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Early energy assessment at the neighborhood level to promote greater energy efficiency. The case of Nabta Smart Town in Egypt

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ABSTRACT

The potential for an early energy assessment to further improve neighborhood/precinct planning and promote greater energy efficiency is considerable, as confirmed by numerous studies around the world and corroborated by the authors' experience. Egypt is certainly no exception and in recent years there is growing research evidence to this effect. However, more knowledge is needed on how to develop affordable and locally viable solutions that are integrated into the urban planning process from the outset. This article discusses the results of the "Energy Efficiency Feasibility Assessment of the Master Plan of Nabta Smart Town (NST)", an "education town" under planning in New Borg el Arab City (NBC), close to Alexandria. The results show how an early energy assessment, carried out as early as the planning stage, which considers local regulations and specific conditions, can help achieve considerable energy efficiency in the future by identifying affordable, evidence-based, and locally feasible solutions that can be further optimized at the design stage. Therefore, the value of this study is not in proposing a new standard solution for everyone, but in showing through an application example how the potential of an early energy assessment at the neighborhood/precinct level can be realized in practice. The immediate benefit is in promoting greater energy efficiency through the design and optimization of renewable energies and passive solutions. This achievement can in turn be used to rethink the planning and decision-making process in the local context. The greatest impact is not only in the selected case study, but in its potential for replicability throughout the Global South.

1. Introduction

The *Sustainable Development Strategy (SDS): Egypt Vision 2030* (Ministry of Planning and Monitoring and Administrative Reform (MPMAR), 2016) represents the aspiration of the Egyptians towards inclusive development and constitutes a strategic roadmap to achieve prosperity and equal opportunities for all through economic and social justice, and to revive the role of Egypt as a regional leader. The SDS is built around 10 pillars organized according to three dimensions, namely, economic, social, and environmental. Energy is the second pillar under the economic dimension. Efficient resource management and the use of renewable energy are promoted as means to achieve economic growth while preserving the environment in compliance with the Sustainable Development Goals (SDGs) (United Nations Sustainable Development Knowledge Platform, 2016).

However, to achieve the global targets of SDG7 - Affordable and clean energy by 2030, it is vital to invest in not only renewable energy and improving energy productivity and infrastructure, but also in better technologies and solutions providing clean and more efficient energy for all. More particularly concerning energy efficiency, the target established by SDG7 is to double the rate of improvement worldwide. This requires a global effort and international cooperation in R&D must be enhanced to facilitate the process. In this sense, the main factors identified affecting the profitability of renewable energy projects for grid-connected electricity generation are technology capacity cost, technology operation and maintenance cost, capacity depending on the renewable potential and effectiveness, project lifetime, feed-in tariff and selling prices, and power purchase agreement (United Nations Economic & Social Commission for Western Asia, 2017). Even though the renewable energy sector is growing globally, and so are the investments, it is still not enough to reach climate and development goals (Carino & Sriskanthan, 2018).

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With a population of around 95 million according to the last census (Central Agency for Public Mobilization And Statistics (CAPMAS), 2017), Egypt is the third most populous country in Africa after Nigeria and Ethiopia. The demand for energy continues to increase due to population and economic growth and the increase in industrial production, which poses considerable challenges to ensure a continuous and stable energy supply. Power cuts are very frequent. Until very recently, Egypt remained one of the least energy efficient countries in the MENA region despite of its 5-year plan to eliminate electricity subsidies. *Egypt's National Energy Efficiency Action Plan (NEEAP, 2012–2015)* contained a 5% cumulative target, but there was no designated agency and no legal framework for energy efficiency measures (Regional Center for Renewable Energy and Energy Efficiency (RCREEE), 2012). Since then, Egypt has implemented energy efficiency codes for residential (2005), commercial (2009) and governmental buildings (2011). Although some efforts have been made to improve the policy, legal and institutional framework to better support energy efficiency and renewable energy integration, considerable obstacles persist that hamper the scale-up of clean and energy efficient technologies. Lack of adequate information and technical expertise coupled with an inflated risk perception prevent both end-users and investors from making informed investment decisions (Energy Efficiency in the Construction Sector in the Mediterranean (MED-ENEC) Project, 2016).

