Renewable Energy Sources Assessment and System Design based on Open Tools and Digital Twin Models towards Zero Energy Districts: the case study of Anzio Port

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ABSTRACT

The present paper deals with an infrastructure digitization policy aimed at optimizing maintenance processes and energy efficiency to transform port areas in ZED (Zero Energy District). The Lazio Region started the process in 2020 for all its ports. Anzio started and developed as a pilot project as it is a particularly representative sample for the Mediterranean Sea reality due to its geomorphological conformation. The study aimed not only at developing energy-saving procedures and strategies but also at integrating production systems from Renewable Energy Systems (RESs) for sustainable mobility. In the article, these strategies described in detail and energy analysis is carried out, starting from the current state and demonstrating the potential energy self-sufficiency of the infrastructure. It also highlights the potential of the investigation utilizing a Digital Twin (DT) of the area, combining the possibility of BIM (Building Information Modeling) and GIS (Geographic Information System), comparing future scenarios even to varying scales to maximize the beneficial impact of energy efficiency measures.

KEYWORDS

Renewable Energy Systems (RESs), Zero Energy District (ZED), Digital Twin (DT), Building Information Modelling (BIM), Geographic Information System (GIS) and Revit software’s.

List of Abbreviations

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

1. INTRODUCTION

Increasing energy demand due to the growing in the population of human societies has led to rising energy prices, pollution and greenhouse gas emissions. In this regards, energy costs can be a significant overhead for ports [1]. Reducing greenhouse gas emissions and air pollution

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directly contributes to ports sustainability and green landscape [2]. It should be noted that energy efficiency in ports is mainly related to providing the same services with less energy consumption and the use of renewable and environmentally friendly energy sources. Countless services have been possible due to the growing technology. Energy efficiency is significant for ports that aim to reduce energy consumption and provide environmentally friendly services. Sustainability and adaptation strategies given the weather conditions that can influence port policymakers, it is vital to help create green ports. Since many of these ports are built near large cities, they play an essential role in air pollution [3][4]. In order to help the sustainability and landscape of the port green, targets have been set in the regulations to reduce greenhouse gas emissions in port waters, yards, and background areas [5]. Reducing greenhouse gas and pollutant emissions directly results from energy efficiency, electrification of equipment, use of alternative fuels, and renewable energy sources. These aspects, along with increasing operational efficiency, can form a large part of the concept of ports in the next generation [6].

There is a solid and positive relationship between port operational efficiency and port energy efficiency. As the increase of operational efficiency of sources reduces energy consumption and significantly increases energy efficiency in ports [7]. 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 renewable energy sources. The energy efficiency sector is strongly influenced by the increasing advances in electricity generation, storage, distribution, conversion and consumption technologies [8].

Power systems used in ports include various components such as batteries, distributors, converters. In addition, new methods have been developed and installed to enhance network intelligence and new devices for efficient energy storage. The use of this updated technology in ports can significantly increase energy efficiency. The use of such intelligent reinforced power distribution systems can increase energy efficiency in different areas of ports. The significant increase in renewable energy technology, which has accompanied by the development of control technologies and the converters installation, has led to the development of efforts to develop energy in ports. The detecting, assessing and then installation of renewable energy converters is crucial for green ports target. In this case, new technologies such as smart grids and microgrids can strengthen energy management in ports managing demand and supplying energy. Ports, especially container ports, have three functional areas namely; quayside, yard side and landside [9][10].

In this regards, the Digital Twin (DT) system is proposed essentially based on an integration of software already widely used, such as Building Information Modelling (BIM) and Geographic Information System (GIS), inserted in a sharing platform and powered in real-time by a series of the Internet of Things (IoT) sensors aimed at implementing the database and optimizing the functioning Artificial Intelligence (AI) systems [11]. The simulations that can be carried out through the use of specific, compatible tools (for example, life cycle assessment, energy diagnosis, fluid dynamics, simulation of flows of people and vehicles, image analysis with behavioral predictions) will allow the use of the DT in multiple fields of study, from architecture to engineering and economics.

Implementing a systemic, digital approach applied to industrial areas and/or urban systems produces diversified digital city models based on the scale of analysis. Above all, the amount of data drawn from the actual urban structure and structured within its DT [12]. This methodology represents the basis for the evolution and progressive technological transformation of the traditional urban map, thus developed, managed, and constantly monitored in its three dimensions through models based on intelligent geo-databases. For example, in the context of buildings, it is possible to link energy-related parameters to the DT of a building or of a portion of the neighbourhood to monitor energy consumption, related costs, and possible measures aimed at their optimization. These monitoring possibilities can find application in the management of individual infrastructures or larger scale of entire commercial and industrial areas, opening up renewed scenarios such as intelligent and evolutionary cities.

Creating an information model based on objects and their specific properties and attributes, with a view to the development of an accurate Digital Twin Model (DTM) [13], means configuring a tool for analysing and evaluating possible scenarios supporting decision-making, connecting to the structures, objects and buildings their complex processes and the interactions between people and the built environment. These models powered by a constant flow of data generated, thanks to the main digital model, i.e., sensors, cameras and smart grids, to update the DTM in real-time. The DTM can progressively collect a large number of data, returning a virtual mirror of reality at any time, using sensors installed inside the buildings and port infrastructures. In particular, in the process components, the DT thus collects operational and environmental information, later processed with analytical techniques and algorithmic simulations. The benefits of this type of modelling are various, and range from predictive maintenance to operational efficiency, to optimization of available Renewable Energy Systems (RESs) [14], as well as to the energy efficiency of the existing structures and infrastructures; with its constantly updated database, it can help all decision-makers through the management of the port area, as well as to make long-term decisions on issues such as infrastructure and source management, urban planning, environmental sustainability. The main economic and environmental benefits would derive from the forecasts of energy load and self-production of the energy systems installed in the perimeter of the port areas. The DT energy of the area, besides guaranteeing a virtuous management of the energy systems of the area, would lead to rationalization and efficiency of the use of energy sources with savings in expenses on overall supplies (gas + electricity) between 15 and 20%, with a consequent improvement also of the microclimatic conditions of the area and the “CO_2” emission levels.

Today, new technologies can be used to increase energy efficiency and reduce greenhouse gas emissions in ports as solutions. Reducing greenhouse gases in ports can have a significant effect on mitigating air pollution in port cities. On the other hand, using boats and ships with electricity can prevent severe marine pollution caused by oil spills. These solutions include the use of electricity as an energy source for independent vehicles, energy storage devices, cooling technologies using renewable sources and clean fuels, lighting technologies, such as cold-ironing [15], equipment [16][17], reefer containers [17], technologies in lighting. This technological improvement can dramatically guarantee the energy efficiency of ports by using LED lamps instead of high-pressure sodium lamps in port storage facilities, management buildings, high lighting towers in the wind space terminal [18].

The ECT Delta terminal in the Netherlands uses LED bulbs to save 922 MWh of annual power consumption, equivalent to € 300,000 [19]. In addition to using LED technology, focusing on lighting levels and designing armatures in ports can help save energy.

Renewable energies and other clean fuels have evaluated and identified as energy sources for ports to reach a green port, such as tidal [20] and wave energy [14], geothermal energy [21], wind and solar energy [22] are available for ports due to the potential of the source of energies. Studying different scenarios, especially wind and solar, allows us to accurately plan and measure the next generation of RESs located in the area to eliminate energy from fossil fuels throughout the ports area [23]. Many studies are addressing port energy management such as the ports of Singapore [24], Hamburg [25], Rotterdam in the Netherlands [26], Antwerp [27], Istanbul [28], Lübeck [5], Genoa [1], Vancouver [29], La Spezia [30]. Sadek et al [31], focused on renewable energy sources to replace fossil fuels of Mediterranean ports. In their research, 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. They state that using fuel cells and offshore wind turbines 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, with the possibility of reducing 22.31% of annual electricity costs.

This study aims to develop energy-saving methods and strategies using the integration of production systems from renewable energy systems (RESs) to increase energy efficiency in the energy ports. In this study, energy-saving strategies are first described in detail in energy analysis. In addition, the research potential of Digital Twin (DT) has been through the integration of BIM (Building Information Modeling) and GIS (Geographic Information System) software’s. Secondly, open-source platform tools such as "Renewables. Ninja", "RSE Wind Atlas", "Giovanni" have been used to evaluate wind speed and solar radiation potential in the port of Anzio. These open-source platform tools are used to discover, extract, and process renewable energy sources data mapping to better understand the port of Anzio as an area of interest, and cover all large maritime areas with very high time resolution (yearly, monthly).

2. Materials and Methods

The DT includes a physical model, a virtual model and a connection between the physical and virtual models. In particular, three different data types (IoT, open data platform such as, “Renewables. Ninja”, “RSE Wind Atlas” and “PVWatt” platforms and MERRA-2 reanalysis data and three software’s types, it means BIM, GIS, Revit software’s have been integrated into the following lines;

2.1. Data and software’s

The data is collected through sensors and actuators (IoT) 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 digital 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", which is the focus of this study, the model can be created through the use of BIM software, such as Graphisoft ArchiCAD, and Autodesk Revit (figure 2). Furthermore, the development of efficient strategies through the identification of individual technologies able to reduce consumption (e.g. lighthouse towers equipped with Light-Emitting Diode (LED) lighting) and through energy diagnoses on buildings performances using dedicated software such as, MC4 and TerMus (Figure 1).

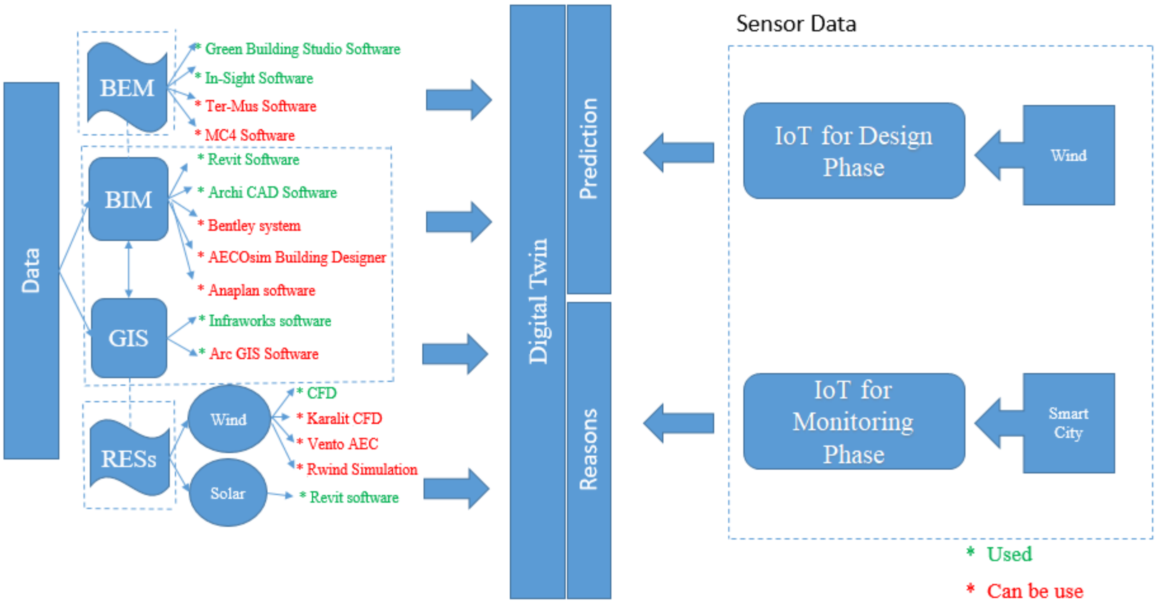

Figure 1. The main stages of the method developed in the port of Anzio. The software's used in this research is shown in green and the software's that can be used is shown in red.

The 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.

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

2.2. Case Study

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 kilometers (32 mi) south of Rome, Lazio (Latium) region, and located on a peninsula jutting into the Tyrrhenian Sea [32] (Figure 2). It is a fishing port and a departure point well known for its seaside harbor setting for ferries and hydroplanes to the Pontine Islands of Ponza, Palmarola, and Ventotene [33].

Figure 1. Anzio port loaction.

Creating DT of the ports areas, which are so complex and characterized by a high number of functions and parameters, beneficial useful for the maintenance, energy and building management of the complexes [34]. Still, it can also create virtuous management of spaces, even about user's social behavior, and monitor in real-time both the conditions of comfort and environmental safety of users and operators and the flow of vehicle goods.

This project, which the competent Regional Directorate of Lazio initiated, concerns the ports of the island of Ventotene and Formia, Terracina, and Anzio. The aim is to improve the area's energy behaviour, reduce emergency maintenance to zero, and minimise failures due to the malfunctioning of energy and plant systems and equipment. This will result in economic savings of between 20 and 25% of the entire maintenance budget. This policy should be seen in the context of an Italian national plan that envisages the digitisation of the entire public infrastructure.

In the timetable set out in Ministerial Decree no. 560/17 implementing European Directive 2014/24/EU on Public Procurement, a gradual digitalisation is envisaged for all public works, with the obligation to digitalise also works with a value of less than one million euros from the year 2025. Precisely because of these factors in the infrastructure sector, a strong impulse for energy efficiency and environmental compatibility of works and 'network infrastructures' in general is to be expected in Italy. The competent Ministry has recently changed its name from 'Ministry of Infrastructure and Transport' to 'Ministry of Sustainable Infrastructure and Mobility'. In addition, projects are underway, financed mainly by the European Community for the Recovery Fund, to improve the energy efficiency, safety, and environmental sustainability of critical infrastructures and restart the country's economic development.

