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MariEMS Learning Material

This is the 30th compilation by Professor Dr Reza Ziarati on the work of the EU funded Erasmus + MariEMS' partners and material extracted from the IMO TTT Course. The material is composed from Chapter 30 of the learning material. Readers are also advised to refer to the papers on IdeaPort and IdealShip projects led by C4FF and published by MariFuture.

30 Energy Audit and Review

30.1 Introduction

Energy audits or reviews are key to a systematic approach to an effective planning for energy management. It represents a quantitative assessment of a company/facility/ship energy inputs and outputs and attempts to balance the total energy inputs, output and losses at top level as well as for major energy using systems and equipment. As such, it is used to assess all the energy streams in a facility (such as a ship) with the main objective of identifying ways to reduce its energy consumption, energy baselines and so on.

As discussed earlier, the main operational expenses of a ship is found to be fuel cost plus other costs such as maintenance and repair and crew wages. If a choice is made to reduce the operational costs via improving performance amongst the above three main cost items, energy would invariably emerge as a top preposition and thus energy management constitutes a strategic area for cost reduction.

Energy audit or review helps to understand in detail about the ways energy and fuel are used in any industry, thus helps in identifying the areas where waste can occur and where scope for improvement exists. The scope of an energy audit or review varies from industry to industry but generally could include supporting the corporate aspects such as reducing energy costs, reducing environmental impacts, ensuring availability and reliability of supply of energy, use of appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc.

Energy audit or review seeks to identify the technically feasible energy conservation solutions taking into account economic and other organizational considerations within a specified time frame. Energy audit and reviews are mandated activities in some of the existing management standards. For example, in development of a CEnMS based on ISO 50001, carrying out energy review is a requirement.

Another example is the EU Directive on Energy Efficiency [Directive 2012/27/EU] that makes energy audit of enterprises a requirement unless they are certified for ISO 50001 that implies they have already undertaken an energy review.

So, in terms of requirement, various standards may have a varied level of requirements on how energy audit or review should be done or documented. For example, on the need for documentation and certification, ISO 50001 advocates the following:

- The methodology and criteria used to develop the energy review shall be documented.
- The energy review shall be updated at defined intervals, as well as in response to major changes in facilities, equipment, systems, or processes.

However, technically speaking, energy audit and review are not that much different. As such, in this section, the techniques for carrying out an energy audit is described, assuming that same techniques could be used to perform energy reviews.
Energy audit is defined in EU Directive 2012/27/EU as:
“Energy audit means a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy savings opportunities, and reporting the findings.”
EU has also developed European standards for energy audits. EN 16247:2012 series of standards provide more formal techniques for energy audits. An abstract of EN 16247-1:2012 states that [CEN website]:
“This European standard specifies the requirements, common methodology and deliverables for energy audits. It applies to all forms of establishments and organisations, all forms of energy and uses of energy, excluding individual private dwellings. This European standard covers the general requirements common to all energy audits. Specific energy audit requirements will complete the general requirements in separate parts dedicated to energy audits for buildings, industrial processes and transportation.”

30.2 Types of Energy Audit

The types of energy audit to be performed depend on:

- Function and type of industry (for example for shipping it will be somewhat different from a production factory).
- Depth and details to which the final audit is needed. This defines the scope of audit and what sort of output is expected from it.
- Potential and magnitude of cost reduction desired.

As a result, energy audit can have varied scopes; however in general terms energy audits are classified into the following two types.

- Preliminary energy audit
- Detailed energy audit

Preliminary Energy Audit: A preliminary energy audit is a relatively quick review of energy performance of facility that aims to:

- Establish overall energy consumption and its profile in the organization/facility.
- Estimate the scope for energy saving.
- Identify the most likely and the easiest areas that could provide saving potentials.
- Identify immediate (especially no or low-cost) improvements/ savings.
- Set a 'reference point' or establish a baseline for the organisation/facility.
- Identify areas for more detailed study/measurement for subsequent assessments.

For preliminary energy audit, normally existing or easily obtainable data are used and does not include any independent measurement campaign. A preliminary energy audit is sometimes referred to as a “walk-through energy audit” as it does not involve significant level of data analysis.

Detailed Energy Audit: A detailed energy audit provides a more comprehensive approach to the issue with detailed data gathering and data analysis for identifying and analysing the EEMs. It aims to provide enough information to enable decision making process or development and planning of energy saving projects. It effectively evaluates all major energy using systems. This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all energy saving measures, accounts for the energy use of all major equipment and includes detailed energy cost saving calculations and project costs.
In a detailed energy audit, one of the key elements is to establish the energy balance for the facility or organisation. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated energy use together with some degree of system modelling that compares well to the actual fuel and energy used; can provide insight into the way energy is procured and consumed.