To address this situation the Egyptian government launched in 2016 the *Integrated Sustainable Energy Strategy 2035 (ISES 2035)*, which aims at having a 42% of renewable energy contribution to the energy mix by 2035 as can be seen in Fig. 1 (Government of Egypt, 2016). The New and Renewable Energy Authority (NREA) under the Ministry of Electricity and Renewable Energy has an instrumental role to play in the implementation of the Strategy. In collaboration with NREA, the International Renewable Energy Agency (IRENA) has prepared the *Renewable Energy Outlook: Egypt* (International Renewable Energy Agency (IRENA). Renewable Energy Outlook: Egypt, 2018), which focuses on the actions of different nature needed to meet the abovementioned targets (e.g., policies and regulations, financial support, capacity building). Furthermore, the report also identifies potential challenges and opportunities for increasing the use of renewable energy in the country. One of the main conclusions is that 53% of power generation from renewable sources can be achieved by 2030 if the right policies are applied and updated regularly to consider new technology developments, cost fluctuation, changes in the energy sector, and regional geopolitics. Apart from diversification through renewables, the Egyptian government is also promoting the introduction of energy efficiency measures, and operation and maintenance programmes. To this end, the report includes a Reference Case based on the energy supply and demand scenario defined by *TARES report* (European Union, 2015), which provides a baseline against which *ISES* energy targets can be quantified. The Reference Case also explores the potential of renewable energy beyond the power sector, namely, in buildings, industry and transport.

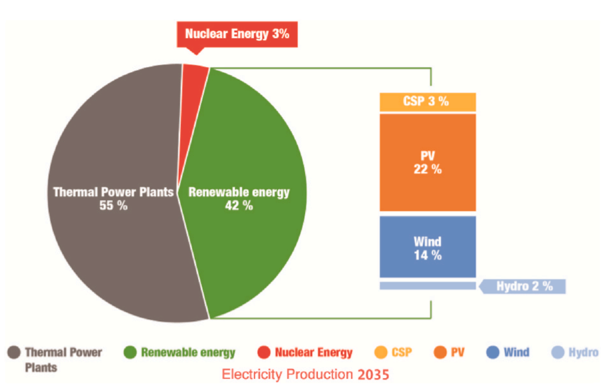


Fig. 1. Egypt's renewable energy targets for 2035. (Source: NREA).

Regarding the building sector in particular, Egypt offers many opportunities for the integration of renewables into different building types, as well as for the implementation of energy efficiency measures. The report *Energy Efficiency and Rooftop Solar* PV *Opportunities in Cairo and Alexandria* (World Bank, 2017), part of an assessment carried out by the World Bank with the support of the Energy Research Centre at Cairo University, presented interesting findings on the potential of rooftop solar PV and EE to contribute to the government's objectives of achieving cost reflective tariffs and address the country's energy challenges. The study analyzes RE and EE potential and measures in relation to public, commercial, and residential buildings, as well as EE potential and measures for potable water, street lighting and transport. Overall, the estimated EE potential for the building types considered is 30–50% for public buildings, 40–60% for commercial buildings, and 30–50% for residential buildings. This study by the World Bank is relevant, but even more in this instance because it involved Alexandria, the second largest city in Egypt with a population of 5.3 million as of January 2019 (Central Agency for Public Mobilization And Statistics (CAPMAS), 2019) and the closest to New Borg El Arab City (NBC) where the case study described in this article is located.

In addition to the abovementioned strategy and assessment studies, which help to define the local context of operation in relation to energy, if returning to the global scale, 68% of the world's population will live in urban areas by 2050 (United Nations Population Division of the Department of Economic and Social Affairs, 2018). This will only increase the already great challenges that rapid urbanization presents for cities worldwide, particularly in the Global South. In African cities, this process has resulted in a particularly intense proliferation of informal settlements where the rapid demographic growth is not adequately supported by the necessary physical and economic infrastructure (United Nations Human Settlements Programme (UN-Habitat), 2014). Urban sprawl, neighborhood fragmentation, and inefficient transport networks often characterize such cities, producing a negative effect on investments, productivity, and access to jobs. It also increases the costs of food, housing, and transport, which in turn leaves cities in Africa *"trapped in the production of nontradable goods and services"* (Lall et al., 2017). The authors conclude that a new urban development path is required to unlock the situation and attract capital investment. Although Egypt is no exception, Cairo ranked first among African cities in attracting foreign direct investment (FDI), due to its proximity and connections to Europe and the Middle East, large internal market, more developed human capital and technology, and strong financial services (United Nations Human Settlements Programme (UN-Habitat), 2018). According to the same report, Alexandria ranked second at country level, but only 23rd in the continent.

This is in short, the global and national context in terms of (unsustainable) urban agglomeration and access to clean and affordable energy for the case study presented here. In response to these challenging conditions, some authors affirm that environmentally conscious architecture can play an important role in development plans as an effective tool to reduce energy and material consumption and to improve quality of life (Ayyad and Gabr, 2013). As a new urban development, Nabta Smart Town (NST) discussed here is an attempt to contribute to the necessary transformation of Egyptian cities towards more sustainable development patterns and better living conditions, which not only requires a new fundamental approach in the form of innovative policies and strategies (Goell et al., 2009), but also concrete examples of good practice. Such examples should be at the same time locally attuned, scalable, and replicable in similar national and international contexts, a balance certainly not easy to strike.

To contribute to this need, several studies have already been carried out in Egypt that highlight the potential of properly optimized hybrid power systems to reduce energy costs, significantly lower CO_2 emissions and secure supply (Elkadeem et al., 2020). Such research covers not only urban communities, like the one just mentioned developed for Safaga, but also isolated rural areas (Abo-elyousr & Elnozahy, 2018). Many of them focus on micro-grids and propose different approaches and frameworks for the optimization of the multiple combinations possible. Furthermore, the same type of research is taking place in many other regions of the Global South, in both urban and rural contexts. As an example, Almasri et al. have recently analyzed the energy consumption in the residential sector of Qassim region in Saudi Arabia and their findings corroborate the importance of raising awareness (even among school children) on rationalizing energy consumption, supporting the introduction of renewable energy solutions (particularly solar), and improving the efficiency of electrical appliances (especially air conditioning systems) (Almasri et al., 2020). Abdilahi et al. carried out a feasibility study on how to supply electricity to a sample residential area in Hargeisa, the main urban center in Somaliland, through a hybrid micro-grid system supplemented by renewable energy (Abdilahi et al., 2014). Similarly, Masrur et al. found in a recent suitability analysis that a PV/Wind/Diesel/Battery hybrid micro-grid system seems to be the best option to replace the diesel-based system currently in use in St. Martin's, a remote island of Bangladesh (Masrur et al., 2020). In Colombia, Haghighat Mamaghani et al. analyzed the combined use of PV panels, wind turbines and diesel generators in a hybrid system for the electrification of three rural communities with different climatic conditions (Haghighat Mamaghani et al., 2016). All of them acknowledge the opportunities presented by hybrid RE-based systems to secure energy access worldwide while bringing down energy costs and emissions. However, they also point towards the need of incentives and supporting policies, in addition to other measures like tax reductions and exemptions, to make it possible for low-income communities to afford the initial investments as well as the operation and maintenance costs. This is crucial to reach the objectives established by SDG7.

