Dear anonymous referee #1,

Thank you very much for reviewing our manuscript. We greatly appreciate your comments and suggestions. We have revised the manuscript accordingly. Please find below our point-by-point responses to your suggestions and concerns.

General comments

This article documents the early design stages of a creative, renewable Power-to-Liquid system. The article is written in generally good language. The technical aspects of the proposed energy ship are documented appropriately for a case study and assumptions/references are transparent. The economic evaluation of the concept is documented transparently too.

No answer required.

The main critique point is specific comment no. (10). The critique refers to the methanol price projections and is decisive for the market potential of the proposed solution and eventually the conclusion of this article. I recommend this point being double-checked by another reviewer.

Please find below our detailed answer to your comment no (10).

Specific comments

1. Line 22: "the cost may be comparable to that of methanol produced by offshore wind farms in the long term" – see specific comment no. (10).

   See our detailed answer to your comment no (10).

2. Line 35: It would be helpful for the reader if you shortly mentioned up to three main reasons for your choice of methanol, based on your referenced previous assessment.

   The following text has been added in the introduction.

   In the proposed system, the fuel is methanol. Hydrogen was not retained because it was found in Babarit et al. (2018) that hydrogen storage and transportation costs could account for nearly half of the cost of the delivered hydrogen when it is produced far-offshore (because of the low volumetric energy density at ambient temperature and pressure conditions which is a well-known challenge for hydrogen storage and transportation). In contrast, the other possible energy vector options (synthetic natural gas (SNG), methanol, or Fischer–Tropsch fuel (FT fuel), Graves et al., 2011; and ammonia, Morgan, 2013) are much simpler to store, transport and distribute (particularly methanol and FT fuel, as they are liquid for standard conditions of temperature and pressure). Moreover, they can be incorporated into existing infrastructure with little to no modification. The drawback is that they each require the supply of an additional feedstock (carbon dioxide or nitrogen depending on the energy vector) and an additional conversion step in the energy conversion process. The additional conversion step decreases the overall energy efficiency and increases the size and complexity of the PtX plant. In a previous study (Babarit et al., 2019), we investigated whether these drawbacks could be compensated for by the easier storage, transportation and distribution of the products, and we found that methanol is the most promising solution; hence it is retained as the energy vector in this study.

3. Line 55 and following: As far as I understand, your proposed design has progressed and you provide comparisons/updates to previous estimates. This documentation in itself may be of value, as it showcases how weight or cost estimates develop throughout subsequent design stages. A short sentence highlighting this value could bring attention to this aspect.

   Thank you for the suggestion. The text after line has been modified accordingly :

   The overall aim of the present study is to investigate the energy and economic performance of the FARWIND energy system. A preliminary energy ship design was proposed in (Babarit et al., 2020) and its energy performance was investigated. The cost of energy was estimated in (Babarit et al., 2020b). It was found that an initial FARWIND system could produce approximately 100,000 tonnes of methanol per at a cost in the range 0.9 to 2.1 €/kg.
   This preliminary design has been reviewed by ocean engineering and marine renewable energy's experts of the Marine Energy Alliance European project (EMEC, 2020); and wind-assisted propulsion experts (Blue WASP, 2020). Based on their feedback, the ship design has been progressed; and an the economic model has been refined. The aim of the present paper is to present that improved design, the economic model, and the resulting cost of energy. The present study also provides an example of how cost estimates develop throughout subsequent design stages.

4. Lines 67 & 88: you refer to eq. 2 from Babarit et al. 2020 twice, hence it seems to be relevant for this study. Consider showing that equation explicitly here instead of only referring to the previous article

   That equation has been added :

   The propulsive force (thrust) T of a Flettner rotor depends on the lift coefficient CL, the drag coefficient CD,the apparent wind speed V, the apparent wind angle α, the rotor area A (height times diameter) and the air density ρ_a*:*

   $$T = \frac{1}{2}\rho_a A V^2 (C_L \sin\alpha - C_D \cos\alpha) \tag{1}$$

5. Line 82 (Figure 4): You could indicate the vector of the propulsive force with an arrow in the left part of the figure. Potentially four arrows with lengths proportional to each FR's force contribution.

