 1996 version. The impact categories are identified from five safe guard subjects (these may be interpreted as "Areas for protection"): human health, ecosystem production capacity, abiotic stock resource, biodiversity and cultural and recreational values.

In the EPS-system, the damage on these safeguard subjects from an emission should be quantified, and these damages are in a later step valued. For example, an emission of CO_2 will cause impacts on biodiversity, production, human health, resources and aesthetic values. All these damages should be quantified and in a later step valued in order to calculate the valuation weighting factor for CO_2.

The impact of materials used are expressed as an index - Environmental Load Units (ELU), once representing 1 ecu or, in the EPS money, SEK. The index is linked to society's willingness to pay for the protection of certain priority areas (biodiversity, biological production, human health, decreased amount of natural resources and aesthetic values). Although such values are difficult to quantify with great accuracy, it does attempt to equate environmental impacts with monetary values.

TELLUS

In a study from the Tellus Institute[10] a valuation system based on control costs of a number of pollutants were used to establish prices for some criteria air pollutants. These were CO, NO_X, Particulates, SO_X, VOC and lead. For lead, the control cost was estimated as $1600 per pound. This value was used together with a ranking system to calculate costs for the remaining hazardous pollutants. The cost for CH_4 was estimated from the control cost of CO_2 and Global Warming Potentials.

The Tellus system[10] uses data on society's willingness-to-pay to calculate valuation weighting factors. They use both data on emission taxes (the Swedish CO_2-tax) and marginal costs for reducing emissions down to decided emission limits.

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9 Steen (1999)
10 Tellus Institute (1992)

LIFE CYCLE INVENTORY ANALYSIS

The Life Cycle of a ship has been broken down in different phases: construction, operation, maintenance and scrapping as the **Figure 7** below show.

Through the whole analysis European electricity- mix has been used. (See more about electricity data it in the later chapter about LCA-data.)

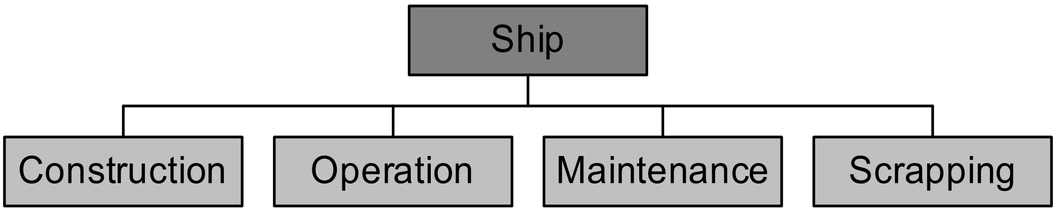

Figure 7 *Phases of the LCA.*

Construction

The construction phase includes all parts that are constructed before the ship is leaving harbour the first time.

To simplify the data collection the project has focused on three major parts of the construction phase, hull, see **Figure 8,** machinery parts, see **Figure 9** and equipment for crew and passengers.

HULL

The hull is approximated to be constructed by steel but if the user of the application want to use aluminium, or a mix of aluminium and steel instead, it is possible. The steel is assumed produced in Sweden.

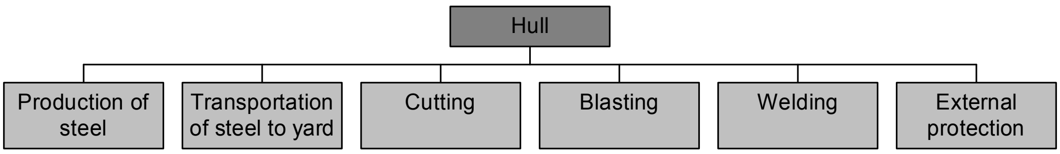

Figure 8 *Hull*

The amount of metals (steel, aluminium etc) is assumed equal to the hull weight. Further, metal plates and profiles are cut. 10 % of the metals are assumed lost in the process and 95% of the cut-off is recycled. Metal plates are then sent to building of sections, which includes sandblasting and welding. The hull weight can be estimated to be 85% of the light ship weight, LSW.

The main consumption of the cutting phase is electricity. It is known from Johnsen et al[11] that 8.5 MJ of electricity is consumed per m^2 during the cutting process. 10 % of the steel is assumed lost during the process.

In the blasting phase the sandblasting method is used. 10 kg of sand is estimated to be required to blast 1 m^2 of steel[12]. In a better application it would be possible to chose between water and sandblasting.

The welding process are based on the knowledge about a specific ship with 1300 tonnes of steel having 117 200 m welding. As a conservative assumption we say that the ratio between welding meters is the same as the ration in tonnage. 15.1 MJ of electricity is used per meter welding according to Johnsen et al[11].

It has been impossible to find specific paint-data. Some of the manufacturers have shown their data with the promises that we wouldn't use them straight out. In fact it has been very hard to get data from the chemistry sector even with promises that their data would not be able to trace.

The whole area below the water line is estimated to be painted with primer and antifouling during construction. 0.397 l paint, 0.284 l antifouling and 0.0782 l primer is used per ton of the hull as external protection This assumption is based on a report by A. M. Fet et al.[12] and calculations carried out by Hempel. It is also estimated that 0.147 kg Zn per tonnes steel is used as anode protection of the steel.

If 75 % of the hull is recycled in the scrapping phase the amount of virgin steel in the production phase is also reduced about 25 %. This positive environmental effect is used to show the environmental benefits with reusing metals. (See more about this in chapter about scrapping.)

MACHINERY PARTS

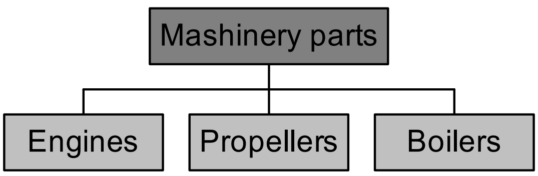

Figure 9 *Machinery*

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11 Johnsen T. et al. (1999)
12 Fet et al, (1994)

Engines

The life cycle of the engines before they are installed into the ship is unknown. Cradle to gate data for the steel in the engines represent the construction phase.

As a simplification using data for steel with the same weight as the engines is recommended. If the weight is not known the weight can be estimated to approx. 7.5 % of LSW.

Propellers

The propellers are often made out of bronze. LCA-data for production of bronze is not known but as a simplification we have used data for copper and tin production. All bronze used in the production is assumed to be C 50100 - C 52400 and to be produced in Korea. The composition of this bronze type is 90% copper and 10% tin[13]. If the weight of the propellers is not known the weight can be estimated to approx. 0.2 % of LSW.

Boilers

As a simplification we have used data for steel with the same weight as the boilers. If the weight of the boilers is not known they can be estimated to approx. 0.7% of LSW. An important simplification here is that isolation in the boilers is left out. This can be important as the isolation material may give emission affecting the ozone layer.

EQUIPMENT FOR CREW AND PASSENGER

The equipment of different ships differs a lot. To estimate the environmental load from this area LCA-data for some materials such as different plastics, steel, textiles etc has been conducted. See chapter, LCA data below.

Operation

The operation phase which include the daily use of the ship is in almost every aspect the phase with greatest environmental load. During operation, combustion of fuel takes place. Data for both production of heavy fuel oil, marine diesel and the environmental impact the use of the fuel is represented in this phase. Other substances used during operation, such as urea can be found in the chapter about LCA data below.

Maintenance

During operation minor work on the hull may be performed. Larger repair work or rebuilding may occur as a part of maintenance. In the application the user chose how often and how much maintenance is expected during the ship life-time. If this is not known an

13 Ullman (1986)

assumption is that 10 % of the steel amount is added during the ship's lifetime. The same data as for construction is used in the maintenance phase.

If no data for equipment replacement is known the user can estimate that half of the materials from the construction phase is changed over a ship life-time.

For each docking 50 % of the area below the water line can be assumed painted with primer and antifouling. Though no data for these protection materials have been collected.