29.3 Ship Energy Audit Process

30.3.1 Overview

A ship energy audit is considered as a specific energy audit that is tailored made for evaluation of a ship energy performance and identification of a ship's Energy Efficiency Measures (EEMs). It is therefore a review and assessment of the overall fuel/energy consumption and efficiency of a ship with the main objective of identifying a set of EEMs *(The ship's EEMs refer to those operational, technical and technology upgrade aspects of a vessel that if implemented, would lead to improved energy performance of a ship)* that when implemented would lead to reduced ship's fuel consumption. Identification of EEMs is the first step for development and implementation of a ship-specific energy saving programme as well as developing an organisations' energy management system (i.e. CEnMS) and a ship's energy management plan (i.e. SEEMP).
In ship energy audit, the focus is on identifying the existing status of a ship's operational processes and technical activities, and their comparison to best-practice or benchmarks. The analysis, depending on scope of the energy audit, involves some level of data collection and data analysis. As a result, areas of energy savings are identified, analysed and documented.
Figure 30.3.1 shows the generic process diagram for such an energy audit / review.

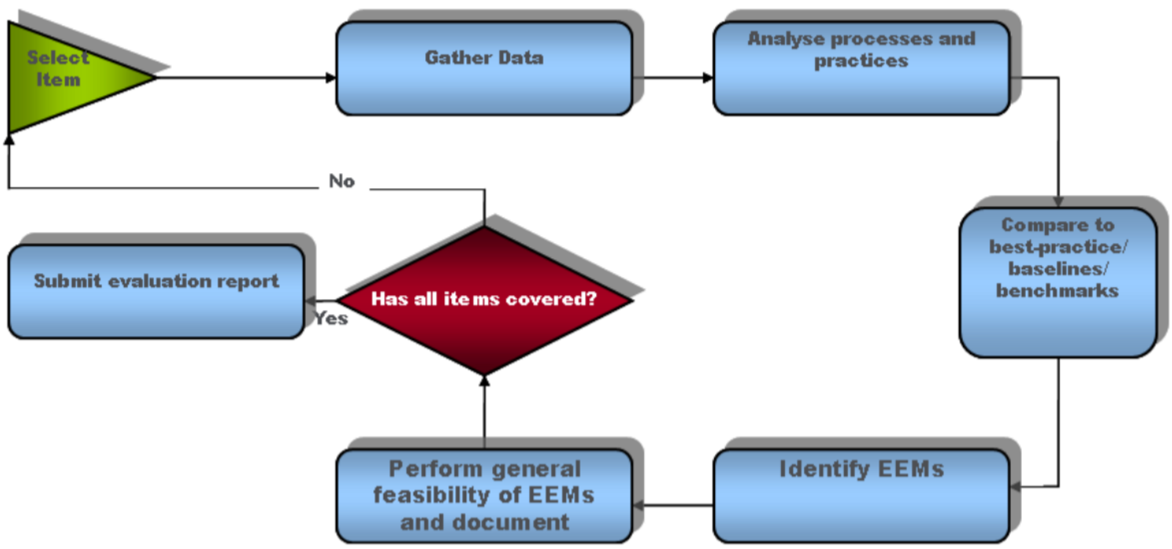

Figure 30.3.1 – Energy audit or review process [Bazari 2012]

In Figure 30.3.1, each “item” (see green triangle) could be a ship engineering system, machinery / equipment or operational activity that needs to be systematically analysed for energy efficiency. For each “item”, relevant data need to be collected and relevant benchmarks defined. Table 30.3.2 and Figure 30.3.2 show examples of main areas and aspects of a ship that should be investigated one by one as part of the ship energy audit.

Hull condition and performance
Ship’s operation and fuel consumption profiles
Ship voyage management and weather routing
Main engine’s condition and performance
Auxiliary engines’ condition and performance
Ship’s auxiliary electrical loads reduction
Auxiliary machinery utilisation and performance
Fuel quality and fuel treatment system
Lighting system and types of lamps
Compressed air system
Steam boilers
Steam system and piping condition
Technology upgrade potential (equipment retrofit)
Personnel training needs
Etc.

