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Eco-District, an Ideal Framework to Initiate Large-Scale Urban Energy Renovation in Morocco

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ABSTRACT

In the perspective of the large-scale application of the Moroccan Thermal Construction Regulations (RTCM) to existing buildings, eco-districts represent an ideal framework to initiate, test, and evaluate such an action. This study aims to present a methodological framework to improve the decision-making process for the energy upgrade of a future eco-district transformation. The case study of a neighborhood in northern Morocco shows that thermal insulation of buildings allows a significant reduction of energy needs that can reach an average annual gain of 52.72% compared to the existing situation. While installing PV systems on 50% of the roof surfaces allows a more critical improvement of the obtained gain: the average annual income in the case of monocrystalline PV can reach 108.14% and 94.87% for polycrystalline PV at the scale of the district.

Keywords: eco-district; energy renovation; solar cadastre; RTCM; GIS, urban scale.

INTRODUCTION

Today's world energy context is characterized by the strong dependence on fossil fuels, the impact of Carbon on climate change, and the scarcity of natural resources has become noticeable, clearly, through the natural disasters that continue to worsen in recent years. Moreover, the increase in energy demand and the instability of prices on international markets have a considerable impact on the evolution of world economies, especially for emergent countries such as Morocco. Consequently, the current global debate is focused almost exclusively on low-carbon transition policies and strategies, especially in urban planning (Cheshmehzangi, 2021), to rapidly reduce GHG emissions and energy consumption. Actions are needed now to address this global issue. The energy transition appears to be one of the promising solutions for confronting these climatic, ecological, economic, and social issues.

Given these challenges, cities are more than ever part of the solution. Consumption is closely linked to urbanization. According to the International Energy Agency, cities contribute to more than two-thirds of global energy consumption and more than 70% of GHG emissions (Energy, n.d.). Consequently, cities are positioned as major levers for a successful energy transition: eco-district/city approach, energy efficiency, urban integration of renewable energy, bioclimatic architecture, resource management, urban mobility optimization.

Over the past decade, the majority of developed countries have made important progress to accelerate the energy transition of their housing stock, but the case remains very limited for other developing countries, including Morocco.

In 2015, the Moroccan authorities approved the decree of the general building regulation setting the rules of energy performance buildings (RTCM). Establishing a classification of climate zones with thermal thresholds to be respected by new constructions. However, the new constructions subject to the regulations only represent an annual rate of 1.5 to 2% of the total existing building park, which implies that the current park will only be replaced when the buildings have reached the end of their life, i.e. 50 to 80 years or more. This makes it clear that a massive implementation of energy renovation of the building population is necessary to promote the energy transition of Moroccan cities. In this perspective, the public authorities are called upon to expand the current thermal regulations so that they cover all types of new and existing buildings. On the other hand, it is necessary as researchers and academics to contribute to the development of new approaches and methods to simplify the implementation of future revisions and regulatory complements.

Therefore, the eco-district represents an ideal framework to initiate, test, and evaluate such an energetic approach, because firstly, it must have its own energy supply to avoid ecological footprints, and secondly, it represents the basic unit and an appropriate intermediate scale to establish a multifunctional urban project adequate for sustainable development.

Similarly, the transformation into an eco-district must cross the criteria of sustainable development, particularly the expected environmental, economic, and social objectives. On the other hand, one of the key points of the sustainable transformation for the environmental component is energy management.

Energy efficiency is considered a key criterion for this type of urban development. Therefore, energy analysis should be carried out in advance to ensure optimal profitability, thus allowing for energy and urban planning adaptations.

This was observed for the two pilot eco-districts "Marchane Djemaa" in Tangier and "UNITE 4" in Marrakech which are currently under construction. Similarly, the state of the art reveals a remarkable lack of publications specific to the Moroccan context examining the modes of integration and evaluation of the impact of these energy solutions on eco-districts and districts more generally.

This paper's contribution is to present a case study to demonstrate to stakeholders the energy gains that can be made in an eco-district approach or in an energy renovation strategy for the Moroccan building stock, and consequently, implicitly encourage them to adopt these types of sustainable approaches. The case study was realized in the neighborhood of "Bouzaghlal" in the city of M'diq, Morocco, which is characterized by a type of residential housing, generally non-regulatory, that requires restructuring and urban rehabilitation.

This work attempts to fill the gaps by proposing a methodological approach to facilitate the decision-making process in terms of energy upgrading upstream of a future transformation of a neighborhood into an eco-district, allowing the evaluation of the energy impact of standard thermal insulation of building envelopes and the installation of photovoltaic systems on roofs at the scale of the district.

BACKGROUND

The approach to sustainable urban development is considered to be different at each territorial level. Therefore, sustainable development must be defined for each of these scales. At the city level, researchers focus on one or several aspects at the same time. Several research issues have been established, including the self-sufficient city (Morris, 2008), the dynamic city (Camagni & Gibelli, 1997) where researchers focus on the integration of economic exchanges in the dimensions of sustainable urban development, and the coherent city (Haughton & Hunter, 2004) which seeks to ensure spatial, environmental, economic and social coherence at once. A sustainable city is a system that integrates the economic, environmental, social, and cultural dimensions, and that meets three main objectives, habitability, sustainability, and resilience, for example, the habitable city of Vancouver in Canada.

At the district level, the approach consists of deploying development projects adopting an environmental approach that includes 1) new construction projects for sustainable districts, 2) urban renewal projects, and 3) operations on buildings and landscaping of public spaces. The three above-mentioned approaches have the common objective of setting up a new type of development: the eco-district.

The eco-district is a sustainable neighborhood designed or renewed that aims to implement a project approach focused on responding at its scale to global and local sustainable development issues, giving rise to an economically efficient, ecologically sustainable, and socially equitable urban ecosystem (Machline et al., 2018).

International background

The application of sustainability concepts at the scale of neighborhoods is mainly concentrated in Europe, dating back to the 1980s as a consequence of the oil crisis. From an energy perspective, the approach is generally based on three fundamental concepts, namely, renewable energy, bioclimatic architecture, and energy conservation. We recall some first eco-district: the eco-district of Darmstadt-Kranichstein (Germany) which had the first passive house in the world in 1988, and the eco-district of Hanover-Kronsberg "EXPO 2000 Project" (Germany), the eco-district Vauban built-in 1996 in the south of the city of Freiburg im Breisgau (Germany) consisting of 68 dwellings rehabilitated by homeowners associations, the buildings of the district are designed lengthwise with roofs oriented to the south and covered with solar panels. The eco-district Bo01 was created in 2001 in Malmö (Sweden) powered by 100% renewable energy and equipped with large green spaces and a network of electric buses. The district of Linz (Austria) is powered by solar energy. The Beddington eco-district was built in 2002 on a former landfill in Sutton (UK) well insulated and powered by solar panels, the example of "ZAC DE BONNE" in Grenoble (France) launched in 2003 composed of 40% low energy social housing and powered by solar thermal panels. The Drake Landing Solar Community (DLSC) in Okotoks (Canada) was built in 2007 with 90% of annual heating needs covered by solar energy. The Eco-Viikki in Helsinki (Finland) is composed of 600 dwellings of various typologies on 40 Ha following ecological construction techniques, solar energy meets 15% of the heating needs for the whole district, and many others (Codispoti, 2021).

The state of the art conducted by the authors (Grazieschi et al., 2020), (Bottero et al., 2019) revealed that globally, scientific production related to the issue of eco-district sustainability is not evenly distributed among the different regions, with the majority of studies concentrated in Europe (especially Northern and Western Europe), North America, Central America, the United States, and the United Kingdom. Africa, the Middle East, South America, and South/East Asia are ranked last due to their low contribution to studies on neighborhood sustainability.

Indeed, successful international experiences can represent a source of inspiration, a framework, and an important learning base for developing countries including Morocco, but this does not prevent eco-districts from being designed taking into account the local context. Because the eco-district concept in developed countries cannot be generalized directly, it must emerge from the local context Ref (Khemri et al., 2021).

Moroccan background

Throughout the last decade, sustainable urban development has gained importance in urban planning and land use in Morocco, several urban projects labeled "sustainable" or "ecological" or "green" and at different scales are implemented namely: on the urban level at the scale of cities such as the green city of "Benguérir", the new green city "Chrafate", the eco-city "Zenata" or at the scale of urban projects such as the pilot eco-districts of "Sabila Djemaa" in Tangier and "UNITE 4" in Marrakech which are part of the national program of sustainable urbanism (maroc. ma, n.d.)

The eco-district projects mentioned above are characterized by the intervention of existing urban fabric. The strategy adopted is to transform these areas into eco-districts by operating on four main axes: mobility, mixed urban, nature, and liveability. The project is made up of a set of recommendations and proposals aimed mainly at improving the living environment through development actions in terms of mobility (accessibility, roads, intermodality, public transport) and common living spaces (landscape, socio-community facilities). While for the energy component, two axes are addressed namely:

- Public transport by promoting the use of electric and hybrid vehicles among public actors.
- Public lighting by promoting the use of low consumption lamps that can be powered with clean electricity produced by photovoltaic plates.

Unfortunately, the axis related to energy efficiency in buildings has not been taken into account in the action plan. This is probably because:

- The buildings are already existing, as opposed to the new ones which will already comply with the RTCM
- The energy renovation is costly for households given their low purchasing power and especially in the absence of national energy renovation programs or financial aid for this type of operation
- The lack of expertise since this is the first experience on a national scale aiming at transforming districts into eco-districts.

The Key measures to be taken when transforming a district into an eco-district include optimizing the energy use of buildings and adopting low-carbon sources. This can be achieved through energy retrofits of the building envelope using renewable energy resources such as solar energy rather than fossil fuels. Furthermore, these actions should be considered in the pre-project planning phase (Mneimneh et al., 2017) and carried out according to sustainable practices standardized in certification frameworks such as LEED for Neighborhood Development and the Eco-districts protocol or others (Grazieschi et al., 2020), (Ramiller, 2019). Similarly, an assessment of owner preferences (Ebrahimigharehbaghi et al., 2021) and needs should be conducted to identify key parameters to consider when designing and sizing the energy plan (Marinakis et al., 2017).

Keeping the study limited to the Moroccan context, the bibliographic search performed in the scientific databases Google Scholar and Scopus used different keywords including RTCM, urban scale, large scale, renovation, archetypes, energy simulation, GIS, urban modeling, energy efficiency, eco-district, sustainable district, green district, zero energy, eco-urbanism... revealed that there is a considerable lack of specific publications on this topic, none of the research to date proposes integrated planning and energy assessment approaches upstream of the design process of a Moroccan eco-district. Similarly, according to the state of the art conducted in the framework of the Ref study (Echlouchi et al., 2022), no study has addressed the energy renovation of buildings at the district level. The majority of studies are limited to the building scale.

Generally, the energy renovation of buildings in the framework of an eco-district approach can be achieved by applying a set of energy efficiency measures according to two approaches; 1) active approach is based on the implementation of photovoltaic or thermal energy production systems, intelligent systems of measurement/monitoring and control of energy use, and 2) passive approach concerns the change of thermal characteristics of the building envelope by insulation to minimize heat losses, as well as the reduction of the consumption of heating and ventilation equipment. In the framework of this study, we limit ourselves to standard thermal insulation according to the Moroccan thermal regulation (RTCM) coupled with the installation of photovoltaic systems on the roofs of the buildings.

From this perspective, this article aims to assess the applicability of sustainable practices including thermal insulation and solar energy in a process of transformation of a district into an eco-district. While examining the following research question: To what extent does thermal insulation according to RTCM specifications combined with the integration of photovoltaics on the roofs minimize the energy needs for cooling and heating at the scale of a future eco-neighborhood in the Moroccan context?

PROBLEM APPROACH

The methodological framework designed in this study is based on a bottom-up approach and uses GIS tools for the processing and multi-scale visualization of the obtained data. The approach combines physical and statistical (gray box) methods, first to segment the building stock into different archetypes to simulate the energy needs for cooling and heating of all the buildings in the district, and then to calculate the solar radiation received by the roofs of the buildings which will be exploited for the estimation of the electrical production in the case of a photovoltaic unit installation. Then, the evaluation of the generated savings and the obtained electrical gains allows one to determine which ratio of surfaces to install in PV at the district level to improve the RTCM thermal insulation scenario and to determine the corresponding energy gains.

The methodology followed consists of five main phases:

1. Data and geometry modeling
2. Calculation of annual energy requirements for heating and cooling and annual savings generated
3. Calculation of roof electricity production from solar potential
4. Evaluation of energy balance
5. Mapping and vulgarization results.

Figure 1 shows the organization and sequence of these different phases. Each phase consists of a set of steps to be carried out. Summaries of each are described in the next paragraphs.

Data and geometric modeling

First, this process consists of collecting data on the building stock from different sources and of different types (geometric and alphanumeric), and then all the data will be stored in a GIS database. The data will be used in the next two steps for the energy simulation of thermal insulation and for the estimation of the roof potential.

