An innovative cruise-ship onshore power supply facility in the port of marseille

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Abstract. This paper proposes a summary of a preliminary technical economic study that has been promoted by the Gran Port Maritime de Marseille (GPMM) and Costa Crociere, which was focused on the possible integration of distributed renewable energy sources at port (i.e. mainly photovoltaic power generation). These were mainly aimed at powering two cruise ships connected at the port electric grid at the same time, by means of an innovative Onshore Power Supply (OPS) system. Going towards a net zero emission port, also the possible use of bio-methane (bioCH_4), produced by means city waste in a site close to the port of Marseille, has been considered in the technical assessment as possible solution for powering a high temperature reversible fuel cell (revHTFC) capable of producing hydrogen or electricity, whether it is used as an electrolizer or as fuel cell, respectively.

Keywords. Onshore Power Supply, Decarbonization, net zero emission, hydrogen, bio-methane, circular economy.

1. Introduction

Waterborne transport moves nearly 90% of all international trade, more than 75% of external EU trade and 40% of internal EU trade [1]. Oceans, seas, inland waterways, and lakes are key to our climate, shape our environment, generate water and are becoming increasingly important as a source of raw materials, food and energy. In addition, they form an essential transport route for the global and intra-continental trade flows and are places for living and recreation. Although less visible, waterborne transport is essential for the functioning of modern economies.

In 2018, more than 130 million tons of CO_2 were emitted from seagoing ships above 5,000 gross tonnage visiting European ports, which represented over 13% of total EU transport emissions. Globally, shipping annually emits around 940 million tons of CO_2, which accounts for 2-3% of total GHG emissions [2].

In this context, both the European Union (EU) and the international Maritime Organization (IMO) have set challenging objectives for the decarbonization of the maritime sector:

- Reduction of 40% of GHG emission from shipping within 2030 (IMO), pursuing efforts towards 70% by 2050, compared to 2008 (i.e., from the 2018 IMO initial GHG Strategy, which will be revised by 2023) [3].
- On 14 July 2021, the European Commission (EC) adopted a series of legislative proposals setting out how it intends to achieve climate neutrality in the EU by 2050 including the intermediate target of an at least 55% net reduction in GHG by 2030 [4].

The decarbonization of the maritime sector has still no game changer solution and it is probable that the right technical solutions are already available today. In fact, there is no single solution to the decarbonization of the maritime sector but, instead, a mix of possible technologies that must be integrated with each other in the best way. The main technologies currently under study and, in some cases, under development are:

- Sustainable Alternative Fuels (SAF), such as: hydrogen, ammonia, methanol, e-methane, etc.),
- Increase the energy efficiency,
- Low emissions technologies (e.g., fuel cells, batteries, etc.),
- Onshore power supply (OPS) of clean energy.

OPS is the most promising solution in order to achieve zero emissions from ships at port, by supplying the electric energy required onboard directly from the port electric grid. OPS allow to move emissions from the port area upstream to the national electric grid generation units. Considering that, in France, the amount of equivalent CO_2 emitted from unit of energy is very low (i.e., close to 70 gCO2 eq. / kWh [5]), there are great benefits in adopting OPS at port. Moreover, in order to achieve the net zero climate impact of the maritime transport at port, it is possible to feed the OPS systems with renewable green energy coming, for example, from photovoltaics and wind sources.

Regarding the technical solutions for ports, it is expected that ships in the next years will have to rely on SAF from renewable resources. Even for this reason, in the coming years the demand for these fuels and clean energy in port is foreseen to increase considerably and, given the difficulty they present for distribution, it would be advantageous to have the possibility of producing

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them directly in the port areas, which would thus become real trading centers for clean energy (see Figure 1), taking advantage and increasing the circular economies of the port areas.

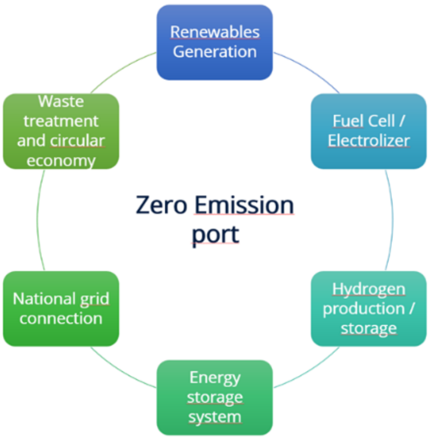

Figure 1. Zero emission port solution.

In addition to this, when already available at ports, power generation systems based on hydrogen fuels have the possibility to overcome these problems and to ensure sufficient power to moored ships.

The investment in Green and Smart infrastructures will allow to make our society more resilient to the great threats that loom over our future, firsts of all the great climate and energy crisis, until recently fueled by a linear economy model characterized by uncontrolled consumption of fossil energy and waste of natural resources and will also make it possible to overcome the economic and social difficulties caused by the current pandemic more quickly.

The large investments in infrastructures that will be necessary for the development of a zero-emission port, as they are distributed throughout the national territory and in part potentially aimed at convergence areas, will make it possible to reduce the territorial gap, contributing to greater social cohesion.

2. Needs and issues definition

The aim of this paper is to evaluate from a technical and economic point of view, the feasibility of creating an innovative High Voltage Shore Connection (OPS), at the Grand Port Maritime de Marseille (GPMM). The purpose is to enable two cruise ships to simultaneously connect to the Port's electric grid, thus permitting the ships to switch off the main engines and so reduce environmental footprint when docked. Additionally, the study considers the integration into the Port electric grid of Distributed Energy Sources (DES) from renewables and Energy Storage Systems (ESS) to limit the supply of energy from the public grid to a single connection point.

In summary, the main objectives of the study presented in this paper are to assess the feasibility of:

- Developing an OPS facility at the GPMM cruise terminal in order to connect two cruise ships at the same time to the Port electric grid,
- Electrifying a selected number of strategic locations within the Port to serve two cruise ships, whether at berth in the cruise terminal or in a dry-dock,
- Integrating distributed renewable energy generation systems at GPMM in order to increase the availability of OPS power and reduce the Port's environmental footprint, possibly also decreasing the unit cost of energy for the end user,
- Integrating a suitable Energy Storage system (ESS) to optimize usage of the energy generated by DES,
- Identifying any reinforcement/expansion work required for the existing Port grid and associated civil engineering/structural modifications; as well as any shipside interventions required to allow the use of an OPS,
- Lowering pollutant emissions (SO_x, NO_x, CO_2, and PM) at port, financial investment, and economic impact.

The overall challenge of this study is to evaluate the different technical possibilities on board and on shore, to obtain a connection capacity of two cruise ships simultaneously with an innovative and reliable solution of distributed generation, resulting in a guarantee of the elimination of atmospheric emissions from cruise ships docked using greener and economically sustainable electricity.

2.1. On-shore context

Environmental pressure continues to grow in Marseille, in Europe, and all over the world, in ports where cruise ship traffic is growing strongly. Therefore, ports and ships are going towards more virtuous operations, as alternatives to conventional fuels.

Concerning the port of Marseille-Fos, different solutions for ships refueling in electricity coexist or have been under study:

1. The port power grid connected to the national network: The port has already signed with the TSO a new contract to have an additional power of 12 MW at the end of 2022 that will be dedicated to cruise ships connections and will provide the power needed to power one berth. Moreover, the port has obtained an increase of this power to 30 MW and then 37.5 MW, whether it will be necessary.
   The goal of this first step is to connect 200 stopovers per year. At a first step, a cruise ship will be able to be connected within the cruise terminal.
2. Renewable energies: the port is studying the feasibility of producing renewable energies in its areas, including the installation of photovoltaic power plants on harbor roofs, connected with an adequate energy storage system, with the aim of improving port energy mix and increasing the overall available power of its network. Other sources of renewable energy production from wind, and fuel cells will be investigated.
   The goal of this second step is to sell back the energy produced from the entire port network, to be close to be able to connect a second cruise ship, simultaneously to the first, at the same time in 2024, while minimizing the price of the kWh that will be sold to the ship-owners.

This second step, which is mainly focused on the possibility to integrate renewable energies and allowing the connection of a second cruise ship simultaneously is the object of this paper.

2.2. On-board context

With regard to cruising, various solutions for the production of electrical energy on board or for refueling in electricity coexist or have been under study by the ship-owners, and in particular:

- Production from LNG: Ship-owners are currently studying this solution in the context of fleet renew (25% of on order vessels are powered with LNG engines).
- Hybrid propulsion: Different ship-owners are currently conducting studies to implement hybrid propulsions, by storing part of the energy produced on board, using batteries to reduce very strongly, if not totally, emissions during specified phases, including maneuvers near inhabited areas or at the entrance to ports.
- Connection to the terrestrial electricity network during the stop-over (Cold Ironing or OPS): this technical solution is the most efficient from an environmental point of view when the ship is docked. It allows to completely stop the generators on board and thus to suppress all the relevant emissions in the atmosphere.

3. An innovative energy microgrid architecture towards a zero emissions port

Port areas are usually close to congested and highly urbanized areas. The presence of one or more high power ships (large cruise vessels for example), spending a large part of their operating lives at ports, and several small ships fueled by fossil fuels represent a significant source not only of GHG which is impacting the environment but also of air pollutants (NOx, SOx, PM) which are harmful to the European citizens. ì

Therefore, it would be desirable that technologies and infrastructures aimed to a rapid diffusion of Sustainable Alternative Fuels (SAFs) will be developed and integrated in the fastest way, to secure a smooth green transformation. This would happen in combination with a fuel transition, for example making SAFs available at ports, which should be considered in the future as real energy hubs.

3.1. Potential energy sources

The main objective of this paragraph is to evaluate the most suitable types of energy sources dedicated to the port of Marseille OPS application. Associated with the TSO power grid the entire system shall provide electrical power to the docked cruise ships.

The final objective of the preliminary feasibility study promoted by the port of Marseille were to couple the energy sources with the local power grid to achieve a total installed power of 24 MW, which is equivalent to two cruise ships connected to the shore at the same time.

Main aims of adopting alternative energy resources at port are:

- Reducing the cost of kWh to ensure that shore connection is cost effective for the ship-owners. The cost of kWh must be similar or lower than the cost of electricity produced by cruise ships diesel generators and electrical grid,
- Reducing the pollutant emissions (SO_x, NO_x, CO_2, PM, etc.) using renewables energies or sustainable energies,
- Providing the surplus of energy produced to the port when the cruise ships energy request is low. By this way, the port can use low-cost electricity instead of directly using the TSO power grid.

For the purposes of this study, only the following energy sources have been studied:

- solar panels,
- hydrogen fuel cells,
- ship to ship,
- power barge generators,
- biogas fuel cells and combined cycles.

3.1.1. Comparison criteria

The comparison criteria have been used to compare all the different technologies. All of them have been identified as interesting points related to the port OPS application. These criteria are divided in 3 group based on the main objectives of the study. The objective is to give a score for each solution based on its strength/weakness regarding the criteria. To be compliant with customer's expectation, a weight is considered on each criterion to increase or decrease the total score of each solution in accordance with the main objective of the study.

3.1.2. Photovoltaics

As it is well known, the photovoltaic effect occurs in solar cells. The aim of this cells is to convert solar radiation into electrical energy through the photovoltaic effect.
PV is the third renewable energy source behind hydro and wind power.

According to Solar Power Europe analysis [6], in 2017, almost as much solar was installed in one year (99.1 GW) as the world had installed in total in 2012 (100.9 GW). This led to a total global solar power capacity of over 400 GW in 2017. Moreover, the 2018 solar market exceeded 100 GW in one year.

To evaluate the possible use of the PV technology at the port of Marseille, the following steps have been performed:

- Identification of available areas on shore in the port land / building roofs for PV installation,
- Global Horizontal irradiation analysis,
- Calculation of PV production potential.

According to GPMM, the main possible areas of interest for this application were (see Figure 2):

- La Joliette,
- Saint Cassien & Arenc,
- Mole Leon Gourret & Cap Janet,
- Forme 10.

Figure 2. GPMM areas that may be available for PV panel installation.

The assessment of the PV power production capacity based on the roof surface area of each of the Port's buildings has been performed by means of two different simulations using real 2019 data. The results show that around 20 MWp of PV power can be installed in the areas highlighted in Figure 2.

Table 1 shows the distribution of the potential PV power production (MWp) and annual energy production (GWh) per area (2019 source data for irradiation and weather).

Table 1. GPMM areas concerned by the PV study

GPMM Area	Potential PV Power capacity (MWp)	Potential Annual PV energy production (GWh)
Joilette	1	2
Saint Cassien	3	4
Mole Leon Gourret & Cap Janet	18	23

Drydock 10	0.5	0.5
Total (port of Marseille)	22.5	29.5

The maximum potential solar energy produced by a PV system as per Table 1, could satisfy 85% of the current annual energy consumption of GPMM.

In this analysis, Mole Leon Gourret & Cap Janet emerged as the most promising area for a PV system installation –firstly thanks to a large roof surface area that would allow to install a maximum of 18.5MWp of PV panels, and secondly being close to the location identified for an OPS facility. The surplus of solar energy produced cannot feed back to the public grid and therefore must be consumed locally by Port loads on its internal grid.

Two options for the capacity of the PV system are considered:

- *Option A*: a first set of roofs installed with 8.4 MWp of PV panels. The load on the new PDL4 electrical network of the port, supplying the Mole Leon Gourret & Cap Janet area, can absorb the solar energy produced without curtailment even when the OPS is not being utilized. The annual energy production in option A is equal to 10.5 GWh (based on 2019 data).
- *Option B*: additional to Option A, a second set of roof surface areas adds 10 MWp of installed PV panels (see Table 3). In this configuration not all the solar power produced can be absorbed by the Port's internal grid downstream PDL4, particularly when OPS is not in use. Therefore, an ESS is necessary to minimize the curtailment of the PV power; an alternative solution to an ESS is to share the PV surplus power to other sections of the Port's grid that are already fed by public grid connection points. However, this latter solution would require an additional switching substation to manage the energy flow.

3.1.3. Energy storage system

Different energy storage technologies and systems have been evaluated to maximize the usage of the renewable energy available at the Port (with the installation of PV systems), to reduce power curtailment and improve the energy flexibility of the Port grid.

A technical-economic analysis identifies and preliminarily indicates the size of an ESS that could meet the needs of GPMM. Considering the maximum installation of PV panels in the Mole Leon Gourett & Cap Janet area (i.e., 18.5 MWp) the study estimates an ESS having a capacity of 30 MWh - 50 MWh of energy with 10 MW of power.

The review of different ESS solutions identifies lithium-ion batteries as the most suitable for the power and energy demand under examination in this application.

Several battery makers have been assessed with the result that a unit cost is expected to be between 300 and 500 €/kWh for Lithium–Iron–Phosphate type and for Nickel–Manganese–Cobalt type battery technologies, respectively. The modularity of a battery technology ESS grants flexibility in the selection of different sizes, thus enabling to meet evolving needs of GPMM.

3.1.4. Bio-Methane

Renewable energy sources (RES) can give a great contribution to the reduction of polluting emissions and greenhouse gases in the port area, as well as in other economic sectors. Nevertheless, as happens for the well-known microgrids in the terrestrial field, RES also have an intrinsically stochastic generative profile in the port area, as these resources depend on naturally stochastic sources such as solar radiation or wind intensity.

At the same time, energy demand is also highly uncertain, both in port and in the land network. For the land network, Transmission System Operators (TSO) normally carry out a day-ahead electricity demand forecast, to properly schedule the generation plants that will have to be in operation to satisfy the demand for power efficiently. On the other hand, providing a power demand forecast for a port electric grid is even more difficult, especially in the case an OPS facility has been implemented.

For these reasons, the introduction of RES requires systems that can reduce uncertainties while guaranteeing at the same time a low or zero environmental impact. In this perspective, some solutions based on low (biogas) or zero (hydrogen) environmental impact energy vectors, which may be available to limit both the uncertainties of RES and power demand at port, are proposed in this paper.

Three main proposals for the power generation at the port of Marseille will be presented and analyzed below:

- use or production of biogas \ biomethane to generate electrical power using high temperature fuel cells,
- shave the uncertainty of power generation due to the photovoltaic systems (PV) installed at the port by generating hydrogen (i.e., by means of electrolyzers or reverse fuel cell systems), which should be stored in special tanks to be accumulated and then used (by means fuel cell systems) when needed,
- combine the use of high temperatures fuel cells with steam or gas turbines to take advantage of a cogeneration system combining heat and power (CHP), allowing significantly high overall efficiency (e.g., 90% for a Solid Oxide fuel Cell combined with a gas turbine).

A possible architecture for this port energy microgrid is proposed in Figure 3.

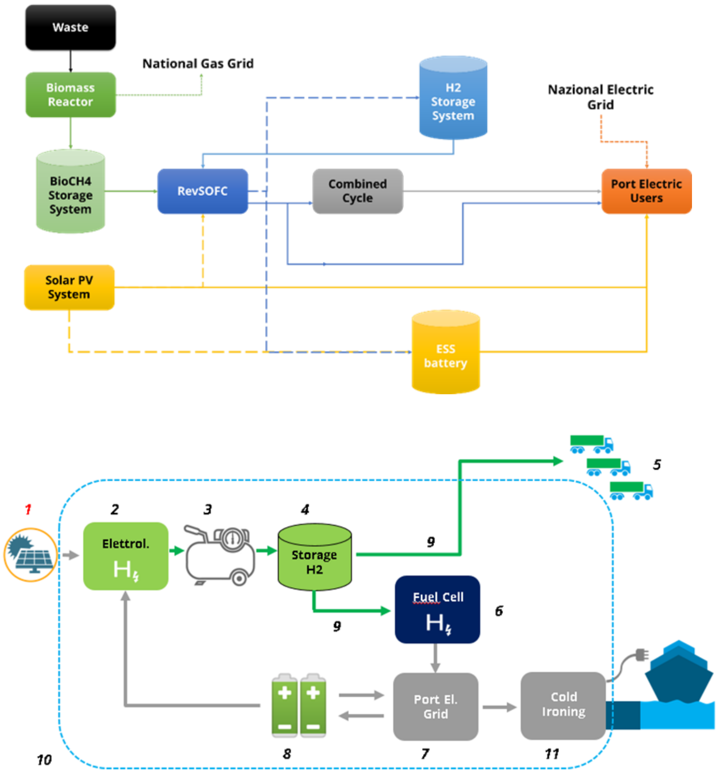

Figure 3. Innovative port energy microgrid.

3.1.4.1. Anaerobic digestors for bioCH$_4$ production

In recent years, a growing interest has arisen in the generation and use of renewable energy sources (RES), to switch from fossil-based to more sustainable production and consumption patterns. RES plays a key role in minimizing several environmental and socio-economic concerns. In particular, bioenergy from waste feedstock represents a valuable prospect that increasingly attracts the attention of populations and governments towards waste-based biorefinery processes. In this perspective, anaerobic digestion (AD) for biogas production seems to be a viable way to simultaneously improve waste management while producing RES [7].

The term AD refers to a complex anaerobic biodegradation process carried out by a variety of different species from two entirely different biological kingdoms (Bacteria and Archaea) [8]. The main product of this bioconversion process is biogas, a mixture which mainly consists of methane (CH4) and carbon dioxide (CO2), but also contains several impurities [9]. Typical composition values depending on the primary product are proposed in Table 2 (i.e., considering agricultural waste, landfills, and industrial waste as possible primary components).

Table 2. Typical chemical composition of bioCH$_4$ depending on the primary component

Component	Agricultural waste	Landfills	Industrial waste
Methane CH_4	50-80	50-80	50-70
Carbone dioxide CO_2	30-50	20-50	30-50
Hydrogen sulphide H_2S	0.7	0.1	0.8
Hydrogen H_2	0-2	0-5	0-2
Nitrogen N_2	0-1	0-3	0-1
Oxygen O_2	0-1	0-1	0-1
Carbon monoxide CO	0-1	0-1	0-1
Ammonia NH_3	Traces	Traces	Traces
Siloxanes	Traces	Traces	Traces
Water H_2O	Saturation	Saturation	Saturation

Usually, produced biogas is burned in on-site cogeneration units to simultaneously produce heat and electricity, for internal consumptions of the AD plant with the injection of electricity excess in the national grid.

Alternatively, it can be purified to increase its CH$_4$ content, thus providing a promising energy carrier, namely biomethane (bioCH$_4$), that can be used as vehicle fuel or injected into the natural gas grid network, similarly to fossil based CH$_4$, as proposed at topside of Figure 4.

Moreover, it is to be highlighted that, under certain conditions, bioCH_4 plants in France are eligible to receive a feed-in-tariff which ranges from around five to 14 Eurocent (EuroCt) per kWh—levels considered generous in comparison to those in the German and Austrian markets where bioCH_4 prices that plants can realize are below 8 c€ per kWh [11]-[15].

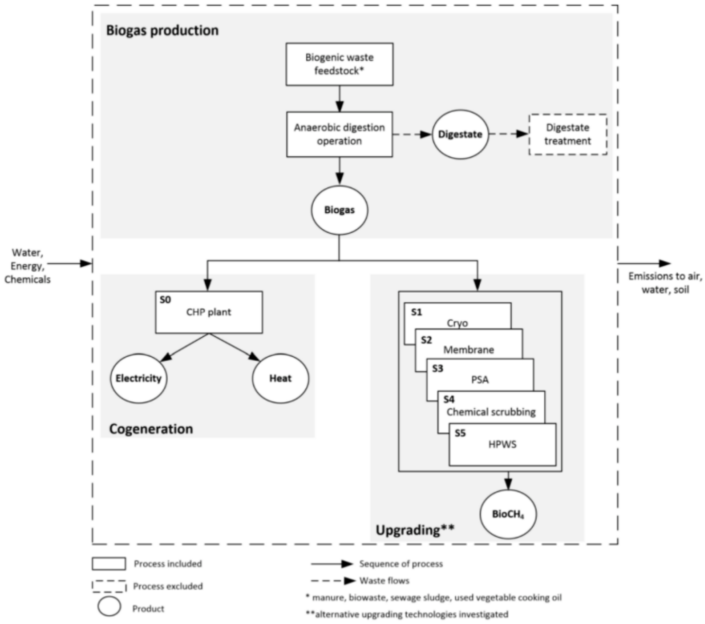

Figure 4. Figure 3. Innovative port energy microgrid. [10]

3.1.4.2. BioCH4 facilities close to Marseille

From 1 January 2019, the biogas produced in the sludge digestion process will be collected, converted into bioCH_4 and injected into the public natural gas network at a rate of 2.3 million Nm3 a year. The facility has been designed with a future extension in mind, allowing for a rate of 3.8 million Nm^3/year, which will make it the largest in France.

Aix-Marseille-Provence metropolitan area will be able to produce enough green energy to supply about 2,500 households [16]. This bio bioCH_4 – in compressed form – could also, in the longer term, be used as a biofuel for public transport running on natural gas (NG).

The new bioCH_4 production plant will offer several environmental benefits. Indeed, the proportion of recoverable biogas will increase by 35% while CO_2 emissions should drop by 30%. Therefore, it is possible to state that from this already operating system may be available:

- 6300 Nm^3/day of biogas derived from the urban black water sludge,
- 4000-5000 Nm^3/day (depending on the gas composition of the biogas produced) of bioCH_4 that can be feed into the city gas grid.

3.1.4.3. bioCH_4 integration with high temperature reversable fuel cells

High-temperature fuel cell technologies like Molten Carbonate Fuel Cells (MCFCs) and Solid Oxide Fuel Cells (SOFCs) are especially fit to operate with carbon fuels due to their (direct or indirect) internal reforming capability. Especially, systems based on SOFC technology show the highest conversion efficiency of gaseous carbon fuels (e.g., natural gas, digester gas, and biomass-derived syngas) into electricity when compared to engines or gas turbines. Moreover, lower CO_2 emissions and ultra-low emissions of atmospheric contaminants (SO_X, CO, VOC, especially NO_X) are generated per unit of electricity output. Nonetheless, stringent requirements apply regarding fuel purity.

The power generation from biogas-SOFC is considerably high, even when the methane content of biogas is below the value that normal combustion could occur. Methane in biogas can be converted into hydrogen and carbon monoxide through the reforming reaction and at high concentration of hydrogen, good performance of SOFC is realized.

3.1.4.4. Challenges and opportunities for bioCH_4 integration at port area

There are some critical issues that must be addressed in order to design, install and manage a system that combines the biogas/bioCH_4 technologies as those here proposed. The main ones are:

- A sufficient supply of a high purity of organic substrate is the most important technical key sustainability factor for a biogas plant. On the other hand, there are chemical and technical treatments available when the ideal substrate condition cannot be met.
- A large-scale biogas plant requires a significant amount of land not only due to the volume of waste that is not significantly reduced after the process but also because of the retention time required and the fact that the dilution in the wet process led to an even larger space requirement.
- Because waste volume is not significantly reduced after the digestion process, securing digestate demand is a critical factor. This factor is especially crucial when the plant is not closely located to agricultural areas.
- Logistic flow of waste, biogas and bioCH_4 from production system to storage and users.

Challenges for SOFCs and SOECs (i.e., revFC) are mainly relate to cost, durability, understanding and optimization of interfaces, performance, and sustainability of materials. On the other hand, there are a good number of opportunities that make this solution interesting and advantageous at the port of Marseille context:

- Producing local renewable and green energy for electricity production, combined heat and power (CHP) and pipeline injection applications.
- Reducing GHG emissions and destroying methane that otherwise would be vented and contribute to global warming.
- Improving local air quality by reducing emissions of volatile organic compounds (VOCs).
- Totally renewable energy source that helps to be energy self-sufficient.
- Enhances the circular economy with the use of waste and different biomass, also coming from the already operating SUEZ biogas system at Marseille with a potential supply of 400 Sm^3/h of bioCH_4.
- Reducing catastrophic wildfires for urban and forest interface, improve forest health, watershed, and timber stand, reduce costs of forest management, reduce risks and improve public health and safety.
- The production and treatment of biogas also promotes the development of local economies.

BioCH_4 may also be produced outside the port area and then transported through the national gas grid or through tankers to port storage facilities.

3.1.5. Hydrogen & reversible fuel cells

As already mentioned, some high temperature fuel cell systems would allow, when powered by electric power, to generate hydrogen at very high levels of purity (e.g., 99,999%). In this perspective the photovoltaics – solid oxide fuel cell system (PVSOFC) may operate mainly in three different modes:

A. a solar-solid oxide fuel cell (SOFC) mode, in case of low solar radiation time, then both the solar photovoltaic (PV) and the SOFC are used together for electric (and heat) load supply.
B. a solar-solid oxide steam electrolyzer (SOSE) mode, in case of high solar radiation time, when PV is used for power supply to the electrical load and to the steam electrolyzer to generate hydrogen (H_2).
C. and, finally a SOFC mode, in case of the electric power (and heat) generation mode of reversible SOFC using the storage H_2 when PV radiation is not sufficient, and the hydrogen stored is available (e.g., this may be the case at night time).

The first operating condition proposed, which considers both the PV system and the SOFC working at the same time, is particularly useful when the PV system is unable alone to supply the loads in sufficient safety or continuity. In this condition, the SOFC can be fed with bioCH_4 (or with natural gas) to generate enough electric power to satisfy the loads.

The second operating mode is particularly advantageous in case of high PV radiation and low power demanded by loads (e.g., clear sky and no ships connected at the port grid). In fact, this operating mode allow to store energy by means of hydrogen that is generated by the SOFC system operating in a reverse mode (i.e., use of electric power to generate hydrogen).

The last operating mode proposed considers only the SOFC system working to supply the electric power required by the loads. In this case, the SOFC system may be fueled by the hydrogen previously stored or, alternatively, by bioCH_4 (or natural gas). This operating mode can be useful for example in night time when there is no solar radiation, the port electric power demanded is low and the power is supplied by the SOFC without costs related to the national electricity fees.

3.2. Preliminary OPS architecture

An analysis of the regulatory and normative context highlights that the French State, European Union, and IMO (International Maritime Organization) are keen to regulate emissions from maritime transport. In the long-term scenario, CO_2 emissions taxation may be introduced (e.g., the President of the European Commission recently proposed that the maritime sector become part of the European Emission Trading System – EU ETS), while low/no carbon solutions could benefit from financial incentive mechanisms (e.g., European Green Deal). The combination of the two approaches may represent an opportunity for solutions such as port OPS facilities.

According to CLIA, thirteen of all ports visited by cruise ships in 2019 can provide cold ironing:

- East Coast of America: Brooklyn, Halifax, Montreal,
- West Coast of America: San Diego, San Francisco, Los Angeles, San Pedro, Long Beach, Seattle, Vancouver,
- Europe: Hamburg Altona, Kristiansand,
- Asia: Shanghai.

In the future, it is expected that more OPS facilities will be created around the world. Regulatory and normative changes, combined with an expected increase in OPS usage, lead to believe that the price of electricity produced on board and on shore will be comparable starting 2030-35. The tipping point will depend largely on the implementation of tax incentives/exemptions and on the success of innovative technological solutions.

3.2.1. Evaluation of Power Generation Systems and Selection of Photovoltaic technology

The study evaluated a number of different power generation systems with the aim of identifying the one having the characteristics most suitable for GPMM. The systems include fuel cells (powered by hydrogen or natural gas), gas plants on land and on barge and photovoltaic (PV) systems.

Based on the score comparison method proposed in section 3.1.1, PV systems showed to be the most favorable generation technology (see Figure 6) using a number of "key performance indicators" (KPIs) including:

- capital investment,
- cost of the energy generated,
- level of generated emissions.

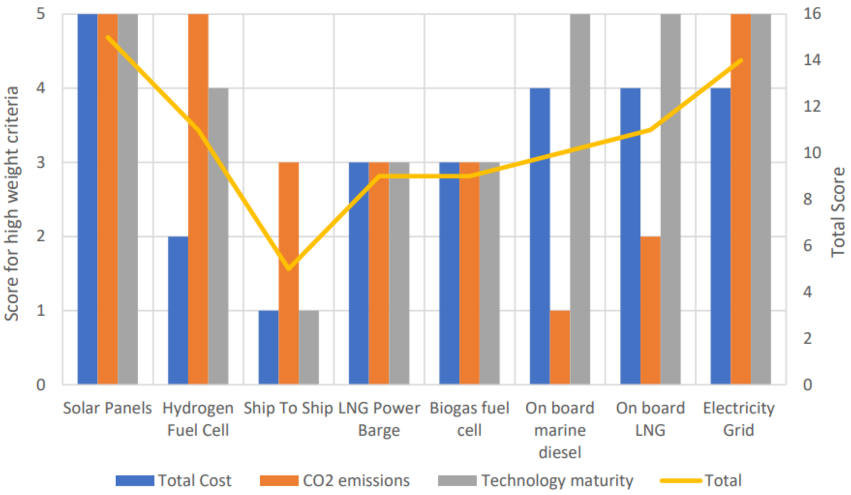

Figure 6. Comparison of energy sources for high weight criteria.

Figure 6 illustrates the scores obtained for each energy source studied for three main selection criteria (Capex and Opex costs, CO_2 emissions and technology maturity). It is important to note that for this study the electricity grid is considered as a “clean source” with no emissions, achieved via a ‘green certificate’ contract with an energy supplier that relies on renewable energy plants.

3.2.1.1. Definition of the preliminary architecture

In accordance with the main objectives of the project, a PV system combined with a “green certificate electrical grid” has been identified as the most appropriate solution. The study therefore focuses on this option to define a preliminary architecture which combines the green grid electricity with PV, ESS and a Smart Energy Management System (SEMS), in accordance with current and future electrical consumption of cruise ships at GPMM.

3.3. Possible users and services

The main users of this OPS facility will be cruise ships, with an energy demand that, according to the forecasting performed in this study, may vary between 7 GWh in 2024 up to 33GWh in 2050. Other important users are:

- port offices,
- port electric vehicle,
- port infrastructures and machineries for loading and unloading of goods.

Moreover, whether a hydrogen facility would be developed at port, it is to be noted that the cost of selling hydrogen, whichever is the primary source from which it derives (i.e., fossil fuels or renewable generation) could allow the sale of this fuel by the port of Marseille to some interested customers.

In addition, in the more general context of the future of naval transport, hydrogen will probably be one of the fuels of the future, allowing in this way the port of Marseille to be one of the first in the world to provide this possibility to the ship-owners interested.

4. Conclusions and future works

This paper proposed a summary of a preliminary study promoted and financed by Grand Port Maritime de Marseille and Costa Crociere focused on the development of an innovative OPS facility in the port of Marseille. Unlike traditional OPS facilities, already operating in some world and European ports, the possible integration into the electricity grid of distributed energy sources (i.e., based on renewable and circular resources) has been under assessment.

As preliminary result of this assessment, a maximum potential of about 22 MWp of solar energy production from photovoltaic panels (PV) installed over the roof of the main buildings has been pointed out. However, due to the intrinsic stochastic nature of the PV generation and due to the scheduled demand of power coming from the cruise vessels at port that may be connected to the port electric grid, an energy storage system (ESS) of significant size has been considered as a suitable option to maximize the benefits coming from the renewable generation. In addition, it should be noted that there is the possibility of providing remunerated services to the national electricity grid, in order to maximize the economic benefits deriving from the possible installation of such an ESS.

Further, other possible sources and vectors of clean energy were also evaluated, one of the most interesting has been the use of hydrogen, which may be produced and used in port both as a long-term energy storage system (i.e., seasonal storage) and as a fuel to power fuel cells for the generation of clean electricity to power port users.

Finally, in order to maximize the benefits of the circular economy of the port, the possibility of using high temperature reversible fuel cells (revFC) that may be fueled with bioCH_4 produced by city waste (i.e., in areas not far from the port) was identified. Even the waste produced on board large cruise vessels, albeit a small percentage of those produced by the city, could be used to intensify the benefits deriving from the circularity of the bioCH_4 production process from waste and its use towards net zero emissions at the port of Marseille.

Acknowledgements

Authors want to thank in the first instance the port of Marseille and Costa cruises, for having financed this innovative and challenging project. Furthermore, we want to thank all the partners of the consortium who participated in this project: Sirenha, Capsim and Pole Mer Meditterranee, without whose contributions we would not have been able to write this paper.

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