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## THE USE OF ELECTRIC BOATS AND PHOTOVOLTAIC ENERGY AS A GOOD PRACTICE FOR REGIONAL SUSTAINABLE DEVELOPMENT

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### Abstract

*Transportation dynamics are essential for the economic development of the urbanisation process. It also interferes the social distribution pattern and the environmental features of urban areas. Either along inland waterways or coastlines, boats might represent a massive source of clean technology, depending on their source of energy and functional specifications. The electric motor for boats joins the range of propulsion supply of new driving components within the context of electric mobility. The option of feeding it with renewable energy resources meets several actions that have been reviewed: new wetted materials, the use of fossil fuels and mostly the emission of CO<sub>2</sub>. Given the assumptions listed, the present study was guided by the use of electric energy produced by photovoltaic cells with favourable results in electric motors. The experimental tests showed that the electric motor could be activated only by photovoltaic panels or have the battery loaded from solar panels. In all the situations the boat movement was similar to the combustion motor. The minimisation of the environmental impact was approached by withdrawing the fossil fuel engines, and the results also corroborated the economic and social use of these boats for transportation, small-scale fishing, sports and sightseeing, representing the blueprint that urban areas intend to achieve in line with the Sustainable Development Goals of the 2030 Agenda.*

**Keywords:** Agenda, regional development, renewable energy, sustainability, transportation modes.

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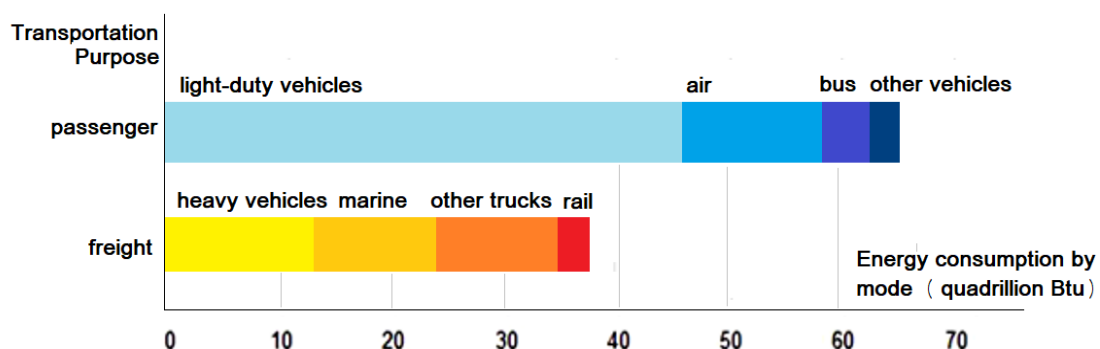
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## Introduction

Transportation dynamics involve all sectors from the society: agrochemicals have to be brought to agricultural sites; agricultural products need to be brought to the distribution centres; people need to commute daily to work and study; industrial goods are also relocated to the commercial centres; hospitals also need a means of transportation to keep their operation and transfer patients. Therefore, the transportation consumption has to be compatible with the energy offer. Many rural areas might reckon on traditional transportation systems that depend on animal power, but urban areas intensively use motorised systems, impacting the environment with gas emission.

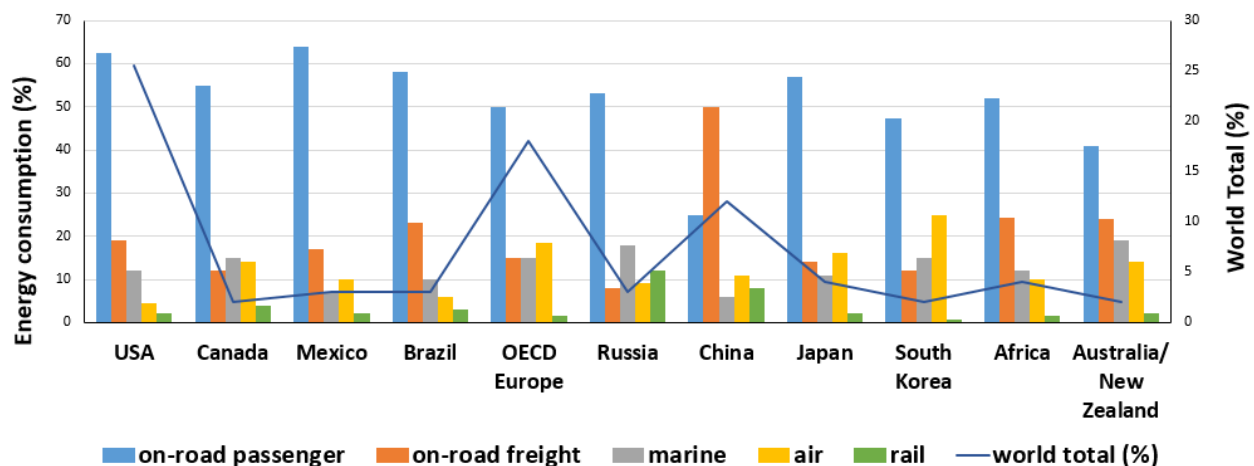
According to the PBL Netherlands Environmental Assessment Agency (PBL NEAA, 2016), the world emissions from fossil fuel combustion considering road transport was 5,547 Mt of CO<sub>2</sub> in 2013. Even though the use of biofuel for transportation (fuel ethanol and biodiesel) increased by 4.3 %, CO<sub>2</sub> emissions from the combustion of oil products also increased by 1.6 % in 2015 (British Petroleum, 2016). CO<sub>2</sub> emissions from road transport corresponded to two-thirds of total oil combustion-related emissions (PBL NEAA, 2016).

As reported by the U.S. Energy Information Administration (US EIA, 2015), the total of about 25 % of the world energy consumption is due to transportation of passengers or freight. Light-duty vehicles mostly use motor gasoline, while heavy-duty trucks use diesel fuel, including ethanol and biodiesel blends, respectively. The transportation of people in light-duty vehicles alone consumes more than all freight modes, including heavy trucks, marine, and rail (Figure 1).



**Figure 1.** Annual global transportation energy consumption by mode in 2012 in quadrillion British thermal units (Btu). Source: Authors apud US EIA (2015).

Although on-road use is the main responsible for the energy consumption everywhere in the world, there is a significant variation considering the other modes of transportation and their locations. Marine transport in South Korea accounts for 15 % of the country's total transportation energy consumption, while in Australia and New Zealand it corresponds to nearly 20 % of the total energy use (US EIA, 2015) (Figure 2).



**Figure 2.** Annual global transportation energy consumption by mode in 2012 for different countries in percentage. Sources: Adapted from US EIA (2015).

In Brazil, the main transportation mode is on road (92 %), accounting for 96 L/1000 tKu of energy consumption. Even with the high potentiality of developing railways and river transportation and low impact on the emission of CO<sub>2</sub>, it only represents 2 % of the transportation mode, with a consumption of 5 L/1000 tKu (Campos *et al.*, 2013).

For the Sustainable Development Goals (SDGs) of the 2030 Agenda, the urban infrastructure should be designed taking into consideration the regional potentialities and physical features, together with "safe, affordable, accessible and sustainable transport systems for all" (United Nations, 2015). Thus, the sustainable economic growth of every country depends on the use of sustainable energy services and transport systems (Roşca, 2018; United Nations, 2015).

The energy demand started increasing after the replacement of the workforce by new technologies and methods in agriculture, industry and civil construction, especially in urbanising areas. Initially, energy was achieved from natural sources, such as wind and water, in mills and waterwheels. This energy was not reliable because of random patterns, such as the direction and intensity of the winds and the depth of rainfalls (Batista *et al.*, 2015).

The economic situation of all countries is entirely influenced by the energy supply, where the security to provide it has to be well planned and established by the governmental policies to avoid a collapse in every segment of the society (i.e. infrastructure, commerce, industries, health and educational facilities, and residential areas) (Sharvini *et al.*, 2018).

According to Batista *et al.* (2015), the increase of the energy demand caused the advent of engines that converted thermal energy into mechanical energy. It also lacked reliability due to the fragility of the boilers and little control of the energy output. Thus, technological devices with internal combustion engines started to be applied to obtain energy from burning fossil fuels making the system more reliable. On the other hand, they caused a considerable increase in the emission of gases, bringing disastrous consequences to life worldwide, such as water pollution, air pollution and global warming (Batista *et al.*, 2015). That is why policy makers have been trying to improve the use of renewable uses of energy (Sharvini *et al.*, 2018).

The sun is the largest source of energy in our lives. Despite that, it has not been intensively explored as energy propeller but only as a supplier (Dupczak *et al.*, 2012). The greater use of this source is passive, which maintains the macro and microbalance throughout the solar system, considering the physical, chemical and biological aspects.

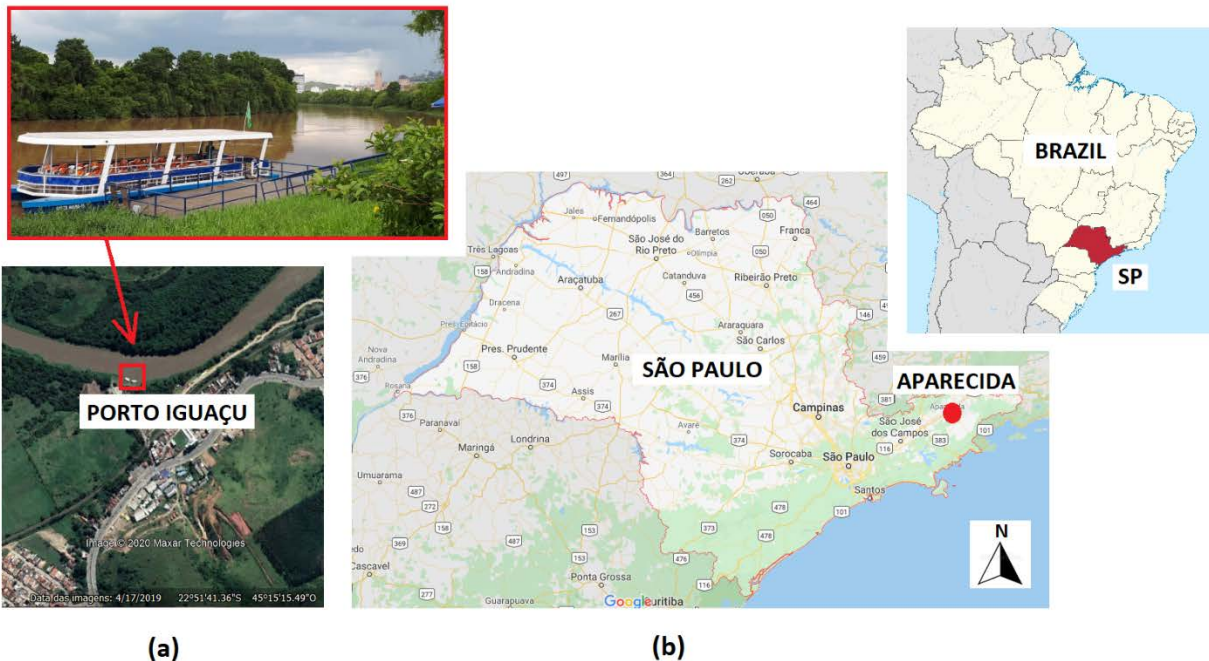
The current electrical mobility calls for a new paradigm of propulsion in transportation obtaining energy from renewable sources. That is one of the main applications of solar energy (Das *et al.*, 2015; Kley *et al.*, 2011).

The recent development of materials and processes is enabling the more significant use of solar energy for the propulsion of transport vehicles, such as bicycles, motorcycles, cars, boats, and even buses and trains. There are several advantages for the use of this new propulsion technology for small vessels, including the minimisation of maintenance costs, water pollution, and noise, particularly in urban developments (Batista *et al.*, 2015).

In the current study, the electrical energy produced by photovoltaic cells is used to convert solar radiation into electricity (Das *et al.*, 2015; Postiglione *et al.*, 2012). This study seeks to test the performance of an electric motor to steer boats up to 2 tons (Hofmann *et al.*, 2016; Xiang *et al.*, 2016; Zhang *et al.*, 2016). However, the main context is to bring up the discussion about the sustainability beyond the use of these vessels in urban areas targeting the SDGs of the 2030 Agenda.

## Material and methods

The experiment was developed in two stages: the static experiment on April 8th, 2016, performed in a water tank, using the apparatus of a motor support, and the dynamic experiment on June 23rd, 2016, by the use of a boat called Mogi Mirim (5.0 m long, 1.28 m wide, 58 kg weight). The navigation was along Paraíba do Sul River near Itaguaçu harbour, in Aparecida, State of São Paulo (Figure 3).

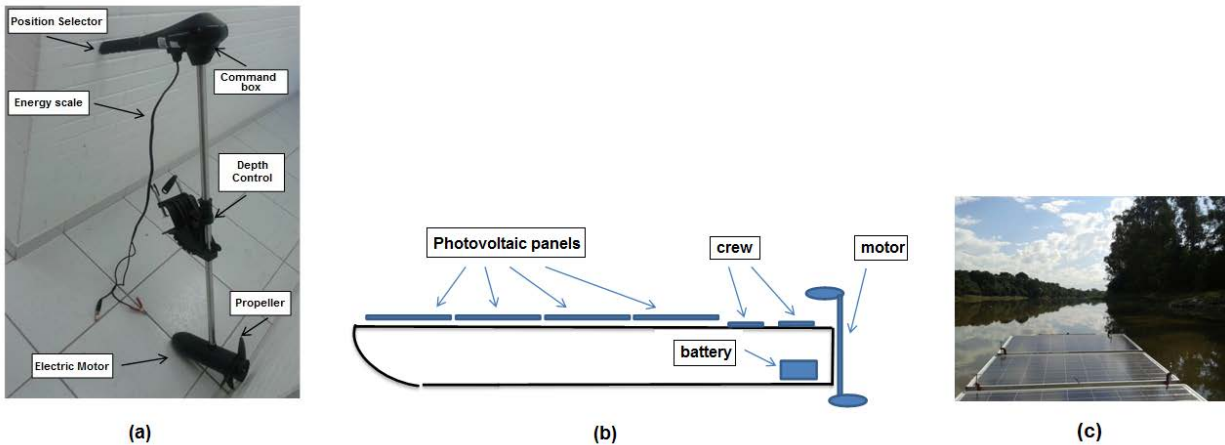


**Figure 3.** Geographic location of the dynamic experiment study area at (a) Itaguaçu harbour in (b) Aparecida, State of São Paulo, Brazil. Source: Authors.

The electric motor is a Phantom (54 lb) (Figure 4a) and belongs to the Institute of Electrical Mobility of the Faculty of Electrical Engineering at FEG - UNESP. It was adapted to multiple height positions concerning the fixation on the boat (to give a lower or higher depth to the propeller), and to the speed changes that can lead to a lower or higher speed to the boat (where 5 goes straight, and 3 goes reverse).

In the static stage, the energy was supplied by photovoltaic panels, 4 plates, with 120W/18 V each connected in parallel. The multimeter HOMIS performed the measurements of the voltage and current. The INSTRUTHERM MES-100 also measured the solar radiation. The speed was taken in 5 positions, chosen from the control lever of the engine. The movement of the propeller in the water occurred without moving the only load imposed on the engine.

In the dynamic phase, the voltage and current travel speeds of the boat were measured by a standard anemometer, INSTRUTHERM AD-250. The plates previously loaded a battery of 12V/60 Ah. The boat sketch and the photovoltaic panels attached to the boat are shown in Figures 4b and 4c, respectively.



**Figure 4.** (a) The electric motor used in the experiment, (b) the schematic diagram of the boat, and (c) the photovoltaic panels on top of the boat along the channel. Source: Authors.

### Experimental results

The static test was developed at 12.30 pm. It was a sunny day and the solar irradiation was  $847 \text{ W/m}^2$ . The most significant power required was in the R3 position. There was a power increase from R1 to R3, but from R3 to R5 the power decreased gradually as the speed increased (as it is shown in Table 1).

**Table 1.** Data achieved from the static experiment.

N.	Positions	Current (A)	Voltage (V)	Power (W)
1	R0	0	19.03	0
2	R1	10.6	17.12	181.47
3	R2	12.3	16.81	206.76
4	R3	21.5	14.00	301.00
5	R4	23.0	12.85	299.55
6	R5	24.5	7.80	191.10

In the dynamic test, the boat moved upstream by the use of a, electricity-powered engine, which had been produced by photovoltaic panels. The day was cloudy and the solar irradiation was  $650 \text{ W/m}^2$  (Table 2). The boat speed was measured by the anemometer. The speeds at R1 and R2 were the same (almost  $1.8 \text{ km/h}$ ), but due to the stream turbulence, the performance of the propeller was affected and there was an increase these speeds.

**Table 2.** Data achieved from the dynamic experiment.

N.	Time (pm)	Positions	Current (A)	Voltage (V)	Power (W)	Boat speed (km/h)
1	1.25	R0	-	19.66	-	-
2	1.28	R1	12.66	17.27	218.64	1.8
3	1.32	R2	13.12	16.03	210.31	1.8
4	1.36	R3	17.16	9.6	164.74	2.2
5	1.45	R4	15.40	8.4	129.36	2.5
6	1.50	R5	17.26	5.7	98.38	3.6
7	1.54	R5	37.56	12.66	465.51	4
8	2.24	R5	35.68	11.24	401.04	4.3
9	2.26	R5	35.68	11.24	401.04	4.7
10	2.44	R5	32.27	10.91	352.07	4.7

At N. 3, there was a rotation, which increased the speed of N. 4. The maximum speed reached in the upstream area was at N. 6, corresponding to  $3.6 \text{ km/h}$ . Items N. 7 and N. 8 were against the river flow, while items N. 9 and 10 were according to the river flow. The battery was used to go upstream ( $12 \text{ V}/60 \text{ Ah}$ ). The required power to go upstream (items N. 7 and 8) ranged between  $465 \text{ W}$  and  $401 \text{ W}$ , and achieved the speed between  $4.0 \text{ km/h}$  and  $4.3 \text{ km/h}$ . When navigating downstream (items N. 9 and 10), the battery had already been used for about 30 minutes to go upstream, but the required power ranged between  $401 \text{ W}$  and  $352 \text{ W}$ , achieving the speed of  $4.7 \text{ km/h}$ . The speed of the stream was measured at  $2.45 \text{ pm}$ , based on the boat movement, and reached the maximum speed of  $4.3 \text{ km/h}$ .

During the experiment, the battery voltage dropped from  $12.66 \text{ V}$  to  $10.91 \text{ V}$ , showing the loss of  $1.75 \text{ V}$  in 50 min of continuous operation. This data was obtained by navigating upstream and downstream, out of the stream central line. Accordingly, it is possible to infer that the total exhaustion of a  $12 \text{ V}$ -battery would occur in 343 minutes (5 hours and 40 minutes approximately).

### Sustainability considerations

The damage caused by the use of conventional fossil fuel engines has affected the flora (i.e. algae, plankton and others) which are the food of the fauna, the first of the chain of this aquatic beings range, entirely devastating mangroves. Several pollution sources have already been found on

marine farms, where the fuel sub-products remain, contaminating the water, fish, mussels or other less common. With the water quality impaired and a considerable amount of fuel waste and lubricants, as mentioned earlier, it becomes inadequate for human use.

The acquisition of electric motors still costs more than the conventional fuel engines, due to the use of photovoltaic panels and batteries to accumulate enough power loads, when it is not possible to use the direct solar irradiation. However, when it comes to maintenance cost, electric motors are significantly more advantageous because they have fewer moving parts and require no fuel and lubricating oil.

For human populations that inhabit the surrounding areas of riverbanks, coastlines and lakesides, water with good quality is directly related to these populations welfare. Even noise pollution is reduced when electric boats are used, improving the reproduction of the fauna and the potentiality of fishing activities.

Many government policies have been articulated to stimulate this kind of energy, even for domestic use. Lots of good practices have been implemented in engineering graduate programs when students need to develop projects aiming to enhance the performance of electric boats moved by solar panels. The first solar boat competition, the Solar Splash, was pioneered in Milwaukee, Wisconsin, the USA in 1994. In Europe, the first solar boat racing was launched in Friesland, the Netherlands, in 2004. In 2014, students from high schools also took part in the Young Solar Challenge, also launched in the Netherlands. In 2019, Toronto, Canada, hosted their Solar Sport Race in a World Cup evolving three different classes (Toronto Solar Boat Race, 2019).

Whilst the experimental tests, the minimum speed was similar to the river flow towards downstream. They showed the compatibility of the achieved speed with the operating power using clean energy from photovoltaic panels, even going upstream when there was a higher demand for energy.

Henceforward, the use of this clean technology would minimise the impact caused by motorized vessels using fuel engines, especially for the achievement of the SDGs of the 2030 Agenda. The SDGs that are related to the study proposal are: Goal 6 - Clean water and sanitation for all; Goal 7 - Access to affordable, reliable, sustainable and modern energy; Goal 8 - Sustainable economic growth; Goal 9 - Resilient infrastructure to promote sustainable industrialization and innovation; Goal 11 - Inclusive, safe, resilient and sustainable cities; Goal 13 - Urgent action to combat climate change and its impacts; and, Goal 14 - Conserve and sustainably use the oceans, seas and marine resources (United Nations, 2015).



## Conclusions

The findings of this study revealed that the use of electric power on boats is feasible for the transportation of passengers and goods. Even for small vessels, similar to the one operated in the experiment, the autonomy would be long enough to make them appropriate to urban waterways. A more significant number of photovoltaic plates installed on top of the roof cover would provide more satisfactory performance and autonomy to the vessel.

It was also possible to conclude that the use of these vessels in urban areas, would minimise the impact of oil fuel on nature, and also the noise pollution effect in fishing areas. When electric power is generated by photovoltaic cells, the results are even more beneficial, as the transportation may count exclusively on clean technology. The use of vessels also minimise the cost of infrastructure implementation and maintenance and maximises the access to public transportation and integrated modes (i.e. bicycles, motorcycles and even larger vehicles transported by vessels). Thus, the use of electric vessels supplied by photovoltaic energy is consistent with some of the 17 SDGs for the fulfilment of the 2030 Agenda.

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