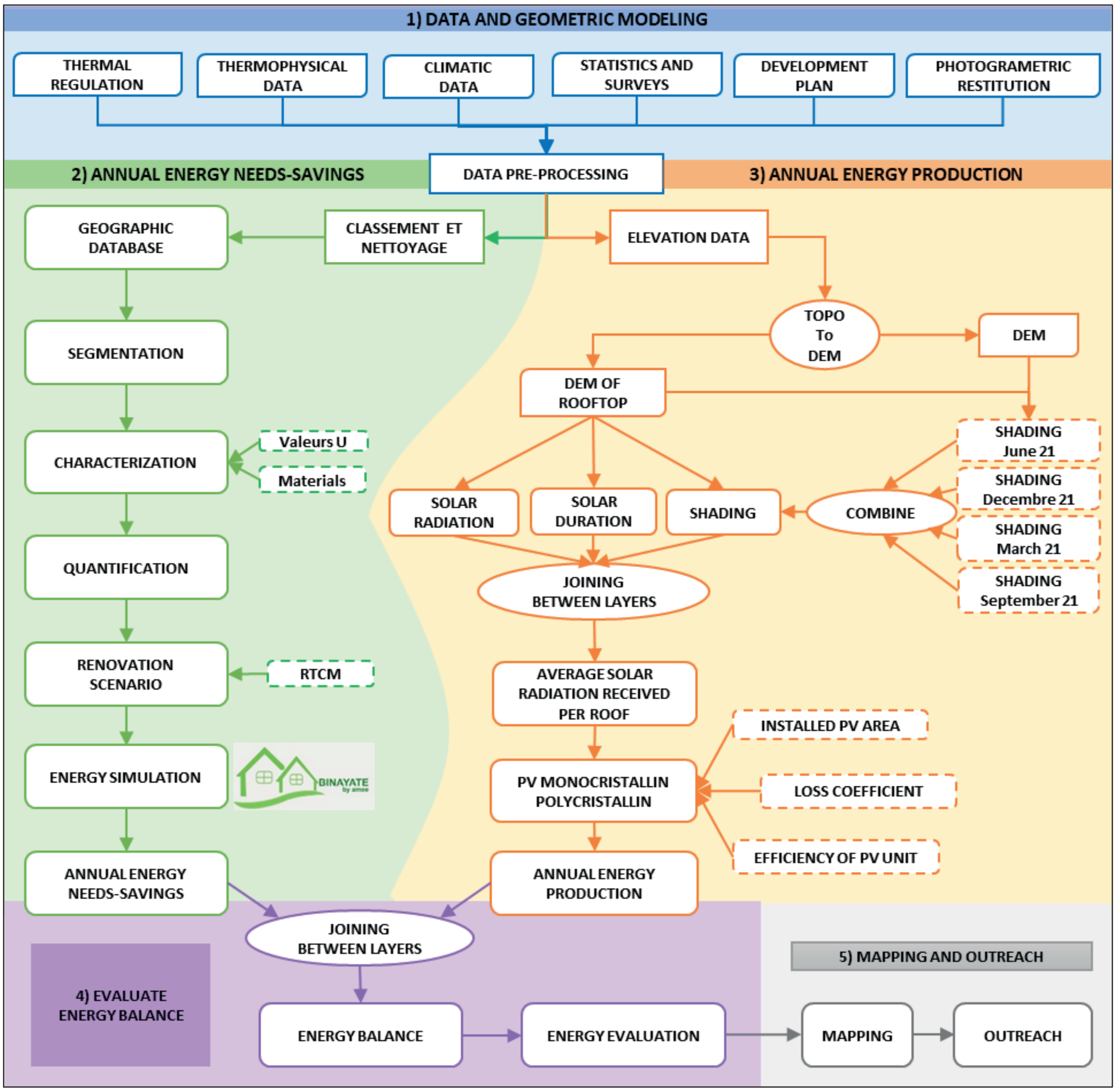

Figure 1. Methodology

The designed GIS database allows access to information about each building in the district such as roof height, number of floors, building area/volume, dimensions, and transmission U-values for each envelope component (roof, facades, windows, floor/lower floor), number of facades, road right-of-way.

It is also possible to generate in this step 3D models (LOD2) of the buildings, this geometric modeling is usually easy to generate with 3D GIS tools, which allows enriching the methodological framework. On the other hand, a statistical analysis (graphs, density map, ...) can be performed to extract trends and graphical summaries of the district.

Annual energy needs-savings

In this process, the methodology designed by Ref (Echlouchi et al., 2022) for pre-and post-thermal insulation energy analysis of buildings under RTCM regulations is used to determine annual cooling and heating energy requirements at the district scale. The approach taken is based on the idea of simulating about 10 representative archetypes of the district rather than hundreds of buildings, which significantly minimizes the modeling and simulation time required for each building in the district.

The segmentation of the district's buildings into archetypes is done through the process of clustering the geometric, typological, and thermal data of the buildings using the K-Means++ algorithm.

Then, the characterization step requires the definition of building materials and thermodynamic parameters (U-values) of each element of the envelopes of the district archetypes (roof, facades, bay windows, floor/low floor). Thus, from the thermal conductivities of the different building materials from the BINAYATE material library (AMEE, 2015) cataloged by the Moroccan Agency for Energy Efficiency (AMEE), the thermal transmittance (W/-K) is calculated according to the following formula:

$$U = 1 / Rt$$

$$Rt = Rsi + R1 + R2 + \quad (1)$$

$$+ R3 + \ldots + Ri + Rse$$

where: Rt – total thermal resistance ($\text{-}K/W$);
Rsi – thermal resistance of the interior surface;
Rse – thermal resistance of the external surface;
$R1, R2, R3, Ri$ – thermal resistance of layers, with: $R = T/\lambda$; T – the thickness of the material (meter); λ – the thermal conductivity.

The exploitation of the GIS database allows for quantifying and classifying each building of the district according to its corresponding archetype and then assigning its previously defined characteristics (typology, materials, U, volume, surface). This makes it easier to extrapolate the results of the energy simulation to the district.

At this stage, archetypes representing all the geometrical and thermal characteristics of the district are elaborated. They will then constitute the basic elements for the energy simulation of the energy needs.

To fit the Moroccan context of the study, the energy simulations of the said archetypes are performed using the BINAYATE software (AMEE, 2015). The simulation results constitute the initial baseline scenario.

This step allowed us to define a so-called "reference" scenario that provides a vision of the hypothetical cooling and heating energy consumption profile of the district as it is without the implementation of energy insulation actions. It is through this "baseline" scenario that we can evaluate the impact of the actions recommended in the improvement scenario.

To carry out the RTCM in 2015, the Moroccan territory is divided into six climate zones based on the examination of climate data collected from different weather stations. The following approach has been adopted on the criterion of the number of degree days winter/summer. The results of the simulations and the optimizations of the annual thermal needs of buildings corresponding to the minimum technical specifications to be respected in six Moroccan cities representing the six climatic zones of the country are summarized in Table 1.

It should be noted that our case study is located in the Z2 climate zone. According to the table below, we consider that the annual energy needs obtained by the thermal improvement of the so-called "reference" scenario are equal to 46 KWh/m²/year. Therefore, the difference between the energy needs of the two reference scenarios and the application of the RTCM represents the annual energy savings.

Annual electricity production

GIS-based and 3D modeling approaches are the most accurate at the urban scale for estimating the potential solar irradiation received by all building roofs. They are based on three-dimensional models generated from photogrammetric or LiDAR data that offer accurate determination of roof characteristics, including area, slope, orientation, and shadowing.

The link that can be consulted below in Figure 2 represents the solar cadastre of M'diq (Echlouchi et al., 2018), it was among the first experiences of applying this approach to a Moroccan city.