Scrapping

At the end of the ship lifetime the ship is transported to a yard for demolition. How much of steel and other materials (not consumption material) that are recycled is up to the user to define. In the application you can chose between different recycling scenarios.

As it was mentioned in the Construction chapter, the scrapping phase effect the construction phase in that meaning that if a major part of the ship is recycled the amount of virgin steel use in the construction phase is limited. See **Figure 10** below.

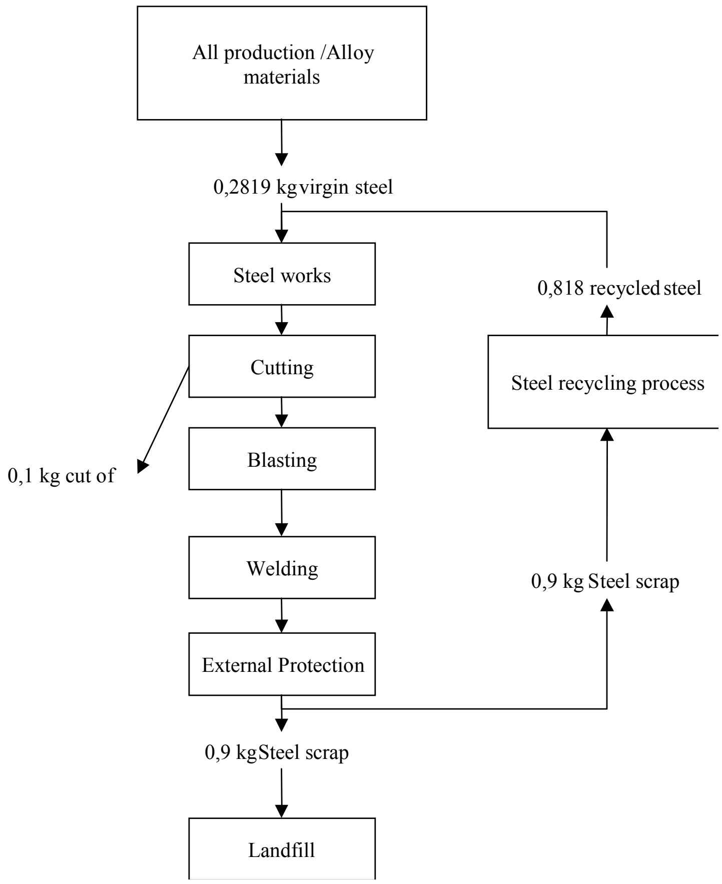

Figure 10 *Steel recycling*

LCA-DATA

Electricity

EUROPEAN ELECTRICITY MIX USED IN METAL, CHEMICAL AND PLASTIC PROCESSES AND FOR SHORE-POWER IN EUROPE

For the European average electricity scenario the electricity production in the European Union (EU-15) is considered. The data includes electricity production from public power plants and from private producers, both excluding heat production by allocation according to exergy content. The data are from 1994 since this is the most recent year for which most types of statistical data were available. Grid losses are estimated to 9 %.

Eurostat and CORINAIR was chosen as the best available sources, of which CO_2, SO_2 and NO_X are measured and checked by authorities. Data from CORINAIR[14] were preferred because they cover both public and private producers whereas Eurostat only cover public power plants[15]. As private producers transform approximately 14% of the fuel for electricity production[16] they cannot be regarded as negligible. Also data from many countries are more recent in CORINAIR than in Eurostat[17].

Data were verified against the values in Frischknecht et al[18], which cover the UCPTE countries. These countries form part of the EU so that Denmark, Ireland, Portugal, Finland, Sweden and U.K. is in EU but not in UCPTE. Poland, Switzerland and former Yugoslavia is in the UCPTE but not in EU-15. The UCPTE electricity production is approximately 75% of EU production.

Emission data for CO_2, SO_2, NO_X, CH_4, NMVOC and N_2O have mainly been taken from CORINAIR[14] and validated against data from Eurostat[17] whenever possible. Renewable fuels are considered CO_2 neutral because only that amount of CO_2 is released, which was accumulated during the growth of the plants. Emissions from hydropower, wind power and geothermal power are assumed to be negligible.

For particulate emissions the Eurostat[17] data are used. Using Eurostat[19] data as a basis, other emissions as well as pre-combustion emissions have been calculated from Frischknecht et al[18].

14 CORINAIR (1996)
15 Eurostat (1997d)
16 Eurostat (1997a)
17 Eurostat. (1997c)
18 Frishknecht R (ed.) (1996)
19 Eurostat (1997b and Eurostat (1997c)

The inputs of aluminium, iron and manganese are non-elementary, i.e. inputs which have not been followed to the cradle (i.e. nature).

The outputs of waste are non-elementary, i.e. outputs which have not been followed to the grave (i.e. nature).

SWEDISH AVERAGE ELECTRICITY USED FOR SHORE-POWER IN SWEDEN

Production of electricity corresponding to an average of the Swedish electricity production in 1995, including 10% grid losses.

Most inputs have been traced back to the cradle (i.e. nature). The inputs of lime, oxygen and sulphuric acid are non-elementary, i.e. inputs that have not been followed to the cradle (i.e. nature). The outputs are emissions to air and water. However, the outputs of waste are non-elementary outputs, i.e. outputs that have not been followed to the grave (i.e. nature).

The data are primarily based on Brännström-Norberg et al[20], 1996 and are presented per kWh produced electricity.

Hull materials

PRODUCTION OF STEEL

The original analysis on which the scenarios are based on Life Cycle Assessment of Aluminium, Copper and Steel by Maria Sunér[21],

The different recycling scenarios are based on allocations between production of virgin steel slabs at SSAB, Luleå, Sweden and the production of scrap-based steel at Fundia Steel AB[22].

Virgin steel

The data are taken from a scenario of production of 1 kg of steel slabs at SSAB, Luleå and represents "100 % allocation", which means that the environmental load is entirely allocated to the main product in each process step. The co-products have been accounted for as "Outflows not followed to the grave".

20 Brännström-Norberg B-M et al. (1996)
21 Sunér M. (1996)
22 Fundia AB (1994)

Scrap-based steel

The scrap-based steel production and the coke production is taken place in Sweden. The alloy material production, limestone and bentonite mining are also assumed to take place in Sweden. Coal is imported from Australia, Poland and USA.

The data for the production of scrap-based steel at Fundia Steel AB[22].

The slag former is assumed to be composed of 50% limestone and 50% bentonite.

Alloy metals mainly consists of manganese compounds. There is no data available for this process. Since the share of alloy metals is very small, data for extraction of iron ore and dressing of iron ores have been used as an approximation. The environmental load associated with the production of explosives is included.

For 1 kg of recycled steel 1.1 kg scrap is required. The mass change factor (out/in) in the recycling process (to which this file is imported) is therefore = 1/1.1 = 0.909.

Production of aluminium

The data on aluminium production have been adapted from EAA[23]. The data include bauxite mining, aluminium production, salt mining, sodium chloride production, limestone mining, lime calcination, electrolysis, anode production, petroleum coke production, pitch production, production of filling materials, cathode production, aluminium fluoride production, cast house and all associated transports (including transport to semi-fabrication plant).

The data from EAA are intended to represent a European average. The data are valid for primary aluminium production using pre-baked anodes since this represents the common technology making up approximately 80% of the total European production and the Söderberg technology being gradually phased out.

Environmental loadings associated with the extraction and refining of raw materials are included wherever they occur.

Some auxiliary materials or raw materials of small amounts are non-elementary inputs, i.e. inputs that have not been traced back to the cradle. Data on these inputs are usually lacking. However, most of these inputs are either of very small amounts, or assumed not to contribute significantly to the total environmental load.

Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

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23 European Aluminium Association (1996)

Cutting

The cutting process is primarily based on two reports. Screening Life Cycle assessment of M/V Color Festival by Johnsen et al[11] and the environmental report from Bruces Shipyard AB in Landskrona, Eriksson et al[24].