3. RESULTS

The results of a new hybrid method are provided using a digital model and RESs. These results offer practical strategies for evaluating wind and solar energy sources in ports to study the zero-energy zone.

3.1. Digital Model and the Efficient Strategies Development

Through Revit software (Figure 3), a series of distinct digital models created by discipline (architectural, structural and MEP), each representing a specific "layer" within the overall digital model of the port area. Each of these models was then populated with three-dimensional families/objects, relative to the specific discipline under investigation, which, used as information containers.

Figure 3. BIM model of the Anzio port area

The main objective of the DT framework is actually proposed to support decision-making using integrated multi-scale digital data sources, and 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 to real-time data, as the digital models are structured to be interconnected to a cloud platform aimed at acquiring useful data both from the models and from IoT sensors, configuring the effective DT. The integration of Artificial Intelligence (AI) systems is going to be implemented in the DT, improving data processing and data management systems for the operation and maintenance phases as well as for further interventions.

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 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, estimate and description of the energy consumption associated with the various facilities in the port area. The consumption of the lighting terminals, which is about 67% of the total electrical consumption (see Table 1) is shown below.

Table 1. Actual electrical load of the port lightning system.

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	657000
STF-A_004.2	Streetlight	LMP_02: H_6m	18	1	80	80	1440	10	365	5256000
STF-A_004.3	Streetlight	LMP_03: H_6m - 3_Proiettori	4	3	100	300	1200	10	365	4380000
STF-A_004.4	Streetlight	LMP_04: H_3m	2	1	80	80	160	10	365	584000
STF-A_004.5	Streetlight	LMP_05: H_3m	12	1	100	100	1200	10	365	4380000
STF-A_004.6	Streetlight	LMP_06: H_6m	4	1	80	80	320	10	365	1168000
STF-A_004.7	Streetlight	LMP_07: H_6m - 1_Proiettore	3	1	100	100	300	10	365	1095000
STF-A_004.8	Streetlight	LMP_07: H_6m - 2_Proiettori	1	2	100	200	200	10	365	730000
STF-A_005.1	Light tower with platform	TRF_P_01: H_12m - 7_Proiettori	1	7	850	5950	5950	10	365	21717500
STF-A_005.2	Light tower with platform	TRF_P_02: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9307500
STF-A_005.3	Light tower with platform	TRF_P_03: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9307500
STF-A_006.1	Light tower	TRF_01: H_12m - 3_Proiettori	7	3	850	2550	17850	10	365	65152500
STF-A_006.2	Light tower	TRF_01: H_12m - 5_Proiettori	6	5	850	4250	25500	10	365	93075000
STF-A_006.3	Light tower	TRF_02: H_12m - 2_Proiettori	1	2	850	1700	1700	10	365	6205000
STF-A_006.4	Light tower	TRF_02: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9307500
STF-A_006.5	Light tower	TRF_03: H_12m - 3_Proiettori	2	3	850	2550	5100	10	365	18615000
STF-A_006.6	Light tower	TRF_04: H_12m - 3_Proiettori	1	3	850	2550	2550	10	365	9307500
STF-A_007.1	Signal light	FRR: H_4m	1	1	100	100	100	10	365	365000
STF-A_007.2	Signal light	FRV: H_4m	1	1	100	100	100	10	365	365000
							71500			**260975000**
									kWh	**260975**

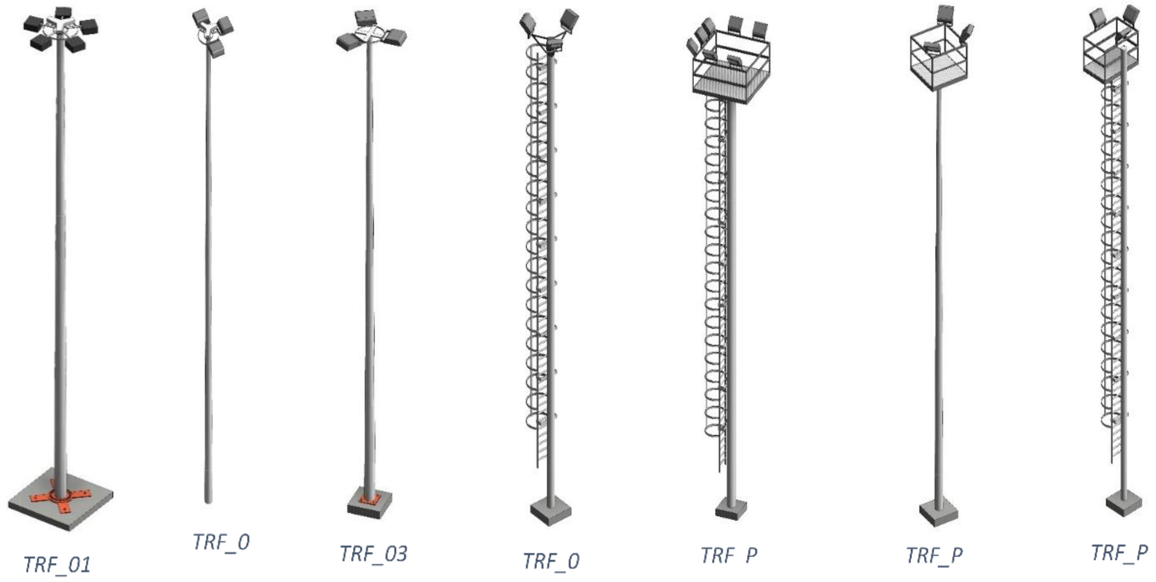

Fig 4. The lighting structures under studies.

The consequent hypothesis of efficiency improvement by replacing the old energy consuming floodlights of the light towers LED lighting structures shown of Figure 4. The results can be summarised as a reduction of about 65% in energy consumption for lighting than the current state as reported in Table 2.