By now, considerable research has also been carried out in the MENA (Middle East and Northern Africa) region to understand how the architectural design, and more specifically the use of passive features and strategies such as orientation, size of openings, shading, insulation, local materials, and natural ventilation can contribute to reduce the net energy demand and to improve the indoor comfort, e.g. (Algendy & Anbar, 2017) (Visser et al., 2017). For instance, in the case of Emirati villas located in a suburban neighborhood in Abu Dhabi (UAE), Birge & Berger found that improved design could potentially reduce CO_2 emissions per household per year as much as 33.7%–49.0% compared to the existing baseline for new construction. This figure could ramp up to 99.4% when combining design and technology (Birge & Berger, 2019). At the urban scale, there is a considerable body of literature on the quality of ecocities built around the world and the extent to which they have achieved their initial goals, particularly in China, e.g., Li & Qiu (Li & Qiu, 2015). There is also increasing knowledge on how to develop sustainable cities in arid regions (Alshuwaikhat & Nkwenti, 2002), as well as how to plan and design energy-efficient neighborhoods (Visser & Yeretzian, 2013). There is also literature on different aspects related to the use of different renewable energies or a combination of them at the urban scale in different countries of the Global South, for example, Razmjoo et al. (Razmjoo et al., 2020). However, few studies have been found related to the benefits of an early energy assessment and the incorporation of energy efficiency measures at the level of planning and design of new neighborhoods and districts, especially in developing countries. Therefore, this paper intends to contribute with a concrete local example to show what can be achieved through early intervention, relatively affordable in the planning stage, and with potential for improvement in the urban design stage (main objective 1).

2. Research objectives and methodology, article structure

2.1. Research objectives and methodology

The main objectives of the research presented in this article were:

1) To show how an early energy assessment, carried out already at planning stage, that considers the local regulations and specific conditions can help to achieve considerable energy efficiency down the line by pointing towards affordable evidence-based solutions that can be optimized even further at design stage.
2) To deepen the understanding of the specific local conditions to ensure a proper adaptation of the solutions proposed for the improvement of NST Master Plan to increase energy efficiency and performance optimization.
3) To develop energy efficient solutions that are viable and affordable in the local context.

Additionally, other objectives were: 4) To capitalize on the recommendations of a project previously coordinated by the Technical Research Centre of Finland Ltd. (VTT) in NBC, "EcoNBC, EcoCity Capacity Building in New Borg El Arab City" funded by the Ministry for Foreign Affairs of Finland. 5) To assess their potential for scalability and replicability. 6) To explore possible beneficial synergistic effects to be covered by future research. Ultimately, this work contributes to the strongly demanded empirical research on the second generation of smart cities, also called smart city 2.0, which unlike the first generation paradigm are characterized by decentralization and people-centricity, and where smart technologies are used to provide solutions to social problems and to address citizen needs (Trencher, 2019). The above objectives are mentioned throughout the text in relation to the findings of the literature review (section 1), the energy assessment designed to adapt to local conditions (section 4), the results (section 5), specific aspects of the project (section 6), as well as in terms of their realization in practice (section 7).

A qualitative research approach was applied using the case study method to deduce meaning from qualitative, complex phenomenological data collected (in this instance) in the form of "inputs bills" that were later reviewed and validated by local experts during several workshops (Eisenhardt & Graebner, 2007) (Yin, 2013). The case study method is particularly adequate when assessing implementation processes (Bryman, 2012). Regarding the materials (or tools) used, based on the data thus gathered and the main building typologies defined in the Master Plan, three building models were generated using Transient System Simulation Tool (TRNSYS) software to calculate the energy demand of NST and to conduct the sensitivity analysis for energy performance optimization.

2.2. Article structure

The structure of this manuscript consists of: **First** framing the case of NST in the global context of the energy targets set by SDG7 - Affordable and clean energy, and the challenges posed, particularly in the Global South, by fast-paced unsustainable urbanization processes. In this instance, the focus of the work was mainly on two targets: 7.2 to increase the share of renewable energy in the energy mix by 2030; and 7.A to enhance international cooperation on clean energy research and technology. Particularly regarding target 7.A, the emphasis is on increasing the share of renewable energy (solar and wind) and improving energy efficiency. Showing the viability of energy efficient solutions and renewable energy (first part of target 7.A) in Egypt is the necessary step before promoting clean energy investments (second part of target 7.A). Incidentally, the solutions developed can also contribute to decrease CO_2 emissions, therefore affecting SDG 13 - Climate action, more specifically in relation to target 13.3 through an improvement of the human and institutional capacity (i.e., training and working with the local partner) on climate change mitigation. **Second**, describing the national context in Egypt concerning the most relevant energy initiatives (strategies, studies, and other relevant documents), as well as pressing urban issues that should be prioritized. The use of this double scale is intended to provide insights into how to develop solutions that can be at the same time adapted to the specific conditions of any given place in a particular country or region - in this case NBC in Egypt, and yet have the potential to be scaled up in other parts of the country, or even replicated elsewhere. **Third**, narrowing the focus to get a close up of the situation in Alexandria and NBC, the cities that are most directly influencing the planning, design and future implementation of NST. **Fourth**, presenting the case of NST and discussing the results of the work carried out by VTT and the local partner, the Khairy Foundation for Human and Social Development (KFHSD). **Fifth**, drawing conclusions from the previously mentioned results while trying to identify additional components, emerging technologies or concepts that could contribute to the maximization of the expected impacts. **Sixth**, contextualize the results and discuss possible ways ahead to accelerate the implementation of energy efficient measures and the integration of renewable energies.