Table 30.3.2 – Ship energy audit – Example areas to be assessed

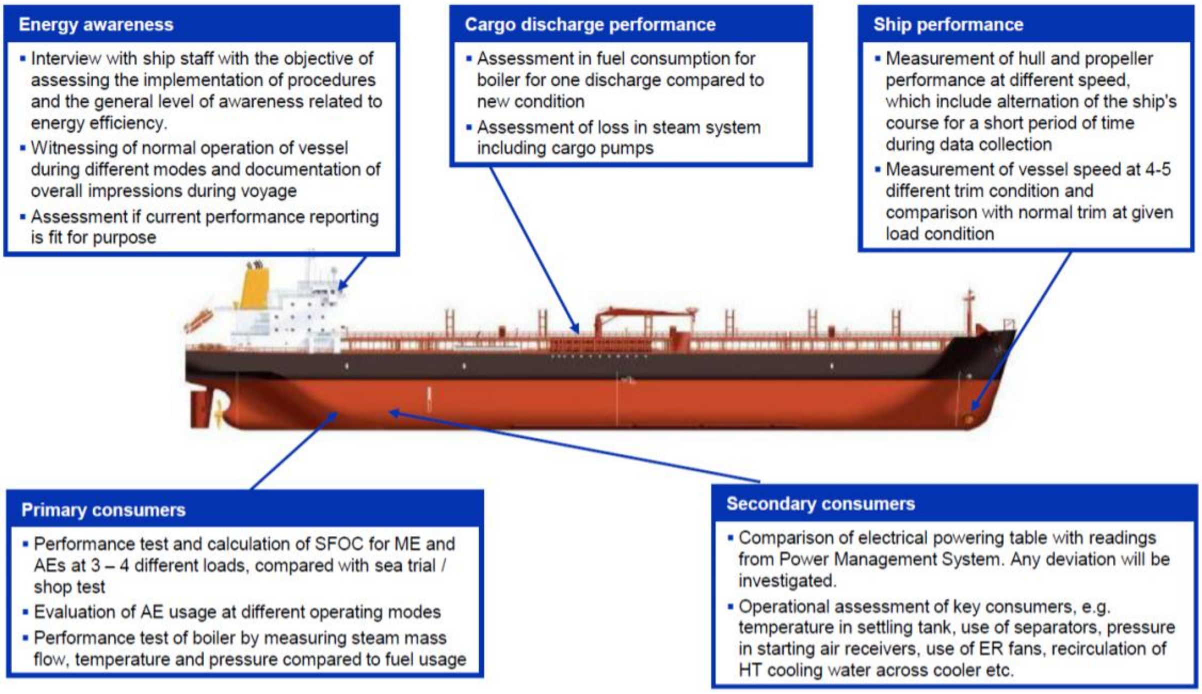

Figure 30.3.2 – Ship energy audit – Example areas to be assessed [DNV 2011]

30.3.2 Ship energy audit phases

Generally, a ship energy audit involves a ship-board survey and thus the audit as a whole may be carried out in three phases:

- **Phase I** – Pre-audit: This relates to all activities before the ship visit and survey. Activities under this phase could include:
    - Preliminary data gathering: The data would include ship's design data, speed trials data and operational data.
    - Initial data review: The preliminary data gathered are reviewed, preliminary candidate areas for further investigation are identified, some benchmarks are developed and the ship-board "energy audit" plan is prepared.
- **Phase II** - Audit: This includes ship survey, data analysis and reporting. Activities under this phase could include aspects such as: o Ship energy survey: The ship is visited and the planned survey activities are carried out, facilitated by ship personnel. This stage consists of a number of activities that involve walkthrough of ship engine room, deck and cargo control room, brainstorming and discussion with relevant personnel in particular the master and chief engineer and detailed investigations and data gathering from relevant record books, manuals, digital archives, etc.
    - Data analysis: Final data analysis is performed with the objective of identifying the final list of EEMs, their relevant energy saving level and the techno-economic feasibility analysis of each EEM.
    - Energy audit report: A report inclusive of findings and supporting evidences is prepared.
- **Phase III** – Post-audit: This refers to activities that may be needed to support the post audit implementation by the client.

29.4 Typical Data Analysis

A ship energy audit/review involves a significant level of data analysis. The depth and breadth of data analysis depends on type of investigation and level of detail agreed. In this section, examples of such types of analysis are given.

30.4.1 Ship operation profile

For improved voyage management and itinerary optimisation, evaluation of ship operation profile is an important area. The objective of this evaluation is to make sure that the itinerary and voyage management are planned and performed according to best practise. The assessment of ship operation profile will normally give an indication of excessive waiting periods or lack of ship activity. For this purpose, the ship duration of stay in ports, anchorage, etc. is an important factor that needs to be evaluated. Figure 30.4.1 shows an example of such a profile for an oil tanker.