Most inputs have been traced back to the cradle (i.e. nature). The inputs of acetylene, oxygen are non-elementary, i.e. inputs that have not been followed to the cradle (i.e. nature). The outputs are emissions to air and water. However, the outputs of waste are non-elementary outputs, i.e. outputs that have not been followed to the grave (i.e. nature).

Sandblasting

The sandblasting process is based on the assumptions from the report *"Renere produksjon i verfsindutrien i Møre og Romsdal"* [12].

Sand production is based on data from Frischknecht et al[18].

Welding

The welding process is based on the knowledge about a specific ship with 1300 tonnes of steel having 117 200 m welding. As a conservative assumption we say that the ratio between welding meters is the same as the ration in tonnage. 15.1 MJ of electricity is used per meter welding according to T. Johnsen[11]. Data for the welding process is collected from Eriksson et al[24] and specific data for welding material comes from ESAB[25].

External Protection

No LCA-data have been identified for primer, antifouling, paint or white spirit. Emissions and resource consumption from cradle to gate per ton zinc anodes comes from is based on production of zinc (Zn) from virgin zinc containing ore.

<u>Zinc</u>
Material balance is based on Frischknecht et al[18]:

Inputs:

- zinc ore (accounted for as pure Zn resource): 1000 g
  zinc ore extraction is based on data from Frischknecht et al.,[18].
- sand: 44 g
  sand production is based on data from Frischknecht et al.,[18]

24 Eriksson T. et al. (1996)
25 ESAB (2004)

- unalloyed steel: 21 g
  steel production data is based on Sunér .[21]

Total inputs: 1065 g.

Output:

- Zinc metal: 1.0 kg.
- Mass change factor (out/in) = 0.939.

Energy consumption:

The energy data are based on reference Frischknecht et al[18].

Emissions of trace elements are based on reference Frischknecht et al[18].

Emission factors associated with the production and combustion of fuels are collected from the internal energy database, from CIT.

Machinery parts

BOILERS AND ENGINES

The life cycle for engines and boilers before they are installed into the ship is unknown. Cradle to gate for the steel in the engines represent the construction phase. Se data about steel production above.

PROPELLERS

Bronze
The propellers is assumed to be constructed of bronze

All bronze used in the production is assumed to be C 50100 - C 52400 and to be produced in Korea. The composition of this bronze type is 90% copper and 10% tin[13].

The environmental load for the production of bronze is not known.

Copper
Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included.

The LCA data on production of copper are based on information for a number of mostly European operations[26]. However, no information concerning the specific countries is included.

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26 Bousted I. & Panvalkar S. G. (1998)

Tin

Tin is assumed to be co-produced with virgin copper at Boliden Mineral, Rönnskär, Sweden. An economical allocation has been done based on average metal prices for 2001[27].

EQUIPMENT

Brass

The amounts of raw materials for the production of brass are based on information from Ullman`s Encyclopedia of Industrial Chemistry[13].

The environmental load for the production process itself is however not included. The production of the raw materials Copper, Lead and Zinc have however been traced back to the cradle (nature), see the notes about copper above when the propeller data is described and zinc under external protection.

Lead

Production of lead (Pb) from virgin lead containing ore. Material balance per kg of lead metals is based on Frischknecht et al[18]:

Raw materials:

- lead ore (accounted for as pure Pb resource): 1000 g
  lead ore extraction is based on data from Frischknecht et al.,[18]:
- limestone: 120 g
  limestone mining is based on Frischknecht et al., [18]
- sand: 90 g
  sand production is based on Frischknecht et al., [18]
- iron ore: 70 g
  iron ore mining is based on Sunér ,[21]
- unalloyed steel: 17 g
  steel production is based on data from Sunér. [21]

Non-elementary inputs are inputs that have not been traced back to the cradle (nature) e.g. chemicals etc. in small amounts or materials for which no data are available.

ABS

Production of acrylonitrile-butadiene-styrene (ABS). ABS is a two phase polymer system consisting of a glassy matrix of styrene-acrylonitrile co-polymer and the synthetic rubber, styrene-butadiene co-polymer.

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27 Svensson R. (2001)

ABS is a well known polymer used in technical and consumer applications such as:

-interior and exterior automotive parts

-housing for domestic appliances such as hair dryers and vacuum cleaners

-kitchen appliances such as mixing machines and refrigerator linings

-furniture parts

-telephones

-toys

-pipes and profiles

The data on ABS production adapted are based on information from a number of European plants[28]. However, no information concerning the specific countries are provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included.

Calendered PVC

The data on calendered PVC production adapted are based on information from a number of European plants[29]. However, no information concerning the specific countries are provided.

Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

Epoxy resin, liquid

Epoxy resins are a group of thermosetting plastics which incorporate the epoxide group into their structure. The most commonly used epoxy resins are produced from bisphenol-A and epichlorohydrin.

Liquid epoxy resins are either reacted with an appropriate crosslinking agent (hardener) to produce a solid, three-dimensional network, or further reacted with bisphenol-A to increase the chain length to produce solid epoxy resins.

Depending on molecular weight and choice of hardener, epoxy resins find many applications ranging from adhesives to metal coatings.

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28 Boustead I. Eco-profiles of the European plastics industry, acrylonitrile-styrene copolymer (ASB), table 1, 2, 4-8.

29 Boustead I., Eco-profiles of the European plastics industry, calendered PVC, table 1, 2, 4-8.

The data on liquid epoxy resin production adapted are based on information from a number of European plants[30]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

EPS

Production of expandable polystyrene.

The data on EPS production adapted are based on information from a number of European plants[31]. However, no information concerning the specific countries are provided.

Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included

Flexible PUR foam

The data on PET resin production adapted are based on information from a number of European plants[32]. However, no information concerning the specific countries are provided.

Raw materials and fossil fuels/feedstocks (such as bauxite, clay, natural gas and diesel) have been traced back to the cradle (nature). (Resources, emissions etc. associated with the production of fossil fuels/feedstocks have been calculated by using emission factors from CIT The outputs are emissions to air and water; emissions associated with the combustion of all fuels are included (i.e. not only from fossil fuels).

The production of the fuels hydrogen and unspecified fuel is not included i.e. they are non-elementary inputs from technosphere.

The waste management is not included, which means that the waste are non-elementary i.e. outputs which have not been followed to the grave.

GPPS

Production of general purpose polystyrene.

The data on GPPS production adapted are based on information from a number of European plants[33]. However, no information concerning the specific countries are provided.

30 Boustead I., (1997b), table 7, 8, 11-14.

31 Boustead I, (1997a), table 58-63.

32Boustead I. (1997c), table 14, 15, 18-21 for TDI, table 22, 23, 26-29 for polyol and table A15 for the flexible PUR foam.

Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

<u>HDPE Resin</u>

The data on HDPE resin production adapted are based on information from a number of European plants[34]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

<u>PC polycarbonate</u>

Polycarbonate, PC, is commonly produced by the reaction of phosgene with bisphenol A. PC is a transparent, crystalline thermoplastic polymer which possesses unusually high impact strength and toughness even at low temperatures, has low moisture absorption, good heat and electrical resistance and good oxidative and thermal stability. It is biologically inert and possesses good chemical resistance.

Typical applications are

-housings for domestic appliances

-office equipment

-electrical systems, switches and housing

-compact discs and optical storage

-medical devices

-food containers and packaging

-glazing and lighting applications

-safety glasses

The data on polycarbonate production adapted are based on information from a number of European plants[35]. However, no information concerning the specific countries is provided.

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33 Boustead I. (1997a), table 46-51.
34 Boustead I., Eco-profiles of the European plastics industry, HDPE resin, table 1, 2, 4-8.
35 Boustead I. (1997d), table 6, 7, 10-13.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

Polyester (textile)

Cradle-to-gate data for 1kg unsaturated polyester. This is produced from propene glycol and maleic anhydride which is then dissolved in styrene.

