Towards Energy Self-Sufficiency: Supporting Port Energy Consumption with PV Panels Based on Historical Load Analysis

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Abstract

This article presents a comprehensive study for integrating photovoltaic (PV) systems into the energy infrastructure of the Port of Durrës, Albania, as a step toward achieving energy self-sufficiency, supporting green transition goals by reducing dependence from conventional energy sources. The study examines terrace potential, computes solar energy output, and analyzes through an experimental methodology historical energy consumption statistics for two important buildings: Administration (ADM1) and Financial Police (FP). On-grid PV topologies, inverter sizing, and a monitoring system enhanced with real-time data collection and visualization are all suggested in a thorough technical design. Annual energy production, return on investment (ROI), and payback duration are revealed by economic evaluation. Furthermore, the study demonstrates how modernizing port infrastructure and improving sustainability in maritime operations may be achieved by fusing digital innovation with renewable energy technology.

Keywords: *maritime industry, photovoltaic panels, renewable energy, smart port, energy transition, on-grid PV system, ROI analysis, IoT monitoring, port sustainability*

1. Introduction

Modern marine terminals face increasing demands for electric power (Sisson & Gauthier, 2019). Energy transition is one of the main priorities today in industry including maritime ports. It aligns with European Green Deal (Uyanık & Arslanoğlu, 2023) and international focus. The application of the solutions related to energy transition in port environments will make them more sustainable and more resistant to climate change and hazardous carbon footprint rates. A solution that supports aforementioned issues and is very suitable in ports is installation of photovoltaic panels, securing also a part of the energy use in autonomous way. Due to the favorable weather conditions in Albania, especially Durrës, there will be enhanced efficiency and reduced environmental impact (Sarkar et al., 2022). The research paper analyzes the energy situation in port of Durrës and describes a study how can it be supported with photovoltaic panels (PV). This paper is an advancement of my previous paper on possible renewable systems for energy efficient port, based on PV panels. The solar energy is applied experimentally and numerically. For performing this resarch as a first step there is done a visit onsite, in the port, and discussed with the staff of port relating to the possibilities of installation of the panels. A real world building –level study goes deeper and analyzes in details the system based on energy data consumption for 3 years, solar irradiance consideration and inclusion of technical system design like inverter application and monitoring system supported by IoT sensors. Through the paper will be presented the following sections that describe the pathway for designing the system: Section II explains the methodology and technical design used for the system Section III presents

PV analysis for the Durrës Port as case study. Section IV describes benefits and challenges followed by Section V Conclusions.

2. Methodology

The methodology workflow is presented in Fig. 1.

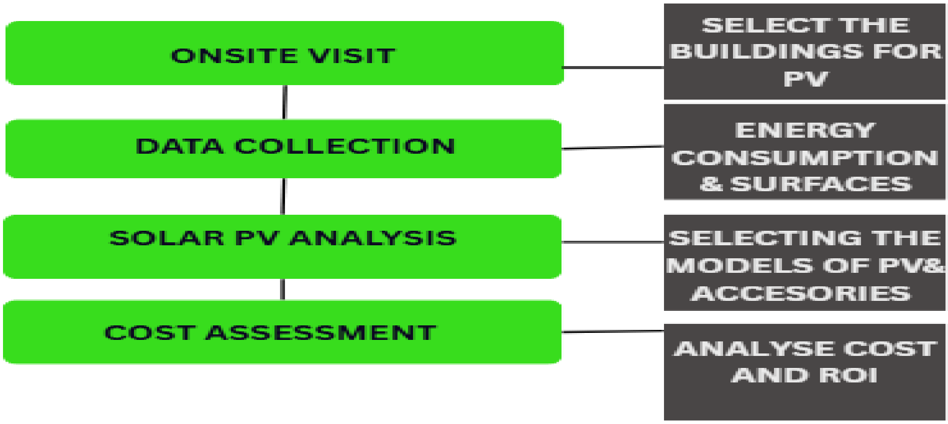

Figure 1: The diagram of the methodology for the design of PV system.

The second step is data collection on the consumption of the energy till 2024 and also getting information on the buildings like the surface of the terraces that will be used for the installation of the supplied PV panels. There are selected only two building that seem to be more appropriate for the study considering their geographical position toward the irradiance of the sun, importance and energy usage. The surface in their terraces are 539 m2 for the Administration building and 336 m2 for Financial Police building.