3. The case of Nabta Smart Town in NBC, Egypt

With a population of 5.3 million as of January 2019 (Central Agency for Public Mobilization And Statistics (CAPMAS), 2019), Alexandria is the second largest city in Egypt after Cairo, the capital, and one of the country's main economic centres. The "Pearl of the Mediterranean" as popularly known, Alexandria enjoys a privileged location between the Mediterranean Sea to the north and Lake Mariout to the south. Despite the beauty of this enclave, its rich history and valuable architectural heritage, Alexandria faces nowadays numerous challenges. Among them, fast population growth; high unemployment, particularly affecting the youth; serious lack of affordable, adequate, and safe housing -e.g., informal settlements keep proliferating, and more than 400 residential buildings collapse every year (Jankowicz, 2017)-; traffic congestion; deficient governance or high environmental pollution in El Mahmoudia Canal and the already mentioned Lake Mariout (Sirry & Woertz, 2018).

NBC, located 60 km to the south-west of Alexandria and 7 km away from the north coast, was established by presidential decree 506/1079 and belongs to the first generation of so-called "Egyptian new towns". The new town policy was launched by the Government of Egypt in 1970 with the intention of alleviating the demographic pressure on the long-inhabited areas along the Nile valley, no longer able to absorb an increasing population. To achieve a more balanced spatial distribution of the population, several new towns were built in desert locations, all with an important industrial base capable of attracting public and private investments (Aafify, 1999). In 1979, the New Urban Communities Authority (NUCA) was created as the body within the Ministry of Housing responsible for establishing new communities. NUCA oversees the whole process from the selection of the sites to the construction of housing and infrastructure. Once the development is completed, NUCA should transfer the jurisdiction to the corresponding governorates for regular municipal administration. The three generations of new towns developed up to date have received considerable criticism from numerous authors due to the many problems identified over the years. Perhaps the main argument against is that they have failed to attract the planned populations, aside of other issues like lack of clarity regarding the criteria followed to select the sites for development, severe environmental problems affecting many new towns, high cost of basic infrastructure, and over-reliance on public investments (Hegazy & Moustafa, 2013).

With a population of around 170,000 people according to 2022 statistics, NBC is an important production centre with 1271 factories (New Urban Communities Authority NUCA, 2015), yet it shows the same flaws and contradictions that afflict most Egyptian new towns. Although most of the workers commute daily from Alexandria, NBC offers several services and facilities (hospitals, schools, mosques, shops, university …) while having to cope with various urban sustainability challenges. A more detailed description of the city's most pressing needs and how to provide locally attuned sustainable solutions can be found in the scientific reports and papers published on the results of the EcoNBC project, like e.g., here (Hedman et al., 2014).