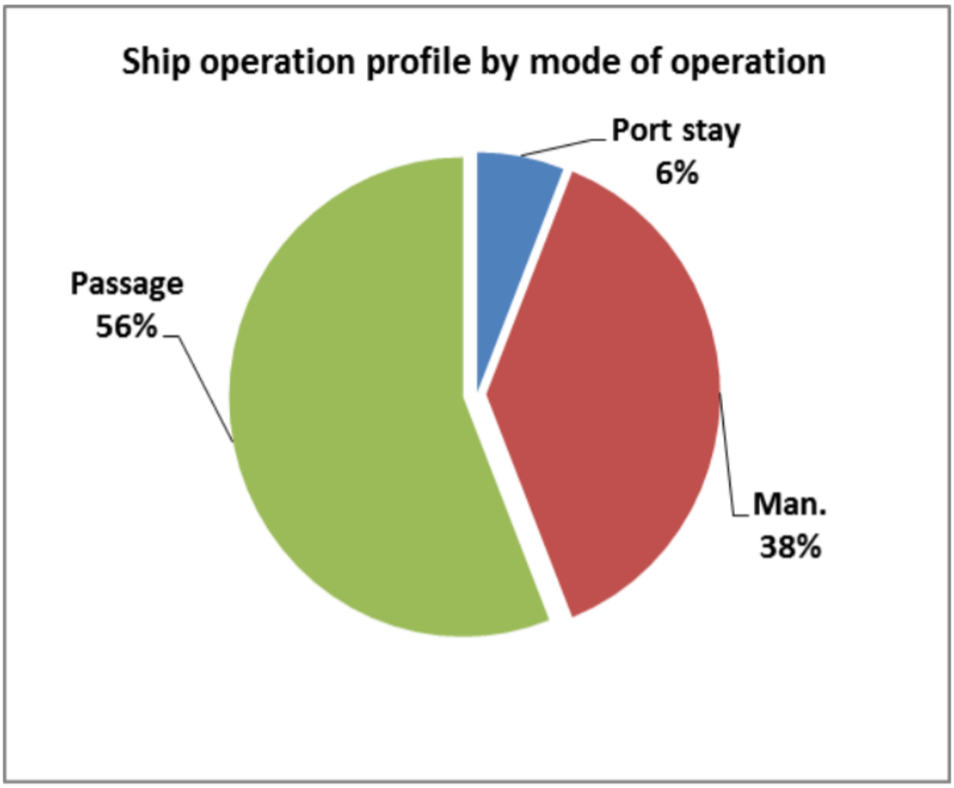

Figure 30.4.1 – Typical ship's operation profile by operation mode

Analysis of the above timings for this tanker then need to be carried out against ideal cases with no waiting by considering time for loading, unloading and bunkering, etc. As a result, it could be decided if there are opportunities for improvement or not.

30.4.2 Fuel consumption profile

The ship fuel consumption profile represents the balance of fuel used by different combustion systems (e.g. main engines, auxiliary engines and boilers). It can give an indication if any of the ship systems consume relatively higher fuel compared to expected best-practice levels. This then could be a good lead for further investigations of the causes of excessive fuel consumption and thereby identification of energy efficiency measures.

Figure 30.4.2 shows an example of a ship's fuel consumption profile; indicating percentages of fuel used by various systems. Comparing these with industry benchmarks and other ships in the fleet will indicate if any of the system may have been used inefficiently.

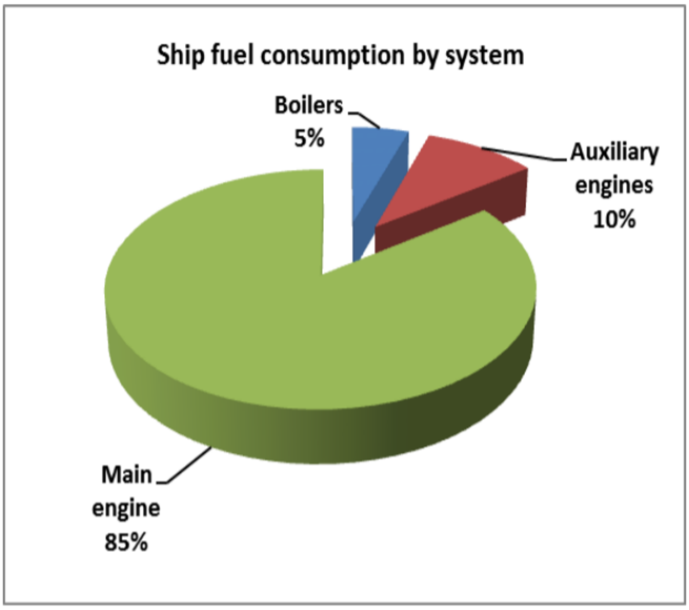

Figure 30.4.2 – Ship fuel consumption profile by system

30.4.3 Hull performance assessment

Analysis of a ship's speed-power or shaft rpm-power is the main analytical way for identification of hull and propeller fouling (see Figure 4.5). Under-water inspection of hull and propeller is an alternative technique. The data analysis techniques used for this type of investigations are similar to those performed under "ship performance monitoring".

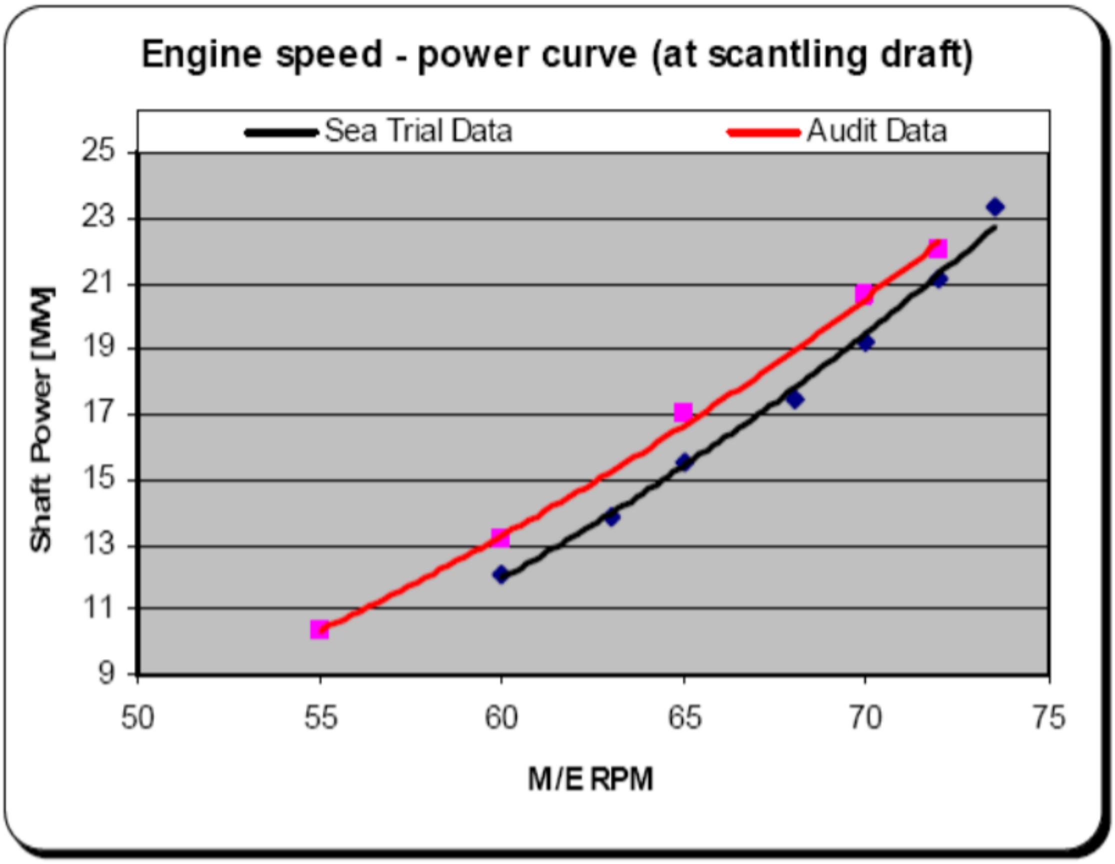

Figure 4.5 – Speed-power curve analysis [Bazari 2012]

30.4.4 Engine performance assessment

The methodology used for engine performance assessment (for both main and auxiliary engines) is based on what is normally used on-board for engine's condition and performance monitoring. Almost all ships perform engine cylinder pressure measurement (see Figure 30.4.4 as example). The system used normally analyse the cylinder pressure diagram and fuel injection profile (if measured) that would indicate anomalies with fuel injection system, cylinder liners, piston rings od engine valves. This test and its analysis are normally carried out on a monthly basis as part of the ship's planned maintenance system.

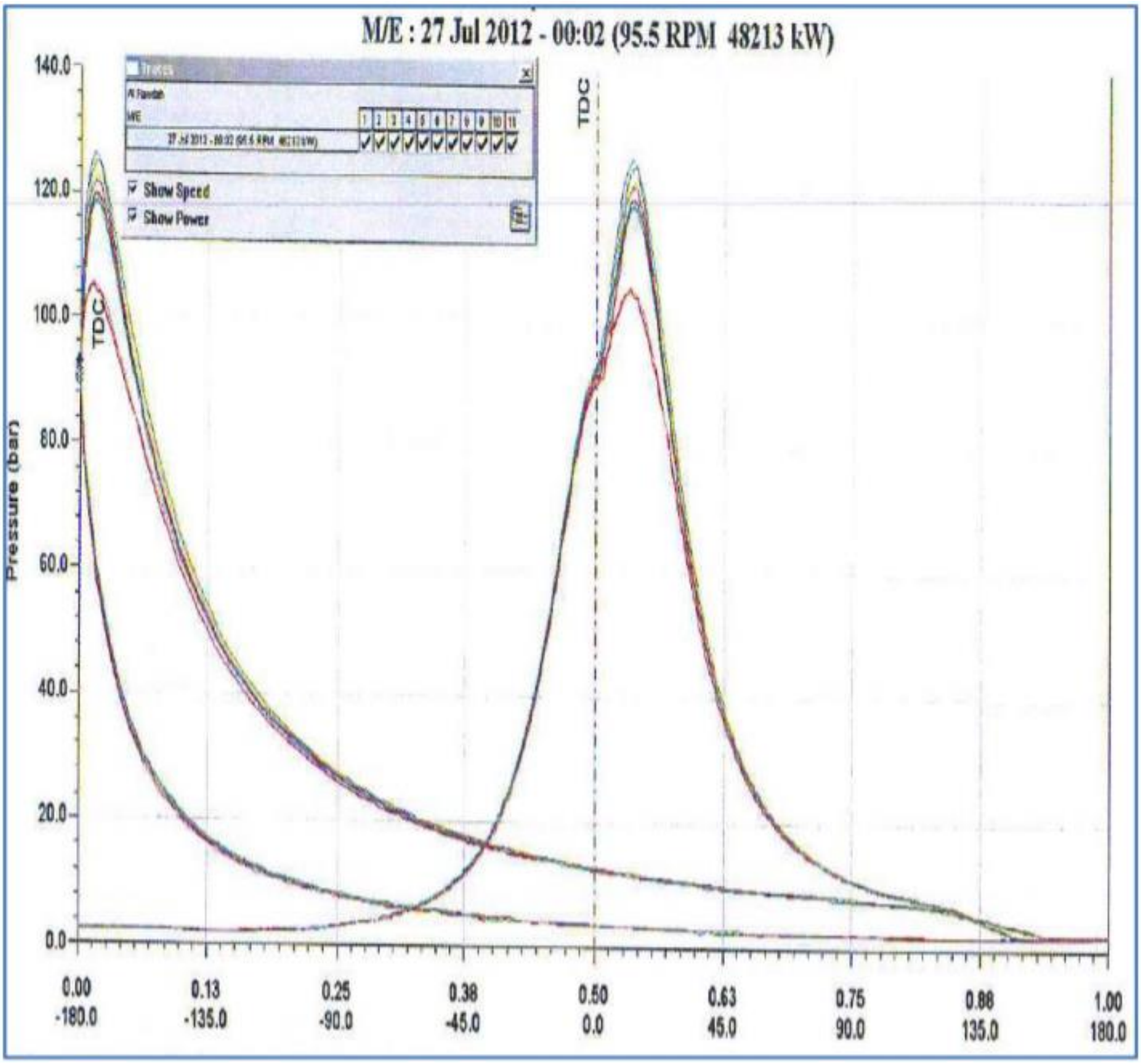

Figure 30.4.4 – Typical on-board cylinder pressure measurement [Bazari 2012]

Such monthly data are normally available on board ships and can be gathered and analysed for this purpose. Additionally, data such as turbocharger speed, scavenge pressure and temperature can be used to re-enforce if the engine is optimised or not. The techniques used during energy audit to assess the performance of the engines are similar to those used for engine performance monitoring.

29.5 Techno Economic Analysis

Identification of EEMs and their potentials for energy saving does not warrant that the saving potential could be realised in practice. Technical aspects and/or economic aspects could act as barriers.

Therefore, each EEM needs to be assessed both technically and economically to find out if they are feasible and cost-effective. As part of the energy audit, such preliminary techno-economic analysis of each identified measure may be carried out.

For a company who is serious about energy saving and efficiency, the techno-economic feasibility will be very important to be carried out correctly. The reason for this is that:

- The choice of EEMs for implementation purposes should be based on a sound technical feasibility assessment by the company. The barriers for proper implementation needs to be identified and planned to be resolved if the EEMs are going to be included in SEEMP and CEnMS.
- Implementation of any measure for energy saving will involve cost either in the form of additional capital or operating expenditures plus additional staff time that can be converted to money as cost.
- Taking these costs in relation to energy saving and cost saving will indicate the cost effectiveness of the adopted measure.

30.5.1 Technical feasibility assessment

The technical feasibility aspect focuses on mainly design, operation and technical aspects as well as ship board details such engineering changes needed, space availability, etc. The extent of technical feasibility study depends on the type of the measure. The preliminary feasibility can be assessed as part of the energy audit during ship survey; however, for major investment EEMs, the ship owner would normally carry out further technical feasibility studies before implementation.

For a specific case of slow steaming or virtual arrival, as suggested in the section on contract of carriage a particular ship on a particular voyage on a particular contact may or may not be able to slow steam or apply virtual arrival techniques, which is why both the ship managers and chartering department must be involved in any policy decision or feasibility analysis of the proposal. Efficiency is also dependent on ships being of a suitable design and size for trade. There must however be sufficient transport demand. Use of large ships may be constrained by port, canal, lock, berth dimensions, cargo gear capacity and the depth of the approach channel. If this is the case the cargo may have to be trans-shipped from a hub port by feeder ships which are smaller and less efficient so negating the gain of using the larger ships particularly with the extra energy and cost of discharging and loading on to another vessel. So these are the aspects that need to be taken in the technical feasibility of this specific proposal.

30.5.2 Economic cost-effectiveness assessment

Perhaps the most important factor when considering energy management is the cost of fuel that can either make or break a GHG strategy particularly when it involves buying expensive equipment to reduce fuel costs. Some approaches to reduce GHGs emissions are only financially viable when oil prices reach a specific level and are expected to stay above that level long enough to provide an adequate financial return on the investment in the particular energy efficiency improvement method. There will therefore always be an element of financial risk or reward when deciding on such policies especially when the price of fuel is volatile. When the price of oil is high, many measures are becoming cost effective and return on investment is proportionally linked to fuel price and is higher. The economic assessment of the measures is required to show if the measures are economically cost effective. For economic evaluation, capital costs and running costs (energy use, maintenance, manning, etc.), and fuel price need to be considered. Economic data is normally difficult to find and they are changing from one ship to another. The extent of economic assessment depends on the type of measure. Economic assessment could be based on simple pay-back period calculations or somewhat more involved methods such as Net Present Value (NPV) techniques. For preliminary feasibility analysis, simple pay back is sufficient. The main techniques are described below [MEPC 62/INF.7].

30.5.3 Payback period

The simplest method to evaluate investments is by estimating the payback period. The payback period is simply the investment divided by the net savings per period. The investment will include cost of technology plus installation. The net saving will include saving due to fuel cost minus any additional operating costs (personnel, maintenance, etc.). For example, an investment of $1000 that saves $400 annually has a payback period of 2.5 years. While the payback period is often used as a rule-of-thumb evaluation of investments, it has some disadvantages. First, it does not properly account for the time value of money as it has no discount rate. Second, it gives no information on the total profits over the life of the investment.

Net Present Value (NPV)

A more sophisticated way to evaluate new investments is the Net Present Value (NPV). It is an indicator of the value of an investment. By definition, this is the difference between the capital costs of an investment and the present value of the future flow of profits. The formula for NPV is:

$$\boxed{NPV = R_0 + \sum_{t=1}^{T} \frac{R_t}{(1+i)^t}}$$

Where:

- R_o – the investment at t=0; to be given a negative number.
- T – the lifetime of the investment
- R_t – the net cash flow (cash inflows minus expenditures) at time t
- i – the discount rate

When calculating the NPV, assumptions must be made on the lifetime of the investment and the discount rate must be determined. The discount rate can be based on the company's borrowing rate or cost of capital or any other rate the company uses for such investments.

For example, an investment of $500,000 today is expected to return net $100,000 of cash each year for 10 years. The $500,000 being spent today is already a present value. However, the future cash receipts of $100,000 annually for 10 years need to be discounted to their present value. Let's assume that the receipts are discounted by 14% (the company's required return). This will mean that the present value of the future receipts will be approximately $522,000. The $522,000 of present value coming in is compared to the $500,000 of present value going out. The result is a NPV of $22,000 coming in.

Investments with a positive NPV would be acceptable and those with negative NPV value would be unacceptable.

Internal Rate of Return (IRR)

Another way to evaluate investments is to calculate the internal rate of return (IRR). It is an indicator of the yield of an investment, not of its value. By definition, the IRR is the discount rate for which the

NPV is zero. Therefore the above formula for NPV can be used but this time NPV=0 and T that is the lifetime of investment is assumed to be known (e.g. 5 years). The term "i" here is referred to as IRR and needs to be calculated. This is a more sophisticated way of appraisal of investment than the payback period that does not consider any discount rate at all.

NPV is the most accurate approach to evaluate investments as it gives information on the total expected profits, and requires the cost of capital as an input in addition to the assumption on the lifetime of the investment. It is not the intention of this course to evaluate the differences between the above economic assessment methods. For those engaged in energy saving activities and not the economic decision making, the simplest method of pay-back period calculation will suffice.

30.5.4 MACC and its development

For overall presentation of cost effectiveness of results as well as potential CO_2 reductions for a ship or a fleet and for management purposes, development of MACC (Marginal Abatement Cost Curves) for the company fleet or ships will be a useful way of communicating the results and priorities on the basis of each EEM and as a whole.

Additionally and apart from ship energy audit, the economic assessment of the EEMs is of utmost importance in CO_2 reduction activities. Many organisations including IMO have carried out studies in this area. The basic requirement is that how much it costs to reduce CO_2 emissions when different measures are implemented. Off course the answer will be specific for each ship.

To answer the above quest, calculation of the Marginal Abatement Cost (MAC) is advocated. Also presentation of results in the form of MAC Curve (MACC) is commonplace. In shipping, SNAME and IMarEst collaboratively have conducted a comprehensive study of MAC. Some of the material in this part is taken from this report [MEPC62/INF.17].

What an MACC shows

Marginal Abatement Cost Curve (MACC) is used to show potential CO_2 reduction of various EEMs versus associated costs/benefits in a very visual and simple way. The MACC shows the reduction potential (tonne/year) and abatement cost ($spent/tonne CO_2 reduction) on one diagram. A typical one developed for international shipping as a whole is shown in Figure 30.5.4 as example. The X axis represents CO_2 reduction potential and Y axis shows the relevant costs per unit of CO_2 abatement.