   The vectors of propulsive force are now indicated in Figure 4. Thank for the suggestion.

6. Line 97: since the displacement has changed, I assume the hull shape has changed too. 'The hull shape (Wigley hull) has been updated based on a more accurate displacement estimate' could clarify this.

   Actually, the hull shape has not changed. It is only the draft that has changed. It was 1.6 m in the initial design. It is 2.1 m in the new design. We forgot to update Table 1 in the initial submission. This mistake is now corrected. To clarify, the following sentence has been added in section 2.2:

   The draught has increased from 1.6 m for the initial design to 2.1 m for the updated design.

7. Lines 116-122: Consider mentioning the efficiency of the H2-to-methanol plant as well in order to increase transparency.

   The efficiency of the hydrogen-to-methanol plant has been added explicity in section 2.4:

   Assuming the same 60% efficiency for the electrolyzer and the same 78% efficiency for the hydrogen-to-methanol plant as for the initial design, the rated power of the hydrogen-to-methanol plant is 680 kW (850 kW for the initial design).

8. Lines 182 & 201: You could improve understanding by framing the annual methanol production capacity in terms of vehicles powered. E.g. units of 5000 dwt bulk carriers propelled:
   70,600t/year = 388,300MWh/year chemical energy assumptions annual energy consumption

   bulk carrier: 1,410kW x 24h/day x 180days/year = 6,091MWh/year

   6,091MWh / 50% thermal engine efficiency = 12,182 MWh/year chemical energy

   388,300MWh / 12,182MWh = 32 vessels that could be powered by the designed fleet

   For sake of illustration, let us estimate the number of 5,000 t bulk carriers which could be powered by a FARWIND system. As mentioned in section 3.1, their propulsion power is 1,410 kW for a service speed of 12 knts. Assuming that they would sail at that speed 292 days per year (80% of the time) and that their engine efficiency is 40%, the required chemical energy is approximately 24,700 MWh per year. 70,600 t of methanol corresponding to approximately 386,000 MWh of chemical energy, the designed FARWIND energy system could power approximately 16 5,000 t cargo vessels.

9. Section 4.2 and 4.3: Would it be more logical to switch the order of these two sections?

   A comparison of alternative carbon-neutral methanol production pathways first and market potential second (potentially only of the best candidate solution) seems more intuitive.

   Agree. The order of the sections has been changed and the text has been updated accordingly.

10. Figures 8, 9 and 10 and lines 360-364: If I understand the concept of learning rate correctly, you assume that the (levelized) cost of methanol decreases by 10% for each doubling in capacity. Many of the capital-intensive systems (shown in Figure 7) use existing technologies, and in particular technologies that are used in offshore windfarms and connected methanol production plants too. The cost for the same technology however will not develop significantly differently depending on whether the technology is installed onboard the energy ship or in offshore wind farms. Put differently, the cost decrease should be seen in relation to the worldwide installed capacity of the technology, not the energy ship (or fleet) alone. In that case, the costs of the energy ship would not fall as quickly as projected and the system thus not be competitive.

    On the other hand, it may be argued that the cost of offshore wind methanol increases with increasing installed capacity, as windfarms need to move to more distant offshore locations. The energy ship seems to be a rather robust solution to this issue, as it is relatively insensitive to shore distance and water depths.

I recommend these cost projections being carefully double-checked. They do not affect the technical assessment, but have a significant effect on the market potential and hence the conclusion of this article.

We agree that the conclusion heavily depends on the assumption for the learning rate.

Your point is that a 10% learning rate is too optimistic because most technologies used in the FARWIND system are existing. Our point of view is that it is actually on the conservative side, for the following reasons.