This is the context in which Nabta Smart Town in NBC, emerged as an ambitious project combining modern residential and commercial facilities with high quality "Educational Magnets" and administrative offices, to create a thriving and inclusive community (see Fig. 2). The local promoters of NST envisioned a culture that fosters sustainable water and waste management, recycling, energy efficiency, renewable energy sources, healthy lifestyles, smart mobility, public green areas, increased biodiversity, and citizens' engagement through participatory processes. Moreover, NST has even further reaching goals like contributing to regional development through science, technology, and culture; providing innovative solutions for products and services in response to important human needs; supporting the creation of new businesses; and establishing technical and commercial cooperation with international partners (Antuña-Rozado et al., 2019a). A good example of the latter is precisely the project "Sustainability Assessment of Nabta Smart Town (NST) and Actions for Improvement" carried out by VTT together with KFHSD and funded by the 10YFP Trust Fund (One Planet Network SBC Programme). With the principal objective of ensuring that the Master Plan and the various building types of NST, including those of Nabta University, would follow the standards of *"a modern smart EcoCity adapted to the local conditions of Egypt"* as expressed by KFHSD, it was the first project making direct use of the findings and recommendations of "EcoNBC Feasibility Study. Transforming New Borg El Arab into an EcoCity" (Antuña Rozado et al., 2015), one of the main outcomes of the already mentioned EcoNBC project. The new project was conceived as a general framework for the development of locally viable projects (i.e., based on locally available technologies and existing local capacity) and affordable smart solutions (understood as an optimized set of measures).

From its inception, the Sustainability Assessment of NST tried to establish direct links with the UN Climate Change Conference, 21COP held in Paris in 2015, and the 2030 Agenda for Sustainable Development. The project as initially planned (Sustainability Assessment of NST Master Plan) was expected to contribute significantly to SDG6, 7, 11, 12 and 13. The first phase, the results of which are presented here, focused on the Energy Assessment of NST Master Plan, described in section 4, and therefore the SDGs impacted are mainly 7 and 13. In addition, it provided the opportunity to align the NST energy targets with those of the country from the beginning, capitalizing on previous experience in this area.

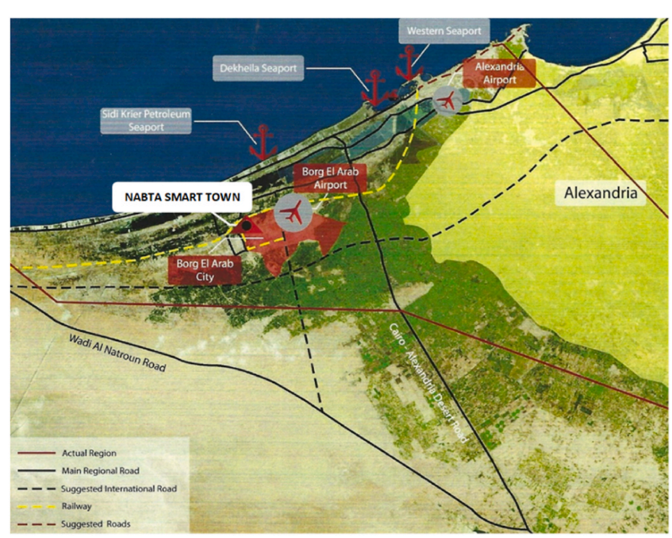


Fig. 2. Map showing the location of Nabta Smart Town. (Source: UPSCALE).

4. Energy assessment of NST Master Plan

This section describes the requirements formulated by the project's initiators based on their goals for the new urban development and the preliminary conditions set by NST Concept Master Plan. It also discusses how the experts involved in the research addressed those requirements in terms of the process followed for the energy assessment of NST Master Plan and the approach taken (software used, data collection, assumptions). Both the process and approach were carefully defined to align with main objective 2 and additional objective 4, and for the results to have a positive impact on additional objectives 5 and 6.

4.1. NST Master Plan

Fig. 3 shows the land use and its distribution, while Tables 1 and 2 provide more details about the projected buildings, their purpose and area, their capacity and even the number of floors, as well as the planned services. Table 1 focuses on the area called Business Bay, while Table 2 focuses on the area known as Knowledge Bay. The information in Tables 1 and 2 is completed with the data collected later in the "inputs bills" to carry out the energy evaluation (see 4.2 and 4.3).

Fig. 4 summarizes the initially proposed construction heights. Subsequently, they selected an Egyptian firm to adapt the design concept developed by Atkins to current local urban planning and construction regulations. It was during this time that the collaboration of KFHSD, one of UPSCALE's trusted partners, and VTT was required to support the sustainable adaptation of the Master Plan to the specific conditions of Egypt and NBC. The results shown in this article correspond to the first phase of the work, which focused on the Energy Assessment of the NST Master Plan.