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	657000
STF-A_004.2	Streetlight	LMP_02: H_6m	18	1	80	80	1440	10	365	5256000
STF-A_004.3	Streetlight	LMP_03: H_6m - 3_Proiettori	4	3	100	300	1200	10	365	4380000
STF-A_004.4	Streetlight	LMP_04: H_3m	2	1	80	80	160	10	365	584000
STF-A_004.5	Streetlight	LMP_05: H_3m	12	1	100	100	1200	10	365	4380000
STF-A_004.6	Streetlight	LMP_06: H_6m	4	1	80	80	320	10	365	1168000
STF-A_004.7	Streetlight	LMP_07: H_6m - 1_Proiettore	3	1	100	100	300	10	365	1095000
STF-A_004.8	Streetlight	LMP_07: H_6m - 2_Proiettori	1	2	100	200	200	10	365	730000
STF-A_005.1	Light tower with platform	TRF_P_01: H_12m - 7_Proiettori	1	7	250	1750	1750	10	365	6387500
STF-A_005.2	Light tower with platform	TRF_P_02: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2737500
STF-A_005.3	Light tower with platform	TRF_P_03: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2737500
STF-A_006.1	Light tower	TRF_01: H_12m - 3_Proiettori	7	3	250	750	5250	10	365	19162500
STF-A_006.2	Light tower	TRF_01: H_12m - 5_Proiettori	6	5	250	1250	7500	10	365	27375000
STF-A_006.3	Light tower	TRF_02: H_12m - 2_Proiettori	1	2	250	500	500	10	365	1825000
STF-A_006.4	Light tower	TRF_02: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2737500
STF-A_006.5	Light tower	TRF_03: H_12m - 3_Proiettori	2	3	250	750	1500	10	365	5475000
STF-A_006.6	Light tower	TRF_04: H_12m - 3_Proiettori	1	3	250	750	750	10	365	2737500
STF-A_007.1	Signal light	FRR: H_4m	1	1	100	100	100	10	365	365000
STF-A_007.2	Signal light	FRV: H_4m	1	1	100	100	100	10	365	365000
							24700			**90155000**
									kWh	**90155**

In addition, in the Anzio port area are installed some charging device for private and public boats. These devices are located in different places and divided into double charging stations and simple interlocked sockets. 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	18000
STF-A_003.3	interlocked socket	PRI: 2P_01	10	4	10	90	36000
STF-A_003.4	interlocked socket	PRI: 2P_02	15	4	10	90	54000
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
							129600

The total amount of optimizing electrical loads of the Anzio port area is 90155 + 129600 = 219755 kw/h for a year. This is the target of implementing the RESs local grid production in the same place to reach a zero-energy district.

3.2. Integration of Renewable Energy Systems (RESs)

Using the Industry Foundation Classes (IFC) file format allows the exchange of information through a standard, open and non-proprietary format. It is possible to exploit all the BIM functionalities, generating an energy model of the building/plant system (BEM). 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 real conditions, identifying and adjusting the most critical parts in the system's annual energy balance [35]. Once the efficiency of the entire port has been achieved, potential areas for the insertion of renewable energy production technologies are identified [36]. Their potential can be identified using appropriate calculation tools, within the model and using the integration between the BIM model and geographical data obtained with GIS tools as shown in Figure 5.

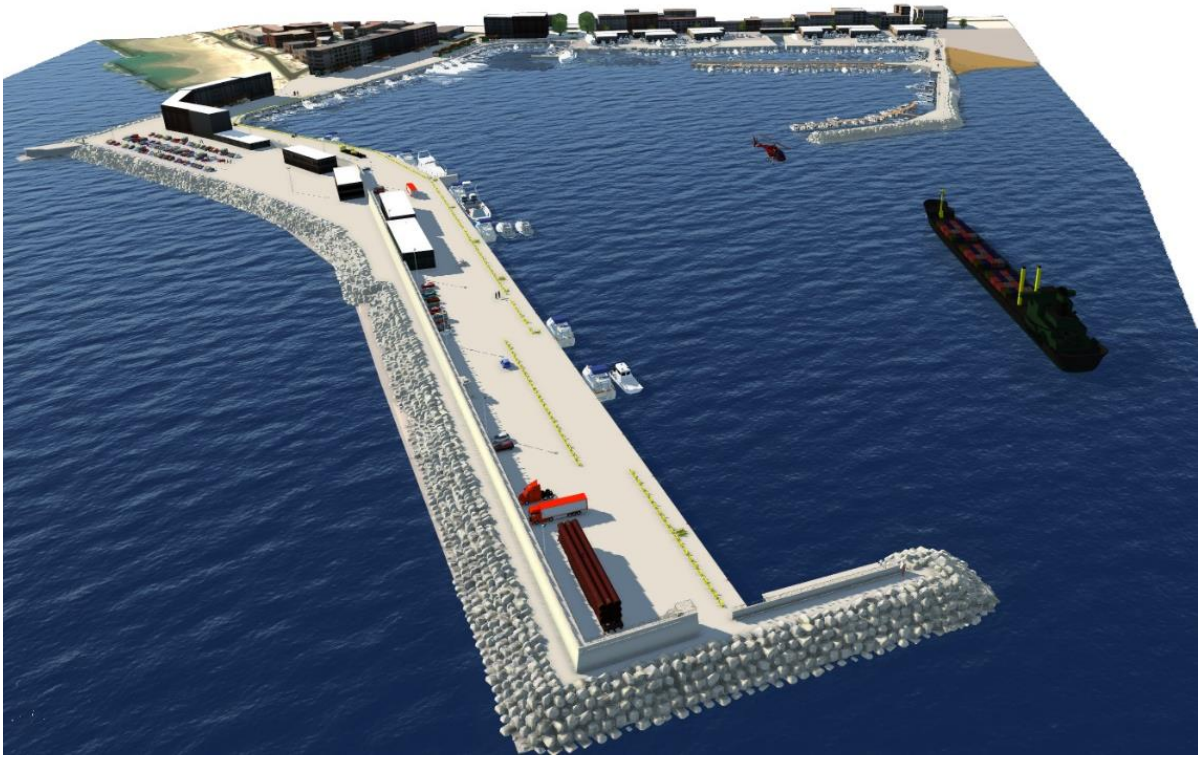

Figure 5. BIM model inside Infra works.

Similarly, with the interoperability between BIM and GIS, operated through Autodesk's Infra works software, the DT information 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. Among possible applications, GIS information can be exploited in a BIM process to improve energy savings. In this sense, GIS informs BIM 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 [37]. The possible integration of Renewable Energy System (RES) concerning essentially systems that exploit solar and wind energy can be evaluated through software such as the Revit plug-in that studies the sunshine of areas, or Autodesk Computational Fluid Dynamics (CFD), Karalit CFD, Vento AEC, Rwind Simulation and similar, solving the Navier-Stokes equations and allowing the study of CFD problems.

3.2.1. Wind potential assessment of Anzio Port

Firstly, more than 40 years monthly data from the MERRA-2 reanalysis dataset have been used to evaluate and identify wind speed potential of port areas, to understand the wind speed (Figures 7, 8) in case of micro wind turbines installation.

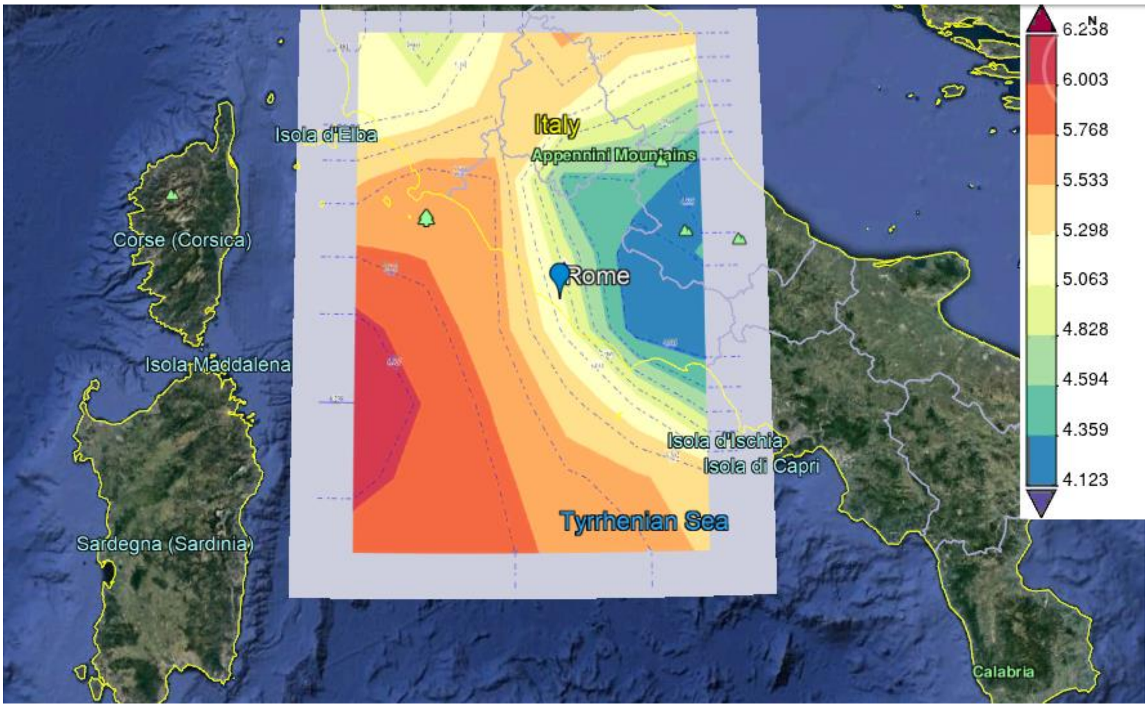

Figure 7. Surface wind speed per (m/s) in the Rome City and also Anzio port showed with blue point for the years from 1980 to 2021.

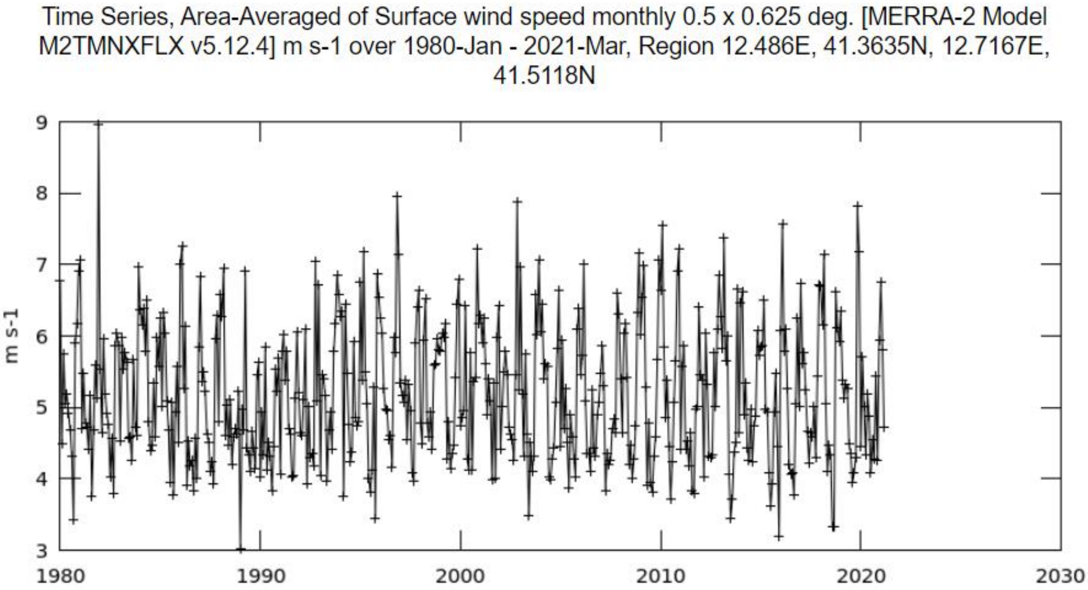

Figure 8. A monthly time-series analysis between 1980 to 2021 for the Anzio port showed.

Secondly, two sites have been located as ideal for the turbines' placement [38]. The locations match the piers at the South and North ends of the harbour (Fig 9), for a total amount of fifteen turbines. Ten of these would place alongside the breakwater spots of the former; the remaining five would follow the breakwaters' lines of the latter.

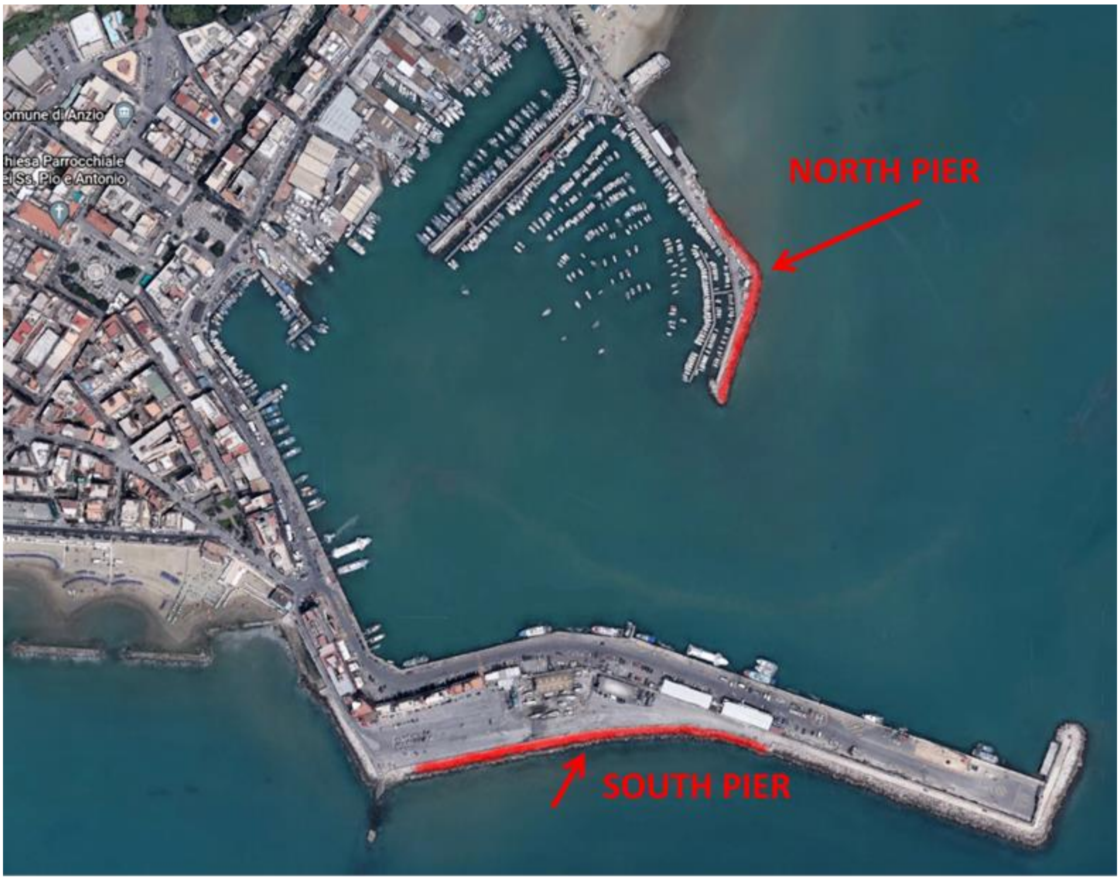

Figure 9. The Micro-wind turbine installation locations.

The micro wind turbine DS3000 model (ETNEO Italia) was chosen to be installed at Anzio Port. DS3000 model is a 3kW 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.

The annual average wind speed was calculated by using the “Renewables.ninja” platform, which provides a database with the hourly average wind speed [39]. 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) [40][38][39]. The wind direction has not been taken into account since, as mentioned above, these models of turbines do not need to be oriented. Regarding the calculation of the turbine's annual energy production, reference was made to the data estimated by the supplier ETNEO Italia, as shown in the Table. 4.

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

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

The numerical analysis, the Matlab "Curve Fitting Toolbox" tool used to obtain the value of the annual energy produced at a speed of 4.75 m/s. specifically, a spline has been selected as the appropriate interpolation function, as shown in the curve in figure 10.

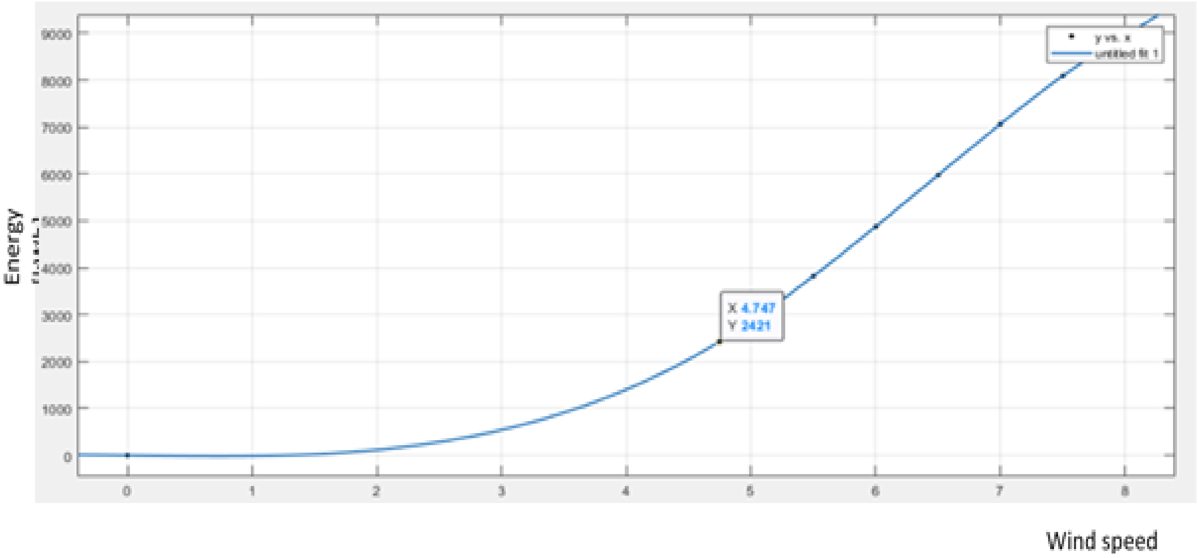

Figure 10. Turbine production data.

Fifteen micro wind turbines are located in external port areas as shown in figure 11 as example. The obtained value is approximately 2420 kWh per year. Therefore, it is possible to produce 36300 kWh per year with fifteen turbines located on the external side of the pier (figure 11).

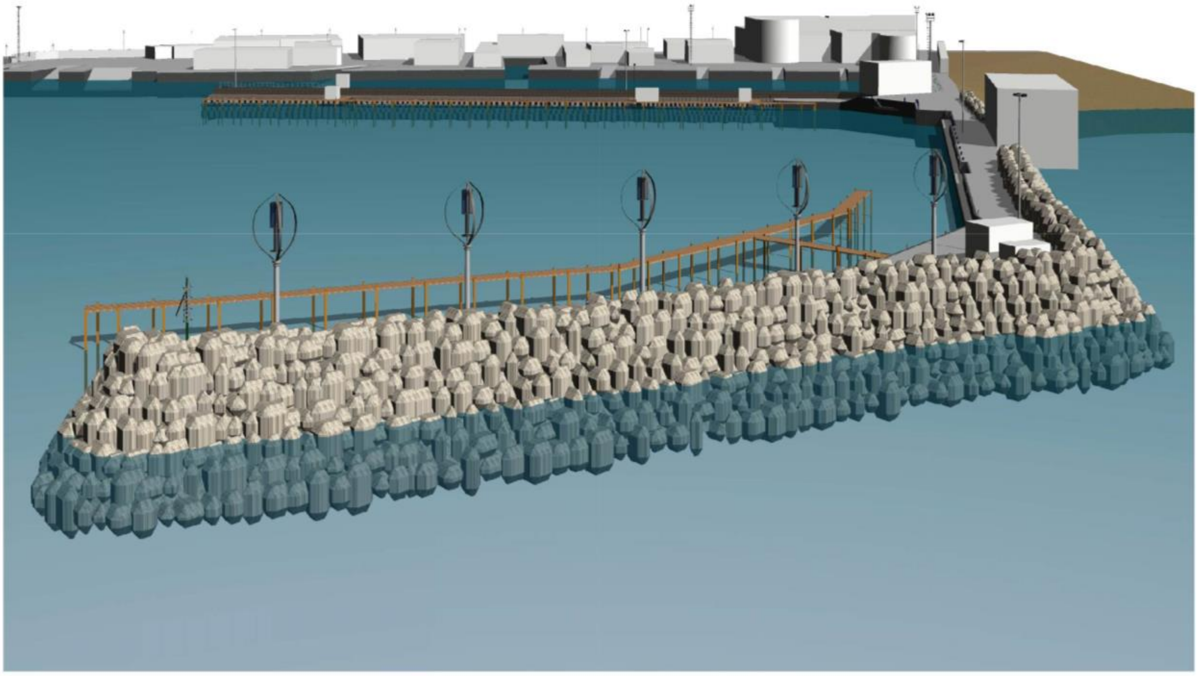

Figure 11. Turbines BIM Model.

