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Where is all the energy going? An energy audit system for Australian fishing vessels

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***Abstract*— The Australian commercial fishing industry has been impacted by dramatic increases in the price of diesel fuel. Combined with the global need to reduce greenhouse gas emissions, there is a clear need to introduce new efficiencies into fishing vessel operations. Many fishing vessels in the Australian fleet are over twenty years old and operate inefficiently when comparing energy input (fuel) with the useful energy output (catch). An energy audit method for fishing vessels, based on similar systems for land-based industries, has been developed. The three-level audit method enables a fishing vessel's energy usage and current level of efficiency to be assessed. It also identifies areas where savings can be made and enables recommendations for changes to make the vessel more efficient to be made. A sample Level 1 and 2 audit has been conducted on an Australian 16 m Danish seiner. The energy performance indicator of fuel cost to revenue was established and shows that the average value is close to falling below the threshold of profitability. The audit leads to proposals for improved efficiencies to combat current and possible future fuel cost increases.**

Keywords*- *fuel consumption; energy audit; fishing vessel; hydrodynamic efficiency

I. INTRODUCTION

The fishing industry is seeking to improve the energy efficiency of its operations, primarily due to the rising cost of fuel and its effect on operating margins. A study by the NSW fishing fleet [1] highlighted the impact of rising fuel costs on the fishing fleet up to 2005. It reduced margins to such a low level that it was rapidly becoming uneconomical for operators to continue to trade. The study surveyed diesel fuel usage across major industries (including mining, agriculture, forestry, road and rail transport) and found that fishing has the highest proportion of diesel costs in relation to all operating expenses, with 30% of total costs being consumed by fuel purchases.

In addition there is a global need to reduce the emissions of oxides of nitrogen (NOx) and carbon dioxide (CO2) from fossil fuel combustion. Latorre and Cardella [2] have estimated that the US fishing fleet produces 306 tonnes/day of nitrous oxides, whilst Tyedmers et al. [3] assessed that the global fisheries industries emit annually more than 130 million tonnes of CO2 into the atmosphere.

The majority of work into fuel usage by fishing vessels has centred on evaluating the ratio of protein output to fuel input, enabling comparisons to be made between fisheries and with other food production methods. A driver for this work was the oil crisis in the 1970s which led to the assessment of the energy intensity of a variety of commercial fisheries [4, 5, 6, 7, 8]. This work also resulted in the acknowledgment that the type of fishing being conducted, combined with the type of fish being targeted, will significantly influence its energy intensity [9]. Whilst trawling for some species, e.g. shrimp and prawn, has been found to be very energy intensive with respect to protein output, generally trawling for ground fish is only slightly less efficient than longlining and more efficient than passive techniques such as handlining, gillnetting and trapping. An exception to this broad approach was the work of Ishikawa et al. [10] where the energy usage onboard a squid fishing vessel was broken down into components. It was found that 59% of the total power was utilised on propulsion, 33% on jigging machines and freezing and 8% on squid lights.

Two studies into Scandinavian fisheries developed metrics to investigate energy consumption and life-cycle assessment - the ratio of litres of diesel per kg of caught fish [11, 12]. Thrane found large variations in efficiency between Danish fisheries targeting groundfish or shellfish and those targeting pelagic fish or industrial fish. This was mainly due to differences in fishing gear and vessel size, with small trawlers having the largest diesel used to fish caught ratio. Several options were proposed for improving the fuel consumption figures: developing passive and semi-active fishing methods; using regulations such as imposition of fuel tax or restriction on engine power; and developing cleaner technology.

Unfortunately little work has been conducted into evaluating the actual power usage of various types of fishing vessels, including the assessment of where the energy is consumed in the vessel e.g. propulsion or auxiliary systems, and appraising the benefits of possible methods for efficiency improvement. Exceptions include the work of Wilson [13] and the recent report by Sterling and Klaka [14]. Wilson reviewed research into small fishing vessel efficiency by examining areas where energy is used throughout fishing operations, and behavioural changes that a vessel owner or operator could make to operational techniques to improve efficiency. Sterling and Klaka examined new and existing technologies in the field of increased fishing efficiency, and methods to reduce energy usage.

Fisheries are highly varied; they harvest a diversity of fish and shellfish using a wide range of vessels and equipment. For example in Australia, the spectrum of vessels range from the high-speed aluminium planing craft used to fish for rock lobster, to traditional timber or steel displacement vessels used as prawn trawlers. It is therefore difficult to generalise about what action can be taken to make each vessel more efficient.

This paper proposes that in order to give vessel owners appropriate proposals for reducing energy usage, first an energy audit process is required. This audit process will identify the amount of energy supplied, the components on the vessel that consume energy, and the applications of energy in the fishing process. Areas where savings can be made may be identified, and changes recommended that would make the vessel more energy-efficient in its fishing practice. Such energy audits will also highlight key design and operational aspects which will benefit from the allocation of future research effort.