First, the number of technologies which are truly existing and fully established is actually limited, and/or for existing technologies they are not mass-produced:

- The rotors account for 30 to 45% of the energy ship's CAPEX. The number of rotors which have been installed to date is no more than 20.
- The water turbine is new (14 to 16% of the cost). There are no water turbines available on the market which match the requirements of the energy ship (MW rated power and 10 m/s flow velocity).
- Regarding the hull (12% to 13% of the cost) and the tanker (8% of the cost), despite shipbuilding is an old industry, there is a 10% series effect on the workload according to the OECD (https://www.oecd.org/industry/ind/37655301.pdf, page 8). This is not really surprising as most of the time a new ship is also a new design.
- Regarding assembly and integration (12 to 14%), this cost can be expected to reduce significantly with the development of dedicated tooling.
- The electrolyzer account for 12 to 13% of the cost. To date, there are approximately 200 MW of installed electrolyzer capacity. Thus, this cost can be expected to reduce very significantly with development of the electrolyzer industry (GWs of deployments have been announced).
- H2-to-MeOH plant (4 to 5%): approximately 90 GW of methanol production capacity are operating to date. Nevertheless, the level of standardization can be expected to be very low as every production site is different. Therefore, similar cost reductions as for the hull could be achieved.

Second, and the most important, there is a significant difference between the learning rate of installed cost (CAPEX/kW) and the learning rate of levelized cost of energy (LCOE, in €/MWh). According to [IRENA, 2021][1], the learning rate of offshore wind installed capacity for the period 2010 to 2020 has been 9.4%. However, the LCOE learning rate has been 15%. For onshore wind, over the same period, the installed cost learning rate has been 16.6% while the LCOE learning rate has been 32%.

In our study, we considered a 10% learning rate both for the installed cost and LCOE cost, which is thus very conservative in comparison to what has been observed over the last ten years.

Technical comments

1. Line 16: consider taking out the reference from the abstract.

   ✓ Taken out

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[1] https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020, page 37 to 39

2. Lines 16-17: you mention the “energy performance has been assessed”. Hence the statement “aim is to estimate the energy […] performance” seems confusing. ‘Revisit’ or ‘update based on design progression’ might clarify this.

   - ✓ Modified, thanks for the suggestion

3. Line 18: “wind-assisted propulsion experts” (without ‘s)

   - ✓ Corrected, thanks.

4. Line 30: consider replacing “low-carbon alternatives” by ‘climate-neutral’/’carbon-neutral’ or similar.

   - ✓ Replaced by carbon-neutral.

5. Line 32: ‘**a** sustainable fuel’ or ‘sustainable fuel**s**’

   - ✓ Corrected, thanks.

6. Lines 38-39: consider replacing “sustainable” by ‘carbon/climate-neutral’ or similar to be more precise.

   - ✓ Replaced by carbon-neutral.

7. Line 49: Do you mean ‘levelized’ cost of energy? In that case, it can be advantageous to mention that explicitly.

   - ✓ Yes, “levelized” has been added.

8. Line 58: Figure 2 (not 3)?

   - ✓ Yes, Figure 2.

9. Line 61: Consider replacing “Justifications” by ‘explanations’ or similar.

   - ✓ Replaced by “explanations”, thanks.

10. Table 1: Be consistent with using either H_2 or H2 and CO2 or CO_2

    - ✓ Corrected.

11. Line 71: ‘formulas’ or ‘a formula’

    - ✓ Corrected, thanks.

12. Line 230: Consider making an ordinary reference to this weblink.

    - ✓ The link has been put in the references.

13. Figure 7: an exploded pie chart (pieces grouped by CAPEX, OPEX and others) can improve the understanding of the figure.

- ✓ As we do not know how to group pieces in an exploded pie chart in excel, we used colours to make groups.

14. Line 401: The title of this reference seems to be wrong.

    - ✓ The title is correct (we acknowledge that the title of the publication is a bit awkward)