Table 1. Minimum technical specifications of Moroccan climatic zones according to RTCM

Climate zone	City representing the climate zone	Minimum technical specifications kWh/m²/year (Residential)
Z1	AGADIR	40
Z2	TANGIER	46
Z3	FES	48
Z4	IFRAN	64
Z5	MARRAKECH	61
Z6	ERRACHIDIA	65

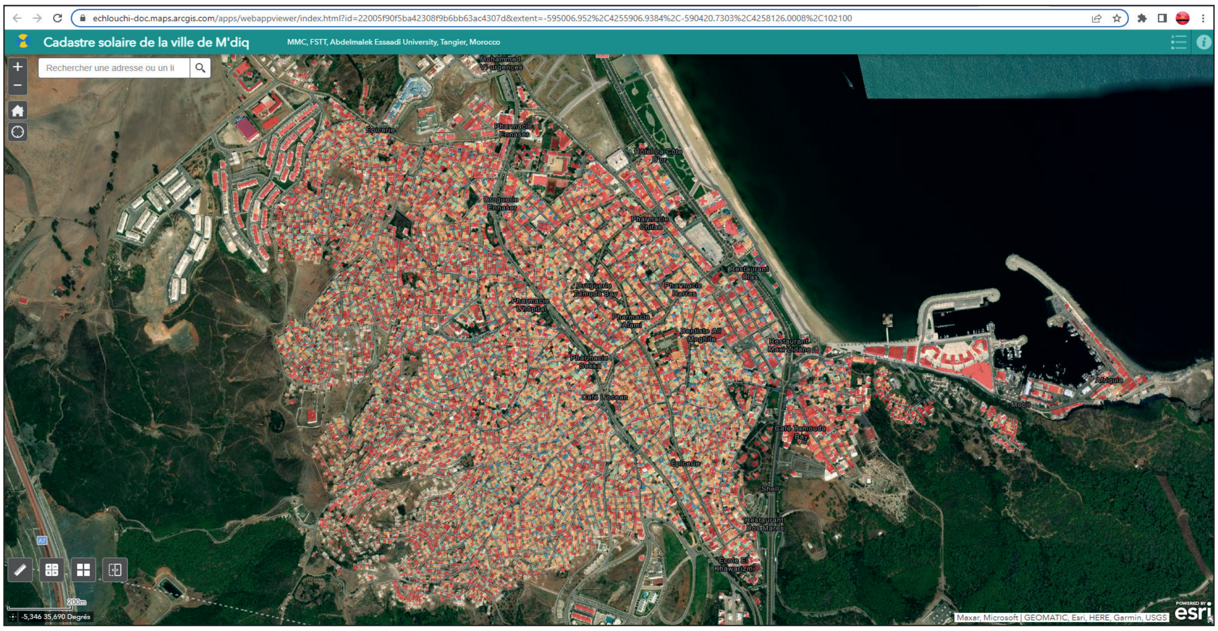

Figure 2. Solar cadastre of M'diq, Solar Cadaster Link [https://echlouchi-doc.maps.arcgis.com/apps/webappviewer/index.html?id=22005f90f5ba42308f9b6bb63ac4307d&extent=-595006.952%2C4255906.9384%2C-590420.7303%2C4258126.0008%2C102100]

In this phase, the methodology developed by (Echlouchi et al, 2018) is adopted for the calculation of the solar irradiance of each roof in the district. The method consists of creating a digital terrain model and generating the roof height model. Then, the annual average solar irradiance of each roof is calculated based on the Solar Analyst model (Fu, 2000). In addition, an analysis of the incident shading on the roofs is used to determine the far shading masks (terrain) and the near shading mask (adjoining building).

It should be noted that the roof surface is not taken into account in its entirety for the photovoltaic installation because of its high cost, which depends on the surface and the number of units. Thus, to evaluate the impact of PV system areas on the rooftop electricity production and final gains of the district, we vary the area of the PV units by 10%, 25%, and 50% of the roof area, then we calculate the equivalent electric production.

The estimation of electrical production is performed for both PV panel technologies, namely monocrystalline PV and polycrystalline PV. The electrical production for each roof is given by the formula given below:

$$P_{PV} = Ir * R * C_p * A_{PV} \quad (2)$$

where: P_{PV} – annual electrical production kWh/year;
Ir – average solar radiation per m² received by the roof of the building;
R – PV unit efficiency (R_{Mono} = 21%, R_{Poly} = 16%);
Cp – loss factor (0.90);
A_{PV} – installed PV area (A_{pv} = roof area * installed ratio).

Evaluate energy balance

This phase aims to analyze the energy impact on the heating and air conditioning needs in the case that an energy retrofit scenario is adopted according to the RTCM regulation coupled with the installation of PV units. Furthermore, to estimate the energy gains obtained concerning the reference state according to the surface of the PV units installed on the roofs.

The GIS environment allows overlaying the map of the results obtained by the PV electricity production and the map of the energy savings obtained by the thermal insulation of the buildings. The spatial join between the two maps groups all the results in the same attribute table. This facilitates the subsequent evaluation of the energy gains of the whole active and passive energy renovation operation (RTCM + PV) compared to the initial baseline scenario. The estimate of the average energy gain can be calculated according to the formula below:

$$\text{Gain (\%)} = \frac{(BE_{ext} - BE_{rtcm}) + P_{PV}}{BE_{ext}} * 100 \quad (3)$$

where: gain (%) – estimated energy gain;
BE_{ext} – energy requirements existing state;
BE_{rtcm} – energy requirements for the renovation scenario (RTCM);
P_{PV} – electrical production of photovoltaic units.

Expected benefits

The expected benefits of thermal insulation of building envelopes and installation of PV on the roofs of the district are related to three main indicators:

- Energy saved/self-produced (KWh/year): this is the amount of energy saved and not consumed compared to the baseline scenario, thanks to the thermal insulation and/or the amount of self-produced photovoltaic energy.
- Cost savings (MAD/year): it is the economic balance directly linked to the energy savings resulting from the thermal insulation and/or the self-generation of electricity from PV.

$$EC = EE \times C_{electricity} \times (1 - T_{costs}) \quad (4)$$

where: EC – total cost savings;
EE – total energy savings;
$C_{electricity}$ – Average electricity price (1.20 MAD /kWh);
T_{costs} – annual maintenance and operating cost rate estimated at (3% for PV and 2% for thermal insulation).

Electricity billing in Morocco is structured around six pricing bands that depend on the number of KWh consumed. In this article, the average electricity price of the six bands is used for the calculations.

This formula for calculating the savings used in this research is indicative, it does not take into consideration the initial investment, the life cycle of thermal insulation materials and solar systems, and the rate of price inflation.

CO_2 savings (kg CO_2/year): this is the environmental benefit equivalent to each KWh of energy saved and/or self-generated obtained through a CO_2 emission factor:

$$ECO2 = EE \times F_{CO2} \quad (5)$$

where: ECO_2 – CO_2 emissions savings;
EE – energy savings;
F_{CO_2} – CO_2 emission factor (0.74 kg CO_2/kWh).