Propene glycol

The data on propylene production adapted are based on information from a number of European plants[36]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

Maleic anhydride

It is assumed that the maleic anhydride is produced from oxidation of benzene [37].

Material balance (per kg maleic anhydride):

Out:
Maleic anhydride 1 kg

In:
Benzene 1.19 kg

Process energy:
0.15 FOET => 42.7*0.15 = 6.4 MJ.

Styrene

The data on styrene production adapted are based on information from a number of European plants[38]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

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36 Boustead I., (1997e), table 14, 15, 18-21.
37 Rudd et.al. (1981)
38 Boustead I. (1997f), table 1, 2, 4-8.

PPS

Production of Poly Phenylene Sulfide (PPS).

PPS is produced from dichlorobenzene[37] and sodiumsulfide[39].

The ratio between the inflows has been calculated assuming 1 mole dichlorobenzene and 1 mole Na_2S is required for 1 mole PPS.

M ($C_6H_4Cl_2$) = 147 g/mole

M (Na_2S) = 78 g/mole

PVC

Production of polyvinyl chloride (PVC) from virgin feedstocks through suspension polymerisation. Suspension PVC is the general purpose grade and is used for most rigid PVC applications, such as pipes, profiles and other building materials. It is also used for most flexible applications, such as cable insulation, foils and various products made by injection moulding. Suspension PVC accounts for more than 80% of the PVC market.

The data on suspension PVC production adapted are based on information from a number of European plants[40]. However, no information concerning the specific countries are provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

Propene

The data on propylene production adapted are based on information from a number of European plants[41]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

Rubber

Data for rubber production is based on data from Boge GmbH, Bonn, Germany. The recipe has been modified so that all crude rubber (39.1%) has been substituted by SB-Rubber.

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39 Flodin P.
40 Boustead I., (1998), table 62, 63, 66-69.
41 Boustead I., (1997e), table 14, 15, 18-21.

The amounts of raw materials and energy consumption as well as the emissions and wastes from the process are included.

The waste is non-elementary output not followed to the grave.

Operation

DIESEL PRODUCTION

The data on diesel production is based on Frees et al. (1998)[42] The data for extraction and refining of diesel are based on Frischknecht et al[18]. The data cover exploration, extraction, refining and transport to stock.

All known inputs have been traced back to the cradle (i.e. nature). The outputs are emissions to air and water. However, the outputs of waste are non-elementary, i.e. outputs which have not been followed to the grave (i.e. nature).

HEAVY FUEL OIL PRODUCTION

Data for the extraction and refining of heavy fuel oil are taken from Frischknecht et al.[18.] The data cover exploration, extraction, refining and transport to stock.

All known inputs have been traced back to the cradle (i.e. nature). The outputs are emissions to air and water. However, the outputs of waste are non-elementary, i.e. outputs which have not been followed to the grave (i.e. nature).

HYDROGEN PRODUCTION

The data on hydrogen production adapted are based on information from a number of European plants.[43] However, no information concerning the specific countries is provided.

Raw materials (such as iron and nitrogen) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included.

COMBUSTION ONBOARD

The user of the application will be able to enter emission factors for the combustion or transformation of any fuel or energy used onboard. Standard emission factors for the combustion of different fuels in different engine types can be found in the literature. The

42 Frees et al., (1998).
43 Boustead I. (1998), table 46, 47, 50-53.

MEET[44] project has for example published proposals of standard emission factors that can be used which can be seen in **Table 1** below.

Table 1 *Standard emission factors from the MEET project (kg emissions per ton fuel)*

Engine type	NO_X	CO	CO_2	VOC	PM	SO_X
Steam turbines – BFO engines	6.98	0.431	3 200	0.085	2.5	20*S
Steam turbines – BFO engines	6.25	0.6	3 200	0.5	2.08	20*S
High speed diesel engines	70	9	3 200	3	1.5	20*S
Medium speed diesel engines	57	7.4	3 200	2.4	1.2	20*S
Slow speed diesel engines	87	7.4	3 200	2.4	1.2	20*S
Gas turbines	16	0.5	3 200	0.2	1.1	20*S

UREA

Production of urea from natural gas feedstock. The data on urea production adapted are based on information from a number of European plants.[45] However, no information concerning the specific countries is provided. Raw materials (such as limestone and nitrogen) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included.

ACETONE

There are a number of different routes to produce acetone; the most commonly used route is as a by-product from the manufacturing of phenol (from benzene and propylene). This route has been used in this application.

The data on acetone production adapted are based on information from a number of European plants[46]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

CHLORINE

The data on chlorine production adapted are based on information from a number of European plants[47]. However, no information concerning the specific countries are provided.

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[44] European Commission (1999), table C15.
45 Boustead I. (1997e), table 30, 31, 34-37.
46 Boustead I. 1997e, table 38, 39, 42-45.

Raw materials (such as bauxite and iron) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

ETHYLENE

Based on information from a number of European plants.[48]

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

ISOPROPANOLE

To produce 1 kg isopropanole 0.73 kg of propylene is required[37] .

Process energy for dehydration of propylene:

0.39 FOET= 42.7 MJ/kg olja * 0.39 = 16.65 MJ/kg isopropanole.

Material balance:

isopropanole: 1 T

fuel gas: 0.02 T

active carbon: -0,01 T

propylene: -0,73 T

<u>Propylene</u>

The data on propylene production adapted are based on information from a number of European plants[49]. However, no information concerning the specific countries is provided.

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

47 Boustead I. (1998), table 30, 31, 34-37.
48 Boustead I. (1998), table 6, 7, 10-13.
49 Boustead I. (1997e), table 14, 15, 18-21.

HYDROCHLORIDE

The data is based on the environmental report from Kemira.[50]

Raw materials (such as bauxite and clay) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

SODIUM CHLORIDE

The data on sodium chloride (as purifide brine) production adapted are based on information from a number of European plants[51]. However, no information concerning the specific countries are provided.

Raw materials (such as bauxite and sand) have been traced back to the cradle (nature). The outputs are emissions to air and water; emissions associated with the combustion of fuels are included. Some outputs are non-elementary, i.e. outputs which have not been followed to the grave (e.g. waste for which the waste management has not been included).

SULPHURIC ACID

Sulphuric acid results from the production of sulphur dioxide, its conversion into sulphur trioxide and finally, absorption of sulphur trioxide by water, giving sulphuric acid. These reactions are exothermic to various extents. The steam produced can be used to produce electricity.

The sulphur emissions are released with the waste gas from the final absorber.

Production of sulphuric acid involves exothermic reactions and therefore electricity, steam for internal use, and district heat is often produced. The net export of steam is 1.06 GJ/ton H_2SO_4.

The sub-activities Sulphur, Sulphur from waste acid, and Sulphuric acid are based on Davis J, Haglund C[52]. The activity steam on-site average has been included in the system to represent the avoided production of steam. The data for steam production are based on Bousted I .[53]

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50 Kemira (1994)
51 Boustead I. (1998), table 22, 23, 26-29.
52 Davis J, Haglund C. (1999).
53 Bousted I. (1999).

ONBOARD ENERGY SYSTEM MODELLING

The energy consumption onboard a ship is large compared too many other energy consumers. A modern Ro/Ro ship could for example use totally 25-75 000 MWh propulsion power per year and consume 500-2 000 MW at quay during loading and unloading operations (depending on ships size etc). This energy is today consumed as bunker oil corresponds to 5-15 000 ton oil per year. The consumption of a single vessel could therefore correspond to a residential district with 500-5 000 detached houses. Even small adjustments to a vessels energy system, diminishing the consumption, will therefore be of greatest interest.

The purposes of the analyses will make information and system description on different levels necessary. Available information will also have impacts on the aggregation level needed when the energy and LCA analyses are performed. Methods and defining levels, when the application has been developed, have therefore been designed so the user can chose aggregation level and complexity of the analysed system.

If for example the consumption of the engines is known it could just be entered. But if the consumption is not known, or in case the system onboard is to be analysed and perhaps optimised, the application contains some unique opportunities.

The developed application contains modules that make it possible to enter known information regarding the energy consumption, fuel quality and the emission standard of the engine system. Required fuel consumption can be calculated on the basis if ship parameters, required speed and system data for the machine system. But the energy consumption could also just be entered in form of bunker fuel consumed per hour for a specific operational phase, as mentioned above.

The base for all defining and calculations of energy use and energy systems are the physics behind the system. The modelling, of energy systems onboard, started with a literature review and with interviews and discussions with engine manufactures, machine room planners and persons with knowledge about system engineering and modelling of technical problems. The process has also contained a theoretic model building on a component level. Real energy flows in existing energy systems onboard vessels have been used in the process to find the best model/method to model the energy system.

The required propulsion power was also a subject for modelling in the project. The basis for this modelling has been SSPA broad knowledge in the field of ships resistance and propulsion power requirements due to vessel characteristics.

Simplifications of energy systems have been necessary for many reasons. An ideal energy model would for example have made it possible for the initiated user to define each component in the system with specific characteristics with all connections/relations to other components in the total energy system. These defining would have been interesting to develop but it has not been possible to justify the needed resources to construct and develop this with this projects limited resources. The requirements that the developed model should satisfy was:

- All known machinery system compositions should be able to handle with the model
- The model should be able to use by a person that has knowledge about ship machinery systems on a system level
- The model should preferable handle planned future engine room compositions as fuel cells, shore to ship electricity connections in harbours etc
- The model should be accurate enough to make it possible to use for sensitivity analyses of changes in the system

Propulsion power modelling

The calculation of propulsive power is based on the standard ship performance prediction method referred to as ITTC-78, which was presented by the International Towing Tank Conference in 1978. This is considered to be the most established method available.

The basic deep water resistance is calculated using the residuary resistance coefficient Cr for the actual ship configuration. Cr has in turn been calculated based on a regression of all displacement ships tested at SSPA. The ITTC-78 form factor is calculated according to Watanabe's formula as default.

The following input data is required for the calculations. For this application *default values* of several input data are used.

Ship type:

1: general cargo ship
2: container carrier
3: RoRo vessel
4 RoPax vessel
5: ferry
6: cruise liner
7: car carrier
8: LNG carrier
9: Product tanker
10: tanker/bulker
11: VLCC

Hull series: Hull series will be chosen based on ship type and length and will control the default calculation of a number of hull and propulsive parameters. The following hull series will be chosen based on the length specified:

- Coaster/Cargo liner: If Lpp < 70 m - coaster is chosen
  If Lpp > 70 m - cargo liner is chosen
- Coaster/Tanker/VLCC: If Lpp < 70 m - coaster is chosen
  If Lpp < 300 m - tanker/bulk carrier is chosen

If Lpp > 300 m - VLCC is chosen

Bulb: (0) for no bulb and (1) for default bulb.

The default bulbous bow is given a section area of 10% of the midship section and a lateral area forward of FP of 1.5% of the ship’s lateral area.

Lpp (m): Ship's moulded length between perpendiculars.

Lwl (m): Ship's actual water line length. Default value = Lpp

Beam (m): Ship's moulded beam at design water line.

Tdes (m): Moulded draft at design load condition.

Tf (m): Moulded draft at forward perpendicular of actual load condition.

Ta (m): Moulded draft at aft perpendicular of actual load condition.

DISP (m^3): Displacement of actual load condition.

BWTH: Number of Bow Tunnel Thrusters (-).

SBK (m^2): Total wetted area of bilge keels. *Default value.*

Tskeg: Conventional (0) or twin-skeg (1). *Default value (*0).

SW (m^2): Wetted surface of hull and appendages except for bilge keels. *Default value.*

LCB (%): Longitudinal Centre of buoyancy LCB (% rel L/2). *Default value.*

FF (-): Form Factor. Ratio between residual and viscous resistance of ship model at a very low speed. *Default value.*

Vs (knots): Design Speed. Required for calculation of propulsive factors and either to calculate the optimum propeller diameter for a given design RPM or the optimum RPM for a given diameter.

D (m): Propeller Diameter (m). If left blank an optimum diameter will be calculated for the given design RPM. If given and design RPM is left blank the optimum RPM will be calculated.

Nk: Design propeller RPM. If given and diameter and pitch ratio are left zero the optimum propeller diameter will be calculated. If left zero the optimum RPM will be calculated for the given diameter.

PTD: Pitch Ratio (P/D). *Default value.*

NP: Number of Propellers. Single or twin-screw propulsion could be chosen. If twin-skeg stern is given, the prediction module will assume 2 propellers.

Ptyp: Type of Propeller. A 4-bladed controllable pitch propeller with 60 percent blade area may be chosen. Calculation can be made for CP propeller at fixed pitch or fixed design RPM .

NB: Number of Blades. *Default value.* Give desired number of propeller blades.

EARS (%) : Expanded Blade Area Ratio. *Default value.*

Tshaft (m): Draft of propeller axis. *Default value.*

ETAR: Relative Rotative Efficiency. *Default value.*

WF: Wake fraction. Default value.

TDF: Thrust deduction factor. *Default value.*

Rudder type:

Rtyp: Conventional / Flap /Schilling Mariner

AR (m^2): Total projected rudder area. *Default value.* SSPA recommendation (AR=CB*Lpp*Beam/100)

Rudc: Rudder resistance correction factor. *Default value.*

AT (m^2): Transverse Area above Water Line. *Default value.*

KS: Hull Roughness (micro-meter). *Default value is 150 μm.*

KP: Blade Roughness (micro-meter). *Default value is 30 μm.*

CP: Trial correction power. *Default value.*

CN: Trial correction rpm. *Default value.*

CP and CN as given by user or calculated by the prediction module according to SSPA standard trial prediction.

TEMP: Sea Water Temperature (^oC). Default is 15 ^oC. *Default value.*

DENS: Density of Sea Water (kg/m^3). Default is 1025 kg/m^3. *Default value.*

WD (m): Water depth. *Default value 1000 m.* The calculation is interrupted when the squat becomes too large, i.e. the bottom clearance becomes zero.

Vkn: Actual speed for power calculation.

The result of the calculation 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.

For calculation of fuel consumption the internal transmission losses should be added to the calculated delivered power.

Onboard energy system

Much effort has been made in order to make it possible to analyse and describe all kind of machinery systems and machine room compositions in a practical and accurate way. The machinery system has been analysed in form of energy flows and coupled relations at component level. A model of the energy flow on a component level can be seen in **Figure 11**. Energy flow into and out of a component can be of different form and quality. The energy flow out from the components will often be of more than one type of energy. In reality, different form of energy from different components as well as energy loops will enter some of the components, as seen in **Figure 11**. Energy loops etc will not be handled in this model.

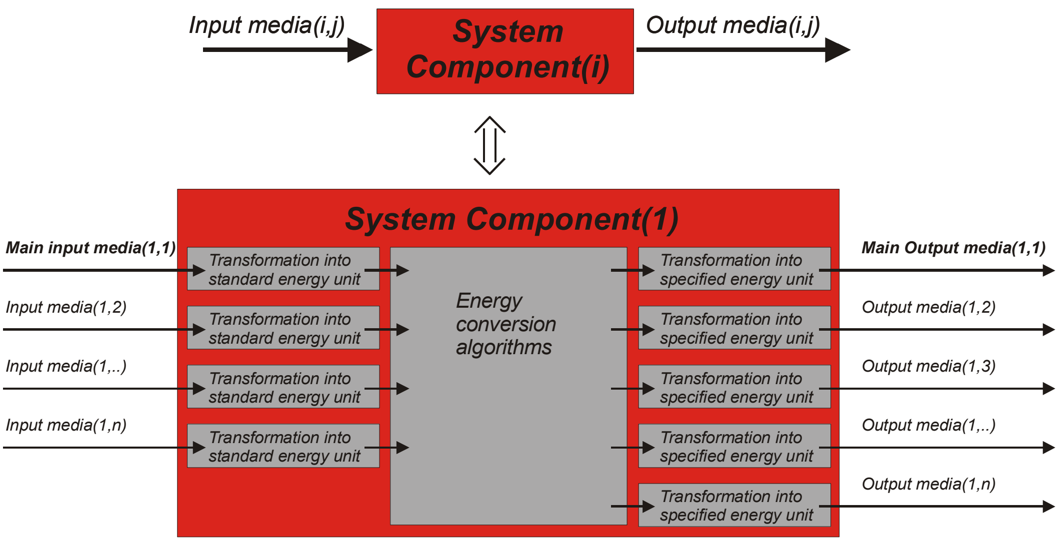


Figure 11 *An engine or machinery component could be defined by input and output flow of energy and algorithms for the energy transformation*

The machinery system onboard in form of used components and how they are connected can vary with the use of the vessel. Therefore all energy is specified and calculations are made for a specific state of operation. For example efficiency of engines will vary with load factor and the uses of systems vary between sea and port state. Some kind of general model was looked for that allowed to describe all kind of engine room compositions, states of operations and energy consumers (see **Figure 12**).

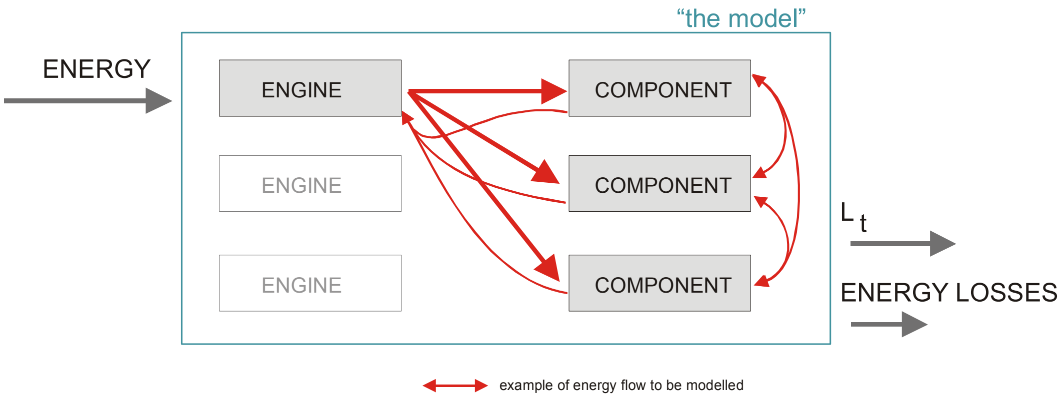


***Figure 12** A schematic model that show engine system for shaft energy production, to be modelled with different levels of aggregation*

The energy system onboard a ship is a complex and interconnected system. Some simplifications are therefore needed to be able to describe; the energy use; the energy transformations; 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 or energy flows, 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. The energy module should also make it possible to module and calculate the energy need according to different technical and operational solutions. An example of the energy flow in a ship machinery room and the electricity flow in an auxiliary electricity generation system can be seen in **Figure 13** and **Figure 14**. Example of electricity consumers onboard a ship can be seen in **Figure 15**.

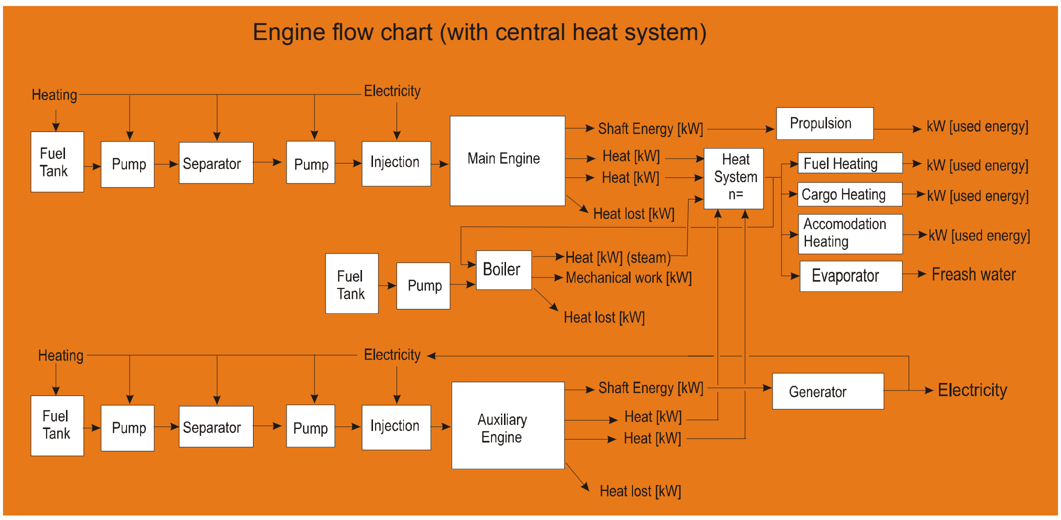


***Figure 13** Example of the engine flow through a specific machinery system*

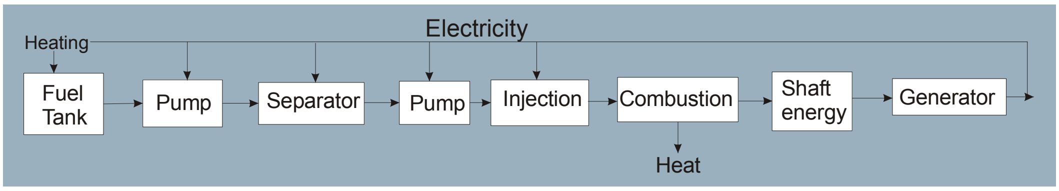


Figure 14 *Example of an electricity generation flow chart*

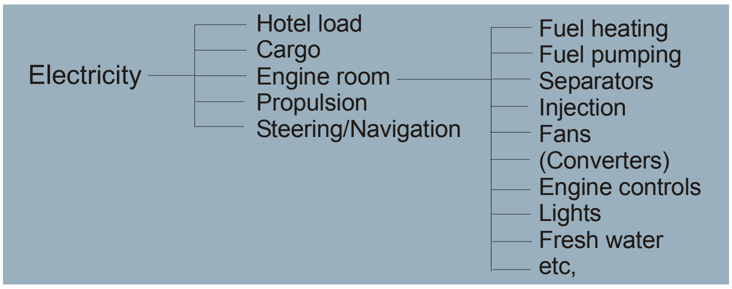


Figure 15 *Electricity users on different system levels*

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. Example of energy flow trough a turbocharged main engine can be shown as a Shankey diagram, see **Figure 16**.

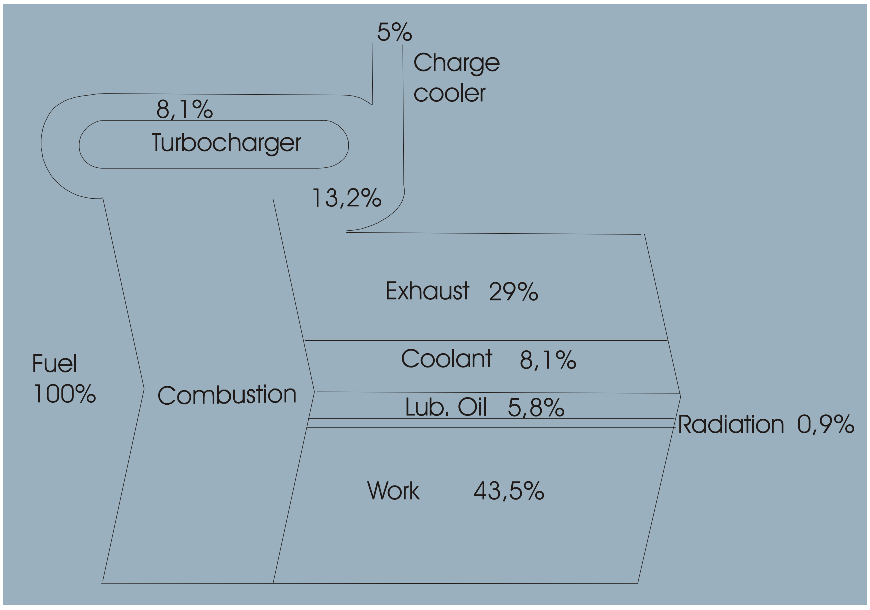
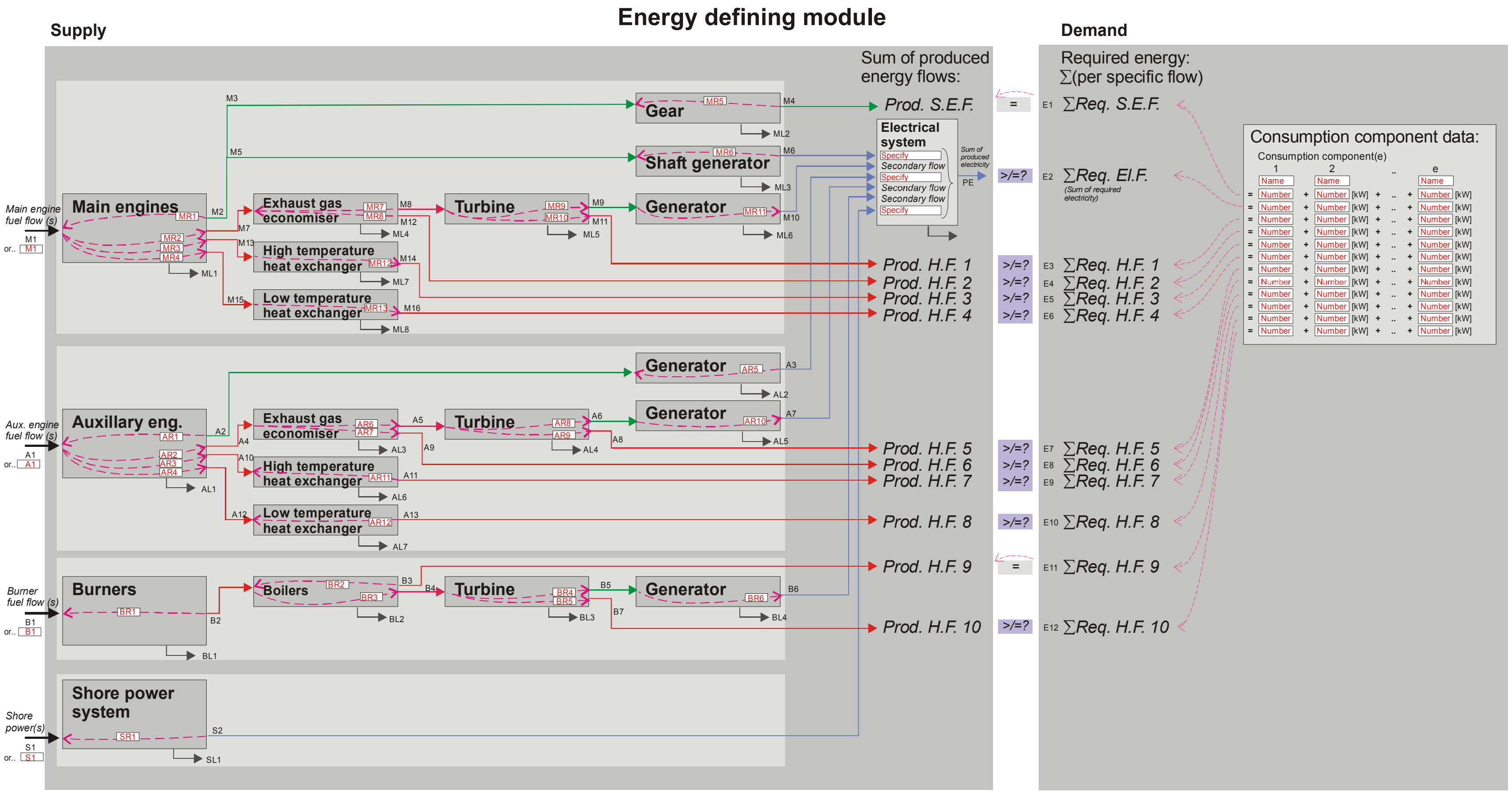


Figure 16 *Shankey Diagram for a Sulzer ZA40S Diesel Engine (Turbocharged)*

A principal model of the energy flow trough the engine room has been developed. The idea is that all normal operational states should be able to be modelled in the system see **Figure 17**.

The most important simplifications of the real energy system flows that have been made in the model are:

- All energy flows onboard will be calculated in kW in the model, the user must therefore know how much of the energy that is possible to use for different purposes
- The model handles energy flow in one way direction through the system from input of for example oil to the output in the end of the system (propeller fans, cargo heating etc.)
- Just one form of energy can be defined entering into each component in the model
- The efficiency and characteristics of many of the components will vary with load factor and conditions. The user must manually alter these variations when systems changes are made.



1. *Specify internal relations in all relevant energy system components*
2. *Enter needed energy for each consumption component*
3. *Check required energy vs. produced energy*

Mechanical energy flow — *Internal component losses*
Thermal energy flow — *Information flow*
Electrical energy flow

Figure 17 *The total energy "production" respectively "consumption" system. Energy enters from the left and is "consumed" at the right*

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?

Note that the user of this 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 30°C will be quite expensive to transform into electricity and the efficiency will anyway be low. A steam flow at high pressure and temperature will on the other hand be more useful onboard for many functions.

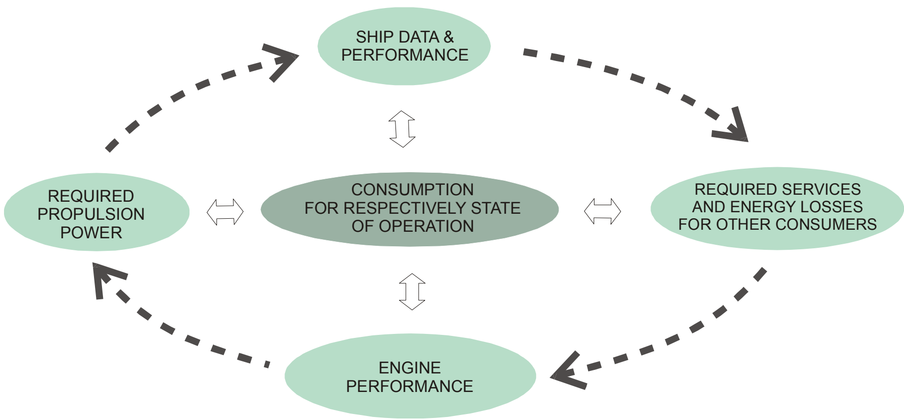


Figure 18 *The design process or the modelling process for an engine system not fully known is an iterative process*

ENERGY FLOW THROUGH THE SYSTEM

The main engine modelling can be seen in **Figure 19** where 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 guided by the user of the application as a distribution of the energy output to define output flows (and losses).

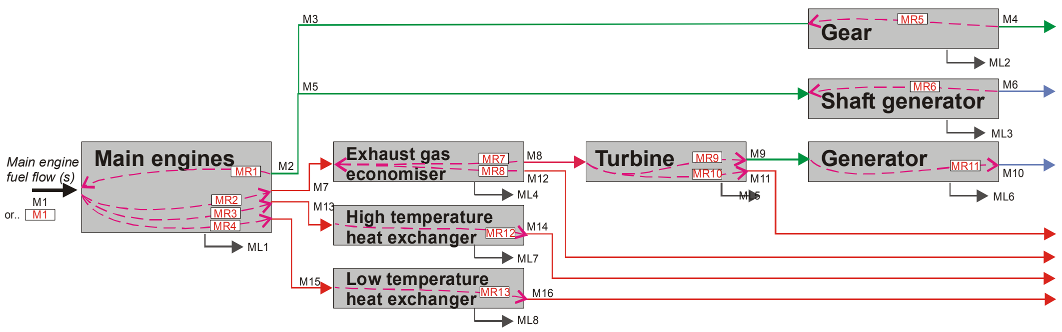


Figure 19 *An example how engines and components can be connected to each other through input and output of energy between the components.*

If the input flow is set to 100% the sum of the defined output flow can never be over 100%. *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 19**) does not exist or is 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%.

The whole energy model for onboard energy generation is shown in **Figure 17** where also the consumption side can be seen.

Energy consumers onboard

After the energy production system onboard is described for the specific *State of operation* the energy consumption should be entered. Energy consumption is entered for one or several *Energy consumers*. It is possible to define all consumption onboard for a *State of operation* in one *Energy consumer*. Each process that is running at a *State of operation* could also be defined by under its 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 20**.

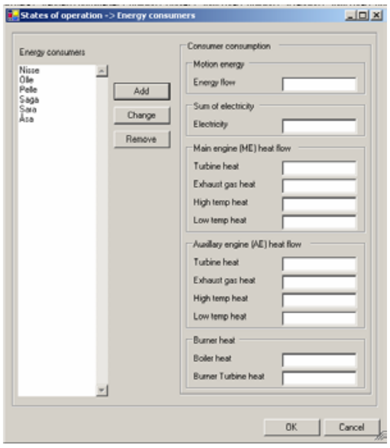


Figure 20 *Wizard for the specification of* Energy consumers

BALANCING THE ENERGY SYSTEM

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

Some types of energy consumption entered as for example Shaft energy 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 is needed from shaft energy production (P). If there is no gear the shaft energy production from the main engine has to be the same as the shaft energy consumption. In our 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 selected fuel, the oil consumption into the main engine could also be calculated. The relation between the energy flow of the main engine and the other outputs (exhausts, low/high temperature flows), these flows can also be calculated.

The primary energy flow into the system onboard must be in defined forms (Heavy Fuel Oil (HFO) etc), connected to related life cycle data. Output of the energy system onboard normally will be energy in a form not possible to use further (heat, friction between hull and water or wave resistance etc). It might be possible that a system will produce energy or other material in a form possible to use in other systems or processes. This output could be handled in the same manner as all other outputs and emissions with the life cycle analysis practice.

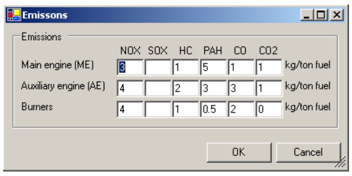


Figure 21 *Wizard for editing emission factors*

MODELING OF DIFFERENT SYSTEMS

The range of possibilities to specify the energy system onboard is very wide. A vessels energy system could for example be very complex specified or just very simple as a Main engine run by oil, producing mechanical energy for the propulsion, an Auxiliary engine run by oil producing electricity and the energy consumption for different operational stages (at sea, loading, idle etc.).

In the application, the modelling of the engine system and energy relations is greatly simplified, but it is still proving to be adequate for evaluation purposes. The engine system will consist of a predefined system with generally valid relations; the user is to specify various *“States of Operations”* corresponding to the intended use of the vessel. For each *“State of Operation”* the user is asked to specify appropriate data regarding; speed and consumption, as well as defining the engine system and the *“Energy consuming components”*. The engine system is defined by the efficiency of the main respectively auxiliary engines and boilers and the amount of energy that leaves the engines in form of heat in the exhaust gas, and in the high and low temperature heat exchangers. This information is stated in percent of total input energy, e.g. fuel consumption, (this kind of information can be found in the engines Shankey diagrams). The user then specifies the efficiency and output media of the following components; Shaft gear, Shaft generator, Exhaust gas economiser, exhaust gas turbine, exhaust gas generator, and the High and Low temperature heat exchangers. If a component is not applicable its efficiency is simply set to 100%. A similar process is required for the auxiliary engines and the burners. If the vessel use *Shore electricity-connections* at berth, this is also stated. All available energy output is labelled. All relevant energy-consuming components are to be specified by the user as well as their required input media (shaft, electrical or some form of heat energy). The application then states all the total available energy flows and the corresponding required amounts, so the user can compare them.

LIFE CYCLE COSTS

Connected to methods and tools for life Cycle Analysis, methods and modules for Life Cycle Cost (LCC) calculations have also been considered in the project

The idea was to establish methods and modules for the calculation of a vessels total life cycle costs. Most of the information needed in these calculations related to consumptions over the life cycle, can be taken from the defining and calculations made in the Life Cycle Analysis. Information that needs to be added is mostly related to the costs for materials and consumables. In order to find State of the Art knowledge about LCC methods and system a small literature review was performed and people with knowledge in the subject was contacted and interviewed.[54]

Two different ways of calculation have been discussed. The first method is the more simple method. All consumption entered or calculated in the application can be given a specific value in a valuation method (in the *Analyse module*). If the value given for electricity, oil, machinery parts, steel etc. is set to the actual cost for these materials, the total paying for these posts can be calculated on the basis of used amounts of materials and consumables. (Manning costs, insurances etc are neglected). This kind of calculation will not be absolutely correct as discounting of future costs into present value are not performed. The second and more advanced method will contain methods or modules where interest rates and in what phase of the life cycle a specific cost will appear.

[54] For example: CEISS (2004), Bengt Dahlgren AB (2000) and Westin

SYSTEM DESCRIPTION OF THE TOOL

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.

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.

The C# code in the application has been commented for further development purposes.

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.

PROPOSED FURTHER WORK

The project will need further support in the area of Life Cycle Data for components and materials. Three areas can be identified as especially interesting:

1. Further investigations about consumed/used amounts of materials, components and consumer goods during the lifetime of a vessel. This is information that is especially needed when new vessel concepts are to be analysed and the figures are not yet known
2. Methods for estimating component consumption, material use etc.
3. Supplementary information about materials, components etc that is used onboard ships and which makes significant contributions to the environmental load during the lifetime (e.g. LCA data)

PROPULSION POWER MODELLING

Proposed further development of the propulsion power modelling would include adding the possibility for users to input information about weather and ship conditions. This could be a useful feature for knowledgeable users who would like to improve the estimate to better match the condition of the ship (age, hull and propeller roughness, etc.) and the weather and water depth for their specific routes. Default sea margin values based on age, time since last hull and propeller cleaning, weather statistics for different sea areas, etc. may be estimated. Other further development could include adding the possibility for knowledgeable users to input vessel specific information for parameters where default values have been used to simplify the model for average users.

FURTHER DEVELOPMENT AND TESTING OF THE COMPUTER APPLICATION.

Sensitivity analyses of ships and sea transportation with the help of the prototype application, in order to investigate what kind of actions that is most effective to reduce energy use and environmental impact.

DISSEMINATION PHASE

DISSEMINATION OF THE APPLICATION AND LCA OF SHIPS OPERATIONS

A seminar is planned to present the project and to demonstrate the application. During the seminar the application and the thoughts behind will be presented as well as discussed. The seminar will also be the base for further work with the application.

RESULTS FROM ENVIRONMENTAL ANALYSIS

The use of the application in real applications makes the tool worth. Results from LCA and energy analyses of vessels and shipping system concepts will be useful and increase the knowledge base on what actions that is needed to achieve environmentally sustainable shipping systems. The project consortia will use the application in the nearest future to perform *Life Cycle Analyses* of vessels and ship transportation system in close cooperation with the industrial partners to the project.

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Personal contacts

Eurostat, 1997d, Catherine Dielens, Eurostat Data Shop

Herbert Nilsson, Kockums Engineering, +46 31 772 3688

Jan Steffensson, Prof. Emeritus., Chalmers University of Technology

Thomas Stenhede, Wärtsilä Sweden AB, +46 520 42 28 53

Mari Westin, Swedish Energy Agency, 016-544 2062