II. ENERGY AUDIT

Land-based businesses, industries and households use energy audits to investigate energy use and identify opportunities for cost effective investments to improve efficiency and effectiveness in their use of energy. The Australian Standard [15] defines three levels of audit: Level 1, 2 and 3. The energy user would usually commence with a Level 1 audit and use the results to decide whether to progress to one of the other levels. Recommendations in relation to energy savings are produced at all levels of audit.

A Level 1 audit evaluates the overall energy consumption of the site, to get a broad picture of the operation's outputs and energy inputs. The audit can determine whether energy use is reasonable or excessive compared to available industry-wide benchmarks. The level 1 process formulates enterprise-level performance indicators that allow the effect of recommended energy measures to be tracked and evaluated over time.

A Level 2 audit maps the use of energy on the site. This task relies on the information from the level 1 audit and a site visit to view the sources of energy, obtain the usage patterns for the supplied energy, and identify the applications of energy in the production process. Recommendations are made regarding areas where the most energy savings are likely to be achieved, along with measures to be taken, and statements of costs and potential savings.

A more detailed analysis of energy usage is made by a Level 3 audit that focuses on the areas highlighted during the level 2 audit as being most critical to the energy efficiency of the operation. Flowing from this are more detailed recommendations for potential savings, and associated cost estimates for implementation.

The level of accuracy of the assessment of costs and savings is improved with the level of energy audit undertaken. For example, the accuracy of costs and savings for a Level 1 audit would generally be within ±40%, for a Level 2 audit within ±20% and for a Level 3 audit within ±10%.

This work proposes that a similar energy audit system is required and beneficial for marine vessels and in particular fishing vessels. Only through an energy audit can accurate energy usage of an individual fishing vessel be determined, and cost effective methods for reducing energy consumption be confidently proposed. In addition, the results of audits will provide valuable direction to future research into specific energy reduction measures that are likely to result in the most benefit. Put simply: knowing specifically where the energy is being used will in itself identify opportunities for its reduction, and allow further research and development to generate new opportunities that are currently unknown. Each fishing vessel will likely be different due to a range of factors including: variety of fishing vessel types and designs, diversity of fishing methods, and specific environmental and operational conditions. Therefore, the audit process should be conducted on a vessel by vessel basis rather than for a whole fleet.

Figure 2. *Anne-Louise*, a 16m Dainish seiner operating in S.E. Bass Strait

The primary aim of this work was therefore to generate an energy audit system for a fishing vessel and test its use on a sample fishing vessel from the Australian fleet.

Level 1: This will be an overview of the energy consumption of the vessel and an annual evaluation to determine whether energy use is reasonable or excessive. A range of data will be required including: fishing method and vessel characteristics catch statistics, units of production, total energy input from billing data, evaluation of load profile data, monthly energy consumption profiles. Preliminary opportunities for reducing fuel consumption may be identified.

Level 2: This will be a more detailed audit including an on-site vessel investigation. It will include the identification of sources of energy, amount of energy supplied, details on what the energy is used for and identification of important factors affecting energy use (e.g. environment conditions, steaming speed, trawling speed). The audit will prepare energy consumption targets and indicators of energy end-use. It will identify areas where savings can be made and recommended measures to be taken including a prioritised list of capital works and general management activities. These recommended activities may include an additional investigation, such as a detailed energy audit or Level 3 audit.

Level 3: This will provide a detailed analysis of energy usage, usually it would be concentrated on one particular item within the vessel, though it could be a more thorough investigation than a Level 2 audit into the vessel as a whole. Examples of individual items to be audited include: refrigeration facilities, propulsion systems, deck winches, vessel drag, and trawl gear.

Further guidance on completing the various audit levels is given in Appendix A. This system was developed in collaboration with Dr John Wakeford [16].

III. LEVEL 1 AUDIT: *ANNE-LOUISE*

A Level 1 energy audit, using the proposed auditing system, was conducted on the *Anne-Louise*, a Danish Seiner operating out of Lakes Entrance, Victoria, Australia.

A. *Vessel and Operational Details*

The *Anne-Louise* is a 16 m displacement-style vessel which operates in south-eastern Bass Strait using the Danish seine fishing method, typically spending between 120 to 150 days per year at sea, see Figure 2. The principal details of the vessel are shown in Table 1.

B. *Production Expenses*

A breakdown of the *Anne-Louise* business balance sheet provided the total expenses of the business through the 2007 to 2008 financial year. This data is shown in Figure 3 which highlights that fuel (14.4%), wages (47.0%) and repairs and maintenance (17.9%) are the main business expenses. The fuel expenses for the *Anne-Louise* are relatively low when compared to the average costs for Australian fishing vessels [1], this is due to the low energy intensity of Danish seine fishing when compared to other methods such as trawling.