The estimation of the panels will be approximate and considered in theoretical scenario from the surface of the buildings terrace and the dimensions for standard panels 2*1 meters and power 450 W and in real –world scenario. In real-world scenarios must be considered layout, installation and utilization constraints. Panels have to be arranged in rows and columns, should have allowance for fire-code setbacks, aisles, and gaps to avoid shading. Also, should be considered and managed different obstacles that may be on the terrace and panels that may crossover the terrace. This study will consider both scenarios to generate a full panorama and to be as close to reality as possible, ensuring that the design reflects real-world installation practices. Approximately on the ADM 1 building terrace will fit 10 rows and 26 columns of PV panels with before mentioned dimensioned and on the terrace of Financial Police will be arranged 13 rows and 12 columns of the same PV panels.

The third step is the analysis of PV panels on the type, number and the required cost for them.

The forth step involves an analysis of the cost for the project considering the rates that Durrës port pays for energy and the band of the energy they take for calculations.

Fig. 2 depicts the buildings that will be equipped with PV panels that are called Administration and Financial Police.

Figure 2: Two buildings that will be equipped with PV panels.

Data of energy consumption collected from port records. The total yearly consumption for the years 2022 and 2023 is presented in the Table. 1.

Table 1. Yearly total consumption for the specified buildings in kWh .

Year	Administration buildings (ADM1) energy consumption (kWh)	Financial Police (FP) energy consumption (kWh)
2022	167809	48797
2023	175741	32468

The data will be used for the numerical analysis. Solar PV capacity is calculated using regional solar irradiance values in Durrës, Albania that rate (~4.5-5.0 kWh/m²/day) and system efficiency approximately (~80%) (Zeneli & Marinova, 2023).

3. Technical Design of the System

The system is designed to operate on-grid configuration.

PV modules are connected in strings of twenty panels in series and string are combined in DC combiner boxes (Tawfik et al., 2023).

There are used inverters, below will be explained the models and number, to convert the DC power produced by the panels to AC power. A monitoring system is suitable to enrich the system with real time information and to finalize with AC distribution and grid connection.

Fig. 3 presents the block diagram of the technical design proposed for two buildings in the port of Durrës.

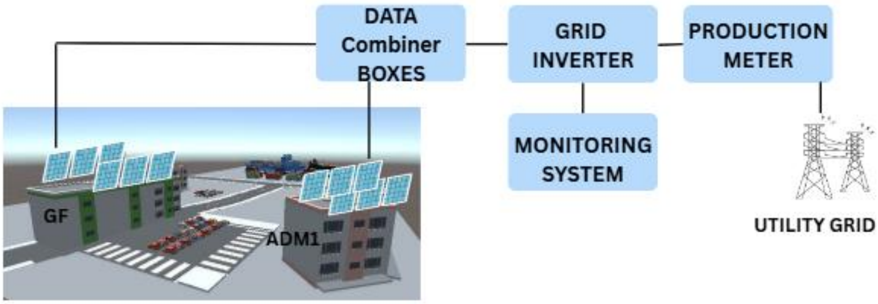

Figure 3: The block diagram of system design.

Following the stages of the design there are proposed the combination of the inverters as below for both buildings. For building ADM1 that is supposed to produce 121.05 kW will be used 3 × 40 kW or 2 × 60 kW inverters. For building GF that is supposed to produce 75.6 kW will be used Inverter 2 × 40 kW or 3 × 25 kW inverters.

The models of inverters that can be used are:

- Huawei SUN2000-40KTL-M3
- Fronius Eco 60.0-3-S
- Sungrow SG40CX
- SMA Sunny Tripower CORE1 STP 25-40

3.1 PV Panels Analysis for Durres Port as a Case Study

The main element of the system is selection of the PV panels that will be used. After a study in the region the most common used panels are the panels that produce 450W with area (~2 m²). The type of the panels selected are monocrystalline photovoltaic panels, due to their high efficiency and performance, especially in the countries with favorable solar conditions like Albania. For the areas of the buildings that will be covered by the panels Table.2 depicts the details and the number of the panels required in both scenarios mentioned above. Total area that needs to be covered for both buildings is 875 m².

Table 2. Details on the number of PV panels required for each building.

Terrace	Gross area (m²)	Usable area factor	Usable area (m²)	Panels = ⌊area/2.0⌋	Capacity @450 W
ADM1	539	100% (no gaps)	539.0	269	121.05 kW
		80% (dense flat)	431.2	215	96.75 kW
		65% (setbacks+aisles)	350.4	175	78.75 kW
		55% (conservative)	296.5	148	66.60 kW
Financial Police	336	100% (no gaps)	336.0	168	75.60 kW
		80% (dense flat)	268.8	134	60.30 kW
		65% (setbacks+aisles)	218.4	109	49.05 kW
		55% (conservative)	184.8	92	41.40 kW

After analyzing panel count and area requirements the situation is as below:

For the building ADM1 with a surface 539 m2 can be mounted 269 panels with 450W each.
For the building GF with a surface 336 m2 can be mounted 168 panel with 450W each.
The PV capacity produced in each of the building will be calculated as below:
For building ADM1
PV Capacity (ADM1) = 269*450W=121.05 kW

$$Annual\ Energy\ (kWh) = System\ Size\ (kW) \times Average\ Sun\ Hours\ per\ Day \times 365 \times Performance\ Ratio$$

Annual Energy (kWh) $ADM1 = 121.05 * 4.5 * 365 * 0.8 = 159059\ kWh/year$
For building GF
$PV\ Capacity\ (GF) = 168\ panels * 450W = 75.6kW$
$Annual\ Energy\ (kWh)GF = 75.6\ kW * 4.5 * 365 * 0.8 = 99.338$ kWh/year
Estimated annual cost savings considering the fact that port pays the energy €0.19 kWh are:
$Savings\ ADM1 = 121.050 * 0.19 = €22.999.5/year$
$Savings\ GF = 75.600 * 0.19 = €14.364\ /year$
Table. 3 presents the capacity, annual energy and savings for four usable area formats

Table 3. PV Capacity, annual energy and savings for four usable area formats

Building	Usable area factor(%)	No. of PV used	PV capacity (kW)	Annual energy (kWh/year)	Cost Savings (€/year)
ADM1	100	269	121.05	159059	€ 22.999
GF		168	75.6	99338	€ 14.364
Total		437	196.65	258397	€ 37.363
ADM1	80	215	96.7	127064	€ 18.373
GF		134	60.3	79234	€ 11.454
Total		349	157	206298	€ 29.83
ADM1	65	175	78.7	103477	€ 14.953
GF		109	49	64451	€ 9.31
Total		284	127.7	167928	€ 24.263
ADM1	55	148	66.6	87512	€ 12.265
GF		92	41.4	54399	€ 7.866
Total		240	108	141911	€ 20.52

3.2 Cost analysis of the panels

Approximately the cost of a panel 450W is €50-€70

Table.4 presents the cost for the total area covered considering the price of each panel €60.

Table 4. The cost of PV panels in details

Building	Usable area factor(%)	No of PV needed	The price of a panel	Cost
ADM1	100	269	€60	€ 16140
GF		168	€60	€ 10080
Total		437	€60	€ 26220
ADM1	80	215	€60	€ 12,900
GF		134	€60	€ 8,040
Total		349	€60	€ 20,940
ADM1	65	175	€60	€ 10,500
GF		109	€60	€ 6,540
Total		284	€60	€ 17,040
ADM1	55	148	€60	€ 8,880
GF		92	€60	€ 5,520
Total		240	€60	€ 14,400

The estimated costs for the inverters relating the combinations are prescribed below:
For ADM 1: $2 \times 60\ kW\ inverters \rightarrow €3{,}000\ each\ Total{:}\ €6{,}000$
Option 2
$3 \times 40\ kW\ inverters \rightarrow \sim€2{,}200\ each$
$Total{:}\ €6{,}600$
For GF: $2 \times 40\ kW\ inverters \rightarrow \sim€2{,}200\ each\backslash Total{:}\ €4{,}400$
Option 2:

$1 \times 60\, kW + 1 \times 20\, kW$
$Total: €3{,}000 + €1{,}200 = €4{,}200$

The next element of the design is the monitoring system which consists of several key components designed to ensure real-time performance tracking, system safety, and integration with advanced visualization tools (Demir, 2023), Gawre & Kekre, 2018). At the core is a smart data logger that collects data from inverters and optional environmental sensors, such as irradiance and temperature, which are essential for assessing panel efficiency and identifying anomalies. Digital energy meters track both the energy generated by the PV system and the building's consumption, enabling performance benchmarking and net metering. Communication is facilitated via Ethernet or wireless gateways, ensuring continuous data transfer to a cloud-based monitoring platform.

Fig. 4 presents the diagram with components of the monitoring system.

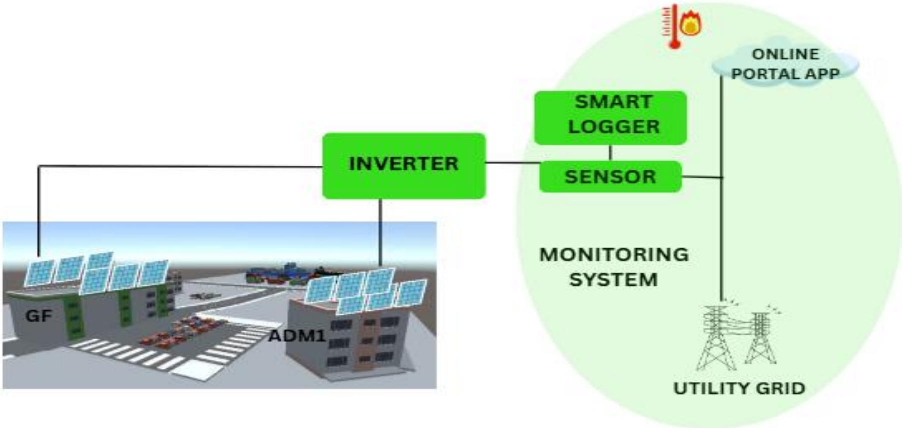

Figure 4: The diagram of the monitoring system

The estimated cost and the elements of the monitoring system is presented in Table.5.

Table 5. The cost of monitoring system.

Item	Estimated Total (Both Buildings)
Smart Logger (1 shared)	€600
Energy Meters (2 buildings)	€1,000
Optional Sensor Kit	€800
Wi-Fi/Ethernet Add-ons	€300
Optional Licensing/API Access	€400
Total Estimated Cost	**€3,100**

Another element that should be considered in the design of the system are the installation costs (Ministry of Infrastructure and Energy, 2024). There are different ways for calculating the installation cost like per day, per person, overall value of the project and per Watt which is the one that will be used in this study (Kayode & Amao, 2023, Gawre & Kekre, 2018). According to many sources the cost for the installations of PV panels varies **€0.35–€0.50 per watt (W)** including labor and accessories for panels 450 W each where the total size of system installation is 121.05+75.6=196.65 kW.

For the total capacity the cost is $196.65\, kW *\!- €0.50 = €98{,}325\, kW$

Panels: 450W each

3.3 System Size

- $Admin\ Building: 269 \times 450W = 121.05\ kW$
- $Guardia\ di\ Finanza: 168 \times 450W = 75.6\ kW$
- $Total\ system\ size = 196.65\ kW$

To make a balance about the investment there is Return of Investment (ROI) parameter that is a key factor in ports.

ROI= Annual Savings /Total investment) * 100%

Total installation costs for both buildings is calculated as below:

$Cost\ of\ PV\ panels + Cost\ of\ inverters + cost\ of\ other\ devices + installation\ cost = €26{,}200 + €10{,}200 + €3{,}100 + €98{,}325 = kW = 137{,}845\ kW$

$Annual\ Energy = 159{,}059 + 99{,}338 = 258{,}397\ kW/year.$

$Annual\ Energy\ Cost\ savings = 258{,}397\ kW/year * €0.19 = 49{,}095\ kW$

$\boldsymbol{ROI} = Annual\ Savings\ /Total\ investment) * 100\% = (49{,}095/137{,}845\ ) * 100\% = 29.6\%$

$\boldsymbol{Payback} = Total\ investment/Annual\ energy\ cost\ saving = 137845\ /49095 = 2.8\ years.$

ROI and Payback estimation for four rates of usable area factor are presented in Table.6.

Table 6. The ROI and PAYBACK evaluation for four usable area factors.

Building	Usable area factor(%)	No. of PV used	ROI (%)	Payback (years)
ADM1+GF	100	437	35.6	2.8
ADM1+GF	80	349	29.5	3.4
ADM1+GF	65	284	24.7	4
ADM1+GF	55	240	21.4	4.7

Fig. 5. represent the ROI and Payback chart.

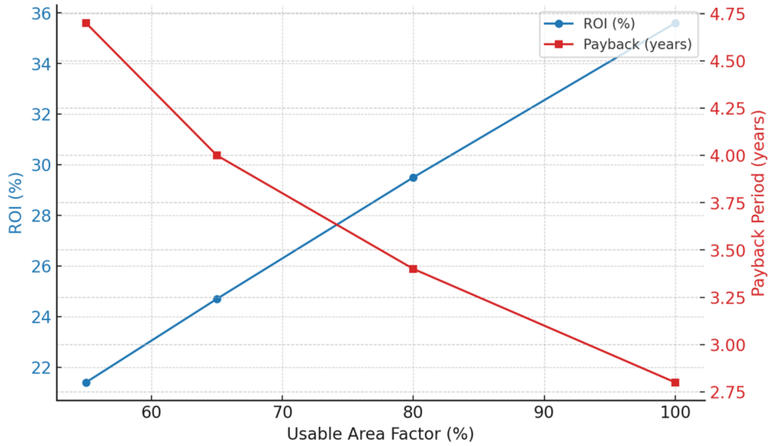

Figure 5: The ROI and Payback chart

It is necessary to clarify as is also mirrored in the formula above in the total capital expenditure (CAPEX) there is included the cost of the panel, installation cost, inverter costs, monitoring costs. There are not included operation and monitoring costs, grid-connection licensing costs, building structure costs.

In the design there is not included the aspect of the shorter time interval with sunlight during winter time, after 5 PM in Durres region, since I could not collect daily load profiles from the buildings.

3.4 Environmental impact

The designed PV system for the ADM1 and Financial Police buildings will produce about 215,338 kWh of clean electricity annually which compensates 81.8 metric tons of CO_2 emission yearly based on the emission factor 0.38 kg CO_2 per kWh (EEA, 2024), (EPA, 2024). This is equivalent with removing 18 passenger vehicles or planting 3700 trees each year [17]. These figures greatly improve the environment elements like local air quality, climate resilience. This also represents an overall alignment with Albania's National Energy, European Green Deal and Climate Plan (NECP) in a coastal city like Durrës (FAO, 2023), (European Commission, 2019), (Ministry of Infrastructure and Energy of Albania, 2023), (IEA, 2024).

4. Benefits and Challenges of Investment

The benefits of this investment are:

- Infrastructure modernization aligning port with most innovative technologies related to green transition.
- Energy cost savings with the energy generated by the PV panels.
- Improves the carbon footprint rate and makes a healthier environment (Kaur & Kaur, 2019).
- Short payback period.
- The system in the future can be extended to other buildings in the port or region.
- Economic, social, and environmental benefits are highlighted (Grebski & Maryniak, 2020).

4.1 The challenges as they are described are: (Samal et al., 2022).

- The investment should be pre allocated since is a considered amount.
- Coordination between authorities DPA, Ministry of Infrastructure and Electricity Distribution Operator (OSHE) (Ministry of Infrastructure and Energy of Albania, 2023), for the permission of installation and adjustments that should be done in the grid.
- Maintenance cost even are smaller to the costs of initial investment should be foreseen (Zucchi et al., 2022).
- Weather conditions considerations in design since there is a coastal and is exposed to humidity, salt, air, wind (Kayode & Amao, 2023).
- Technical expertise for designing the main parts of the project that is monitoring system (Ansari et al., 2021).

5. Conclusions

In order to support energy self-sufficiency and sustainability goals, this study shows that installing photovoltaic (PV) systems on two important administrative buildings at the Port of Durrës —ADM1 and Financial Police—is both feasible and strategically valuable. The suggested system design produces an estimated yearly energy production of over 215,000 kWh using historical consumption data, solar irradiance measures, and on-site evaluations. This results in a predicted annual cost savings of €40,914.

PV panel integration gives a rapid return on investment (ROI) of 35.6% with a payback period of only 2.8 years, being in line with European Green Deal goals. The technical solution is flexible enough to accommodate future expansions because it has scalable design features, on-grid inverters, and a real-time monitoring system.

Implementation will necessitate careful collaboration with pertinent agencies, investment planning, and maintenance methods to address typical environmental issues of coastal areas, notwithstanding the encouraging results. Future research should concentrate on improving tools for predictive energy analytics and port-wide energy management, incorporating real-time data, and extending the PV infrastructure to additional buildings.

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