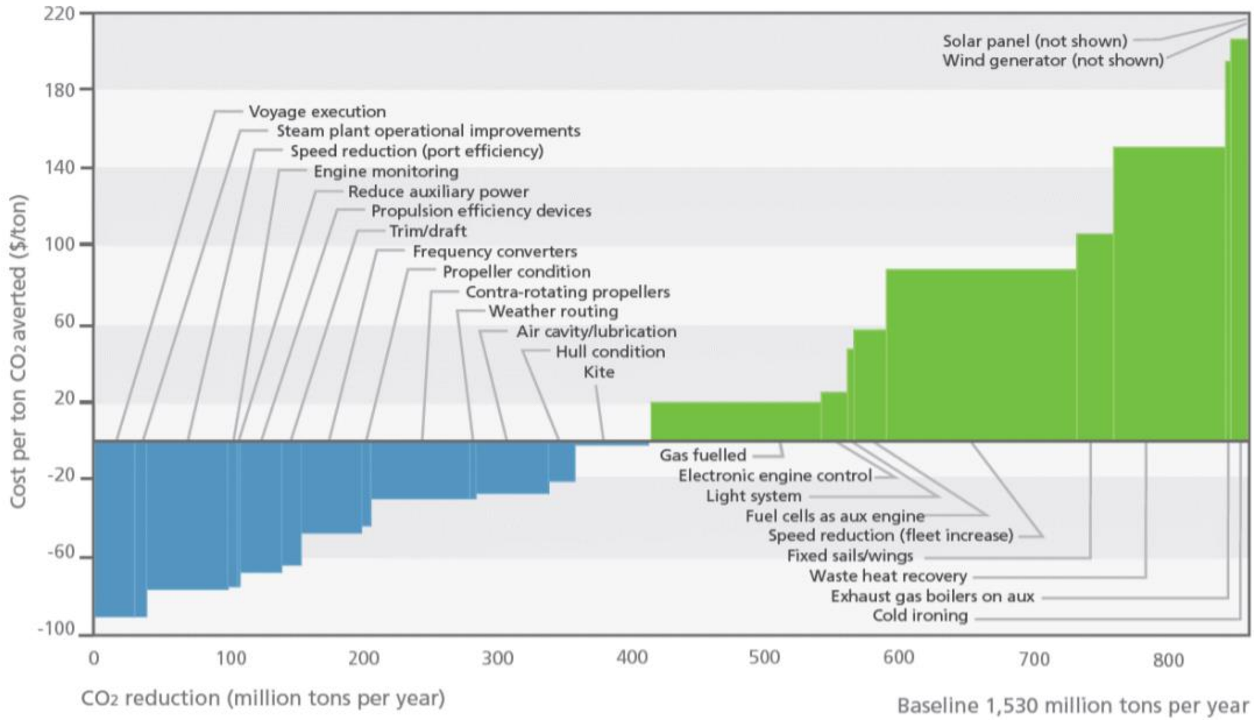

Figure 30.5.4 – Typical MACC for international shipping [DNV 2010]

How to develop a MACC

To develop the MAC curve as in Figure 30.5.4 but for a single ship, the following steps need to be taken:

1. Step 1 – Identify EEMs and their energy saving potentials in terms of for example percent reduction in the ship's fuel consumption. This is best to be done via an energy audit or review as explained above. From fuel consumption reduction, one can calculate the CO_2 reduction level using relevant emission factor and normalise to an annual value. This will provide a number that later on could be used for X axis.

2. Step 2 - Calculation of the cost-effectiveness of individual measures: Cost-effectiveness is by definition the ratio of costs to saving levels both measured financially. There are various financial methods to estimate the cost effectiveness including payback period, IRR and NPV as discussed earlier. However, and for CO_2 studies, a far better method is use of Marginal Abatement Costs (MAC). The relevant calculations can be done as outlined below. The MAC calculation per unit of CO_2 reduction will be used for Y axis.

3. Step 3 – Ranking and putting in order the EEMs from lowest MAC to highest MAC (i.e. lowest cost EEM to highest cost EEMs).

4. Step 4 – Plotting the MACC. Use the ranking system, each EEM represented by a rectangle where its vertical side is the MAC and the horizontal side is the CO_2 reduction level. These rectangles will be next to each other as shown in Figure 30.5.4.

Thus MACC is formed by plotting of the cost effectiveness of measures against the resulting cumulative reduction in CO_2 emissions. For each combinations of ship type, size and age, there are a suite of technical and operational measures that can be applied, thus MACC for ships will change depending on their circumstances.

Simple formula for MAC development

The following formulas can be used to estimate the X and Y axis value for the MACC [MEPC62/INF.17].

$$\boxed{\Delta C_j = K_j + S_j - E_j + \sum O_j} \text{ - - - - - - - - - - - - - (1)}$$

Where:

- ΔCj is the change of annual cost of for the implementation of EEMj, estimated as per equation (1)
- Kj is the capital cost of the EEMj, discounted by the interest rate and written down over the service years of the technology or the remaining lifetime of the ship, whichever is shortest;
- Sj is the service or operating costs related to the application of EEMj.
- ΣOj is the opportunity cost related to lost service time and/or space due to the installation of the EEMj such as the cost of days off hire for the vessel; and
- Ej is the fuel cost savings as a result of the EEMj, which is a product of the price of fuel and the saving of fuel as described in Equation (2).

$$E_j = \alpha_j \times F \times P \text{ - - - - - - - - - - - (2)}$$

Where:

- αj is the fuel reduction rate of EEMj (% reduction in ship fuel consumption);
- F is the pre-installation or original fuel consumption for a ship,
- P is the fuel price.

The MAC value is then calculated as the ratio of change in annual cost divided by the relevant reduction in CO2 emissions as shown in equation (3).

$$MAC = \frac{\Delta C_j}{\alpha_j \times CF \times F} = \frac{K_j + S_j - E_j + \sum O_j}{\alpha_j \times CF \times F} \text{ - - - - - - - - - - - - - (3)}$$

Where:

- CF is the carbon factor of fuel that shows the tonne CO_2 generated per tonne of fuel burnt.
- F is total annual fuel consumption.

As the above formulas indicate, the main inputs to formulas are the estimated fuel saving potential in percent, the capital and operating costs associated with implementation of the EEM, the total fuel consumption of the ship (or any other system under consideration) and most important of all, the fuel price. Any uncertainty in the input data will make the result uncertain. For this reason, in developing MACC, evaluation of the sensitivity to input parameters should be considered. As some of the parameters are uncertain in particular the future fuel prices, this sensitivity analysis will provide a way to making a better financial decision.

30.6 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

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