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Renewable Energy System Controlled by Open-Source Tools and Digital Twin Model: Zero Energy Port Area in Italy

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Abstract: The present paper deals with an infrastructure digitization policy to optimize maintenance processes and energy efficiency to transform port areas to ZED (Zero Energy District). The Lazio Region started the process for all its ports in 2020. The Anzio port started and developed as a pilot project as it is a particularly representative sample for the Mediterranean Sea reality due to its geo-morphological conformation. The study aimed to develop energy-saving procedures and strategies and integrate production systems from Renewable Energy Systems (RESs) for sustainable mobility. In the article, these strategies are described in detail and energy analysis is carried out, starting from the current state and demonstrating the potential energy self-sufficiency of the infrastructure. Finally, the investigation's potential utilizing a Digital Twin (DT) of the area is highlighted. Furthermore, the BIM (Building Information Modeling) and GIS (Geographic Information System) combining possibility to maximize the energy efficiency measures beneficial impact are discussed.

Keywords: Renewable Energy Systems (RESs); Zero Energy District (ZED); Digital Twin (DT); Building Information Modelling (BIM); Geographic Information System (GIS); Revit software's

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1. Introduction

Increasing energy demand due to human society's population growth has led to rising energy prices [1], pollution and Greenhouse Gas (GHG) emissions. In this case, energy costs can be a significant overhead for ports [2]. Reducing GHG emissions and air pollution directly contributes to ports sustainability and green landscape [3]. Energy efficiency in ports is mainly related to providing the same services with less energy consumption and Renewable Energy Sources (RESs) and environmentally friendly [4]. Energy efficiency has a critical role for ports to reduce energy consumption and provide environmentally friendly services. The weather conditions that can influence port policymakers, sustainability and adaptation strategies are vital to helping create green ports [5]. Since many of the ports are located near large cities, they play an essential role in air pollution [6–8]. Ports, especially container ports, have three functional areas: quayside, yard, and landside [9,10]. Reducing GHG and pollutant emissions directly results from energy efficiency, equipment electrification, alternative fuels [11] and RESs. Along with increasing operational efficiency, these aspects can form a large part of the ports concept in the next generation [12].

There is a strong relationship between port operational efficiency and port energy efficiency. The increased operational efficiency of sources reduces energy consumption and significantly increases energy efficiency in ports [13]. Energy consumption in ports can be either electricity or fossil fuel. In recent years, practical steps have been taken to electrify equipment using electricity generated in ports through RESs, including the increasing advances in electricity generation, storage, distribution, conversion, and consumption technologies [14]. Furthermore, those technologies used in ports can significantly increase energy efficiency [15]. The significant increase in renewable energy technology, accompanied by the control technologies development and the converter installation, has led to the development efforts to develop energy in ports considering the existing potential [16].

Today, new technologies can increase energy efficiency and reduce GHG emissions in ports as solutions. On the other hand, using boats and ships with electricity can prevent severe marine pollution caused by oil spills. These solutions include the electricity use as RESs for independent vehicles, energy storage devices, cooling technologies and clean fuels such as cold-ironing [17], equipment [18,19], reefer containers [19], technologies in lighting. This technological improvement can dramatically guarantee energy efficiency using the Light-Emitting Diode (LED) lamps instead of high-pressure sodium lamps in port storage facilities, management buildings, high lighting towers in the wind space terminal [20]. For example, the Netherlands Delta terminal uses LED bulbs to save 922 MWh of annual power consumption, equivalent to € 300,000 [21]. In addition to using LED technology, focusing on lighting levels and designing armatures in ports can help save energy.

Renewable energies have been evaluated and identified as clean sources, such as tidal [22] and wave energy [23], geothermal energy [24], wind [25], and solar energy [26,27] are available due to the geographical location areas for ports. Many studies are addressing port energy management such as the ports of Singapore [28], Hamburg [29], Rotterdam in the Netherlands [30], Antwerp [31], Istanbul [32], Lübeck [8], Vancouver [33], La Spezia [34]. Sadek et al. [35] focused on RESs to replace fossil fuels of the Mediterranean ports. The offshore wind turbines and fuel cell units have been used as two examples of energy sources in ports. Their research shows that the combined system of wind turbines and fuel cells is the best choice for the unit cost of electricity generation with 0.101 and 0.107 of Alexandria port. Furthermore, they state that using fuel cells [36] and offshore wind turbines [37] as a green power concept will reduce "CO_2", "NOx" and "CO" emissions per year. Finally, they point to using a combination of renewable energy and green energy supply in the port of Alexandria, possibly reducing 22.31% of annual electricity costs.

In this regard, maritime transport is under increasing pressure to reduce the harmful effects of climate and the environment. Maritime transport can be responsible for 10% to 15% of the annual emissions of sulfur (SOx) and nitrogen oxides (NOx) and also approximately 3% of the global carbon dioxide (CO_2) emissions [38]. In 2018, the International Maritime Organization (IMO) member states set a 50% reduction in greenhouse gas emissions by 2050 compared to 2008, referred to as the "Paris Agreement on Shipping". Achieving this goal in 2050 requires the different sectors' strenuous installation and development of new technologies and other political measures by governments to adopt the maritime sector to zero emissions [39]. Hence, five critical factors in reducing port pollution have been identified by the World Port Climate Declaration at the international level: (1) reduce CO_2 from ships that sail the long and deep sea to ports, (2) evaluate how CO_2 is reduced from port operations, (3) evaluate how CO_2 is reduced from inland shipping, (4) study how to use RESs as an alternative way, and (5) further develop methods for calculating CO_2 in ports [34].

The Digital Twin (DT) system can be proposed essentially based on integration of softwares that has already been used, such as Building Information Modelling (BIM) and Geographic Information System (GIS). In addition, sensors aimed at the database implementing [40] and the functioning Artificial Intelligence (AI) systems optimizing [41] can be inserted in a sharing platform and powered in real-time by a series of the Internet of Things (IoT). The simulations can be carried out using specific, compatible tools that will allow the use of the DT in multiple fields of study, from architecture to engineering and economics [42]. Implementing a systemic, digital approach applied to industrial areas and urban systems produces diversified digital city models [43] based on the scale of analysis [44]. The DT methodology presents the traditional urban basis map's evolution and progressive technological transformation and is developed, managed [45], and constantly monitored in three dimensions through models based on intelligent geo-databases [46].

In buildings, energy-related parameters can be linked to the DT building portion of the neighborhood to monitor energy consumption, related costs and optimization [47]. Opening up renewed scenarios such as intelligent and evolutionary cities, and these monitoring possibilities can find application in the management of individual infrastructures or more extensive scale of entire commercial and industrial areas. Creating an information model based on objects, specific properties and attributes to develop an accurate DT model [48], means configuring a tool for analysing and evaluating possible scenarios supporting the decision-making process. Information models are powered by a constant flow of data generated [49] to update the DT model in real-time of the main digital model, i.e., sensors, cameras and smart grids [50]. The DT model can progressively collect a large number of data using sensors installed inside the buildings and port infrastructures, returning a virtual mirror of reality at any time. In particular, the DT thus collects operational and environmental information in the process components [51], later processed with analytical techniques and algorithmic simulations.

This study aims to develop energy-saving and increase energy efficiency methods and strategies using the RESs integration production systems in the energy ports. Firstly, energy-saving strategies are described in energy analysis detail [52]. Furthermore, the research potential of DT has been through the integration of BIM and GIS software. Secondly, several open-source (online and free access) platform-tools have been used to evaluate the Anzio port's wind and solar energy potential. Finally, these open-source platform tools are used to discover, extract, and process RESs data mapping, assessment and modelling to understand better the port of Anzio with very high time resolution data.

This paper is organized as follows: Section 2 explains the materials and methods, Section 3 describes the Anzio port as a case study, the results are provided in Section 4. Section 5 presents research discussion and Section 6 presents conclusions.

2. Materials and Methods

The DT includes a physical model, a virtual model and a connection between the physical and virtual models. In particular, several online open-platform data such as "Renewables. Ninja", "RSE Wind Atlas" platforms and MERRA-2 reanalysis data were used as input data of three software types such as, BIM, GIS and Revit software were used for analysis and integrating the model.

2.1. Efficient Strategies Development and DT Model

Firstly, the IoT data is collected through sensors and actuators sharing information to the DT in the cloud. Furthermore, the DT simulates its operation based on the information collected and uses these simulations either as a benchmark for comparison with the actual performance or to modify the operation/setting of the duplicated physical object.

The realisation of the DT model related to the product, system, organisation or activity process investigated. In the case of DT in the urban context, the idea of "Smart City" is the focus of this study. The model can be created using BIM software, such as Graphisoft ArchiCAD and Autodesk Revit (Figure 1).

Furthermore, the efficient strategies developed through the identification of individual technologies able to reduce consumption (e.g., lighthouse towers equipped with Light-Emitting Diode (LED) lighting) (Figure 2) and through energy diagnoses on buildings performances using dedicated software such as MC4 and TerMus. Autodesk's simulation engine, Green Building Studio (GBS), has been utilized; it enables the energy analysis functions in Revit and Insight, the web interface for interacting with the results produced by GBS.

As an example, the use of the electric multi-scale digital BIM and GIS model allows the detailed analysis of energy consumption, both through a punctual computation of all local loads such as lighting fixtures and electric recharging columns for boats and through the calculation of the actual consumption of public buildings [51] in the area (harbour master's office, ticket office, etc.).

The inclusion of appropriate shared parameters in the BIM model has allowed a detailed calculation [53], estimate and description of the energy consumption associated with the various facilities in the port area. For example, the consumption of the lighting terminals, which is about 67% of the total electrical consumption (see Table 1), is shown below.

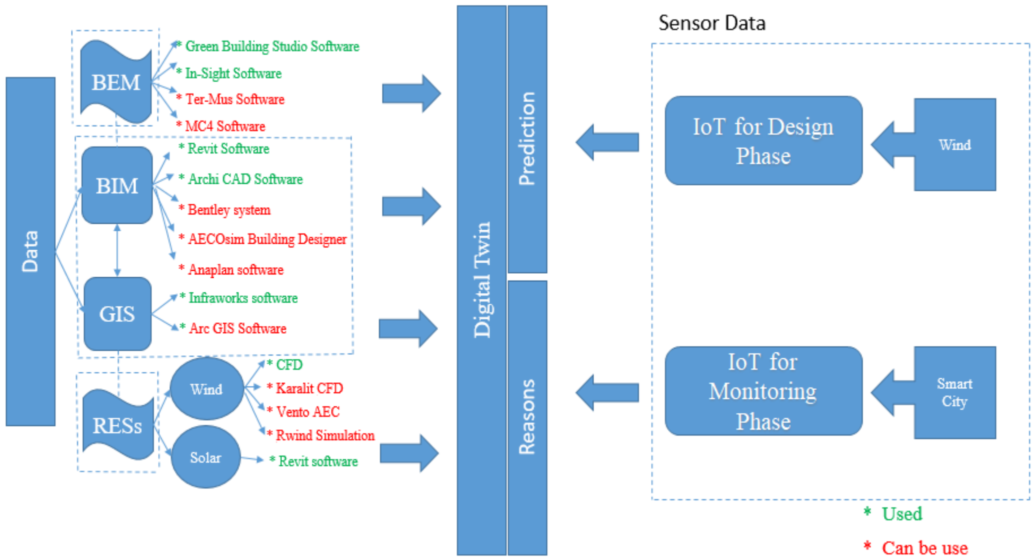

Figure 1. The main stages of the method developed in the port of Anzio. The software's used in this research is shown in green and the software's that can be used is shown in red.

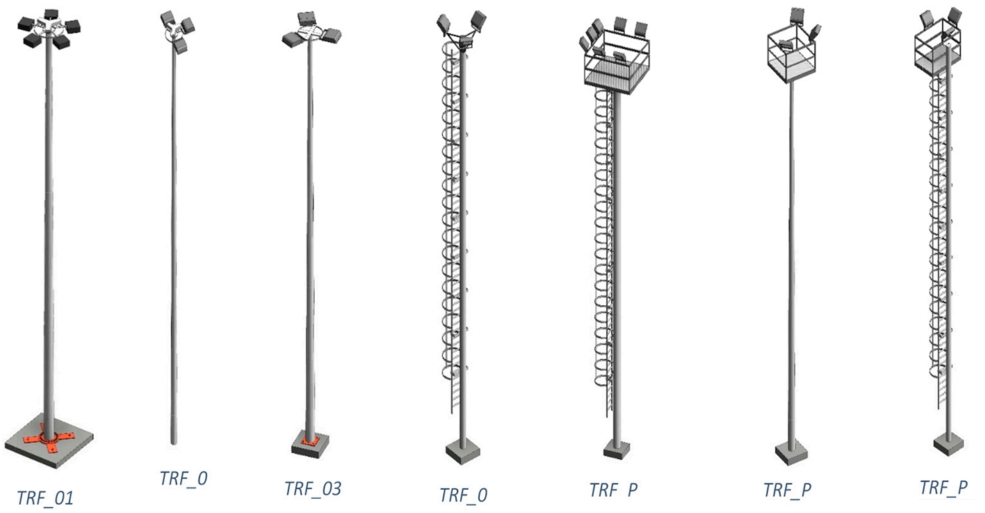

Figure 2. The lighting structures under studies.

The consequent efficiency improvement hypothesis by replacing the old energy-consuming floodlights of the light towers LED lighting structures is shown in Figure 2. The total load, following the efficiency measures, is therefore equal to:

$$C_I + C_{cr} \tag{1}$$

With C_I the consumption of the new lighting system and C_{cr} that of the charging stations. Therefore, after the interventions, the overall energy saved is equal to:

$$E_{AO} - E_{PO} = MWh\ per\ Year \tag{2}$$

where E_{AO} and E_{PO} represent the pre- and post-construction consumption respectively.

Table 1. Actual electrical load lighting system of the Anzio port.

Existing Phase—Consumption Estimate—Lighting										
Data Sheet	**Description**	**Family and Type**	**Quantity (n)**	**Spotlight (n)**	**Spotlight Power (W)**	**Type Power (W)**	**Total Power (W)**	**Hours of Use (h)**	**Days of Use (n)**	**Annual Consumption (Wh)**
STF-A_004.1	Streetlight	LMP_01: H_4m	3	1	60	60	180	10	365	657,000
STF-A_004.2	Streetlight	LMP_02: H_6m	18	1	80	80	1440	10	365	5,256,000
STF-A_004.3	Streetlight	LMP_03: H_6m - 3_Proiettori	4	3	100	300	1200	10	365	4,380,000
STF-A_004.4	Streetlight	LMP_04: H_3m	2	1	80	80	160	10	365	584,000
STF-A_004.5	Streetlight	LMP_05: H_3m	12	1	100	100	1200	10	365	4,380,000
STF-A_004.6	Streetlight	LMP_06: H_6m	4	1	80	80	320	10	365	1,168,000
STF-A_004.7	Streetlight	LMP_07: H_6m - 1_Proiettore	3	1	100	100	300	10	365	1,095,000
STF-A_004.8	Streetlight	LMP_07: H_6m - 2_Proiettori	1	2	100	200	200	10	365	730,000
STF-A_005.1	Light tower with platform	TRF_P_01: H_12m - 7_Proiettori	1	7	850	5950	5950	10	365	21,717,500
STF-A_005.2	Light tower with platform	TRF_P_02: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9,307,500
STF-A_005.3	Light tower with platform	TRF_P_03: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9,307,500
STF-A_006.1	Light tower	TRF_01: H_12m - 3_Proiettori	7	3	850	2550	17,850	10	365	65,152,500
STF-A_006.2	Light tower	TRF_01: H_12m - 5_Proiettori	6	5	850	4250	25,500	10	365	93,075,000
STF-A_006.3	Light tower	TRF_02: H_12m - 2_Proiettori	1	2	850	1700	1700	10	365	6,205,000
STF-A_006.4	Light tower	TRF_02: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9,307,500
STF-A_006.5	Light tower	TRF_03: H_12m - 3_Proiettori	2	3	850	2550	5100	10	365	18,615,000
STF-A_006.6	Light tower	TRF_04: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9,307,500
STF-A_007.1	Signal light	FRR: H_4m	1	1	100	100	100	10	365	365,000
STF-A_007.2	Signal light	FRV: H_4m	1	1	100	100	100	10	365	365,000
							71,500			260,975,000
										260,975 kWh

2.2. Wind Energy Potential Assessment

In this context, MERRA-2 reanalysis data has been used to wind speed potential mapping and time series analysis of the areas of Anzio port over 41 years between 1980 to 2021. The wind speed time-series analysis and mapping can help in decision-making about the RESs in the Anzio port areas.

Furthermore, the numerical analysis, the MATLAB software "Curve Fitting Toolbox" tool used to obtain the value of the annual energy produced. With the turbine control, it is possible to produce:

$$N_t \times E_t \ (kWh) \ per \ year \tag{3}$$

With N_t the number of devices and E_t the energy produced in a year by each of them.

2.3. Solar Energy Potential Assessment

MERRA-2 reanalysis data has been used for solar irradiation potential analysis of the areas of Anzio port over 41 years between 1980 to 2021. The solar energy sources time-series analysis and mapping can help decision-making and better understand the RESs in the Anzio port areas.

In this step, two areas for installing solar panels have been investigated, (i) Photovoltaic (PV) asphalt, (ii) the parking PV shelter.

Finally, the total area of the PV plant was calculated:

$$S = \frac{P_p}{\eta} = m^2 \tag{4}$$

where P_p is the peak power of the system and η the average yield of the modules. With the same energy produced with solar asphalt:

$$P_p = \frac{E_{as}}{E_{1kw(p)}} \approx kWp \tag{5}$$

With E_{as} the electricity produced overall by the solar asphalt and $E_{1kWp(pens)}$ produced by a 1 kWp system mounted on the shelters. Therefore, the number of shelters can be easily calculated:

$$\frac{P_p}{P_{pp}} = PV \tag{6}$$

Since each shelter covers an area of 50 m^2, the surface occupied by all the infrastructure is equal to:

$$S_p \times N_p = m^2 \tag{7}$$

Corresponding exactly to that of the parking area identified.

2.4. Energy Produced Balance

The total energy produced by the two RESs, it means wind and solar is equal to:

$$E_f + E_e = MWh \ per \ year \tag{8}$$

The goal of transforming the area into a ZED has been achieved. The optimized annual energy requirement of the port area is fully covered by the on-site production of wind and photovoltaic systems.

$$E_{FER} + C = +2.8 \ MWh \ per \ year \tag{9}$$

With E_{FER} the energy produced from RESs and C the consumption of the port.

2.5. CO_2 Emissions Avoided

The energy upgrading of the port area can significantly contribute to the reduction of CO_2 emissions and the reduction of energy absorption from the national electricity grid.

The calculation of avoided CO_2 emissions consists of the electricity generated from RESs by the average annual CO_2 emission factor associated with the electricity grid.

The table with the emission factors, taken from the "Joint Research Center", shows the quantity in tons of CO_2 emitted per MWh of energy produced by some energy carriers. Therefore, first of all, it is possible to calculate the CO_2 not emitted as a result of the area's consumption reduction interventions:

$$C_{a-p} \times F_{re} = t\ Per\ \mathrm{CO_2} \tag{10}$$

where C_{a-p} is the difference in pre- and post-construction consumption, and F_{re} is the considered emission factor. On the other hand, the share of CO_2 emissions not emitted into the environment following the installation of RESs, is equal to:

$$E_{FER} \times F_{re} = t\ Per\ \mathrm{CO_2} \tag{11}$$

With E_{re}, the energy produced by RESs. Therefore, the CO_2 not released into the environment compared to the starting situation is:

$$\mathrm{CO}_{2e} + \mathrm{CO}_{2FER} = t\ Per\ \mathrm{CO_2} \tag{12}$$

To this value, an additional quantity of CO_2 not emitted into the environment should be added, i.e., that of the boats that would use the recharging service through the columns installed along the quays of the port (whose CO_2 emission factors from the electricity network are in any case lower than those of conventional fuels).

Unfortunately, the estimation of the "carbon footprint" applied to boats parked on the quay or when approaching/leaving the port is a rather complex operation since the data relating to the turnout of boats in the harbour are not available. Furthermore, the environmental benefit of the measures adopted should be extended to the lack of emissions of pollutants such as $PM_{2.5}$ and NOx from boats.

3. Case Study

Ports can be considered one of the most well-known places where human activities and environmental issues are indirect. Many important ports are focused on local and regional development and have been able to preserve local traditions for a long time because they are directly related to the development of their immediate city. Ports are therefore publicly owned in most parts of the world, although they have been privatized in the operational sector, which is usually required due to the nature, size, and long-term prospects of the investments required [54]. Hence, energy management plans in ports are highly dependent on energy management strategies in the nearby city [24]. Therefore, ports are directly dependent on the national electricity grid as an energy source to meet the needs of domestic electricity and ships stationed [35].

Anzio (41°26′52.61″ N–12°37′44.59″ E) is a city with 43.43 km^2 (16.77 sq mi) and commune on the coast of the Lazio region of Italy, about 51 km (32 mi) south of Rome, Lazio (Latium) region, and located on a peninsula jutting into the Tyrrhenian Sea [55] (Figure 3). Anzio is a fishing port and a departure point well known for its seaside harbour setting for ferries and hydroplanes to the Pontine islands of Ponza, Palmarola, and Ventotene [56].

Figure 3. Anzio port.

4. Results

In this section, the research results are presented with a new integrated method using digital and RES models. These results offer practical strategies for evaluating wind and solar energy sources in ports to study the ZED.

4.1. Integration of DT Models and LEDs

The main objective of the DT framework is proposed to support decision-making using integrated multi-scale digital data sources, BIM and GIS information containers for simulation purposes about the implementation of strategies improving energy performance in the entire port area.

Future developments will integrate multi-scale digital simulations into real-time data. The digital models are structured to be interconnected to a cloud platform to acquire valuable data from the models and IoT sensors, configuring the effective DT.

Through Revit software, a series of distinct digital models were created by discipline (architectural, structural and MEP), each representing a specific "layer" within the overall digital model of the port area (Figure 4). Each of these models was then populated with three-dimensional families/objects, relative to the specific discipline under investigation, used as information containers.

Using the Industry Foundation Classes (IFC) file format allows exchanging information through a standard, open and non-proprietary format. As a result, it is possible to exploit all the BIM functionalities, generating an energy model of the building/plant system. Consequently, it is possible to analyse the actual state of different energy loads thanks to a detailed analysis of heating, hot water and cooling requirements in natural conditions, identifying and adjusting the most critical parts in the system's annual energy balance [57]. Once the efficiency of the entire port has been achieved, potential areas for the insertion of renewable energy production technologies are identified [58].

Similarly, with the interoperability between BIM and GIS, operated through Autodesk's Infra works software, the DT information is enriched with geospatial information describing the urban environment. This systems cooperation creates a reliable model where geographic information and design data are integrated to understand different asset interactions with the surrounding city.

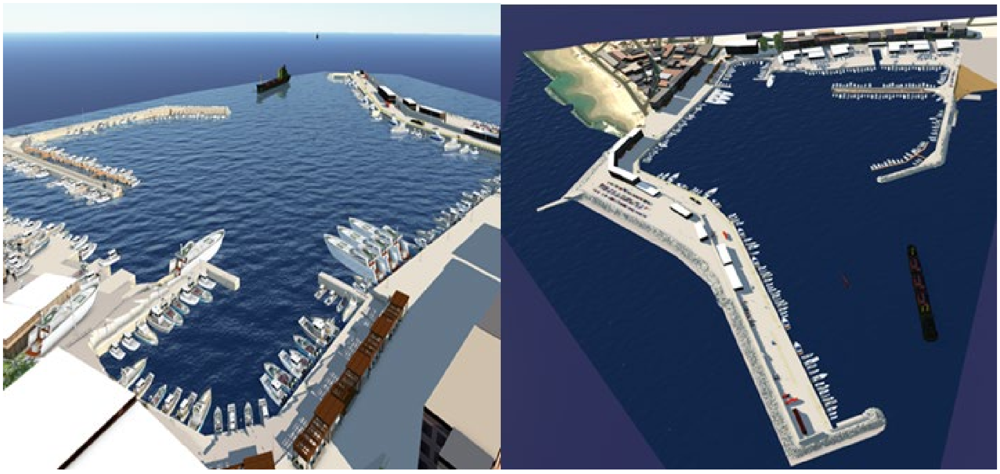

Figure 4. BIM model of the Anzio port area.

Among possible applications, GIS information can be exploited in a BIM process to improve energy savings. In this sense, GIS informs BIM that by exploiting data such as building heights and footprints, it is possible to identify areas with high energy loads or those with the highest priority for energy retrofitting [59].

The inclusion of appropriate shared parameters in the BIM model has allowed a detailed calculation, estimate and description of the energy consumption associated with the various facilities in the port area. The lighting terminals' consumption is about 67% of the total electrical consumption. The consequent efficiency improvement hypothesis is shown by replacing the old energy-consuming floodlights of the light towers with LED lighting structures. The results can be summarized as a reduction of about 65% in energy consumption for lighting than the current state as reported (Table 2).

In addition, some charging devices are installed in the Anzio port area for private and public boats (Figure 5). These devices are located in different places and divided into double charging stations and simple interlocked sockets.

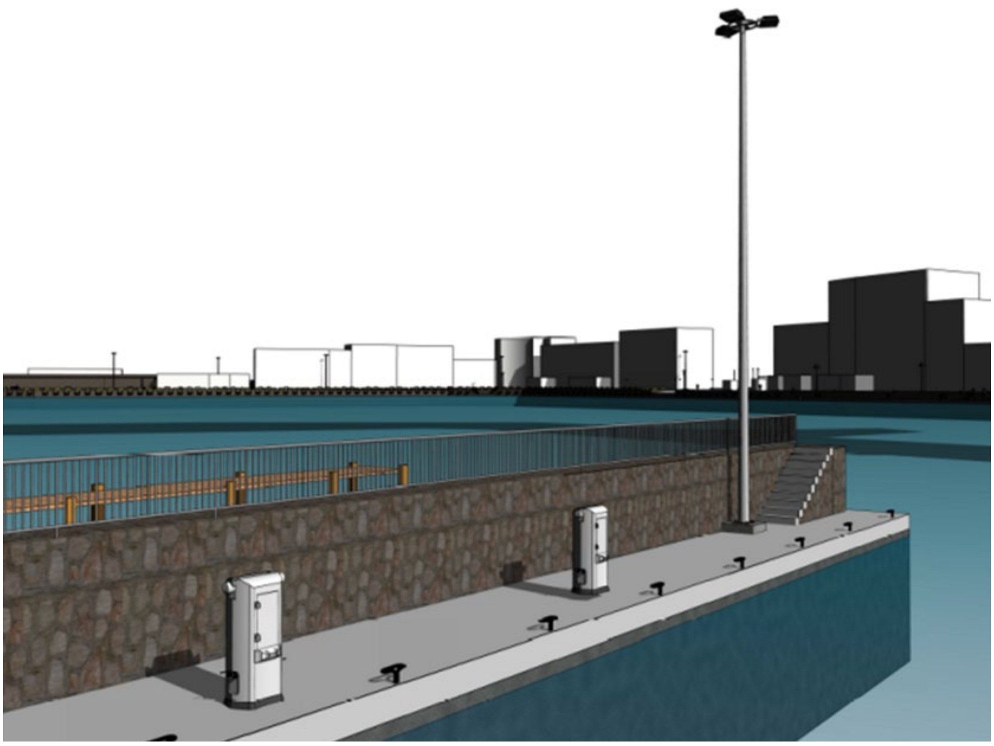

Figure 5. BIM model of the charging stations.

Table 2. Optimized electrical load of the port lightning system.

Project Phase—Consumption Estimate—Lighting										
Data Sheet	**Description**	**Family and Type**	**Quantity (n)**	**Spotlight (n)**	**Spotlight Power (W)**	**Type Power (W)**	**Total Power (W)**	**Hours of Use (h)**	**Days of Use (n)**	**Annual Consumption (Wh)**
STF-A_004.1	Streetlight	LMP_01: H_4m	3	1	60	60	180	10	365	657,000
STF-A_004.2	Streetlight	LMP_02: H_6m	18	1	80	80	1440	10	365	5,256,000
STF-A_004.3	Streetlight	LMP_03: H_6m - 3_Proiettori	4	3	100	300	1200	10	365	4,380,000
STF-A_004.4	Streetlight	LMP_04: H_3m	2	1	80	80	160	10	365	584,000
STF-A_004.5	Streetlight	LMP_05: H_3m	12	1	100	100	1200	10	365	4,380,000
STF-A_004.6	Streetlight	LMP_06: H_6m	4	1	80	80	320	10	365	1,168,000
STF-A_004.7	Streetlight	LMP_07: H_6m - 1_Proiettore	3	1	100	100	300	10	365	1,095,000
STF-A_004.8	Streetlight	LMP_07: H_6m - 2_Proiettori	1	2	100	200	200	10	365	730,000
STF-A_005.1	Light tower with platform	TRF_P_01: H_12m - 7_Proiettori	1	7	250	1750	1750	10	365	6,387,500
STF-A_005.2	Light tower with platform	TRF_P_02: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2,737,500
STF-A_005.3	Light tower with platform	TRF_P_03: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2,737,500
STF-A_006.1	Light tower	TRF_01: H_12m - 3_Proiettori	7	3	250	750	5250	10	365	19,162,500
STF-A_006.2	Light tower	TRF_01: H_12m - 5_Proiettori	6	5	250	1250	7500	10	365	27,375,000
STF-A_006.3	Light tower	TRF_02: H_12m - 2_Proiettori	1	2	250	500	500	10	365	1,825,000
STF-A_006.4	Light tower	TRF_02: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2,737,500
STF-A_006.5	Light tower	TRF_03: H_12m - 3_Proiettori	2	3	250	750	1500	10	365	5,475,000
STF-A_006.6	Light tower	TRF_04: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2,737,500
STF-A_007.1	Signal light	FRR: H_4m	1	1	100	100	100	10	365	365,000
STF-A_007.2	Signal light	FRV: H_4m	1	1	100	100	100	10	365	365,000
							24,700			90,155,000
									kWh	90,155

In Table 3 is reported the overall electrical consumption of all the devices.

Table 3. Electrical load for charging systems.

Consumption Estimate—Electrical Device							
Data Sheet	**Description**	**Family and Type**	**Quantity (n)**	**Power (W)**	**Hours of Use (h)**	**Days of Use (n)**	**Annual Consumption (Wh)**
STF-A_003.1	Charging station	CLL_01_QMC200B: GW68832W	2	4	10	90	7200
STF-A_003.2	Charging station	CLL, 02: 4P	5	4	10	90	18,000
STF-A_003.3	interlocked socket	PRI: 2P, 01	10	4	10	90	36,000
STF-A_003.4	interlocked socket	PRI: 2P, 02	15	4	10	90	54,000
STF-A_003.5	interlocked socket	PRI: 3P	2	4	10	90	7200
STF-A_003.6	interlocked socket	PRI: 4P	2	4	10	90	7200
							129,600

The total amount of optimizing electrical loads of the Anzio port area is 90,155 + 129,600 = 219,755 kWh for a year. This is the target of implementing the RESs local grid production in the same place to reach a ZED (Figure 6).

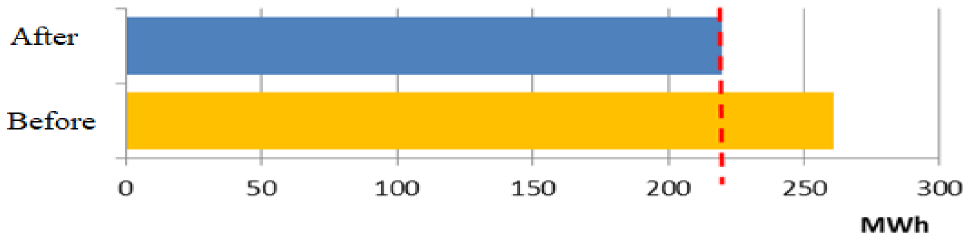

Figure 6. Electricity consumption of Anzio.

4.2. Wind Energy Potential Assessment

More than 40 years of monthly data from the MERRA-2 reanalysis dataset have been used to understand better the wind speed potential and mapping of port areas and understand the wind speed (Figures 7 and 8) in the case of micro wind turbines' installation.

Secondly, two sites have been located as ideal for the placement of the turbines [60]. The locations match the piers at the South and North ends of the harbour (Figure 9) for a total amount of fifteen turbines.

Ten wind turbines will be located next to the previous breakwater points, and the remaining five will follow the second breakwater lines.

The micro wind turbine DS3000 model (ETNEO Italia) was chosen to be installed at Anzio Port. DS3000 model is a 3 kW vertical axis micro-generator, equipped with a Savonius rotor mounted on the central axis of the turbine, valid for the starting of the rotation with low winds, and three Darrieus blades to increase the production with medium/strong winds. The Savonius blades, oriented on the four cardinal points to capture the wind from any direction, do not require the orientation of the rotor (Figure 10).

The annual average wind speed was calculated using the "Renewables. ninja" platform, which provides an hourly average wind speed [37]. For both Region of Interest (ROI), the obtained value at the height of 10 m is around 4.75 m/s (data confirmed by the RSE Wind Atlas platforms and MERRA-2 reanalysis dataset) [60–62]. Regarding calculating the turbine's annual energy production, a reference was made to the data estimated by the supplier ETNEO Italia, as shown in Table 4.

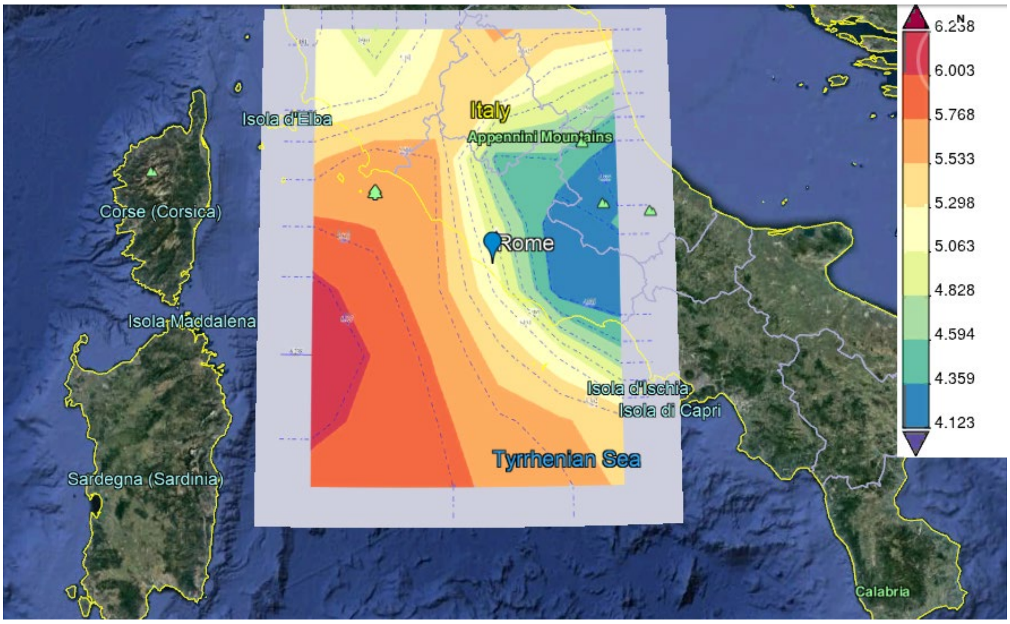

Figure 7. Surface wind speed (m/s) in the Rome City and Anzio port showed a blue point for 1980 to 2021.

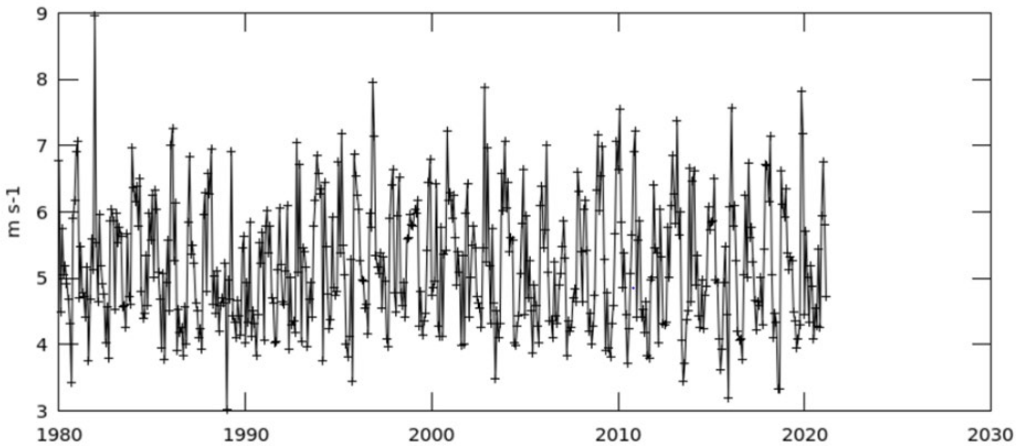

Figure 8. Showed a monthly time-series analysis between 1980 to 2021 for the Anzio port.

With the power curve in MATLAB the energy value produced by the calculating turbine for a vehicle speed of 4.75 m/s is approximately 2420 kWh. Fifteen micro wind turbines are located in external port areas, as shown in Figure 9 as an example. Therefore, the obtained value is approximately 2420 kWh per year. Therefore, it is possible to produce 36,300 kWh per year with fifteen turbines located on the outer side of the pier (Figure 9). Specifically, a spline has been selected as the appropriate interpolation function, as shown in the curve in Figure 11.

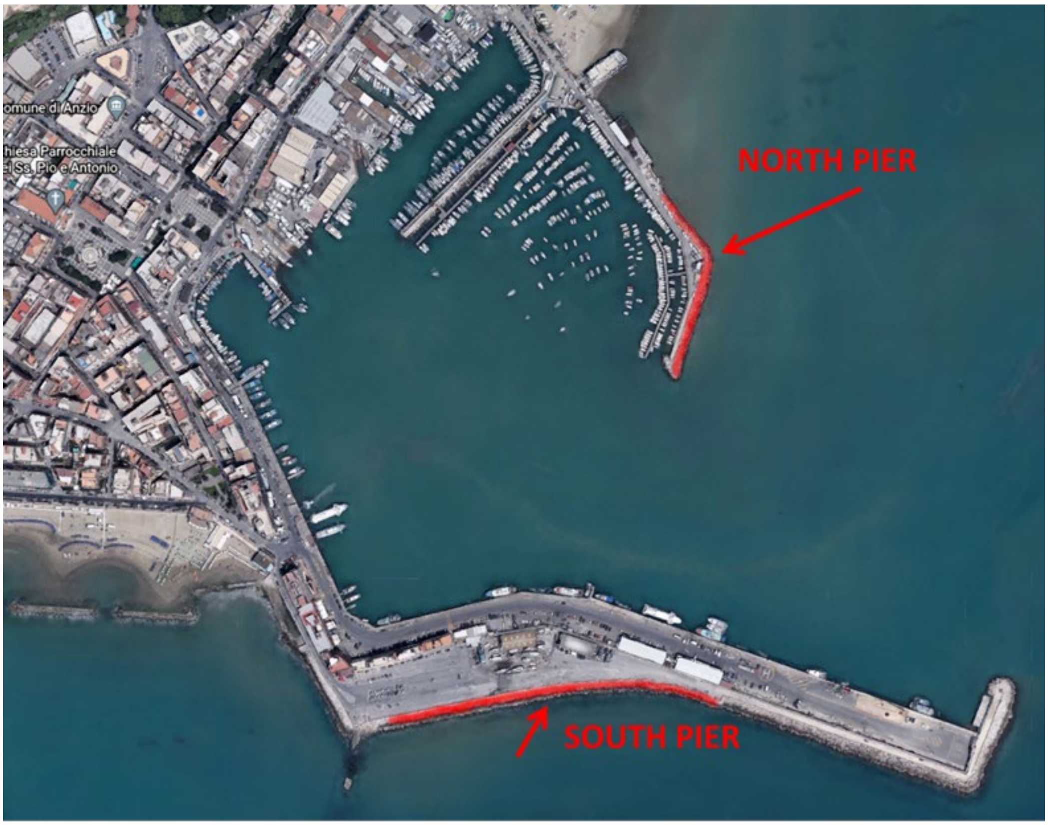

Figure 9. The micro-wind turbine installation locations.

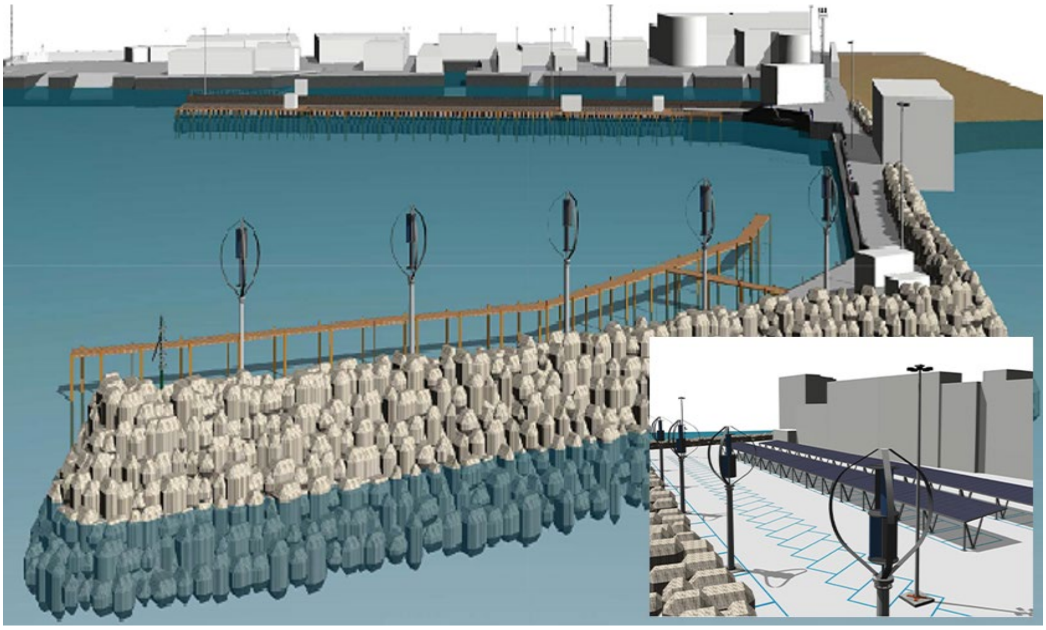

Figure 10. Turbines BIM Model.

Table 4. Turbine's Annual Energy Production (AEP).

Average Wind Speed (m/s)	AEP (kWh)
5	2.851
5.5	3.819
6	4.877
6.5	5.975
7	7.061
7.5	8.088
8	8.945

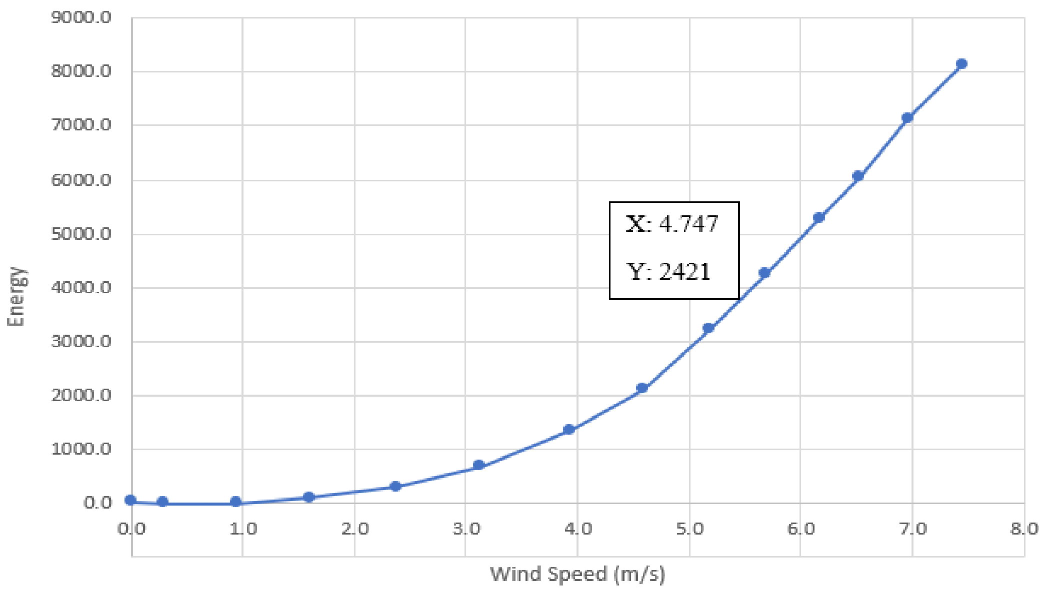

Figure 11. Turbine production data.

4.3. Solar Energy Assessment (PV System)

More than 40 years of monthly data from the MERRA-2 reanalysis dataset have been used to map PV solar irradiation analysis mapping of port areas with exciting potential to evaluate the solar irradiation potential (Figures 12 and 13) for PV installation.

Secondly, electric power production from a solar source should be performed by positioning a dedicated PV panel directly on the ground in port areas without significant cars. The technology of solar roads rapidly increases its penetration, especially on infrastructures and installation characterized by wide spaces without buildings and people presence [63–65].

For installing the photovoltaic modules, the area at the end of the southern pier was chosen. It's a large area, characterized by good exposure and without shading (there are no buildings nearby), as shown in Figure 14, with indicated in the red zone with the arrow. Let's consider the latter solution: the parking area identified is shown in the figure. It is an area of about 800 m^2, with parking spaces oriented at 30° to the south.

Photovoltaic canopies are car park covers that have the dual purpose of covering parked vehicles and generating clean energy. They are mainly made of galvanized steel, a highly resistant material supporting the photovoltaic module system. The photovoltaic system for electricity production is placed on the sloping roof, which can be connected to the grid or even to the charging columns of parked electric cars (Figures 14 and 15). These systems protect cars from prolonged exposure to the sun, transforming a potentially harmful agent for the car into a source of clean energy.

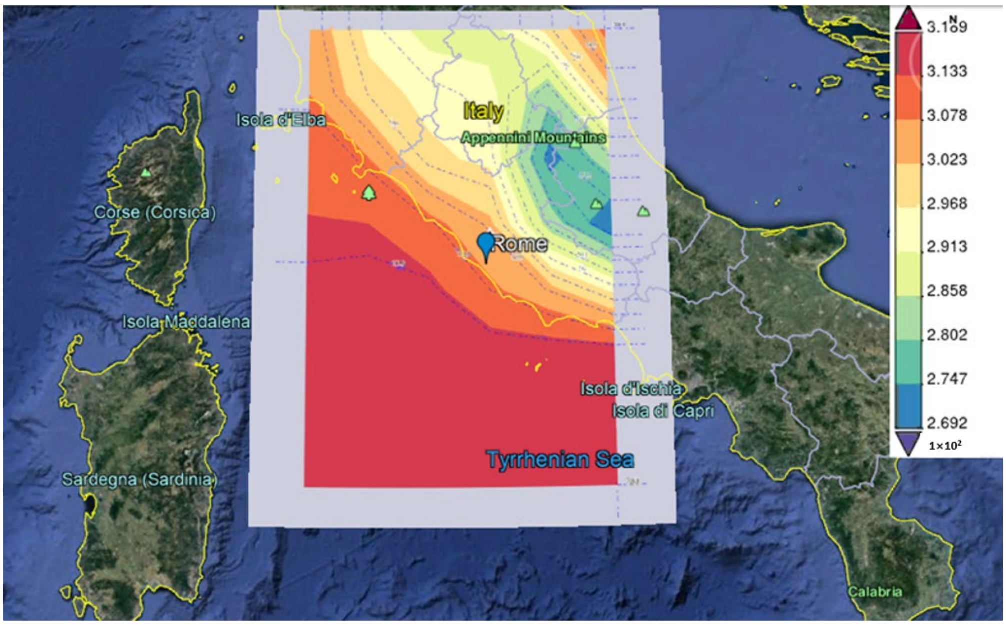

Figure 12. Solar irradiation in the Rome City and Anzio port showed a blue point from 1980 to 2020.

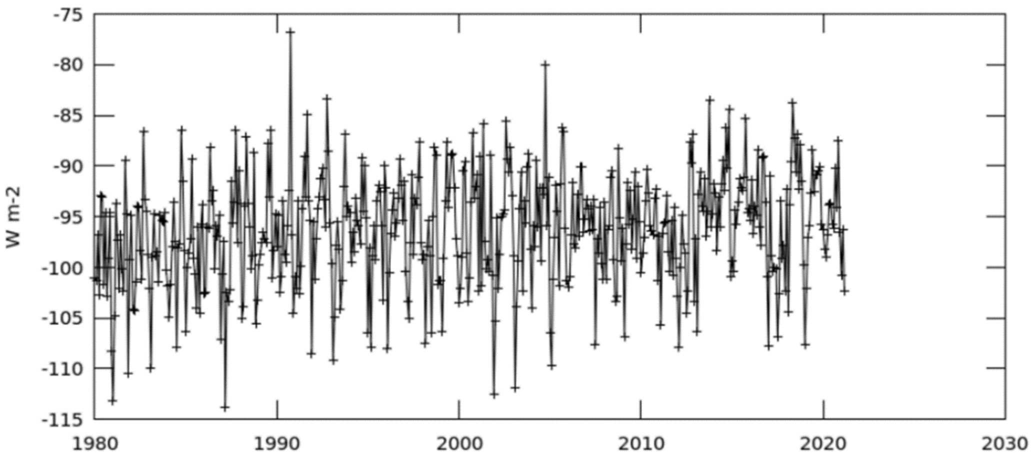

Figure 13. Showed a monthly time-series analysis between 2019 to 2020 for the Anzio port.

The structure also offers shelter from precipitation, hail and snow. From the data collected in the literature, the modules used for solar asphalt have average yields of around 9%. The performance of this technology is lower than standard modules, but it is still worth studying its application in the port also in the perspective of future technological advances. To cover the remaining energy requirement, the peak power required to be available is approximately 150 kWp.

The orientation and inclination have been set to 0°, and also the "integrated in the building" option has been chosen as the mounting position. From the calculation performed with PVGIS, the energy produced is equal to 186,254.63 kWh per year. The results were obtained from the simulation for the 150 kWp plant.

To estimate the energy production of the PV shelters, the azimuth angle of the car parks has been inserted as the "tilt" angle of the wall unit's design. The energy produced per kW is much greater than in the previous case (1334.22 kWh/kW compared to 1241.69 kWh/kW of the solar asphalt).

A single shelter with P_{pp} = 9k the PV system peak power. Taking into account the rounding up, the shelters produce a total of 192.13 MWh per year, with a total peak power of 144 kWp.

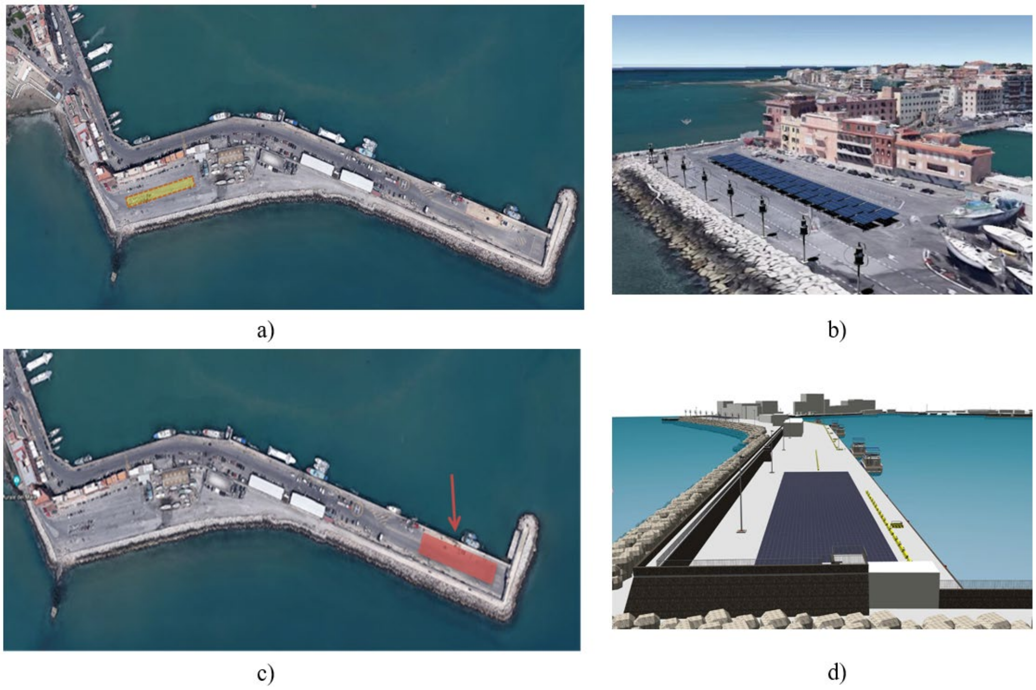

Figure 14. (**a**,**b**) Photovoltaic (PV) solar asphalt area, (**c**,**d**) PV asphalts.

Figure 15. Photovoltaic shelters.

4.4. Energy Produced Balance

As shown in the pie chart, the energy contribution of wind turbines is significantly lower than that of solar asphalt (Figure 16 and Table 5). The goal of transforming the area into a ZED has been achieved. The optimized annual energy requirement of the port area is fully covered by the on-site production of wind and photovoltaic systems.

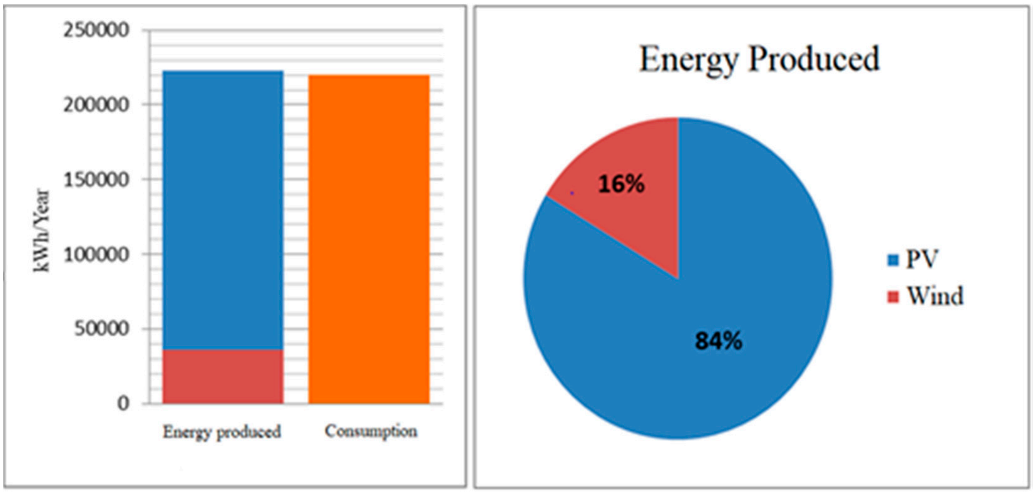

Figure 16. Comparison of consumption - energy produced by RES (**Left**), Subdivision of energy produced by RES (**Right**).

Table 5. Annual production of energy from RESs.

Annual Energy Production of FER-Anzio		
FER	**Technology**	**kwh/year**
PV	Asphalt PV	186,254.63
Wind	wind turbine	36,300
		222,554.63

4.5. CO_2 Emissions

The energy upgrading of the port area can significantly contribute to the reduction of CO_2 emissions and the reduction of energy absorption from the national electricity grid. The calculation of avoided CO_2 emissions consists of the electricity generated from RESs by the average annual CO_2 emission factor associated with the electricity grid.

The table with the emission factors, taken from the guidelines of the "Joint Research Center", shows the quantity in tons of CO_2 emitted per MWh of energy produced by some energy carriers (Table 6):

Table 6. Emission factors.

CO_2 Emission	**Amount**
Gas	0.202
Diesel	0.267
Electric tariffs	0.276

An additional quantity of CO_2 not emitted into the environment should be added, i.e., that of the boats that would use the recharging service through the columns installed along the quays of the port (whose CO_2 emission factors from the electricity network are in any case lower than those of conventional fuels) (Figure 17).

Unfortunately, the estimation of the "carbon footprint" applied to boats parked on the quay or when approaching/leaving the port is a rather complex operation since the data relating to the turnout of boats in the harbour are not available. Nevertheless, the measures adopted should be the environmental benefit to the lack of pollutants such as $PM_{2.5}$ and NOx from boats.

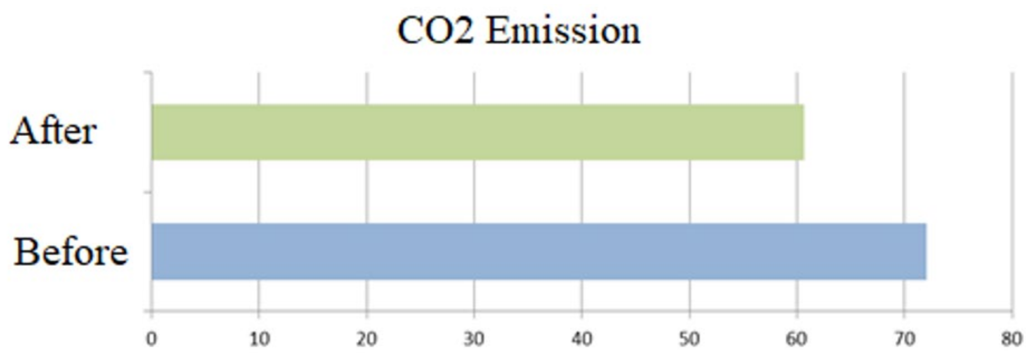

Figure 17. CO_2 emissions before and after construction.

4.6. Economic Evaluation

In this paragraph, we will limit ourselves to making an account of the investment costs relating to installing wind and PV systems. As already explained above, there are no reliable references in the literature concerning the costs of solar asphalt technology. Therefore, for the economic analysis, reference will be made to the installation costs of the photovoltaic shelters. For the latter, the 9 kW model from Kit. Solutions were chosen from the quotes consulted online. The cost of each cover amounts to € 19,650. Regarding the micro-wind plant, the price list was provided to us by the supplier company Etneo Italia Srl. From the quotation of the bidding company (Table 7), it appears:

Table 7. Cost of turbine components.

RES	Cost
DS3000 Turbine	9600 €/cad
On grid turbine	2350 €/cad
Huawei inverter 4 kW	1250 €/cad
Total	13,200 €/cad

The calculation of expenses is shown in the Table 8 below:

Table 8. RESs cost.

FER	P_n [kW_p]	Amount [n]	P_p plant [kW_p]	Energy Produced [kWh/Year]	Energy Produced Plant [kWh/Year]	Cost [€]	Total Cost [€]
PV	9	16	144	12,008	192,128	19,650	314,400
Turbine	3	15	45	2420	36,300	13,200	198,000

The overall cost of the infrastructure installed is, therefore, equal to 512,400 euros. This expense must be added to that relating to installation, which we assume equal to 45% of the cost of the devices (Table 9):

Table 9. Total investment.

	Cost [€]	FPO [€]	Total Investment [€]
PV Shelters	314,400	141,480	455,880
Turbine	198,000	89,100	287,100
			742,980

For micro-wind turbines, there are state incentives that concern the production of energy and not the installation of the system and are provided by the Energy Services

Manager (GSE). This means that the return on investment is more significant the more energy is produced (if the wind turbine is located in a windy area). The two methods of incentive proposed are the all-inclusive rate and the "exchange on-site". All-inclusive tariff involves a gain of EUR0.30 for each kWh fed into the national grid and has a duration of 15 years, after which one can access the free market or the so-called "dedicated collection". The "exchange on-site" incentive is more suitable for small plants.

In this case, the gain amounts to EUR0.20 per kWh without time constraints. The calculation mechanism consists of the difference between the energy produced and the energy consumed: if the result is negative, it is charged to the bill. If positive, there is an energy "credit" scalable on future billing. In addition to the GSE incentives just outlined, for the installation of RES plants, such as wind power, the 2020 Budget Law allows a tax deduction of 65% (micro-generators) up to a maximum expenditure of EUR100 thousand. Photovoltaic systems on canopies are always a convenient solution, even without the incentives of the energy bill. In fact, by exploiting the "Exchange on-site" and sizing the system concerning actual consumption, thus aiming for self-consumption, it is possible to reduce the electricity bill significantly.

5. Discussion

Energy efficiency is one of the hot research topics that advances in existing technology directly affect future research prospects [66]. In this case, innovative approaches, economic analysis [67], operations optimization, the new technological advances effects [68], and management analysis will be the most important for future ports research. Economic and environmental analysis for automated and electric ports are also necessary and inevitable [69]. Therefore, integrating independent and electrical equipment with energy storage devices makes smart meters more potent and straightforward, making the significant range possible for further analysis [70]. Next-generation ports will use automation, electricity and intelligent energy management systems. To this aim, the role of independent or electric vehicles in the smart grid is unavoidable, which should be further discussed for future port operations.

Energy management can be considered one of the management tools prominent features to move ports towards greater sustainability with the environment and reduce greenhouse gases. That is why energy management in ports is more focused on Environmental Management Systems (EMS). For example, the European Maritime Ports Organization (ESPO) supports and encourages European ports to develop environmental management programs [3], but EMS is only approved by half of the European ports. Therefore, interaction with shareholders can be considered basic and essential to implement EMS in ports better [33].

The ports' main challenges in the EMS development can be identified in the following cases; (1) balancing economic and environmental goals in ports and (2) sharing knowledge and joint production and successful experiences in national and international ports [71]. In this regard, several ports define specific programs for energy management, which can be considered with the protection policies of the European Union, including projects for the renewable energy use to reduce air and environmental pollution [27].

Managing sustainable energy development using RESs is an emerging issue for ports [12]. In this regard, a conceptual framework for energy management systems, similar to the model in their construction, can be very effective [72]. Unfortunately, there are no studies analyzing barriers to energy efficiency in ports. These barriers to energy efficiency in ports include most technical, economic and regulatory aspects. There are also barriers to the supply of clean fuels and other technologies [1], so barrier analysis is invaluable to industry and academia. In the port industry literature, most technical reports explain the RESs use.

Researchers can focus on intelligent grid analysis and evaluate smart grids operational and environmental performance using simulation tools. Balancing energy demand and supply in the smart grid is a complex task [73]. Furthermore, more research in the initial step should have high data quality to perform a successful analysis. Assessing and evaluating aspects of monitoring has benefits for ports, (i) assessing the level of environmental pollution in ports, (ii) improving the environmental and energy management impacts, and (iii) helping to reform port strategies and policies, (v) the possibility of evaluating energy consumption studies and environmental risk management in ports to estimate and determine practical goals and measures in the future [74,75].

In this regard, to support decision-makers and port managers in selecting and implementing sustainable technologies, the need for actual empirical research and accurate implementation of the tools selection, technologies and operations [76]. Hence, there is a need to transfer more practical information from the scientific community to decision-makers to help port decision-makers. Furthermore, this knowledge transfer to port decision-makers who have more experience in implementation decisions will help them make the final decision [77].

Furthermore, conducting studies that act as a guide by considering the necessary standards can be very useful in developing a strategy to reduce GHG emissions in ports [78]. These studies can be used from a technical point of view, availability and cost analysis of alternative energy technology study with new development, evaluation, and implementation that increase regulatory regulations in ports [35]. The proposed DT framework aims to configure a digital integrated and multi-scale database for simulation purposes. It is intended to be integrated into real-time data from sensors and improve data management.

6. Conclusions

The project proposed presents an Anzio port digital transformation process of the Lazio Region, starting from their infrastructural centre. The implications of this transformation directly concern the environmental, economic and social spheres, setting the port area as the epicentre and extending to the city. The port has potential for public buildings, water sports schools, boat workshops and association headquarters, not the subject of this paper, which can be incorporated into the DT. Due to their geometric characteristics and location, a maximum of two-level buildings is easily transformable into ZEB buildings. A further implementation of the DT and extending the harbour representation can improve its environmental and economic management.

The data can be entered into a BIM and GIS environment within a sharing platform predictive scenario derived, and the urban fabric resilience with the creation and use of appropriate tools can be estimated. This allows planning in a well conscious way, respecting environmental sustainability and interventions aimed at economic, commercial and social activities. Critical from a design and then construction point of view is the cost estimate accuracy of interventions in such a critical area. Together with the costs, it is fundamental to estimate and plan the risks related to the execution of works, which will change the social impact during their implementation.

The "Port of Anzio" DT implementation digitalization area makes it possible to start from the digital and ecological transformation epicentres and spread throughout the territory. The exchange flows studying with the surrounding territories, linked to transport by sea, land, road, and rail. It would also replace electricity production's economic and environmental costs for public lighting and electricity supply to moored boats by switching from carbon to renewable energy sources.

With repercussions in all fields, this digital transformation will open new scenarios and higher efficiency in managing public finances, especially in the green deal area. There will be substantial energy and environmental benefits already in the construction phase of the works. In the planning and design phase, it will be possible to accurately assess various implications related to the implementation of the work and its territorial, environmental, and social context. The other important factor is the possibility of minimising the project's costs by simulating different scenarios. This means monetary, environmental, and social costs, not least those due to the construction times uncertainty. This factor scares off potential private, national, and international investors. That can be predicted by adding more future factors such as horizontal transport infrastructure, roads and railways; the parameters will significantly increase the analytical data volume under study. Therefore, the data analysis with current methods will be very time consuming and complex. So, given the data diversity, such studies require a rigorous data management method and analysis to define a digital structure integration approach

Various ports appear to have attempted to install intelligent energy management systems. However, it should be borne in mind that the systems effectiveness in different ports is directly related to the port's geographical location. This relationship varies according to the RESs availability and their type for efficiency in ports. On the other hand, various studies show that evaluating new measures and technologies with a high potential for intelligent energy management systems concerning sustainable and long-term goals is very effective.

In this regard, it can be said that the lack of cooperation between stakeholders and decision-makers is the main reason for stopping various projects in ports. In addition, despite the increase in academic studies on port sustainability, the exploitation of real-world research results in port infrastructure has not yet been well implemented. The main reason for this can be the lack of case studies with regional diversity in small ports. The central gap that should be considered in future studies is the energy efficiency report of a technology or techniques studied in ports. This may indicate the need to combine existing and new measures and technologies to promote the ZEDs concept design in leading studies.

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Abbreviations

BIM	Building Information Modelling
GIS	Geographic Information System
RESs	Renewable Energy Systems
CO_2	Carbon Dioxide
MWh	Mega Watt Hour
GBS	Green Building Studio
ROI	Region of Interest
EC	European Community
IoT	Internet of Things
DT	Digital Twin
ZED	Zero Energy District
DTM	Digital Twin Model
PVs	Photovoltaics
LED	Light-Emitting Diode

CFD	Computational Fluid Dynamics
IFC	International Foundation Class
AI	Artificial Intelligence
GHG	Greenhouse Gas
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2
GSE	Energy Services Manager

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