4.2. Energy assessment process

In recent years, renewable energy sources have gained importance and strategic investments to increase wind, solar and other sources capacity are planned for this decade in Egypt (Salah et al., 2022). As pointed out by Mondal et al. investing in renewable energy represents a necessary step towards a low-carbon society, but also a means to improve Egypt's energy security by diversifying the energy mix and reducing reliance on fossil fuels for power generation (Mondal et al., 2019).

When multiple renewable generation systems have been considered, advanced power design through simulation and optimization is a well-recognized method among the scientific community to properly size power systems, as reflected in the literature (Laitinen et al., 2021; Rehman et al., 2019). Therefore, in this study, the authors have used simulation and optimization to design the district power systems, as photovoltaic and wind generation technologies have been considered. Furthermore, they focused only on energy optimization and not economic optimization, as economic evaluation was not part of the project plan. The economic evaluation should be part of a future study. Building on the methodologies previously developed by VTT (Antuña-Rozado et al., 2016), the Energy Assessment of NST Master Plan was carried out according to the following process:

In detail assessment of NST Master Plan. Since the quality of the data is essential to ensure adequate results, KFHSD experts collected the data needed for the energy assessment (including passive features and user behavior) according to the methodology and instructions provided by VTT experts. The data collection took the form of an "inputs bill" that was also used later for the TRNSYS seminar that followed. As an example, the "inputs bill" for the Residential building type included information on occupancy patterns (e.g., number of people per unit, hours), infiltration rates and domestic hot water (DHW) profile, appliances in use, thermal details of building materials (external wall, roof, ground floor, internal floor, and windows), energy system (air source heat pump, photovoltaic system). The data gathered was jointly reviewed during a workshop facilitated by VTT to remove any possible misunderstandings in relation to its accuracy. For instance, DHW provided for Office and Educational buildings appeared to be rather high, particularly in the case of Office buildings. Upon discussion with the local experts, it seemed that very often this kind of Business and Commercial initiatives have a high DHW consumption due to the availability of multiple amenities, e.g., swimming pool, spa and beauty salons, or sports clubs. Considering this possibility, high DHW was assumed for the Office building model (which in turn was used for both Office & Educational) to be on the safe side of the analysis. Inputs bills are not included here to prevent this article from being too long.

Training of KFHSD staff on specific software. An intensive 4-day course was arranged to provide training on building energy optimization using TRNSYS and GENOPT so that KFHSD experts could help to build the catalogue of NST building types (see next step) supervised by VTT. The course also included nearly and Net Zero Energy Buildings (NZEB).

Energy categorization of NST building types. Different building types included in NST Master Plan (Educational, Residential, Commercial) were categorized in terms of energy consumption (e.g., low/zero energy consumption, energy plus).

Modelling and simulation for energy performance optimization. Modelling and simulation tools available in Finland (particularly those used by VTT, more detailed in Section 4.3) and Egypt were used to