It should be noted that these indicators are calculated at both the building and district levels. All the results will be published via a web mapping application allowing to consult these data and indicators for each building of the district.

Mapping and outreach

The digital mapping of energy retrofit scenarios represents, on the one hand, a decision support tool for actors and authorities in charge of the study of energy retrofits in eco-districts; and on the other hand, a tool to boost citizens to get involved in the process of transforming districts into eco-districts. The maps of renovations carried out can be used as a means of communication and vulgarization of energy information that can be consulted via geoportals (Echlouchi et al., 2020).

STUDY AREA

The case study was carried out in the district "Bouzaghlal" located in the north of M'diq city in Morocco (latitude: North 35.6853, longitude: East -5.32744) see Figure 3.

The district belongs to the climatic zone Z2. It represents a suitable example to apply an eco-district approach, it is a recent district located on the outskirts of the city and spreads over a total area of 45 ha of which 11 ha is occupied by residential buildings. It is characterized by a type of habitat "modern Moroccan house" generally non-regulatory requiring restructuring and urban rehabilitation.

RESULTS AND DISCUSSION

Energy production

Figure 4 represents the results of the estimation of the annual irradiation received by the roofs of the district "Bouzaghlal" which depends on several parameters such as position, height, the orientation of the roofs, shading generated by adjacent buildings. The descriptive statistics show that 66.30% of the annual irradiation received by the district is between 1200 kWh/m²/year and 1321 kWh/m²/year, while the average annual irradiation is equal to 1201 kWh/m²/year with an important global solar potential of about 1.44 GWh/year which corresponds to a roof surface of 12.37 ha.

The results of the estimation of annual irradiation received by the cities of Casablanca

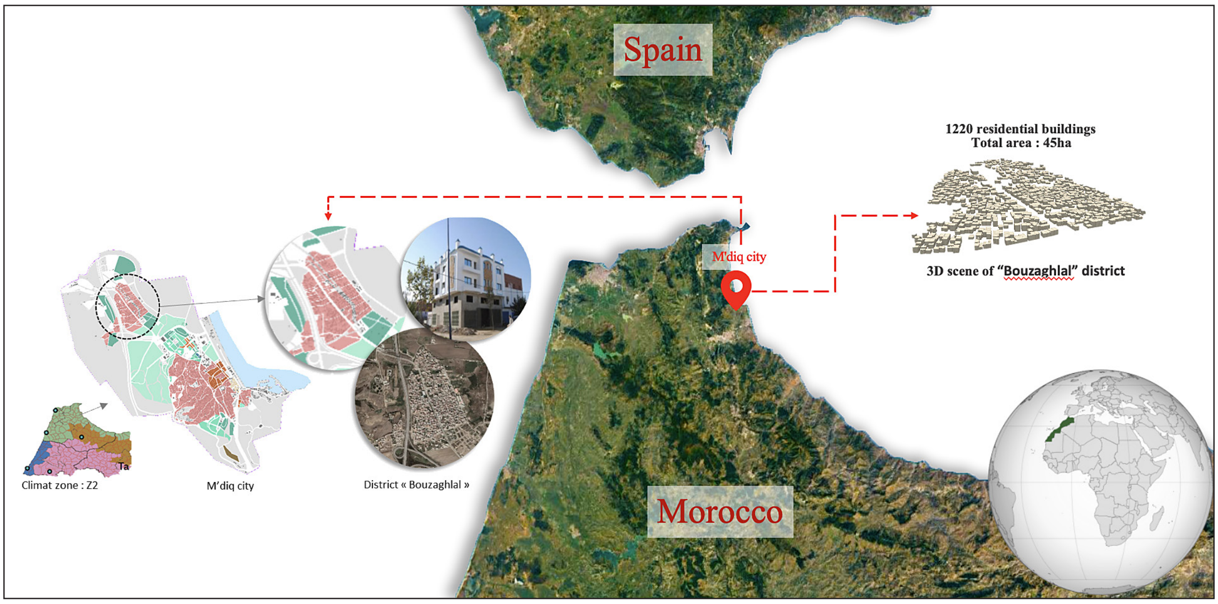

Figure 3. Study area

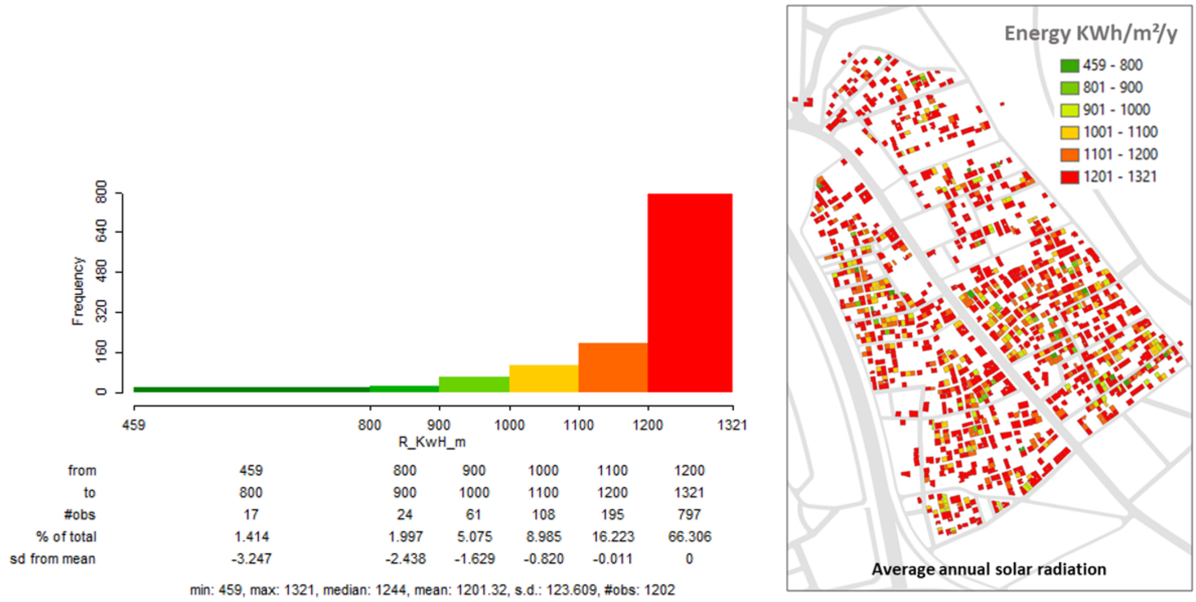

Figure 4. Annual irradiation received by the roofs of the "Bouzaghlal" district

and Nador (El-Bouzaidi et al., 2018), (Soubki et al., 2020), (Achbab et al., 2022), (Lambarki et al, 2020) with the results obtained in this study and the article (Echlouchi et al., 2018), we notice that the range of values of calculated solar irradiation received by the roofs of these cities is very close, they vary in a range of 500 to 1400 kWh/m²/a. The small differences found can be explained by the accuracy of the input data, the methodology followed, and the factor of the climatic zone (Z1 for Casablanca, Z2 for M'diq, and Nador).

Table 2 and the maps in Figure 5 show the distribution of the amount of electricity produced by the roofs of the "Bouzaghlal" district for ratios of 10%, 25%, and 50% of the total roof area according to the type of photovoltaic panels.

The results show that the difference between the productions of the two types of PV (Monocrystalline and Polycrystalline) becomes more important with the big ratios installed compared to the small ratios: It is noticed that there is a slight difference between the two types of PV for the ratio 10% of the order of 674,12 MWh/year on the other hand for the ratio 50% the difference becomes very important of the order of 3370,57 MWh/year. This shows that on a large scale, PV-Monocrystalline is a

Table 2. Electricity production according to the ratio of the surface and the PV technology of the district of "Bouzaghlal"

Total roof area (m²)	PV installed area (%)	Installed PV area (m²)	Electricity production PV Monocrystalline (MWh/year)	Electricity production PV Polycrystalline (MWh/year)	Differences between the productions (MWh/an)
123771	10	12377.10	2831.28	2157.16	674.12
	25	30942.75	7078.20	5392.92	1685.28
	50	61885.50	14156.40	10785.83	3370.57

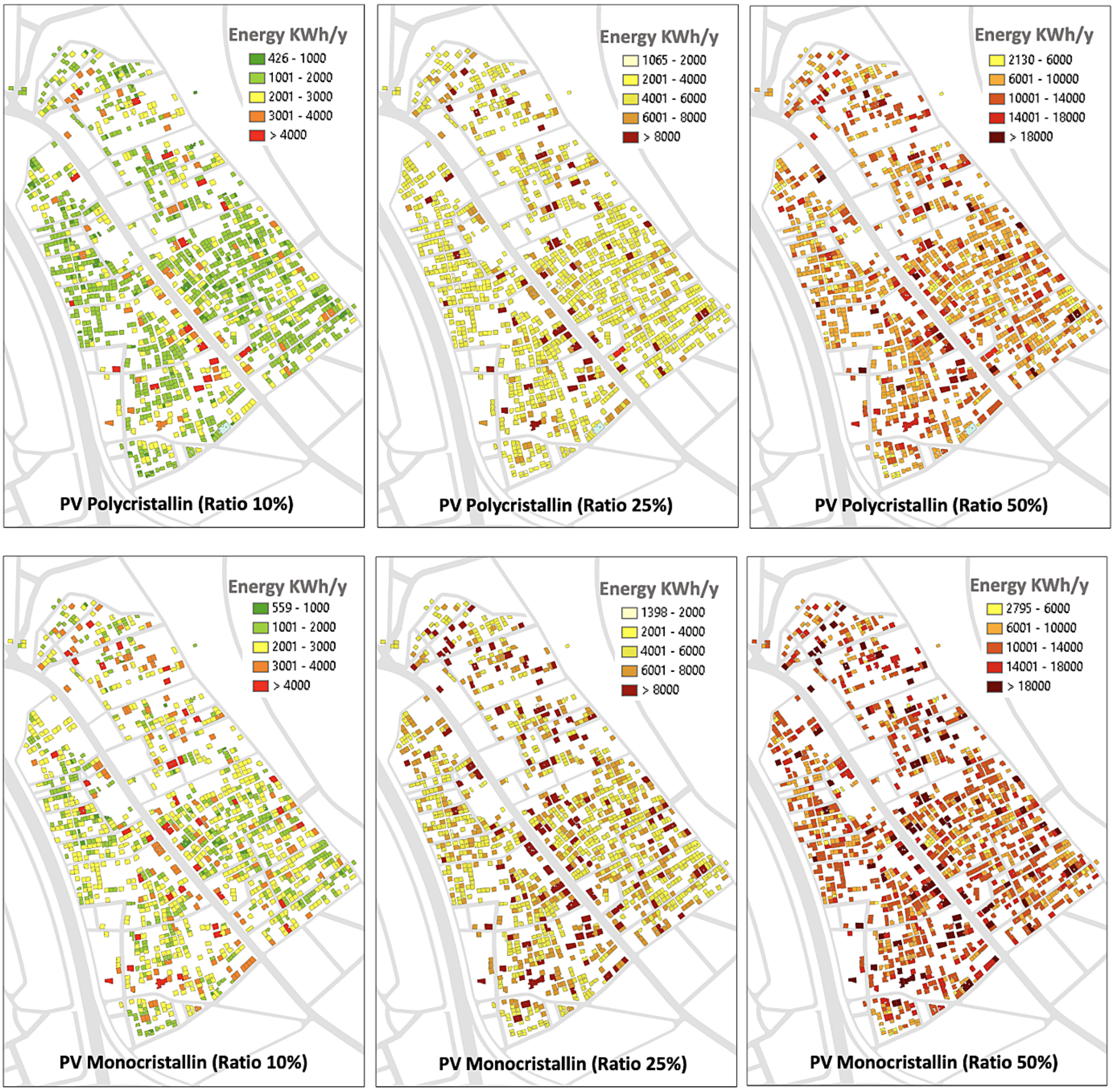

Figure 5. Spatial distribution of electricity production by area ratio and PV technology in the "Bouzaghlal" district

highly recommendable solution from a performance point of view and since the initial installation costs between the two are close to the gains obtained for a lifetime of 25 or more.

Energy savings

Maps in Figure 6 show results of the spatial distribution of energy needs of each building in the district before and after thermal insulation

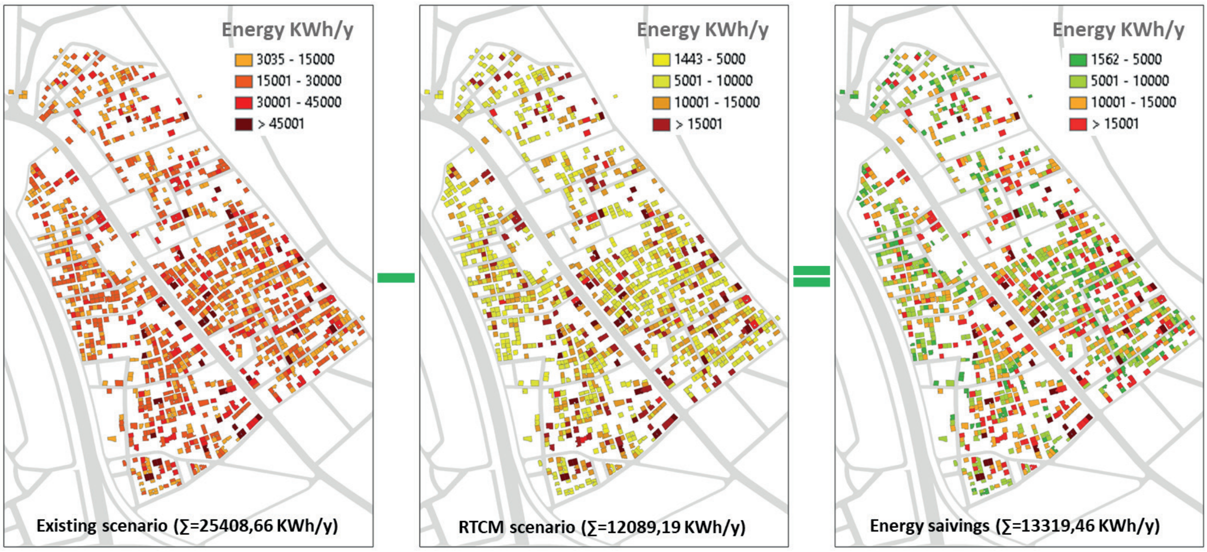

Figure 6. Spatial distribution of energy needs (heating and cooling) and savings achieved

according to the RTCM regulations and the energy savings obtained.

The results obtained show that the energy renovation, in particular the thermal insulation of the buildings of the district according to the thresholds required by the RTCM, allows a significant reduction of the heating and air conditioning needs which may reach an average annual gain of 52.72% compared to the existing situation, equivalent to 13.32 GWh of energy savings at the scale of the "Bouzaghlal" district.

Evaluation of energy gains

The amount of energy saved, the photovoltaic electricity production, and the energy gains obtained from the buildings in the district are summarized in Table 3.

The results show that the installation of the photovoltaic systems allows a greater improvement of the thermal insulation, the average annual gain at the level of the whole district for the case of Monocrystalline PV improves up to 108.14% if 50% of the roof surfaces of the district are equipped with PV units and 94.87%, 73.65% for roof ratios of 25% and 10% respectively. Similarly, for the Polycrystalline PV type, the results give average gains of 94.87%, 73.65%, 60.91% for roof ratios of 50%, 25%, and 10% respectively.

In the following paragraph, we detail more the ratio of 50% of the roof surface which generates more gains. The maps and histograms in Figure 7 present the results for the distribution of the average energy gains of each building in the district after thermal insulation according to the regulation (RTCM) and the installation of PV panels for both PV-Monocrystalline and PV-Polycrystalline types.

The statistical analysis of the spatial distribution of the average annual gains of each

Table 3. Energy gains generated for an RTCM renovation scenario coupled with a PV installation

Type of installation	Installed PV area (%)	Electrical production (MWh/year)	Amount of energy saved (MWh/year)	Energy produced + saved (MWh/year)	Energy needs (existing situation) (MWh/year)	Gain (%)
Roof without PV	0	0.00	13319.46	13319.46	25408.66	52.72
Monocrystalline	10	2831.28		16150.74		63.56
	25	7078.20		20397.66		80.28
	50	14156.40		27475.86		108.14
Polycrystalline	10	2157.16		15476.62		60.91
	25	5392.92		18712.38		73.65
	50	10785.83		24105.29		94.87

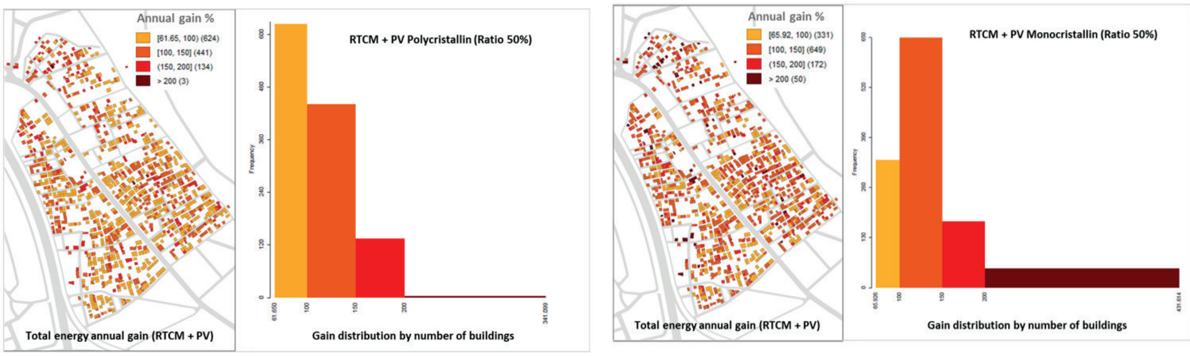

Figure 7. Spatial distribution of energy gains in the "Bouzaghlal" district

building shows that in the case of PV-Polycrystalline: 48.08% (578) of the buildings in the district generate gains that exceed 100%, on the other hand in the case of PV-Monocrystalline: 72.46% (871) of the buildings generate an annual gain of over 100%.

Similarly, we notice that a percentage of 24.37% (293) of the buildings did not exceed the annual gains of 100% in the case of PV-Polycrystalline, but they exceeded it with PV-Polycrystalline.

Another important observation is that for both types of PV, large buildings with large roofs generate more significant annual gains, which can reach more than 150%, especially in the case of PV-Monocrystalline where we observe that 50 buildings exceed annual gains of 200%.

Summary of expected benefits

Table 4 summarizes the expected cost and environmental impact benefits of thermal insulation of building envelopes under RTCM and PV installation on the roofs of the district for the ratios of 10%, 25%, and 50% of the installed roof surfaces. The summarized results show that the optimal option for an MTRP retrofit scenario with a PV-Monocrystalline installation of 50% of the building surfaces in the Bouzaghlal district yields significant production and savings that can reach a total of 27475.86 MWh/year. This is equivalent to a saving on the energy bill of about 32.14 million DH with an average per floor of 140 DH/m²/year and an environmental impact in an annual reduction of CO_2 emissions of 20332 14 TCO_2/year with an average per floor of 89 kg CO_2/m²/year.

Based on these results, energy upgrading of buildings at the eco-district level is strongly recommended over other urban planning recommendations and proposals. Applying energy efficiency measures on buildings such as thermal insulation supported by a large installation of photovoltaic panels on the roofs, allows households to meet their energy needs (cooling and heating) and produce energy for other consumptions such as lighting, appliances, hot water, or powering the local grid. Therefore, the transformation into an eco-district with the consideration of these types of measures at the urban scale makes our cities autonomous and energy-producing

Table 4. Expected benefits for an RTCM renovation scenario coupled with a PV installation for the "Bouzaghlal" district

Measures		Installed PV area (%)	Self-generation + energy saved (MWh/year)	Cost savings (million MAD/year)	CO_2 savings (TCO_2/year)
Thermal insulation according to RTCM		-	13319.46	15.66	9856.40
PV Installation	Monocrystalline	10%	2831.28	3.30	2095.15
		25%	7078.20	8.24	5237.87
		50%	14156.40	16.48	10475.74
	Polycrystalline	10%	2157.16	2.51	1596.30
		25%	5392.92	6.28	3990.76
		50%	10785.83	12.55	7981.51