TABLE 1. *ANNE-LOUISE*: VESSEL DETAILS

Length overall	16.15 m
Length waterline	15.25 m
Draft	2.27 m
Beam	5.2 m
Displacement (Lightship)	52 t
Displacement (Loaded)	90 t
Construction Year	1986
Fishing Gear	Danish seine
Construction	Steel
Vessel Type	Displacement, fwd wheelhouse
Base Port	Lakes Entrance
Fishery	S.E Bass Strait
Target species	Flathead, ling, flounder, whiting, snapper
Byproduct species	Squid, mackerel, shark, nannygai
Bycatch species	Octopus, gurnard, starfish, sea cucumbers
Main Engine	IVECO 8281SRM50 - 368kW @ 2200 rpm
Winch Motor	FIAT N45 100 - 63kW @ 2800 rpm
Genset	ONAN MDKAF - 22.5 kVA

C. *Energy Performance Indicator*

To assess the energy performance, the amount of fuel used was compared to the marketable fish catch for the 2007/08 season, as shown in Figures 4 and 5. A linear regression line has been fitted to this data and the R^2 value, or coefficient of determination, determined as 0.1786; this indicates a weak relationship between the amount of fish delivered to the market and the fuel consumed. This is not surprising since fishing, unlike most manufacturing processes, does not always share a strong correlation between inputs and outputs, because the potential of a fishing vessel and crew to catch fish efficiently can easily be eroded by bad luck (i.e. failure to locate high concentrations of vulnerable fish) and unfavourable environmental factors capable of affecting catching performance.

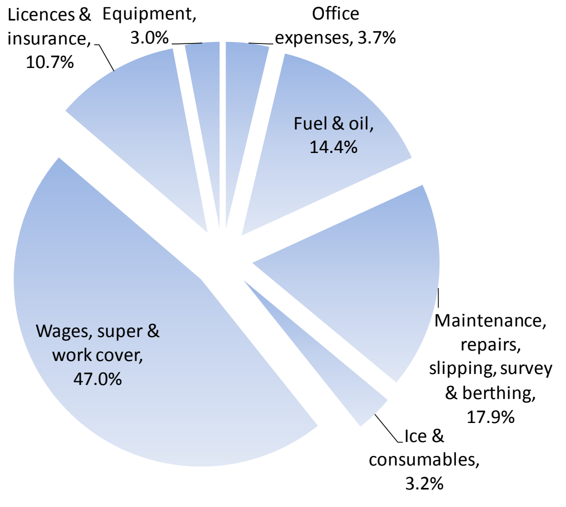

Figure 3. *Anne-Louise*: breakdown of expenses for 2007-08 financial year

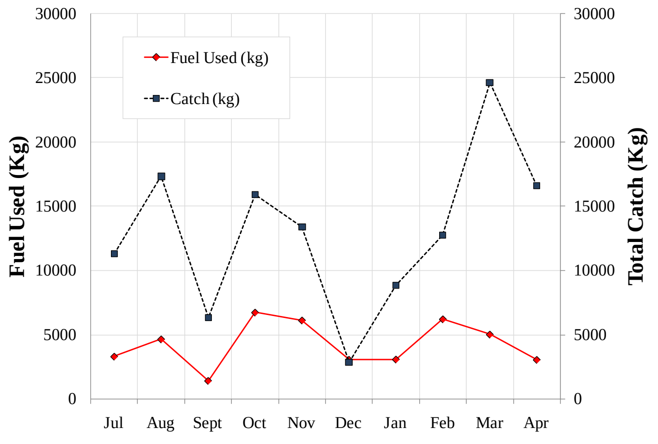

Figure 4. *Anne-Louise*: system input (fuel - kg) to output (marketable catch - kg) for 2007-08 financial year. (May and June are omitted due to vessel downtime and season closure)

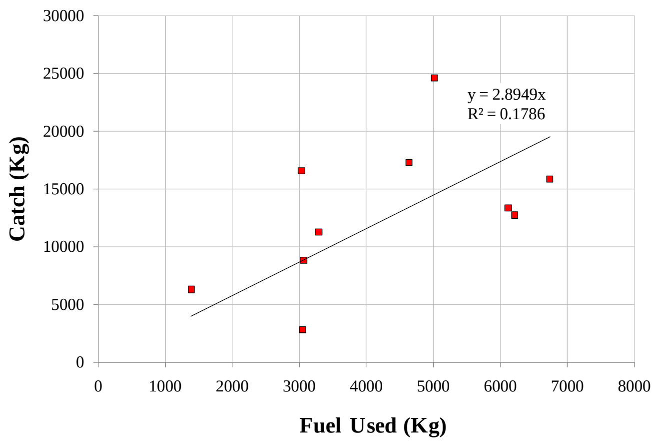

Figure 5. *Anne-Louise*: fuel consumption (kg) to marketable fish catch (kg) for 2007-08 financial year. Each point represents a value for a calendar month;

To establish an energy performance indicator, the ratio of fuel consumption to marketable catch was further analysed. Figure 6 shows the average fuel consumption/marketable catch ratio for each month during the 2007/08 season. The average through the year was 0.4, but in December more fuel was used than marketable fish caught in terms of mass. The target profitability ratio of 0.48 was derived by analysing the business balance sheet with respect to ongoing expenses and a desired level of profit; it was based on an average fuel price of $1.30 per litre and a market price of $3.50 per kg of fish.

D. *Energy Performance Indicator Comparisons*

Whilst it has been possible to assess the *Anne-Louise*'s energy performance against a target level of profitability, without published benchmarks for comparable businesses it is difficult to gauge how this vessel is performing against other operators. As a comparison, Level 1 audits were available for two prawn trawlers operating in the Queensland East Coast Trawl Fishery [16]. The two trawlers, *Ella-Mae* (see Figure 7) and *C-King*, are 13.7 m and 15 m long respectively, and utilise low-opening multi-net trawl-systems to target tropical prawns.

Their average ratio of fuel consumption to marketable catch was calculated over the period of one year with *Ella-Mae* having a value of 4.4 and *C-King* a value of 3.9. These are approximately 10 times the average value derived for *Anne-Louise* (0.4), which is due to the significantly lower mass catch rates of prawns. Therefore it is proposed that the ratio of fuel cost to revenue would provide a better indication of comparative energy performances between fisheries, these values were derived for the three vessels and are shown in Figure 8. The values between the three vessels are much more comparable, although the average value for the *Anne-Louise* (0.19) is still significantly lower than that for the *Ella-Mae* (0.34) and *C-King* (0.32); thus suggesting that it is more energy efficient than the prawn trawlers with regard to revenue. Again a target profitability ratio (0.23) has been derived by analysing the business balance sheet with respect to ongoing expenses and a desired level of profit. It should be noted that ideally such a comparison of energy performance should first be conducted against vessels operating in the same fishery. Additionally a much larger sample of fishing vessels would be needed before meaningful comparisons could be made between fisheries.

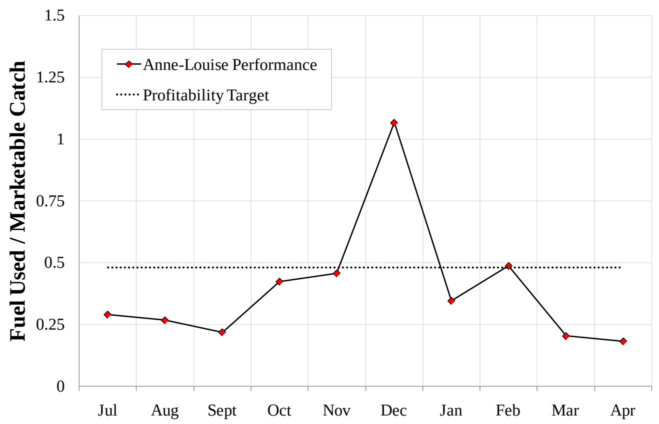

Figure 6. *Anne-Louise*: fuel consumption (kg) to marketable fish (kg) catch ratio for 2007-08 financial year. (May and June are omitted due to vessel downtime and season closure)

E. *Level 1 Audit Recommendations*

Through the Level 1 audit an overview of the energy consumption of the *Anne-Louise* was established. Comparison with two prawn trawlers demonstrates that the indicator of revenue to fuel cost is more appropriate than fuel used / marketable catch for comparison with vessels from other fisheries. The energy performance indicator shows that the average value is close to falling below the threshold of profitability; therefore, it appears that this vessel would benefit from improvements to its energy efficiency. The primary recommendation for further action was to conduct a higher-level energy audit (Level 2), to gather finer-scale details of fuel usage in the operation.

Figure 7. *Ella-Mae*, a 13.7m prawn trawler operaing in S.E. Queensland

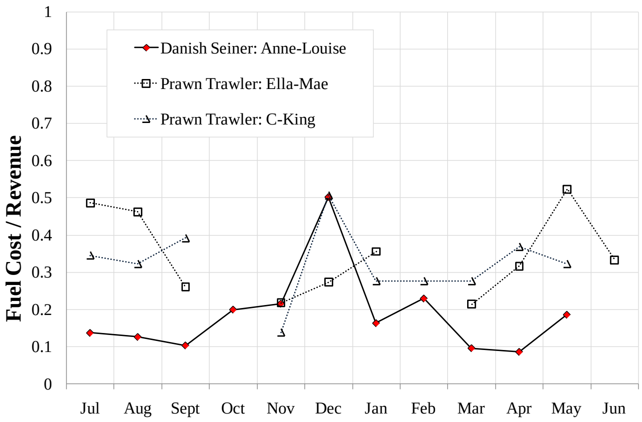

Figure 8. Comparison of revenue ($) to fuel cost ($) ratio for three fishing vessels. (Various months are omitted due to vessel downtime and season closure)

IV. LEVEL 2 AUDIT: *ANNE-LOUISE*

A Level 2 energy audit was conducted on the *Anne-Louise* during an on-site investigation. This included the identification of sources of energy, the amount of energy supplied, details on what the energy is used for and the factors affecting energy use (e.g. environment conditions, steaming speed, fishing speed). It identified areas where savings can be made and recommended measures to be taken, including a prioritised list of capital works and general management activities.

A. *Vessel and Operational Details*

More information on the vessel was gathered including details on hull form parameters, appendages, propeller, roll stabilisation system, rudder, engines and on-board systems. Additionally information on the operational profile of the vessel during a typical fishing trip was obtained.

B. *Engine Use*

There are three main energy flows onboard: the single diesel engine for propulsion, the diesel engine generator (genset) for electrical demand, and a diesel engine driving a hydraulic pump for the net winch.

On average each voyage is two days, leaving before dusk to arrive at the fishing grounds before dawn the next day and usually fishing during daylight hours only. The vessel spends approximately 5 to 8 hours at 9 knots steaming to and from the fishing grounds. When added to additional steaming time within the fishing grounds the vessel will spend approximately 20 hours per voyage at steaming speed. Danish seines are similar to a small trawl net but are more simply constructed with no otter boards and very long sweeps; the boat sets the long wire sweeps and the net around the fish, and as the gear is hauled, the action of the sweeps herd fish towards the central net. Therefore during fishing operations the vessel only travels at approximately 3 knots and has only minimal additional drag from the net and warps until the final phase of the hauling operation. During each voyage, 20 hours of light engine use is utilised whilst fishing is conducted.

The generator is the vessel's sole source of electrical power and it can supply up to 22.5 kVA when running. It runs almost full time when at sea, the exception being when the vessel is at anchor for a short period overnight. Generally only 1 to 2 kVA is required to service the hotel load except when cooking takes place for a short period requiring 8 kVA. The winch motor runs full time during daylight hours, usually at 1800 rpm for fishing operations. For anchoring, approximately 30 minutes per day, it only runs at 600 rpm.

C. *Energy Consumption*

Load profile and fuel consumption data were determined from the voyage timings and use of a 'FuelScan' fuel monitoring system. This information is summarised in Table 2 with a breakdown of engine usage and fuel consumption shown in Table 3.

An energy tree was then produced to display the breakdown of energy flow, from the fuel loaded on the vessel to the final application of energy to the various onboard processes. These breakdown quantities have been estimated using the equipment specifications and approximations of their relative use. Figure 9 shows an energy tree where all percentages are referenced to the total energy used by the operation.

TABLE 2. *ANNE-LOUISE*: LOAD PROFILE AND FUEL CONSUMPTION FOR TYPICAL FISHING VOYAGE

	Night			Day			Night			Day		
Time (Hrs)	4	8	12	16	20	24	28	32	36	40	44	48
Main motor (Steaming 9 knots)												
Main motor (Fishing 3 knots)												
Winch Motor												
Genset												
Domestic Demand												
Lighting (Interior)												
Lighting (Exterior Heavy)												
Lighting (Exterior Light)												
Fuel usage (litres)	172	172	104	104	104	172	0	12	104	104	204	172
Total fuel usage per voyage (litres)	1424											

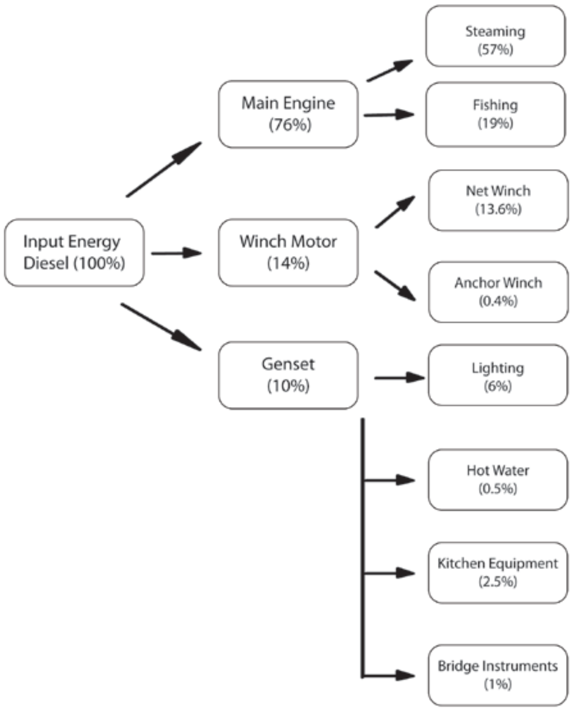

Figure 9. Energy tree where all percentages are referenced to the total energy used by the operation

The diagrams illustrate that the majority of energy is being utilised by the propulsion system. This suggests that initial work to reduce fuel consumption should focus on the prime mover; although other significant energy users are the net winch and refrigeration/freezing facilities. Focussing on the hydrodynamic performance of the hull may not always be the best solution for fishing vessels. For example, the energy audit on the prawn trawler Ella-Mae showed that 20% of the propulsion energy was used on steaming whilst 80% was used on towing the trawling gear. Therefore, it may be more appropriate for such a vessel to focus energy reduction methods on drag reduction of the trawling gear.

D. Refrigeration System:

Once landed onto the *Anne-Louise*, the fish are separated by species and placed in 55 litre fish bins with a layer of ice and stacked in the insulated cool room until unloaded at the wharf. The ice used to chill the fish is loaded onto the vessel from an on-shore ice making facility before departure. Although the energy required to produce this ice has not been included in this energy audit, arguably it should have been since it represents a significant component of the overall energy consumption of the fishing process. The current method of using purchased ice is a good option for the cold storage of fish on board the boat since a low amount of capital equipment is required and the ice is produced using power from a coal-fired power station, which is a cheap and relatively efficient source of the energy required (though poorer in terms of greenhouse gas emissions).

An alternative method for keeping the fish cool could be to utilise the waste energy from the main engine to drive an onboard refrigeration system. Waste heat from the cooling water and the exhaust stream represents approximately 60% of the energy supplied by the fuel input [14]. Recovery of some of this energy can represent a sizable amount of energy, which could be used to generate refrigeration using absorption (liquid sorption) or adsorption (solid sorption) systems [17]. These systems can use diesel engine waste heat to refrigerate seafood directly with very little additional energy input or can be used to help condense refrigerant in a conventional vapour-compression refrigeration system, and achieve very high refrigeration efficiency.

E. Opportunities for Increased Efficiency

There is a range of possible options that may be implemented to enhance the *Anne-Louise*'s efficiency: reducing the service speed; replacing the main engine with a more fuel-efficient model; changing hull appendages; fitting a bulbous bow; changing the hull and propeller cleaning regime; downsizing the genset and upgrading the lighting.

Service speed reduction: From the data obtained using the onboard fuel monitoring system, it was found that if the operator of the vessel was to reduce the service speed from 9 knots to 8 knots there would be a reduction of 48% in fuel use per hour whilst steaming with only small increases in travel time. Since crew wages are based on a percentage of the catch, this increase in travel time will not increase crew costs. However it would have a social cost with the crews being away at sea slightly longer to produce the same wages.

Bulbous bow: Since *Anne-Louise* travels large distances to get to its fishing grounds and operates in the typically rough Bass Strait she is a good candidate for a retro-fitted bulbous bow. The vessel has a block coefficient of 0.55 and a Froude number of 0.31. From Watson [18] the addition of a bulbous bow is predicted to decrease resistance by up to 10%.

Appendage alterations: There are two main sets of appendages on the *Anne-Louise*: the keel cooling pipes and hinged bilge fins. The three diesel motors are all cooled via a closed loop keel cooling system on the outside of the vessel in 50×100 mm rectangular pipe. This system could be converted to a heat exchanger, thus eliminating the need for external cooling pipes which would have a 2 – 3% effect on steaming resistance [14]. However when the vessel crosses a shallow water sand bottom entrance, on the way in and out of port, the heat exchanger system would be vulnerable to sand ingress. This could block the water flow or damage the water pump and cause the main engine to overheat; therefore this option is not proposed as viable. The vessel is fitted with hinged bilge fins (rectangular flat plates with an average chord of 1 m and a span of 2.4 m) for roll reduction purposes. At present the cross section of the fixed hinge bilge fin is not a shape that gives maximum efficiency. Changing the cross sectional shape and plan form of the bilge fins was estimated, using lift and drag theory [19, 20], to reduce vessel drag by approximately 2%, but still maintain their roll damping characteristics.

Hull and propeller cleaning regime: Maintaining a clean hull surface and propeller is important for reducing frictional drag and ensuring good propeller efficiency. Currently the hull is cleaned and re-antifouled annually, as part of a full maintenance programme, at a significant cost of approximately $10,000 and is out of service for 7 to 10 days. Due to the cost it is essential to find a balance between an acceptable increase in vessel resistance due to marine growth and regular cleaning and repainting. At this stage, due to the unpredictability of marine growth no recommendations can be made on the frequency of cleaning.

TABLE 3: *ANNE-LOUISE*: ENGINE USAGE AND FUEL CONSUMPTION.

Engine	**% of time used during voyage**	**Fuel consumption (litres/hour)**	**Fuel consumption during voyage (litres)**
Main engine – Steaming (9 knots)	42%	40	810
Main engine – Fishing (3 knots)	38%	10	275
Winch engine	50%	8	200
Genset	92%	3	140

Genset use reduction: At present the 22.5 kVA generator runs for approximately 18 hours per day, but the electrical load is only 1 – 2 kVA for the majority of that time. Therefore a significant fuel saving may be obtained by only using the generator when 8 kVA is required for cooking (approximately 2 hours per day). Since the main engine would be a more efficient generator of this low electrical power; for the other 16 hours per day a new DC alternator would be used on the main engine to charge a set of batteries. It is estimated that on a typical trip this would equate to savings of approximately 8% of the total fuel used. Additionally the use of bottled LPG for cooking should be investigated since this would potentially negate all use of the generator.

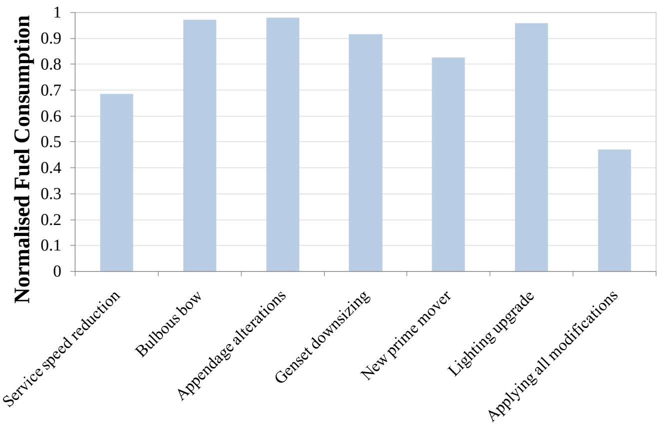

Figure 11. Estimated change in fuel consumption due to modifications (Normalised fuel consumption = fuel consumption after modification/original fuel consumption)

New prime mover: The current main engine usually runs at an appreciably lower power and rpm than its maximum rating. It could therefore be replaced with a new, more fuel-efficient and significantly smaller engine (10.8 litre as opposed to the current 17 litre engine) using electronically controlled fuel injection. This could result in an estimated reduction in fuel usage per year of up to 17.4%. Whilst an expensive option, it would also have the advantage of improved reliability and less requirement for maintenance.

Propeller change: The current propeller has 4 blades with a diameter 1.2 m, which is the maximum size that can be fitted for efficient use. It is recommended that further investigation be conducted (Level 3 Audit) to determine if a new propeller could produce worthwhile fuel savings.

Lighting upgrade: Changing interior and exterior light to either LED or compact fluorescent lights would significantly reduce the electrical lighting load. It is estimated that this could halve the lighting requirement, thus reducing the overall fuel consumption of the vessel by around 3%.

F. Effect of Capital Works or Management Activities

The various modifications that could be implemented onboard to increase fuel efficiency are shown in Figure 11. Each new modification is presented against the current operation of the vessel. It can be seen that the top three energy savers are: downsizing the generator, upgrading the main engine, and reducing the steaming speed to the fishing ground. In total, if all modifications are applied, the fuel consumption per trip may be reduced from an average of 1424 litres to approximately 670 litres, a reduction in fuel use of 52%.

The cost of implementing each modification was estimated and then compared against the fuel saving that they would offer. From this the time taken to obtain a return on each investment can be established, as shown in Figure 12. This gives an indication of which modification should be considered first. The first three modifications are beneficial because not only do they take the shortest period to pay off, they are also the modifications that require low amounts of vessel downtime on the slipway.

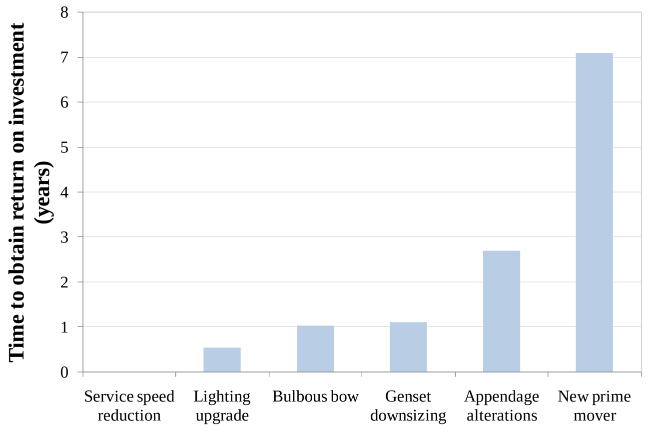

Figure 12. Estimated time until return on investment

To establish which modification to undertake, a more detailed investigation must be carried out into their potential impact on the business, including the influence of future changes in the price of fuel. Obviously it is hard to ascertain what the cost of fuel will be into the future. However CSIRO [21] has estimated that the cost to the fishing industry may rise to $1.80 per litre by 2012. Using this as a guide, and allowing market price and business expenses to rise with inflation estimates [22], a new energy performance indicator target has been set to maintain a sustainable business, fuel cost/revenue = 0.15. Note that any additional business expenses to finance loans for capital works are ignored. Figure 13 shows the predicted influence of the recommended modifications on the fuel cost to revenue ratio. With no changes by 2012 the business would be significantly over target with respect to fuel costs. The operational change of speed reduction has a significant effect on the energy performance indicator, nearly allowing the target to be met. However, the additional modifications of lighting upgrade and retro-fitting a bulbous bow would be needed to satisfy the energy target.

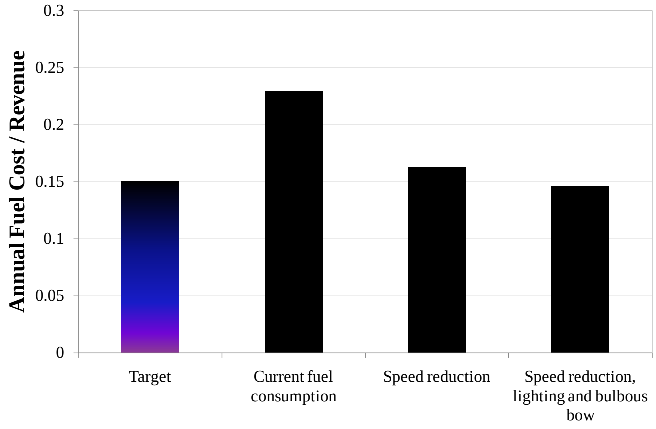

Figure 13. Annual revenue ($) to fuel cost ($) ratio for various actions and modifications

G. Level 2 Audit Recommendations

The Level 2 audit has established that the area for greatest potential energy savings is the steaming performance of the vessel. This may primarily be achieved by reducing the service speed, which would meet short-term energy performance targets. However additional measures such as replacing the main engine with a more fuel-efficient model; changing hull appendages; fitting a bulbous bow; downsizing the genset and upgrading the lighting systems may be required to meet future targets. At this stage a Level 3 audit or a more detailed investigation of any operational area is recommended to investigate in more detail a range of issues including: propulsion (is the vessel a candidate for sail or kite power?); winch systems (are more efficient winch systems available?); refrigeration system (could the waste heat from the engine be used for refrigeration purposes?) and vessel drag (would a new low-drag hullform, such as a multihull, be an appropriate design?)

V. CONCLUSIONS

In order to provide appropriate proposals for reducing energy usage by fishing vessels it is proposed that an energy audit needs to be conducted. A three-level energy audit system, following that used for land-based businesses and organisations, has been proposed. This audit process will identify the amount of energy supplied and the flow of energy within the vessel. Areas where savings can be made are therefore identified and changes recommended to make the vessel more efficient in its fishing practice.

A sample Level 1 and 2 audit has been conducted on a typical vessel from the Australian fleet (16 m Danish Seiner). The energy performance indicator of fuel cost to revenue was established and shows that the average value is close to falling below the threshold of profitability. Comparison with two prawn trawlers demonstrates that this indicator of revenue to fuel cost is appropriate for comparing with vessels from other fisheries. An energy tree was produced to display the breakdown of energy flow throughout the fishing process. This showed that the majority of energy is being utilised by the propulsion system, particularly during steaming. Therefore, energy reduction may primarily be achieved by reducing the service speed, which would meet short-term energy performance targets. However additional measures such as: replacing the main engine with a more fuel-efficient model; changing hull appendages; fitting a bulbous bow; downsizing the genset and upgrading the lighting systems may be required to meet future targets.

The next stage of this work is to extend the audit process to a range of Australian fishing vessels. This will help identify research priorities for maximising future efficiency gains.

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APPENDIX A

Level 1 Audit

(a) Acquire the following data:

(i) Fishing method and vessel characteristics:

- fishing gear classification (FAO);
- vessel size (length, displacement);
- vessel construction (e.g . steel, wood, fibreglass etc.);
- vessel type (displacement or planing etc.);
- fishing location.

(ii) Composition of harvested catch:

- target species;
- byproduct species;
- bycatch.

(iii) Unit of production:

- marketable catch;
- revenue created;
- Joules (energy yield from edible protein).

(b) Determine:

(i) Total energy input from billing data and/or installed loads (over 24 months):

- Diesel;
- LPG.

(ii) Monthly energy utilisation profiles and plot monthly energy consumption profiles over 2 years.

(iii) Prepare energy performance indicators:

- Fuel costs ($)/revenue ($);
- Litres of fuel /revenue ($);
- Litres of fuel /fishing day (hrs);
- Joules of fuel / joules of protein energy (Energy Return On Investment – allows comparison across food production industries, if required).

(iv) compare the above performance indicators with benchmark data.

(c) Tariff analysis:

- compare prices from alternative suppliers;
- compare prices for alternative fuels;

(d) Identify opportunities for reduced fuel consumption and costs. Form recommendations for further action (e.g. training, capital works, maintenance, alternative fuels, tariff changes, higher level energy audit).

Additional input for Level 2 Audit

(a) Acquire data, preferably by undertaking a vessel visit as well as fishing trip, on:

- Energy usage patterns during periods of fishing activities and inactivity. (For active periods - align consumption rate to distinct phases within the operation);
- Plant and equipment operation and maintenance;
- Detailed vessel and gear characteristics e.g. transom sectional area, half angle of entry;

(b) Acquire and analyse the vessel's energy use:

- Sources of energy;
- Amount of energy supplied;
- Detail what the energy is used for;
- Identify important factors affecting energy use (e.g. environment conditions, steaming speed etc.).

(c) Evaluate load profile data:

- Produce load profile, at an appropriate time scale (eg. 24 hours or trip) based on a description of the operating cycle supplied by the owner or skipper;
- Assign fuel usage to different phases of the operation.

(d) Prepare energy consumption targets and indicators of energy end use:

- Produce cost/benefit analysis of recommended capital works or management activities;

(e) Provide itemised list of recommendations to reduce energy consumption and cost, including both capital works and general management options.

Additional input and output for Level 3 Audit

(a) For the vessel, or required on-board equipment or system:

- Preparation of hourly consumption profiles of all fuels used over a period of 7 days. This will require provision of all meters, instruments and equipment necessary to meet the intent of the audit, and ensuring their accuracy.

(b) Detailed technical analysis of possible savings. For example if the level 2 audit has indicated that a bulbous bow may be a suitable option, this would be investigated in more detail to determine more exact potential savings based on appropriate design.

(c) Provide more detailed recommendations for potential savings, and associated cost estimates for implementation.