3.2.2. PV system. Energy from “Solar Roadway”

Firstly, more than 40 years monthly data from the MERRA-2 reanalysis dataset have been used to evaluate and identify PV solar irradiation potential analysis of port areas with exciting potential to evaluate the solar irradiation potential (Figure 12, 13) for PV installation.

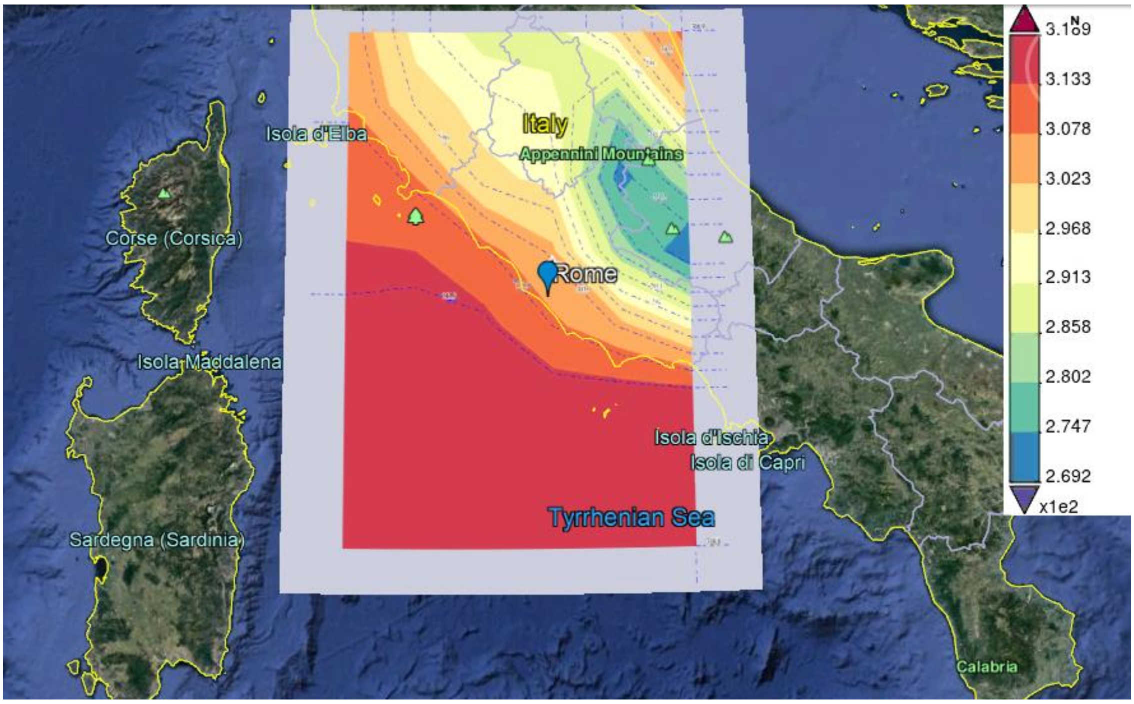

Figure 12. Solar irradiation in the Rome City and Anzio port showed with blue point for the years from 1980 to 2020.

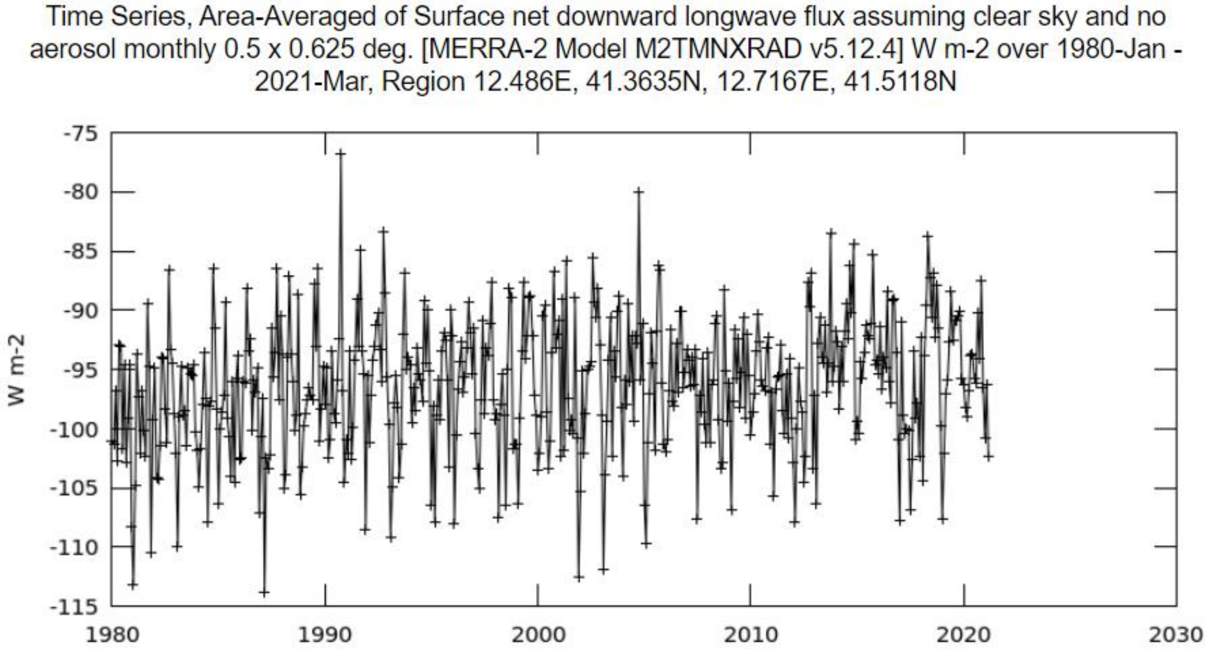

Figure 13. A monthly time-series analysis between 2019 to 2020 for the Anzio port showed.

Secondly, electric power production from a solar source should be performed by positioning a dedicated PV panel directly on the ground in some 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 [41][42][43]. For installing the photovoltaic modules, the area at the end of the Southern pier 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 red zone with arrow. As shown in Figure 14 it is possible to evaluate how the area covered by the modules is much smaller than that available areas about 2663 m^2.

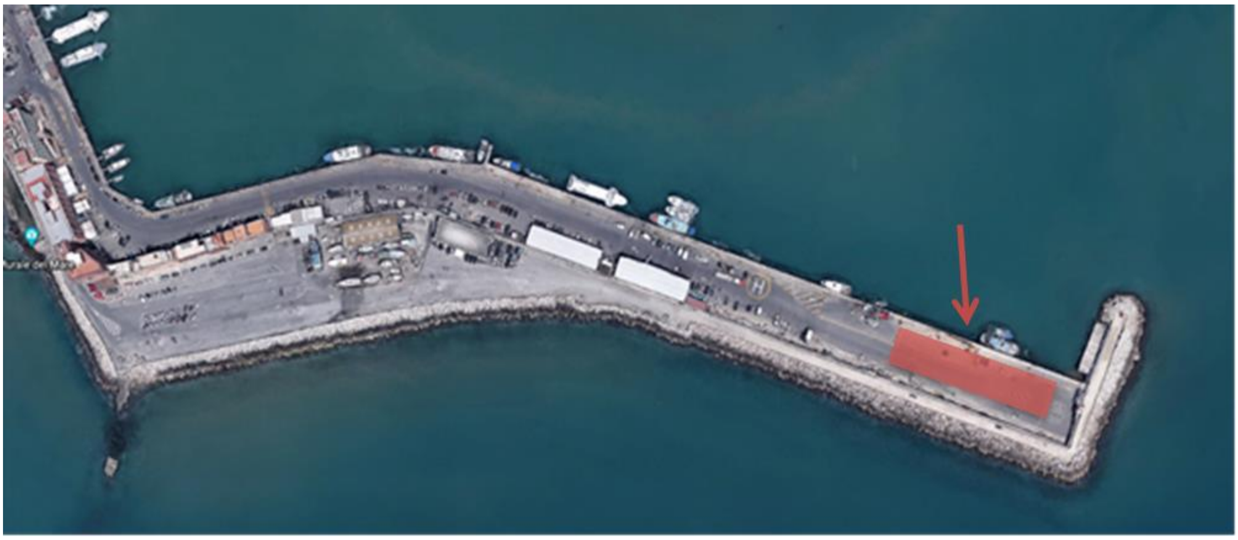

Figure 14. PV solar asphalt area.

Tables 5 show the PV monthly energy production values of solar radiation (kWh / m2 / day), AC energy (kWh) and value ($) for the selected area in the port of Anzio. These values are obtained using the PVWatt online platform. Finally, table 6 shows the PV system specifications of the Anzio port. This is necessary to understand better and demonstrate the performance of installed photovoltaic systems.

Table 5. PV monthly energy production.

Month	**Solar Radiation (kWh / m^2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	1.56	16,143	6,457
February	2.19	20,774	8,310
March	3.42	35,223	14,089
April	4.73	46,171	18,468
May	5.79	56,476	22,590
June	6.26	57,868	23,147
July	6.36	60,025	24,010
August	5.62	53,022	21,209
September	4.37	40,937	16,375
October	2.93	29,376	11,750
November	1.74	17,240	6,896
December	1.30	13,486	5,394
Annual	**3.86**	**446,741**	**$ 178,695**

Table 6. PV system specifications of the Anzio port.

DC System Size	399.5 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

4. DISCUSSION

In recent years, due to the rapid growth of science and technology on energy efficiency in ports, there are still significant research gaps, especially operational ones, that need to be addressed in future research. Energy efficiency is one of the hot topics of research that advances in existing technology directly affecting future research prospects [44]. In this case, innovative approaches, economic analysis [45], optimization of various operations, the effects of technological advances and management analysis will be the most important for future research of ports. Economic and environmental analysis for automated and electric ports are also necessary and inevitable [46]. 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 [47]. 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.

Managing sustainable energy development using renewable energy source is an emerging issue for ports [6]. In this regard, a conceptual framework for energy management systems, similar to the model in their construction, can be very effective [48]. Unfortunately, there are no studies analyzing barriers to energy efficiency in ports. These barriers to energy efficiency in ports include most of the technical, economic and regulatory aspects. There are also barriers to the supply of clean fuels and other technologies, so barrier analysis is invaluable to industry and academia. In the port industry literature, most technical reports explain the use of renewable energy sources. However, this literature lacks studies explaining economic contribution, durability, application, and best practices.

Furthermore, investing and developing in renewable energy sources is a big project. Such investments require careful economic investment analysis. Researchers can focus on intelligent grid analysis and evaluate smart grids operational and environmental performance through simulation tools. Balancing energy demand and energy supply in the smart grid is a complex task [49]. Since the supply of energy through renewable energy sources is mainly fluctuating, and it is challenging to predict energy demand due to the complexity of operations, mathematical analysis, artificial intelligence algorithms (deep learning and machine learning) to configure and design an intelligent network will be very positive. In addition, more research in the initial step should have high data quality to perform a successful analysis. The proposed DT framework is aimed at configuring a digital integrated and multi-scale database for simulation purposes, and it is intended to be integrated to real-time data from sensors and improving data management.

5. CONCLUSION

The project proposed represents the first phase of a digital transformation process of the coastal cities 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 rest of 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.

Predictive scenarios derived from data entered into a BIM and GIS environment within a sharing platform, with the creation and use of appropriate tools, the resilience of the urban fabric can be estimated. This allows planning in a well conscious way, respecting the environmental sustainability, the interventions aimed at the growth of economic, commercial and social activities. Critical from a design and then construction point of view is the accuracy of the cost estimate 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 of the place during their implementation. As a consequence, the digitalisation of the area, through this first implementation of the DT of the "Port of Anzio", makes it possible to start from the epicentre of this digital and ecological transformation, to spread throughout the territory, studying the exchange flows 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.

This digital transformation, with repercussions in all fields, will open new scenarios and higher efficiency in the management of public finances, especially in the area of the green deal. There will be substantial energy and environmental benefits already in the construction phase of the works. In fact, already 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 to minimise the project's costs through the simulation of different scenarios. This means monetary costs, environmental costs and social costs, not least those due to the uncertainty of construction times. This is a factor that scares off potential private, national, and international investors.

That can predict by adding more future factors of this study such as horizontal transport infrastructure, roads and railways; the parameters will significantly increase the volume of analytical data under study. Therefore, the analysis of this data amount with current methods will be very time consuming and complex. So, given the diversity of data, such studies require a rigorous data management method and analysis to define a digital structure integration approach. Therefore, to achieve this accurate understanding, artificial intelligence algorithms will be used for the development of this study in the next stages.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Francesco Nardi for the important contribution to the research team.

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