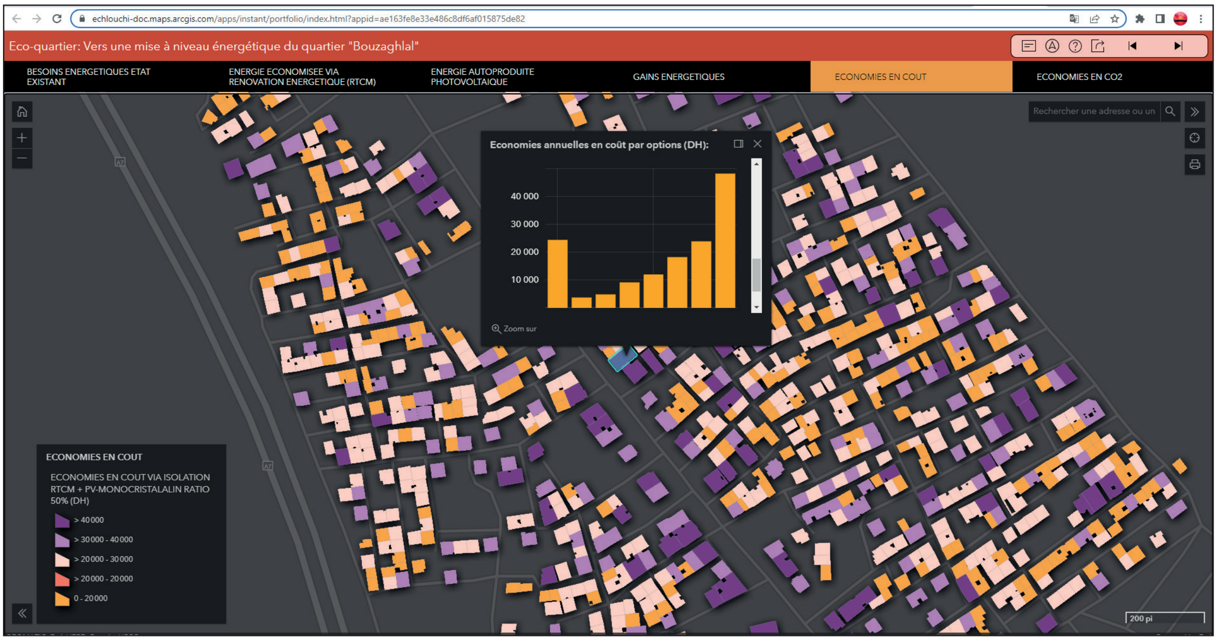

Figure 8. Energy geoportal of the "Bouzaghlal" district

Mapping and outreach

As part of the outreach of this study, an energy geoportal is set up to share the results of this research with the scientific committee, and to offer a communication tool oriented towards the general public in order to encourage them to adopt energy efficiency solutions in buildings. Also, to provide a decision support tool for stakeholders to encourage consideration of the energy dimension in the transformation of districts into eco-districts.

This type of solution facilitates the evaluation of the gains and the estimation of the global costs during the realization of such an operation.

Figure 8 represents the energy geoportal of the "Bouzaghlal" district developed within the context of this research, it is accessible via the following link: GEOPORTAIL Link [https://echlouchi-doc.maps.arcgis.com/apps/instant/portfolio/index.html?appid=ae163fe8e33e486c8df6af015875de82] in the form of a web mapping application facilitating access to spatial and energetic data of buildings at the neighborhood scale. The platform offers the possibility to consult the solar potential of the roofs for a photovoltaic installation while evaluating the technology of the panels, as well as to evaluate the theoretical energy savings if thermal insulation according to the RTCM is applied. Moreover, several information can be consulted in a dynamic way, such as: geometrical parameters, energy needs before and after thermal insulation, annual gains, comparisons, and balances.

CONCLUSIONS AND PERSPECTIVES

Future districts will not only consume energy but will have to save their needs through energy efficiency and will also produce renewable energy through solar systems as a low carbon energy source and as an essential component of the sustainability of the cities of the future. From this perspective, the need to save and produce energy at the urban level leads us to study how we can renovate our districts and transform them into autonomous eco-districts that produce green energy.

In Morocco, the thermal regulation approved in 2015 applies only to new buildings. While the energy renovation of existing buildings remains non-mandatory, no policy has been adopted to encourage or facilitate its implementation, which slows down the energy transition of Moroccan cities. This highlights the need to extend the current thermal regulations to the new and existing buildings. Furthermore, it is clear that launching energy renovation strategies across the Moroccan building stock will accelerate its energy upgrade and strengthen its energy supply security. Pending this regulatory reform, eco-districts represent an ideal framework to initiate, test, and evaluate such an energy approach, as the district is an appropriate intermediate scale to establish a multifunctional urban project suitable for sustainable development.

In this study, a methodological framework has been presented to improve the decision-making process for the energy upgrade of a future eco-district transformation, allowing the evaluation of the energy impact of standard thermal insulation of building envelopes coupled with the installation of photovoltaic systems on roofs at the district scale. The case study was carried out in the "Bouzaghlal" neighborhood located in the north of the city of M'diq, classified in the Z2 climatic zone, characterized by the non-regulatory "modern Moroccan house" type of housing. The main conclusions of the analysis are the following. The energy renovation of the buildings in the neighborhood is cost-effective for a standard scenario, it allows an average annual gain of 52.72% compared to the existing state. In addition, efficient insulation with significant insulation thicknesses can result in more gains. The installation of PV on the roofs of the buildings in the district strongly supports the thermal insulation and significantly improves the energy profitability of the operation: the energy gains for a ratio of 50% of the roof surfaces equipped with PV units can reach an average rate of 108.14% for the monocrystalline type and 94.87% for the polycrystalline type. Therefore, the eco-district can offset their electricity needs related to air conditioning and heating. In a scenario of installing PV on half of the roof surfaces, we get just 48.08% of the buildings that generate annual gains that exceed 100% for PV-Polycrystalline, on the other hand, 72.46% of the buildings generate an annual gain of over 100% for PV-Monocrystalline. This shows that at the urban scale, PV-Monocrystalline is the highly recommendable solution from a performance point of view. Similarly, large buildings with large roofs generate more significant annual gains, which can reach over 150%. The RTCM renovation scenario with a PV installation of 50% of the surfaces of the buildings in the "Bouzaghlal" district allows the production and significant savings that can reach a total of 27475.86 MWh/year, which is economically equivalent to 32.14 Million DH and having an environmental impact in an annual reduction of CO_2 emissions that can reach 9891.31 TCO_2/year.

The energy upgrade through the coupling of thermal insulation with the installation of photovoltaic systems transforms the district into autonomous urban entities and producers of green energy. The results of this research highlight the potential of adopting eco-district approaches and energy retrofit strategies at the building stock level. The success of such an experiment at the eco-district scale may encourage other cities to adhere to this sustainable approach and adopt more climate change measures and achieve energy transition of the entire Moroccan building stock. The next work will focus on the finalization of the study in its financial component, including the overall cost and returns on the investment required for thermal insulation and installation of photovoltaic units at the district scale.

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