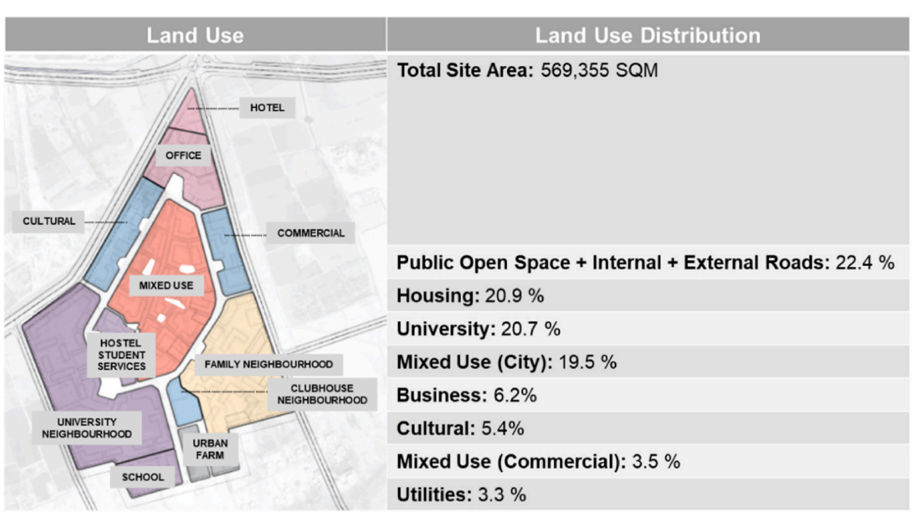


Fig. 3. NST Master Plan: Land use and land use distribution. (Image: UPSCALE/Atkins).

Table 1
Summary description of the Business Bay area.

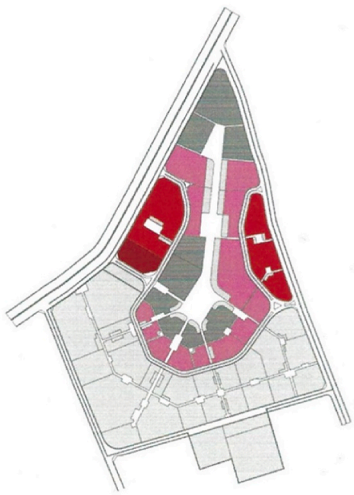
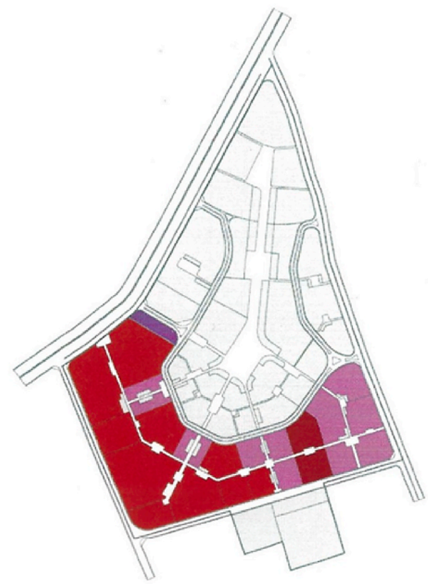
BUSINESS BAY	
Residential and Mixed Use Total area: 181,600 m^2 on 4 floors ***Teaching staff hostel*** *For Faculty and students, 150 rooms (single and double)* ***Residential area planned*** *200 single bedrooms* *20 duplex outdoor triple bed.* *1100 double bedrooms* *20 twin houses* *300 triple bedrooms* *15 villas* *100 duplex indoor triple bed.* **Administrative office area** Total area: 30,800 m^2 *2 data centres* *1 command and control centre* *111 offices including meeting rooms, teleconference, and innovation centres*	
Commercial area Total area: 28,800 m^2 48 commercial services (cafes, restaurants, and leisure) 18 warehouses 75 commercial shops (boutiques, indoor-outdoor shops)	**Utilities** Total area: 36,830 m^2 ***Telecom utilities*** *1 satellite facility* *19 office facilities including call centres*
Public services (bank, post office, medical facilities) *50 private clinics* *13 waiting areas* *6 labs for x-rays* *15 offices* *6 operation rooms with ICU* *5 storages*	**Islamic centre** Total area: 3,550 m^2 Capacity: minimum 500 simultaneous prayers
Social & Sports Club Total area: 10,850 m^2	**Movie theatre** Total area: 7,100 m^2

Table 2
Summary description of the Knowledge Bay area.

KNOWLEDGE BAY	
Campus Total area: 117,100 m^2 Planned number of students: 7,800 Planned buildings: University Main Building +10 Faculties ***Faculties planned*** Engineering & Applied Science (1,500 students in 4 years) Biotechnology (500 students in 4 years) Dentistry (1,500 students in 5 years) Pharmacy (1,500 students in 5 years) Physical Therapy (400 students in 4 years) Applied Medical Science (400 students in 4 years) Entrepreneurship & Economics (800 students in 4 years) Mass Media & Communications (400 students in 4 years) Foreign Languages & