An institute for shipbuilding engineering at a university might be found to assume some of the development effort. Seminar papers or theses could be devoted to developing mathematical models for vessel handling or energy balance or to testing models in a wave tank, or these might otherwise be used for demonstrations during instruction. Finally, part of the funding could also be achieved by participating in public tenders or entering the invention in award competitions. Some efforts of this kind have been made but have been unsuccessful up to now. Nomination by a third-party is required for some awards, so I would be dependent on experts convinced of the quality of the Eco-Trimaran to propose it for such an award. I would be happy to receive any offers to this.

Publishing information

Author and copyright: Jörg Sommer
Web design: Jörg Sommer
Ship model: Jörg Sommer
Image montages created using the ship model and marine photographs by Bernd Emmerich, Lüneburg (used with his kind permission)
First published on the WWW on 18 May 2005
Version: No. 9 of 28 November 2006
Last modification: 20 November 2006
Contact: joerg-sommer(et)oeko-trimaran.de
(please replace (et) by @ - spam protection !)
Visitors to date: see the relevant page of the web presentation

About the author:

Jörg Sommer, Dipl.-Psychologe (Master's in psychology), Dr. rer. nat. (Doctorate in natural science). I have educated myself in general engineering science and in shipbuilding in particular; for all of my life I have had a keen, ongoing interest in technical and scientific matters.

As a psychologist, I have done research on interdisciplinary topics related to engineering and physics, such as physiological phenomena accompanying emotions and the influence of illumination on performance at work. While measuring and recording physiological reactions or designing and testing lighting equipment and recording performance at work, I time and again encountered technical problems which in some cases needed to be solved in cooperation with engineers. Some of these studies have consequently been published jointly with engineers.

The motivation for developing the Eco-Tramaran is related to my keen interest in environmental protection. It is my dream to one day travel as a passenger aboard such a ship!

I ask each one of you to write to me with your criticisms, feedback and suggestions for improving this project.

- The Eco-Trimaran exhibits less linear upward and downward motion on rough seas
- The Eco-Trimaran exhibits less linear acceleration (especially negative acceleration) in the direction of travel on rough seas.
- The Eco-Trimaran exhibits less drag when making a turn (on calm seas)

3. Possibility of **building an experimental vessel to a smaller scale**, perhaps without a wave power plant but with solar cells and a wind turbine. Load capacity: one person and measurement equipment.

4. Test runs with the experimental vessel; in addition to the hypotheses listed above (item 1), the following issues could be investigated using the prototype:

- Steering using the front float
- Drag when using floats that are able to move freely around the horizontal transverse axis compared to using fixed floats
- Course of the vessel against the wind or close to the wind: What is the maximum vessel speed up to which the wind turbine still produces a positive energy balance?

5. Wind turbine: Calculation of wind pressure and resulting heeling in crosswinds. This could result in a larger diameter and consequently in greater energy production.

6. Full-size construction of the ship: Approx. 20 – 25 m (66 – 82 ft) long and wide; wind turbine diameter of approx. 14 m (46 ft).

7. Testing and improving the ship.

8. Theoretical work: Determination of the optimum float length for generating energy based on a statistical distribution of wave lengths and amplitudes in various ocean areas; extrapolation of the design to larger vessels, perhaps requiring more than three floats that are smaller, in relation to the main hull, than the present ones.

Financing

Through my own funds I have up to now been able to finance research for patenting the mobile wave power plant as well as to draw up the patent application, build a model and publish these web pages. In the future I intend to pay the annual fees for maintaining the patent application and, later, the patent, once it is granted. The expense of taking the additional steps outlined above in order to realise the project is far greater than the resources at my disposal. In the final instance, sponsors and/or interested parties will need to be found in order to finance the development and construction of the ship. These might be individuals wanting to purchase a private yacht. Possible motives include an interest in ecological issues, finding the design of the ship pleasing or the attention able to be obtained through such an unusual ship. The Eco-Trimaran might also be of interest to institutions concerned with ecological issues that wish to demonstrate this concern publicly (we have already made an offer to Greenpeace but this has aroused no interest up to now). Even though I have applied for a patent for the wave power plant, I do not expect this to result in any great earnings. The Patent Act allows anybody to manufacture the protected object for private use or for experimental purposes, and this is precisely my hope for the Eco-Trimaran: that somebody would have it built as a private yacht or that a shipyard would build it for experimental purposes.

In the near future at least, I do not expect the invention to be exploited commercially; only then would I be able to reap financial benefits from property rights on the wave power plant.

January and February 2006: Calculations of the theoretical maximum capacity of compressed air storage tanks. To do this, it was necessary to become familiar with thermodynamics.

March 2006: Thorough revision of this presentation.

April 2006: Short article in P.M.-Magazin.

June 2006: TV - Production (by Pro7, Galileo) of a short feature devoted to my project; the feature was broadcast without mentioning the source of the invention.

Summer and fall of 2006: Calculation of energy consumption and energy production on the ship using sun, wind and waves; rejection of compressed air storage due to insufficient capacity and choice of hydrogen fuel cell technology.

Thanks:

I extend my thanks in general to the many who have expressed interest in my project and who have criticised it and in some cases provided valuable suggestions. This took place primarily in various Internet forums, of which I would like to mention “Wer-Weiss-Was”- Netzwerk in particular. There it is possible to obtain advice from recognised experts. My very special thanks go to **Alexander Bahn** of Hanseatic Yacht Care Cyprus, Crewagency Germany, who advised me especially on practical issues related to the operation of yachts.

The next steps

1. Design modifications: The **floats** need to be enlarged in proportion to the main hull. Under present conditions it is not possible to extend them, as the floats would otherwise touch when turning around their vertical axes. Widening them would result in the disadvantage of increased flow resistance. A deeper draught would reduce the effectiveness of the wave power plant, since wave activity decreases rapidly the farther below the waterline. One solution would be to position the legs diagonally outward. This results in three advantages:

a) the floats can be still further extended; b) reduced risk of capsizing in storms; and c) improvement in the appearance.

2. Examination of the **manoeuvrability** and **behaviour on rough seas** using mathematical models or physical models in a wave tank (at a shipbuilding testing institute or technical university). Testing of the following hypotheses:

a) Tests with only a model of the Eco-Trimaran:

- Movable floats result in less drag in waves than fixed floats.
- Slamming affects only the floats and is hardly noticeable on the main hull.
- Limits to the capacity of the design to withstand static and dynamic stress during extreme environmental conditions (large waves or hurricanes).

b) Comparison of a model of the Eco-Trimaran and a model of a conventional single-hull vessel having the same water displacement:

- The Eco-Trimaran exhibits slightly more drag in calm waters.
- The Eco-Trimaran exhibits less drag in rough waters.
- The Eco-Trimaran pitches slightly more when travelling transverse to wave fronts.
- The Eco-Trimaran is less susceptible to rolling when holding a course at a sharp angle to wave fronts.
- The Eco-Trimarans yaws slightly more.

This led to several additional advantages in the areas of safety and comfort (refer to the corresponding pages of this presentation). This concept resulted finally in a **patent application** entitled “Mehrrumpfiges Schiff mit beweglichen Schwimmkörpern als Wellenkraftwerk” (“Multihull ship with movable floats as a wave power plant”) which was disclosed by the German Patent and Trade Mark Office on 22 July 2004 (3). No application has yet been made to have the patent granted, but the deadline for this is 8 January 2010. The application will be maintained for the time being by paying the annual fee.

Combining these three sources of energy and coordinating them with each other for the purpose of creating a zero-emission ship would normally have implications for **ship design**. Yet, in this case too, research into the subject did not reveal any satisfactory solutions (refer to the section entitled “Other environmentally friendly motor ships” in the annex), and thus it was necessary to develop a new design.

In order to lucidly illustrate the invention, a model was built to a scale of 1:50, which was also used for this presentation.

The **presentation** was published on the WWW on 18 May 2005 and then registered with a number of search engines. I subsequently informed all of the **shipbuilding engineers and institutions for shipbuilding engineering** (at first only in Germany) that I was able to find of my design and invited them to present their opinions. Several interesting suggestions for improvement were made which led to further development of the Eco-Trimaran.

The most important new developments since the first presentation:

Definitive choice of hydrogen as the energy storage medium (a number of other storage options had previously been considered; refer to the chapter entitled “Other storage options” in the annex).

Consideration was given to using a horizontally rotating wind turbine because of the resulting reduction in wind pressure, but this was rejected on account of the poor efficiency rate compared to a vertically rotating high-speed turbine (refer to the section entitled “Other wind turbines” in the annex).

Other drive units were examined as alternatives to the conventional ship propeller. Yet it was found that additional research is required in these areas, and so we decided to stay with the propeller for the time being (refer to annex, “Other drives”).

The first **presentation** by a third party was made in the form of a short article in Brennstoffzellen-Newsletter, no. 163, an electronic publication (25).

The first presentation in **print media** was a short report in P.M.-Magazin 4/2006 (24).

Insufficient funds are available for having **feasibility studies performed by shipbuilding engineers**. Attempts to raise funds for research have remained unsuccessful up to now. I have submitted the invention to the following competitions for ecologically relevant innovations: 1. “Aesculap-Umweltpreis” (Aesculap Environment Award); 2. Rolex Awards for Enterprise; the decision was negative in both cases.

August 2005: The first opinions were received from shipbuilding experts. These were encouraging for the most part, and the idea of using several regenerative sources of energy simultaneously is praised. The floats are judged to be too small in relation to the main hull, while wind power is regarded as the source of energy with the highest yield.

November 2005: In-depth e-mail discussion of the advantages and disadvantages of the “drive based on inversion kinematics”.

October 2005: Development of the “Entenfuß-Antrieb” (“duck-foot drive”).

consumed. The latter presupposes a technique for storing energy.

2. Coordination of the various energy sources with one another by means of compromises, if necessary, or in the ideal case by achieving a synergy in which the various systems mutually support one another.

Development method:

1. Examination of existing developments: energy converters that transform the energy found in the sun, wind and waves into a utilisable form; methods of storing energy; and suitable ship designs.

2. Critical evaluation of existing technologies in the endeavour to improve on these.

3. Thought toward developing a new design.

This process can probably never be terminated; above all it demands continuous involvement in professional discussions and consultation with other individuals and institutions.

Development efforts to date and the “next steps” as well as what is planned next are presented in the following.

In the end, all of this requires funding, and the possibilities for this are found on the page entitled “Financing”.

Development to date

Possibly the most important and time-consuming phase of project development is that of **investing thought in a basic design**. This effort is hardly perceived from the outside and cannot be presented in detail. I can only say that the dream of a sea-going motor ship capable of independently meeting its energy needs has haunted me for decades.

Another important piece of preparatory work was to become knowledgeable of the **most recent technology** in all areas related to the Eco-Trimaran.

With the aid of sails, **wind energy** has been used for thousands of years. This method of utilising energy is the most effective imaginable, since it converts wind energy into drive energy directly by using simple techniques. Its most significant disadvantages are: 1) its use is dependent on the course; 2) wind is unstable over time (lulls); 3) the lack of a means of storing energy; and 4) the large amount of human effort required in operating sails. Newer developments only concern item 4) above. Sailing ships have been developed on which the sails are operated mechanically, i.e. using motor power (refer to “Wind ships” in the annex under “Links and sources” no. 17). The most advanced product of this development approach is the “**Flettner rotor**”, also termed a “rotating sail”. It succeeded in considerably improving the manoeuvrability of sailing ships.

This approach was nevertheless not further pursued because the first three disadvantages mentioned above remained. As an alternative to sails, **wind turbines** had in the meantime reached a level of technical perfection.

Mobile wave power plants are still in a rudimentary stage of development (in contrast to stationary plants, which are already more advanced). Currently known techniques are presented in the section entitled “Other wave power plants” (annex). As these have all proven unsatisfactory, we have had to develop our own technology.

Our innovation is found in a mobile wave power plant that combines two technical principles which up to now had been realised and proposed independently of one another: 1) the movable arrangement of floats for multihull ships and for trimarans in particular; and 2) the utilisation of float motion to produce energy.

Comfort

In the following only such aspects of comfort are discussed as may be inferred from the general design features of this particular trimaran. Comfort features resulting from the size and furnishings of the vessel are not therefore treated here. Generally speaking, we always compare the trimaran with a single-hull ship of a conventional design having the same water displacement.

Availability of energy:
Even under "worst-case" conditions a daily average of 60.37 kWh is produced by sun, wind and waves. While mooring, this is sufficient for energy requirements on board and for replenishing short-term storage, so that there is also enough on-board electricity available at night. Yet, during periods of travel, there is little left for the motors, as has been pointed out on page 16 in the chapter entitled "Drive". On the other hand, energy required on board has always been deducted when calculating the drive power available for the motors, i.e. the on-board energy supply of 33.8 kWh a day has been given priority over the ship drive.

Household and drinking water:
Rainwater can be collected on the large roof of the main hull and then used as household water or, after appropriate treatment, as drinking water. If energy is produced in abundance (refer to the previous section), this may be used to derive additional drinking or household water from seawater. Especially when the vessel is moored for longer periods and operates in areas with plenty of rainfall, it should be able to meet water needs independently.

Harmful or annoying emissions:
In this case there is no stench from (burned or unburned) diesel fuel or petroleum and no dust particles harmful to health. The ship's motors are not in the main hull and hardly produce any noise anyway; they should therefore be almost inaudible. Noise due to waves slapping against the side of the ship practically does not occur, or only in very rough seas (refer to the information on "Slamming" in the previous section). Wooden roller bearings are used for mounting the floats and wind turbine mast, resulting in less bearing noise than would be the case with steel roller bearings.

Vessel motion on rough seas, particularly motion responsible for seasickness:
With respect to linear movements resulting in speed changes, the Eco-Trimaran ought to slow down less when encountering a wave and should be comparable to a conventional vessel in the case of upward and downward motion. With respect to circular motion, the Eco-Trimaran is likely to pitch more strongly, yet slamming, which is particularly unpleasant, should hardly be felt at all. It should roll considerably less. While yawing is hard to predict, it is not very relevant for seasickness.

Refer also to "Trimaran motion in waves" (page 20) and "Types of vessel motion" (appendix).

Development

Development objective:
A sea-going motor ship that runs exclusively on renewable (regenerative) sources of energy available on the ocean, i.e. a "zero-emission ship".

Development task:

1. Utilisation of all sources of energy available on the ocean (i.e. sun, wind and waves) in as many ways as possible and additionally time as a source of energy, i.e. in the form of operating phases during which more energy is produced than

This absorbs pressure and, in the event of damage, would prevent the metal tank inside from flying apart in fragments. Such damage would only shred the fibres and the gas would escape gradually.

This is also important, insofar Hydrogen gas gets warm by decompression; this is limited by slowing down decompression process.

Trimaran motion in waves

For a better understanding of the naval terms used in the following, such as “rolling”, “pitching” or “yawing”, please refer to the chapter in the annex entitled “Types of vessel motion in waves” *. In the following, we compare the trimaran with a single-hull ship of a conventional design having the same water displacement.

Let’s first look at **linear motion** and in particular at acceleration, both in the positive (acceleration) and negative (deceleration) sense.

The trimaran is **slowed down** less when it encounters a wave, since the floats react more quickly due to their smaller mass. The wave lifts the bow of the float and it slides over the wave. In contrast, the bow of a conventional vessel drives more deeply into a wave.

Positive acceleration is not relevant for safety and thus we will not go into this issue any further here.

Upward and downward linear motion reaches a maximum when waves are of such a size that the vessel fits completely on the crest and in the trough of a wave. With its broader but shorter shape, our trimaran is susceptible to more extreme upward and downward motion when travelling transverse to wave fronts. The reverse is true when pursuing a course parallel to the wave front. In this case wave crests could be broad enough for a conventional vessel to be lifted to the top of them, while the floats of the trimaran, being broader, would still be on either side of the wave crest while the main hull is lifted less.

*At present, only the German version of the annex is available

Pitching, a **type of circular motion**, generally begins when a vessel holds a course transverse to the wave front and the wave is at least as long as the ship. With its broader basic shape, the Eco-Trimaran is shorter than a conventional ship and would thus be more susceptible to pitching.

Slamming, a special, particularly unpleasant form of pitching, is as likely to occur with individual floats of the trimaran to the same degree as with conventional vessels. Yet this motion is hardly transferred at all to the horizontal axes of the trimaran and thus not to its main hull.

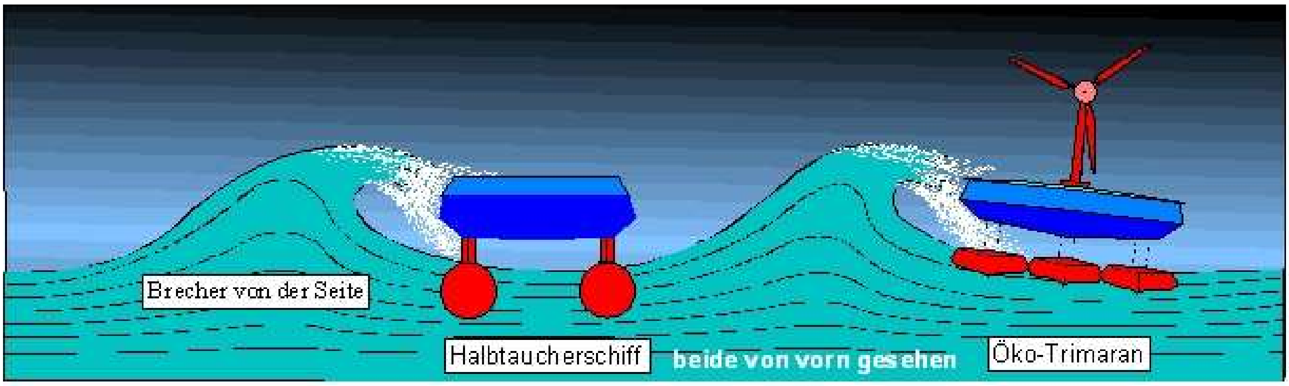
Rolling, which mostly occurs when holding a course at a sharp angle to the wave front, is not as pronounced with a trimaran, since it is better supported at the sides by the two rear floats.

Heeling, a type of motion related to rolling, occurs in crosswinds and can in extreme cases lead to capsizing. There is less risk of this with the trimaran, due to its shallower and broader design, than with a conventional vessel.

The amount of **yawing** is difficult to predict for a trimaran, but this movement is not relevant for safety. Yawing makes it harder to hold course, but, in an age of satellite navigation, this is hardly an issue any more.

In summary we may conclude that, to the extent that vessel safety depends on its motion in rough seas, the Eco-Trimaran can on the whole be judged safer than a conventional vessel with the same water displacement. **With respect to the particular kinds of motion relevant to safety, such as slamming, rolling and heeling, the Eco-Trimaran must clearly be judged superior.**

Safety



The safety philosophy pursued here is based on the principle of **giving way to natural forces** or at least **resisting them as little as possible**. By way of illustration, we compare the Eco-Trimaran with a “semi-submerged catamaran or” or “Small Waterplane Area Twin Hull” (SWATH), which reflects an entirely contrary philosophy (annex, links & Sources No. 2). The semi-submerged catamaran (seen from the front in the illustration) has two long, streamlined floats which are each joined to the main hull by a narrow “neck”. The “neck” spans almost the entire length of the float. The amount of buoyancy is calculated so that the floats remain in deeper water below the waterline, out of the reach of waves. This makes the vessel stand “as firm as a rock” even in rough seas. Mechanical stress results from the interaction of forces between the submerged floats, which act as “fixed points”, and the main hull, which is exposed to environmental forces.

The Eco-Trimaran, in contrast, offers only little resistance to wind and waves. Both can simply flow past it, even under the main hull. The tubular float axles located there are only a minor obstacle. The floats hardly protrude above the waterline, so that breakers are able to roll past them. And since the floaters are movable, they are able to adapt to the particular wave and current conditions.

To answer the question of whether the Eco-Trimaran’s movable components enhance safety more than detract from it, it is helpful by way of comparison to refer to the suspension of land vehicles. Even though a suspension system requires additional engineering effort, it reduces stress on the materials used in the structure as a whole and so enhances safety. Or, conversely, without a suspension system, the parts of the body supporting loads would have to be designed more strongly and more heavily in order to achieve the same level of safety.

In the next chapter we will take a closer look at trimaran motion in waves, since this aspect is particularly relevant to security.

Doubts could arise about the safety of the hydrogen storage tanks. Yet hydrogen gas is only flammable or explosive when mixed with air or oxygen. This can, however, not occur within the pressure vessel. Should a pressure vessel or hose develop a leak, due to its light weight the hydrogen will immediately escape upward. If the spaces in the ship where the pressure vessels are stored have vents opening upward which are always open, no hydrogen gas can collect inside the hull (refer to test crashes with hydrogen-powered vehicles on this point annex, links & Sources No. 30). The following can be said about the risk of the pressure vessels bursting as a result of the high pressure (700 bar): first, it is planned to distribute storage volume among a number of individual tanks. Second, the vessels are to be fitted with a jacket of carbon-fibre composite material.

kW (58 hp) results for the north and 30 kW (41 hp) for the south. The motors are in operation in this case for a maximum of 6 hours each day during the day. The operating range of the vessel would also be unlimited in this case.

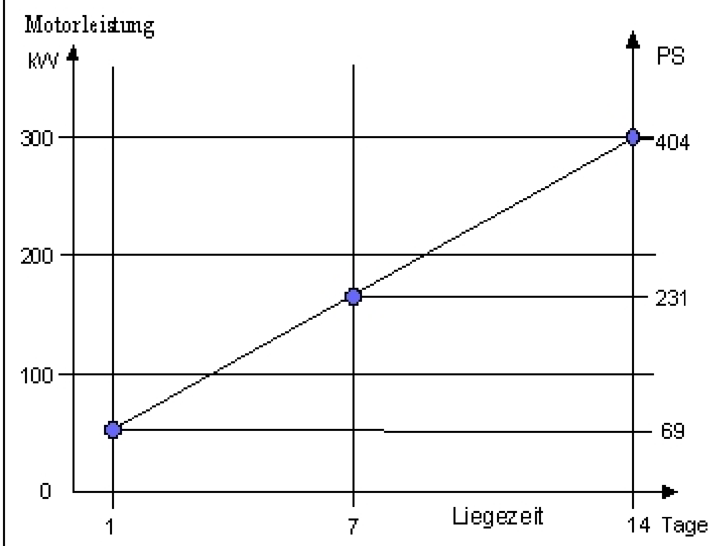
For comparison: The 82 – ft catamaran "Solarschiff Heidelberg" (appendix, links & Sources No. 16), whose batteries are additionally charged during night by the socket, performs 2 – 3 kts (average) and 7 kts (max.)

When the energy collected in **long-term storage** during mooring time is used, an average drive power of 148 kW (201 hp) is obtained for the standard northern scenario and 125 kW (170 hp) for the south. This also assumes a daily motor operating time of 6 hours and a travel period of 42 days.

If the annual **travel period is shortened**, more energy becomes available to the motors from long-term storage. This relationship is illustrated in the diagram on the previous page. Here all other assumptions for the standard scenarios remain the same. Only the standard northern scenario is discussed here, since the tendency is the same for the other scenarios.

The value originally selected of 42 days of travel per year (6 weeks) turns out to be a key variable. With shorter travel periods, the amount of power available increases dramatically, while in the case of longer travel periods this figure falls only gradually, asymptotically approaching 148 kW, the level already mentioned above, at which no energy can be taken from long-term storage.

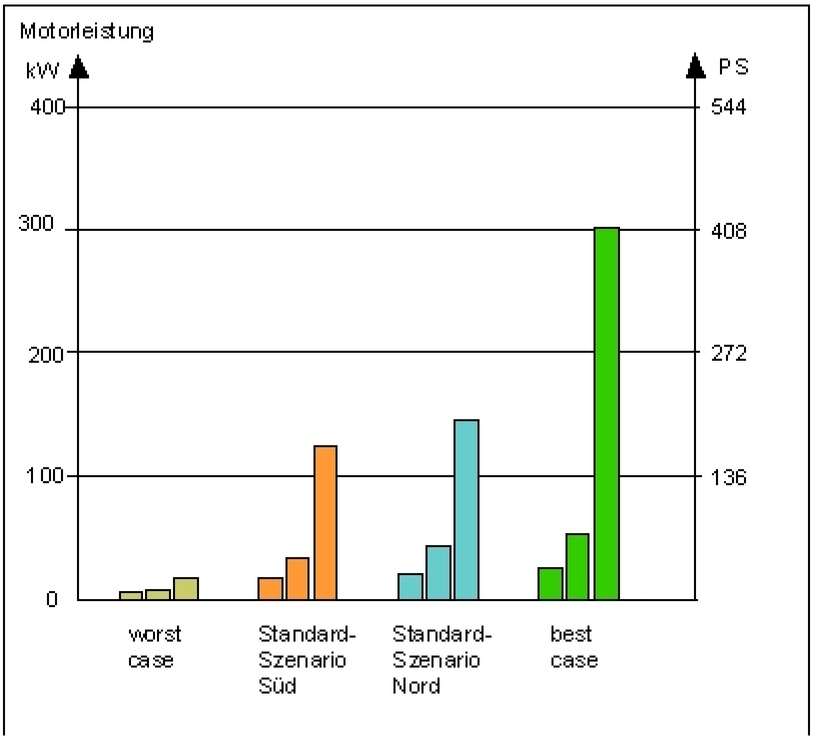
Finally, let's examine another scenario. The ship lies at anchor near a beach for several days, then travels on to the next beach. Long-term storage is initially empty. The trip lasts only one day, during which the motors are in operation for 6 hours. Sun, wind and wave conditions are the same as those in the standard northern scenario. As may be seen from the diagram above, at 51 kW (71.4 hp) the motor power available after mooring for one day is only slightly higher than the value cited above without long-term storage yet with short-term storage. After mooring for one week, 170 kW (238 hp) is available, while this amount is 300 kW (420 hp) after 2 weeks.



It is assumed that the vessel will be on voyages a maximum total of **42 days per year**, each time for several consecutive days. We further assume that the motors will run continuously for **6 hours daily** during daylight hours, when solar energy is available. During the other 18 hours a day, the ship will lie at anchor on the open sea (possibly using a sea anchor). Short-term storage is replenished during this period. Solar energy is not reckoned with during this phase.

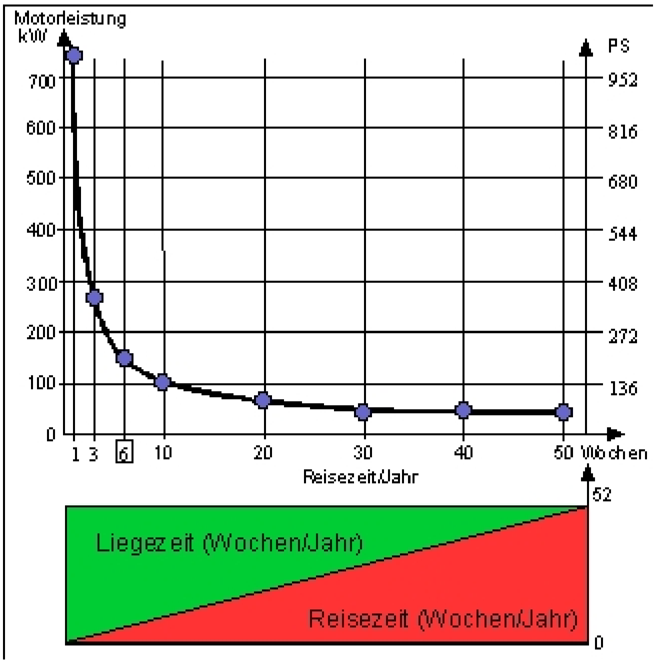
A short-term storage facility may actually be physically present in the form of a separate hydrogen pressure vessel or it may be merely virtual, i.e. as part of long-term storage capacity. In any case, the term "short-term storage" is introduced for the sake of simplifying calculations and rendering them more intelligible. In the diagram at right, there is a group of three bars for each of the four scenarios.

1. **Left bar** in each group: energy immediately available to the motors from solar cells, the wind turbine and the wave power plant.



2. **Centre bar** in each group: potential motor power from (1.) plus energy from short-term storage.

3. **Right bar** in each group: potential motor power from (1.) and (2.) plus energy from long-term storage.



The diagram allows the following conclusions: by **directly** utilising the energy produced on board in the northern standard scenario, the vessel would be able to travel with an average of **20 kW** (27 hp) of drive power. In this case the motors would only be in operation during the day, as long as solar energy is available. The operating range would be unlimited. On-board energy demands are already included in this figure. The corresponding average for standard southern conditions is **18 kW** (24 hp).

(For comparison: The 56 feet solar driven Catamaran "Sun 21" (appendix, links & sources No. 31), with which an Atlantic crossing will be tried in 2007, performs with a drive energy of 16 kW a velocity of 5 – 6 kts.)

When **short-term storage**, for which energy is collected mostly at night, is added to this, average drive power of **43** have been maintained. In this respect, significant energy savings may be expected in the future as LED technology is further developed, yet presently "energy-saving light bulbs" are still just as efficient. However, the energy needed for lighting amounts to a mere 2.34 kWh per day.

No distinction has been made between the northern and southern area of operation in this regard, since the amount of energy saved in the north from air conditioning is conversely required there for heating.

Under the conditions described here, an **average energy consumption rate of 33.8 kWh per day** has been calculated for operating times with a crew, while no distinction is made between travel and mooring periods. The comparable figure for **periods without a crew** is **0.099 kWh a day**, as in this case only bilge pumps, position lights as well as the electronic circuitry for controlling energy production, conversion and storage would need to be powered.

Drive

1. Technology

Nowadays propellers are predominantly used to drive vessels. One might get the impression that this is the most efficient type of drive. This is, however, not the case. In the "Other drives" chapter in the annex *, the disadvantages of the propeller are presented and comparisons made with other drive types. Yet more research is required before being able to implement alternatives. For the time being, therefore, we will remain with a propeller drive for the Eco-Trimaran.

If mounted at the usual position, i.e. on the stern of the floats, the propellers would stick out of the water too often when riding over waves. Since electric motors are to be used anyway, pod drives would appear to be the best choice.

Here each of the ship motors are mounted in their own pods which are fastened to the keel of each of the floats underneath the vertical pivoting axes, i.e. at the lowest point. At this position the ship drive also does not influence the passive movements of the float around the vertical axis when breakers hit the side or when making turns. With single-hull vessels, the pod containing the drive is able to pivot around a vertical axis, thus improving navigability in harbour areas. This is not necessary with the Eco-Trimaran; pods may be connected rigidly to the floats. Instead, a bow thruster is planned for the front float. This makes it possible to turn in place by positioning the front float at a right angle to the longitudinal axis of the vessel and switching on the main drive of that float.

*At present, only the German version of the annex is available

2. Energy

Electricity is used to drive the vessel. This energy is obtained **in part directly** from the wind turbine, the solar cells and the wave power plant and **in part from the pressure vessels**, where it is stored in the form of hydrogen gas. The pressure of the hydrogen gas is reduced as it is fed to fuel cells, where it is then converted into electricity. We will assume an efficiency rate of 70 % in this case. Detailed calculations may be found in the annex ("Physics - Calculations").

The operating scenario assumed here is described in greater detail in the "Energy" chapter, while further differentiation in terms of "northern", "southern", "worst-case" and "best-case" scenarios may be found in the chapter entitled "Wind".

4. Comparison with other storage media

In order to store 37.28 MWh of energy, the amount determined for the standard northern scenario, in rechargeable batteries, they would have a weight of 845 t, which is of course absurd for a 72-ft trimaran. Compressed air in the magnitude of 774 cu m (27330 cu ft) at 300 bar or 332 cu m (11723 cu ft) at 700 bar, at a weight of 279 t in both cases, would need to be stored. If diesel fuel were used, almost 4 cu m (141 cu ft) at a weight of 3.17 t would have to be kept on board.

Energy consumption

In calculating energy needs, the **drive motors are excluded** here, since these are treated in the section entitled “Drive”. This is based on the strategy of first calculating available energy and then deducting on-board energy requirements, so as to be able to use the remainder, with the addition of stored energy, for the motors.

Bord energy

Mastervolt, an international supplier of electrical and electronic accessories for yachts, has made available on the web “Mcalc”, an interactive database for estimating electricity requirements for yachts of varying sizes. The largest class of yachts presented there, 49 - 66 feet, is the category most closely approximating the “Eco-Trimaran”.

Here a spreadsheet is found which includes all conceivable applications consuming electricity, 79 in total, from engine room sockets and the coffee machine on down to air conditioning. Yet the motors are not included here, since they are usually powered by diesel fuel. The power rating and average running time (based on experience) is given for each electrical device. The company mentioned caters to an international market, while the spreadsheet “Mcalc” is written in English. We may thus assume that it is based on energy consumption habits prevalent in the UK and the US, where energy is used less sparingly than in Germany. In addition, the company’s business interests make it likely that a more generous estimate of energy needs is provided by “Mcalc”. It may, on the other hand, be assumed that the crew of the “Eco-Trimaran” will be inclined toward an environmentally conscious use of energy. Thus we remain on the safe side in using “Mcalc” to estimate energy needs.

We have omitted or rated conservatively in “Mcalc” the larger battery charging devices. Only a smaller, 530 W charger has been included; such a device would be able to be used on the “Eco-Trimaran” to charge a lead-acid battery for the emergency power supply (in the event that the fuel cells fail). The assumption for the energy consumed by air conditioning and refrigeration has been reduced to one-half, since the cold collected from depressing the hydrogen gas when filling the storage tank could additionally be used for these purposes.[1] The heat obtained from decompression when the hydrogen tank is emptied is to be used for heating. Once the storage tanks are full, the hydrogen that continues to be produced can be used directly for heating. The estimate of energy requirements for the bow thruster has also been reduced by one half, since, due its special design involving three movable floats, the “Eco-Trimaran” is expected to require significantly less energy when turning. Energy estimates for equipment serving to stabilise the position of the vessel’s hull in rough seas as well as for equipment to heat diesel fuel have been eliminated entirely. On the other hand, the energy needed to power the bilge pumps has been increased, as three of these are required (i.e. for the three floats). Values given for lighting

[1] Unlike most other gases, hydrogen cools when compressed and becomes warmer with reduced pressure.

Storing energy

1. Production of hydrogen gas

The chapters on “Wind”, “Sun” and “Waves” explain in more detail how these energy sources are utilised on board of the ship to produce direct current electricity. This electricity, if not consumed directly, is fed to an **electrolyser**. This device, well known for a long time, is used to break water down into its component substances, oxygen and hydrogen, with the aid of electricity. The following draws on product information are provided by the Swiss firm AccaGen (Appendix, “Links & sources”, No. 29)*. This process is rated at 71 % efficiency, i.e. 100 kWh of electricity is enough to generate hydrogen gas with a calorific value of 71 kWh, or 2.5 kg (5.5 lbs). While the oxygen is not further required, some of it may be filled into pressure bottles and used in the ship’s workshop for welding.

2. Storing hydrogen gas

Upon leaving the electrolyser, the hydrogen is already under a pressure of up to 200 bar. It is then further compressed to 700 bar using a conventional compressor and subsequently stored in pressure vessels that, out of practical considerations, are found in the floats of the trimaran.

Utilizing the changes of temperature which occur during the compression, the efficiency rate of this process may be settled to 90% (refer to “Physics – calculation” in the annex for more detail) *.

Of the 100 kWh supplied originally, 71 kWh is outputted by the electrolyser, of which 71 * 0.9 = 64 kWh reaches the storage device.

*At present, only the German version of the annex is available

3. Data for the 72-ft trimaran

As has already been explained in the section on “Energy”, only energy surpluses accumulated while mooring are stored in a long-term storage medium. Energy produced during travel is completely used up by on-board energy requirements and the ship’s motors. When it is assumed that the vessel is moored for 273 days a year, the amounts of energy determined in the chapters on “Wind”, “Sun” and “Waves” result in the values shown in the table below:

gespeicherter Wasserstoff	Stand. Nord	Stand. Süd	max.	min.	
Energie	37,28	33,70	87,94	3,50	MWh
Gewicht	932	843	2199	87	kg
Volumen	16,40	14,83	38,96	1,54	cbm

The “Stand. Nord” and “Stand. Süd” columns refer to the standard operating scenarios presented in detail in the “Wind”, “Sun” and “Wave” chapters. For the sake of simplifying calculations, mooring time of 273 days and 42 days of travel were assumed. These operating periods can, of course, be further divided up. If, for example, they are divided in half, the required storage capacity is also reduced to half of the value given above in each case.

Remaining with the volumes given in the table, concrete storage specifications for the ship are obtained as follows.

A conventionally shaped pressure vessel (i.e. a cylinder with a hemispherical covering on both sides) is installed in each float. The total volume of 15,77 cu m (557 cu ft) determined for the standard northern scenario could be accommodated in pressure vessels, mounted in each of the floats, with a diameter of 1 m (3.28 ft) and a length of 6.4 m (21 ft; including cover).

The hydraulic oil coming out of the hydraulic motor, which is no longer under pressure, flows into a supply tank, from which it is once again pumped into circulation by hydraulic cylinder HZ. Since it is virtually impossible to compress hydraulic oil, the smallest movement of the float results in oil being pumped. In the case of reduced wave activity, it takes a commensurately longer period of time for one of the two pressure vessels to be filled with hydraulic oil and thus become pressurised. The corresponding electricity generator will then be driven in longer intervals yet always with the same amount of force. In order to further increase the range of waves utilisable for this purpose, bearing L of the hydraulic cylinder is mounted to slide within a rail VS toward pivoting point M of the float. This acts as an infinitely variable gear shifter.

One issue still remains to be resolved in developing this mobile wave power plant. As the floats are able to move, **vessel drag is reduced** in rough seas, which saves energy required to power the vessel. Yet, producing energy hampers float movability to a certain degree. This leads to the question of the proper amount of energy to save in relation to the amount produced. This issue needs to be resolved by carrying out investigations at a research laboratory for shipbuilding. (Further details see “float bearings”, page 5)

2. Energy yield

It is not yet possible to calculate the energy yield of the mobile wave power plant described here. The figures serving as the basis for such a calculation, i.e. the energy content of waves, might yet be determined. One would need to take into consideration the range of wave activity in the marine areas where the vessel could operate, i.e. empirically determined probability distributions for wave height and length.

What is missing in order to do further calculations is an energy efficiency rate reflecting the degree to which this primary energy source is converted by the wave power plant into usable energy. Data from the stationary wave power plant “Pelamis” (Appemdix, “Links & sources”,No. 6)* which functions in a similar manner, could be referred to for this purpose. An efficiency rate of 40 % is given for that plant.

As long as such calculations remain unavailable, a rough approximation based on the wind turbine will need to suffice. By way of a cautious estimate we assume that the wave power plant achieves 50 % of wind turbine performance on the open sea. This seems reasonable inasmuch as wave activity correlates with wind force.

Under these conditions, and in accordance with the other assumptions described more fully in the chapter on “Wind” (i.e. travel time and mooring time within and outside of harbours, northern and southern scenarios), and assuming that no wave energy whatsoever is available in harbours, an energy yield of 7.82 MWh per year or 21.42 kWh per day is obtained for the worst-case scenario. The best case results in 46 MWh per year or 125 kWh per day. Under the conditions given for the **standard northern scenario, 28 MWh** per year or 78 kWh per day would be collected, and for the **standard southern scenario 17 MWh** per year or 46 kWh per day.

---

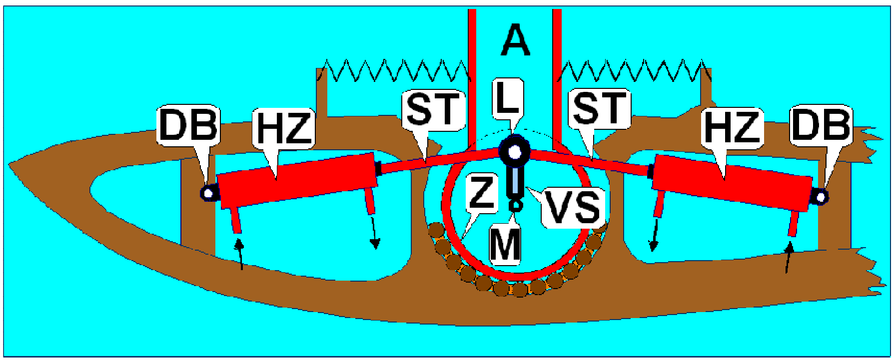
*At present, only the German version of the annex is available.

diameters. From the chart on the previous page (where blue is the northern, yellow the southern scenario) it may be seen that, when rotor diameter is increased from 14 to 16 m (45 to 52 ft), for example, annual capacity increases by one-third. Considering that our mechanism for securing the rotor in storms is very effective and responds quickly, potential for greatly improving energy production would seem to exist.

Movable floats – a wave power plant

1. Mechanics

Illustration above: The bow of the front float tilts downward after passing over the crest of a wave. Illustration below right: A sectional view shows how the float generates utilisable energy by moving around its horizontal transverse axis. On the lower end of the vertical axle A, which connects the float with the main hull, cylinder Z may be seen. This serves as a pivoting bearing connecting the main hull with the bottom of the float. A bearing, connected at the upper circumference of the cylinder, pushes or pulls the two rods (ST) and each of the corresponding pistons of the hydraulic cylinder whenever the float rotates in the waves around point M . The hydraulic cylinders are in turn mounted to pivot within the float by means of bearings DB. The piston of each of the hydraulic cylinders acts as a pump, pressing hydraulic oil into a pressure vessel filled with air (not shown). The air within is thus compressed to an increasingly smaller volume, causing pressure to increase. Once an upper pressure limit is reached, the hydraulic oil continues to be pumped, but it is automatically fed into another pressure vessel, and the process continues. The first vessel, under pressure, represents a mechanism for storing energy. This pressurised hydraulic oil may be used to power a hydraulic motor which in turn is connected to an electricity generator. When a certain lower pressure limit is reached, the outlet valve to the hydraulic motor closes automatically and the intake valve coming from the hydraulic cylinder HZ opens, allowing the pressure vessel to once again fill with hydraulic oil and become pressurised.



anchor in a shallow coastal area also within the high-wind zone 5. Even during the total travel time of 42 days the ship does not leave the high-wind zone. This scenario is far from being unrealistic. A glance at the European Wind Atlas reveals that such conditions are found in the harbours and marine areas near Skagerrak, near northern England and Northern Ireland, yet also in the Mediterranean in the Gulf of Lion (between Marseille and the Costa Brava). Under these conditions the wind turbine would produce 56 MWh per year or 153 kWh per day.

Standard scenario: due to the variety of local wind conditions, a basic decision needs to be taken as to whether the Eco-Trimaran will operate mostly in bodies of water in the north (North and Baltic Sea or North Atlantic) or in the Mediterranean. For this reason a distinction is made here (just as for solar energy) between “northern” and “southern” versions of the standard scenario.

Liegezeiten mit Besatzung

	Standard-N.		Standard-S.	
	Tage	Wind	Tage	Wind
Windgesch. Hafen	45	4	45	3
Windoffener Hafen	50	4	50	4
Ufer vor Steilküste	20	5	20	2
Ufer vor Flachküste	158	3	158	3
Tage insgesamt	273		273	

Liegezeiten ohne Besatzung

	Standard-N.		Standard-S.	
	Tage	Wind	Tage	Wind
Windgesch. Hafen	30	4	30	3
Windoffener Hafen	20	4	20	4
Tage insgesamt	50		50	

Reisezeiten	Stand. Nord	Stand. Süd
	Tage	Tage
Kurs in Windzone 1	0	5
Kurs in Windzone 2	1	12
Kurs in Windzone 3	3	15
Kurs in Windzone 4	17	9
Kurs in Windzone 5	21	1
Tage insgesamt	42	42

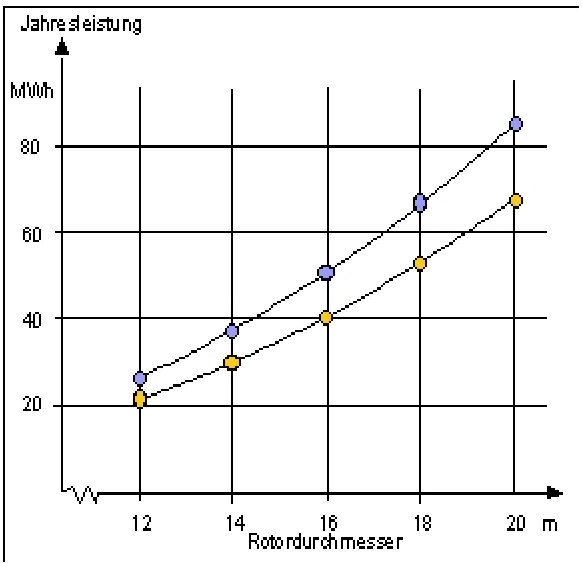
It is assumed that the ship, including crew, will lie in a wind-protected harbour on 45 days and in a harbour exposed to the wind on 50 days (see table below). On 20 days it will lie at anchor near a steep coastline (e.g. for scuba diving). The remaining 158 days are divided among various beaches for bathing along a low-lying coast. The assumptions regarding wind conditions in the north and south can be found in the table on the previous page (in the “Wind” column), in which the wind zones are given according to the “European Wind Atlas”.

It is assumed that the ship, without crew, will lie in a wind-protected harbour on 30 days and in a harbour exposed to wind on 20 days.

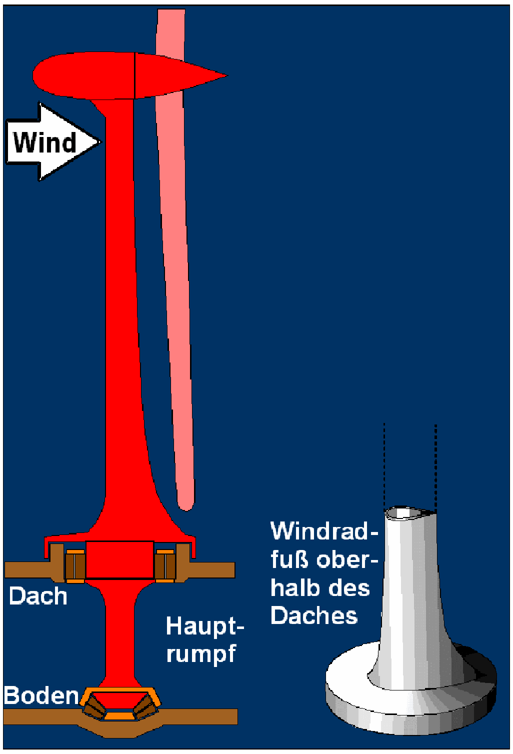
The ship will travel for a total of 42 days divided up among the various wind zones as shown in lower table at left side.

Under these conditions the wind turbine would produce **38 MWh** per year or an average of 103 kWh per day according to the northern scenario. In the south, with generally poorer wind conditions, annual energy production would be **30 MWh** or 82 kWh per day on the average.

The preliminary assumption for rotor diameter, reached intuitively, is 14 m (45 ft). This value, still to be set more precisely, requires calculation of wind pressure (dynamic pressure) on the wind turbine and resulting vessel heel. This could conceivably make it possible to realise even larger rotor dimensions.



In order to estimate potential consequences for energy production, I have also calculated annual energy production for other rotor



wind flow to the turbine, running behind the mast, as would be the case with a round mast. This presupposes that the mast **always turns in the wind with the wind turbine**, i.e. the mast must be mounted on pivoting bearings.

The radial forces on the wind turbine mast (i.e. wind pressure) are transferred to the roof of the main hull by a cylindrical roller bearing, while the axial forces (i.e. the weight of the entire wind turbine structure) as well as the remaining radial forces (i.e. wind pressure resulting in leverage) are transferred by a cone roller bearing to the bottom of the main hull.

The roller bearings can be made of hardwood impregnated with paraffin, rendering them seawater-resistant. (Paraffin serves as a lubricant and repels water.) This offers the additional advantage of reduced noise as compared to steel roller bearings. While wooden bearings have more play (only in the case of the radial bearings), this is tolerable for the applications presented here.

2. Wind energy

Assumptions about wind conditions need to be made for all of the locations where the vessel may be found in the course of a year. To this end we have based assumptions on the five wind zones depicted in the **European Wind Atlas**. The Wind Atlas gives an average wind speed at 50 m (164 ft) above ground (or water) for each zone. Wind speeds at 50 m altitude are then converted to the height of the wind turbine hub, while various “roughness exponents” need to be determined for the open sea, harbours and other mooring points (refer to the annex, “Wind turbine” section in the “Physics” chapter, for details)*. Hub height, which is 14 m, is determined by taking the height of the roof above water and adding the radius of the wind turbine plus a safety margin between the roof and the lowest blade tip position. We assume than an adult is able to stand on the roof with arms stretched upward and not touch the rotating blades.

The calculations presented in the following are based on the standard operating scenario, described more fully in the section entitled “Energy”, using the ratio: mooring time without crew : mooring time with crew : travel time = 50 : 273 : 42 days and a motor operating time of 6 hours per day of travel.

Worst-case scenario: in this case the vessel lies in a wind-protected harbour, with or without crew, in zone 1, a light-wind zone. The ship also remains in zone 1, with light winds, during its voyages. Under these conditions the wind turbine would produce 1.93 MWh per year or 5.29 kWh per day.

Best-case scenario: on 50 days a year the ship lies in a harbour exposed to winds in the high-wind zone 5 and on 273 days it lies at

Wind-Zone	Geschütz-tes Terrain	Offene Ebene	Meeres-Küste	Offenes Meer	Hügel & Bergkämme
5	> 6,0	> 7,5	> 8,5	> 9,0	> 11,5
4	5,0 – 6,0	6,5 – 7,5	7,0 – 8,5	8,0 – 9,0	10,0 – 11,5
3	4,5 – 5,0	5,5 – 6,5	6,0 – 7,0	7,0 – 8,0	8,5 – 10,0
2	3,5 – 4,5	4,5 – 5,5	5,0 – 6,0	5,5 – 7,0	7,0 – 8,5
1	< 3,5	< 4,5	< 5,0	< 5,5	< 7,0

*At present, only the German version of the annex is available

Best-case scenario: average annual global radiation of 1850 kWh/sqm (172 kWh/sq ft) is measured for the area south of Sicily. If the ship is both moored and operates in this area, the amount of energy produced by the solar cells would be 15 MWh per year or 42 kWh per day.

Standard scenario: as global radiation is strongly dependent on the degree of latitude, a basic decision needs to be taken as to whether the Eco-Trimaran will operate mostly in bodies of water in the north (North and Baltic Sea or North Atlantic) or in the Mediterranean. The standard scenario thus needs to be further differentiated to include a "**northern**" and a "**southern**" scenario. These scenarios are presented in the table below, with the rows giving the radiation data ("Rad." column in kWh/sqm per year).

Reisezeiten

	Standard Nord		Standard Süd	
	Tage	Strahlg.	Tage	Strahlg.
	11	800	11	1400
	7	850	7	1850
	14	1000	14	1650
	1	950	1	1500
	3	800	3	1750
	6	900	6	1450
Summe	42	Tage	42	Tage

The values for radiation, while determined arbitrarily, are approximately representative

Liegezeiten ohne Besatzung

	Standard Nord		Standard Süd	
	Tage	Strahlg.	Tage	Strahlg.
	30	900	30	1450
	20	1100	20	1550
	0		0	
	0		0	
Summe	50	Tage	50	Tage

Liegezeiten mit Besatzung

	Standard Nord		Standard Süd	
	Tage	Strahlg.	Tage	Strahlg.
	45	900	45	1450
	50	800	50	1600
	20	1200	20	1850
	158	1000	158	1750
Summe	273	Tage	273	Tage

for the regions as depicted in the global radiation maps in each case.Under standard conditions the amount of energy produced by the solar cells would be **12 MWh** per year or 33 kWh per day while moored or travelling in **northern** areas. At **southern** latitudes, **21 MWh** per year or 58 kWh per day would be obtained.

* Note: Here the "best-case scenario" was sought within the Mediterranean Sea. Yet better radiation conditions by far are found in other areas of the globe, for example near the Canary Islands or the California coast.

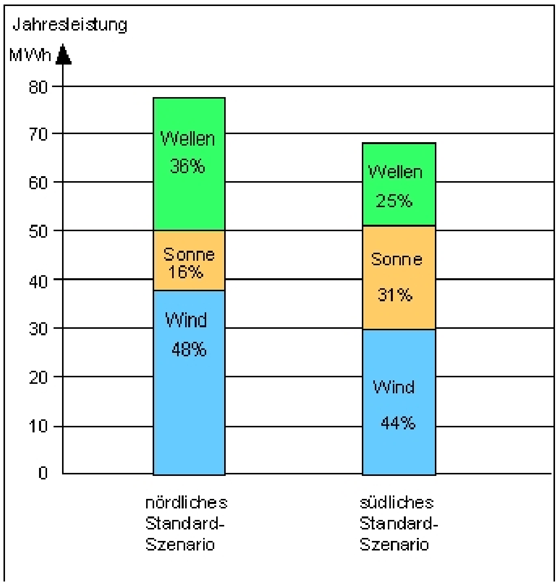
Wind

1. Wind turbine

The most important aspect in wind turbine design is to ensure that **as little wind pressure as possible** comes to bear on it. This allows for maximum size and height and maximum power without too great a danger of capsizing in a storm. Since the high-speed, three-blade wind turbine has become the standard, wind pressure during operation, when generating power, is specified; while freedom in design remains only with regard to the appearance of the mast and mechanisms for securing it in storms.

Conventional techniques for securing rotors in storms, e.g. braking the rotor and bringing it to a standstill, result in the disadvantage that wind pressure still remains too high in the secured position. It is therefore proposed that the **blades be able to tilt backward** (seen from the wind direction) and fold against the (imaginary) extension of the rotation axis. This presupposes a **leeward turbine**, i.e. one that operates **behind** the mast as seen from the wind direction. This offers the additional advantage of always turning into the wind automatically, without any other mechanisms. The mechanism securing against storms also needs to be activated when travelling at high speeds against the wind.

Wind pressure on the wind turbine mast is minimised by selecting a **streamlined design** for the cross section. This also has the advantage that there is less disturbance of the scenario in detail.



Sun

1. Solar cells

The roof of the main hull and parts of the floats protruding out from under it are fitted with solar cells. Solar cells that are able to be walked on are planned to be used on the sun deck. A total surface area of **939 sq ft** can thus be obtained.

The wind turbine poses something of a problem as it periodically casts a shadow, which reduces the production of electricity. The reason for this is that each individual solar cell has only a low voltage and thus several need to be connected in series. Thus, electricity production is interrupted in the entire series of cells if just a single cell drops out. This problem is mitigated in the Eco-Trimaran by keeping the series short, as the amount of voltage required for the electrolyser does not need to be very high. With the solar power generator there is also no need for an inverter or voltage converter, since the electrolyser operates on direct current. This reduces energy loss, allowing us to assume an **efficiency rate of 12 %.** In the end on account, **20 % is deducted** for the shadow of the wind turbine as well as other losses (connecting lines, unfavourable operating temperatures).

2. Electricity yield

Solar energy is available on the earth’s surface partially in the form of direct sunlight and, when it is cloudy, partially as diffuse radiation. Both types are subsumed under the term “**global radiation**”. It is the strongest near the equator and is weaker with increasing proximity to the poles and in frequently cloudy areas. For our calculations, we require average values for many years for all possible areas of operation and all possible moorings. These are obtained from special maps or tables available on the web. In this case the “Photovoltaic Geographical Information System” (PVGIS) was used (see annex, Links & sources No 27)*.

The calculations presented in the following are based on the standard operating scenario, described more fully in the section entitled “Energy”, using the ratio: mooring time without crew : mooring time with crew : travel time = 50 : 273 : 42 and a motor operating time of 6 hours per day of travel.

Worst-case scenario: the longstanding average for global radiation on the North Sea north of Scotland is approx. 800 kWh/sqm (74 kWh/sq ft). We will assume that the ship is both moored and operates within this area. In this case the amount of energy produced by the solar cells would be 6.71 MWh per year or 18.37 kWh per day.

* At present, only the German version of the annex is available

Generating, storing and consuming energy

The key idea of the project as a whole **is to consistently utilise the most important sources of energy available at sea**. Since this project is likely to be initially realised using a yacht, which for most of the year would lie at anchor, great stress is to be placed on **storing energy**. Wind and solar energy, in the least, are continuously available during mooring periods, and these can be converted into a form able to be stored. **Compressed hydrogen gas** is planned to be used for storage; the reasons for deciding on this medium are presented in the section entitled “Storage options” (annex).

In order to obtain concrete results, we proceed as outlined in the following.

First, the amount of energy able to be generated on the vessel from the sun, wind and waves is determined. To do this, an operating scenario for the vessel is required, i.e. assumptions regarding: the proportion of mooring time to travel time; the average number of daily operating hours of the ship’s motors during voyages; and the areas where the vessel is likely to operate, since there is a great amount of variation among marine areas with respect to sun, wind and wave conditions. Based on a survey of individuals familiar with the practical operation of large yachts, it **is assumed that our vessel will be travelling an average of 42 days per year**, while the rest of the time it will either be moored at a pier or lie at anchor near a beach. Such assumptions can be verified when large used yachts are sold. In such cases the number of hours of operation accumulated thus far by the ship’s motor is made public, and this figure can then be divided by the number of years of operation.

Mooring periods then need to be further broken done into phases during which crew or passengers are on board. For a generous estimate of energy needs, **the period without a crew** (i.e. non-use of the vessel) has, at **50 days per year**, been intentionally assumed rather conservatively. All of the calculations presented below are based on a proportion of 50 : 273 : 42 days (mooring time without crew : mooring with crew : travel time) **with 6 hours of motor operation on each day of travel**.

Once the amount of available energy has been determined, energy requirements need to be calculated. First, **board energy** requirements are ascertained, i.e. energy necessary for the crew’s comfort (heating, air conditioning, lighting, kitchen appliances etc.) as well as energy needed for other equipment on board (electronic and electrical steering components, bilge pumps, position lights etc.).

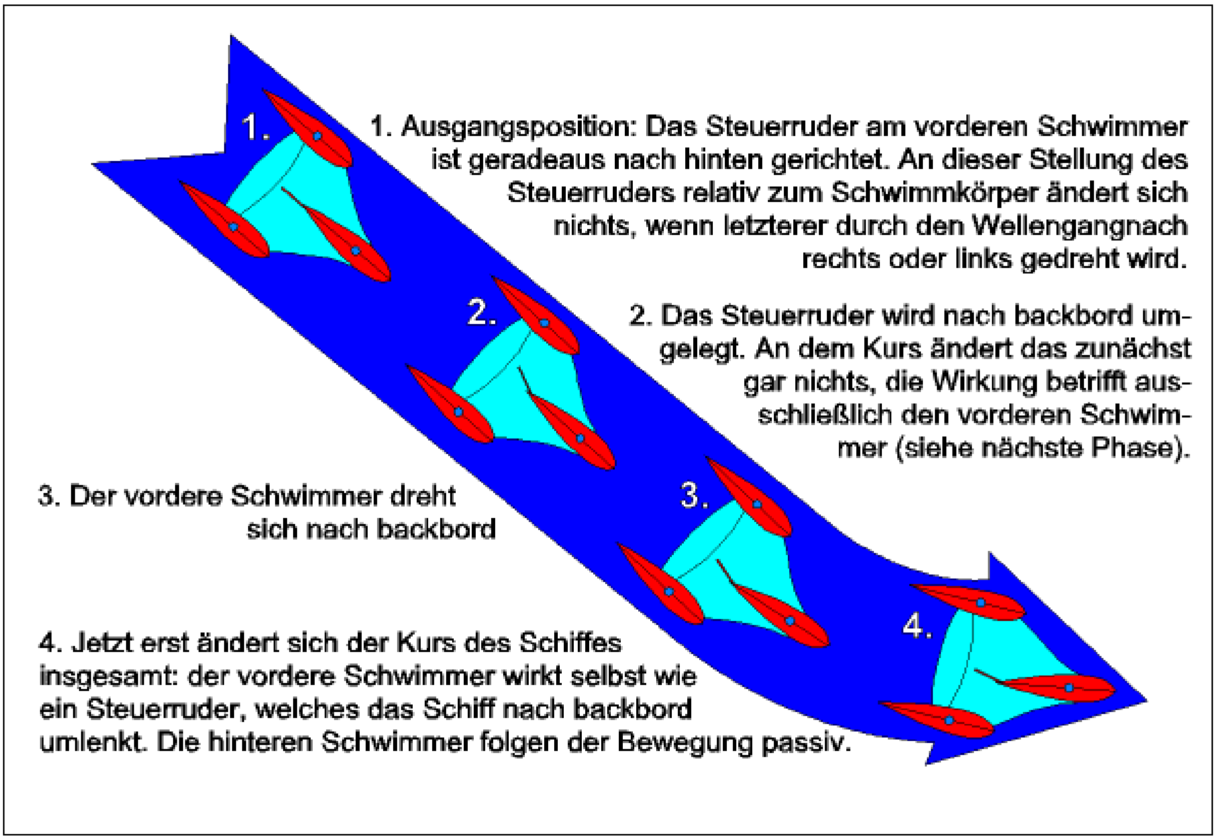
The energy surplus, i.e. the difference between available energy and board energy requirements, is consumed by the ship’s motor during travel and stored while mooring. During voyages the motors can thus run on the energy produced directly and additionally on stored energy.

Generating energy

An annual total of **78 MWh** is produced according to the northern scenario and **68 MWh** according to the southern scenario. The drawing (next page) shows the distribution of energy quantities among the three primary energy sources. Wind and waves predominate in relative terms in the northern scenario, while solar energy plays a stronger role in the southern scenario. Yet in each case wind is the major source.

The following chapters, entitled “Sun”, “Wind” and “Waves”, describe in greater detail how the share of each of these three types of energy are produced and a description of the “northern” and the “southern”

Steering



Steering wheel movements on the bridge are transferred to the rudder on the front float in such a way that **any passive movement of the float due to waves does not affect the rudder position**. In other words, turning the wheel causes the rudder to turn only relative to the float but not relative to the main hull.

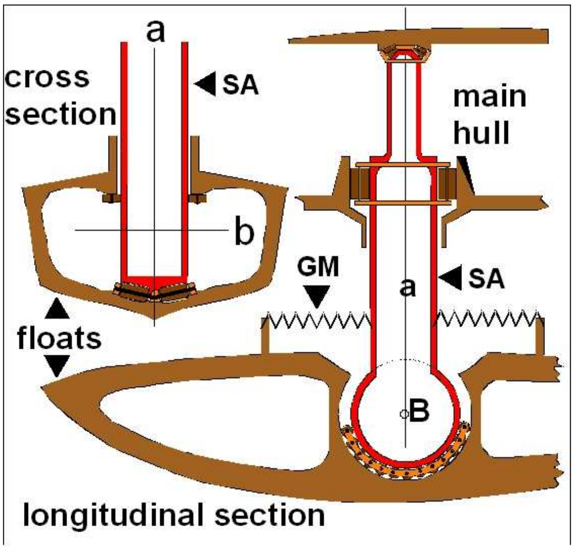
The rear floats, having their vertical axes of rotation at the front, only passively follow any change of course. Therefore, when making a turn, these floats always assume a position that reduces drag to a minimum. The overall result is significantly less drag in turns than would be the case with conventional vessels. (Please refer to “Making turns” on page 3 of the annex.*)

A bow thruster on the front float is used to navigate in harbour waters. When this float is turned at a right angle to the longitudinal axis of the vessel and the main drive of this float is started, the ship immediately turns in place.

---

* At present, only the German version of the annex is available

Float bearings



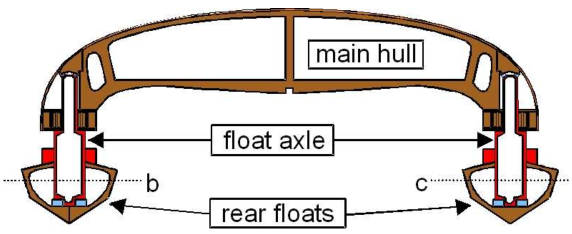
The float axle SA, consisting of a tube mounted on bearings located in the main hull, pivots together with the float around a vertical line a. The float also pivots around a horizontal axis at the lower end of the vertical axis. This pivoting axis is represented by line b in the cross section and point B in the longitudinal section. The corresponding bearings are found in the float. The vertical axle is mounted on two sets of bearings in the main hull. Radial forces are transferred to the bottom of the main hull by a cylindrical roller bearing. At the top, both radial and axial forces are absorbedby a cone roller bearing mounted at the roof.

A spherical roller bearing allows the float to pivot around the horizontal axis. This bearing transfers mostly axial force (weight of the main hull) but also some radial force (i.e. caused by waves impacting from the side). This is facilitated by having the vertical axle end at the bottom in a transversely mounted cylinder. A segment of the spherical roller bearing is sufficient for this purpose, since the float is only able to deviate from the horizontal position by a maximum of 30°. Several gearwheels connected to the bearing (not shown in the drawing) ensure that this roller segment remains centred beneath the vertical axis when the float is in the horizontal position. A number of rollers with rigid axes are additionally mounted at the upper part of the float in order to transfer radial forces (see cross section).

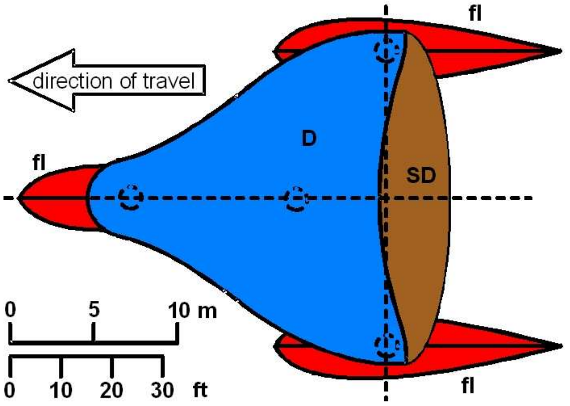
The bearings are sealed at the float by means of a rubber sleeve GM and at the bottom of the main hull by means of a radial drag seal made of rubber.

The rollers of the bearings are made of teak impregnated with paraffin (which serves as a lubricant and prevents water absorption).

Ship design illustrated using a 72-foot yacht as an example



The drawing above shows a vertical cross section of the main hull and the two rear floats. In this part of the vessel, the roof is drawn downward at the sides. The vertical float axles pivot on bearings in the main hull, i.e. they turn along with the floats. The floats can also pivot horizontally around the b and c axes. Refer to page 5 for details on float bearing mounting.



This drawing shows a view of the vessel from above. The roof of the main hull (D) is almost completely covered with solar cells. In the rear part there is a sun deck (SD) that could also be fitted with solar cells able to be walked on. The parts of the floats protruding out from under the main hull (fl) could also be used for solar cells. The dotted circles mark the vertical axes around which the three floats and the wind wheel turbine are able to pivot. The scale shown below the drawing corresponds to a version designed as a 72-foot yacht.

The floats are able to turn about their horizontal axes. This serves three purposes during rough seas:

1. Reduces the drag

2. Generates energy

3. Improves stability

The ability of the floats to turn around the vertical axes serves two purposes:

1. Greater manoeuvrability and reduced drag when making turns

2. Enhanced stability on rough seas

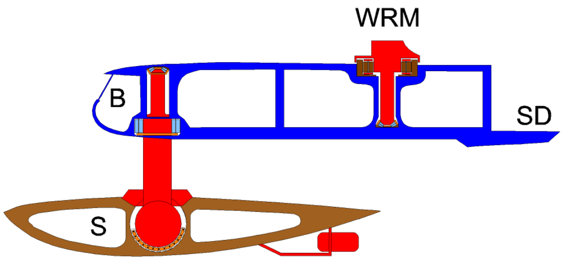
The broad, shallow shape of the main hull serves four purposes:

1. Reduced sensitivity to sidewinds and headwinds

2. Less danger of capsizing, particularly when there is wind pressure on the wind turbine

3. Large surface for solar cells

4. Large surface for collecting rainwater

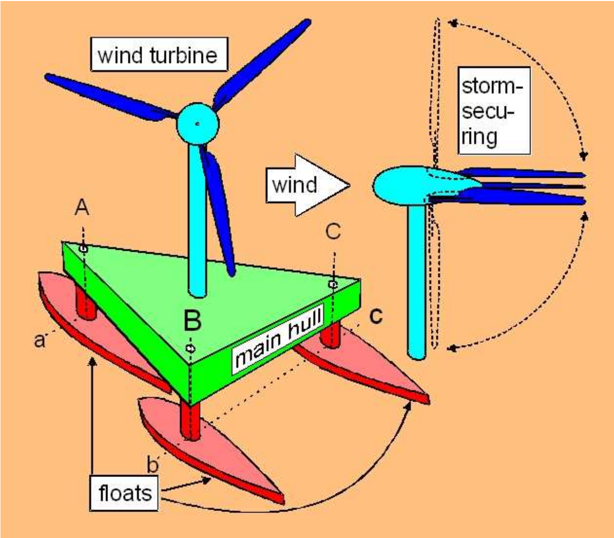


The drawing above shows a vertical longitudinal section of the main hull and the front float (S), with the bridge (B) at left and the sun deck (SD) at right in the main hull. WRM designates the lower part of the wind turbine mast which is able to pivot on roller or cone bearings (see page 8 for more detail).

Engineering

This is an overview of the various technical aspects. Further details are found on the following pages. The implications which the technical solutions proposed here have for ship comfort are presented in a separate chapter.

Basic form of the vessel: on page 4, the advantages of the shallow, triangular main hull, carried above the waterline by three floats that are able to pivot around both the A, B and C and a, b and c axes, are demonstrated with reference to a 72-foot yacht.



Under "**Steering**" on page 6, a description is given of how the ship can be kept on course by means of a rudder mounted on the front float. The following pages then explain how this results in less drag in turns.

The vessel is powered by electric motors and propellers housed in pods on the keels of the floats. Under "**Drive**" on page 15 you will learn about the quantities of energy available for powering the vessel.

The roof of the main hull provides ample space for **solar cells**. Solar cells that are able to be walked on are planned to be used on the surface of the deck. Parts of the floats protru-ding out from under the main hull may also be fitted with solar cells. Pages 8-9 present data on the amount of power that can be expected to be generated by the solar cells.

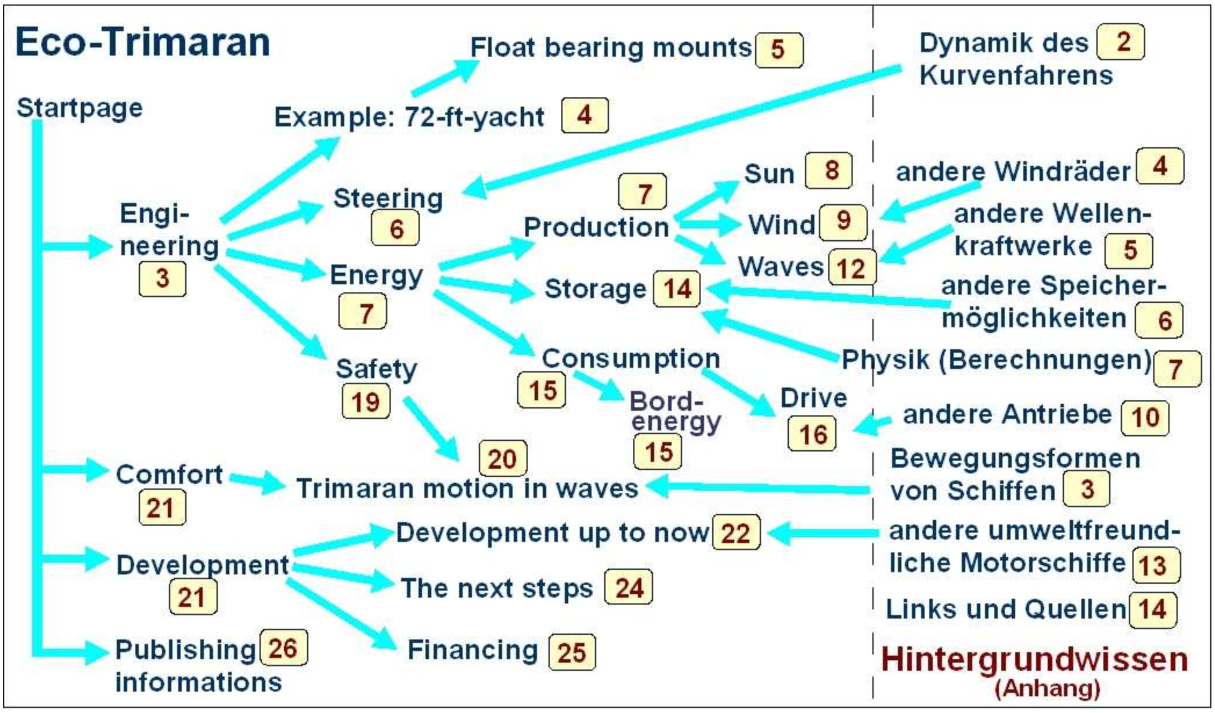
The **wind turbine –** pages 9-11: this is large and tall, since the floats serve as a broad "base", securing the vessel against capsizing even in storms. There you will find out what is meant by a "leeward wind turbine" as well as the benefits for storm safety provided by backward-tilting rotor blades. The amounts of energy expected to be generated are also listed there.

To take advantage of **wave energy**, newly deve-loped, movable floats serve as a kind of mobile wave power plant (page 12-13). The following pages describe how this relates to a reduction in drag.

Under "**Energy**" on page 7, as well as on the following pages, you will find a description of how solar, wind and wave energy are stored in the form of compressed **hydrogen gas** and then utilised by means of **fuel cells**. Heat and cold are also emitted, which are used for heating and air conditioning.

Do the movable floats compromise vessel **safety** in storms? This and other safety questions are discussed on page 17.

Overview



Note: the annex is currently being translated into English. At present, only the German version ("Anhang") is available.

The Eco-Trimaran – a motor ship powered only by renewable energy

www.oeko-trimaran.de

Version 9 November 2006 – last modified on 10/1/2007

Latest modifications: See German version

Sun, wind and waves – unlimited sources of renewable energy on the oceans and seas! All of these can be used to power ships, making petroleum superfluous.

Contents – main chapters: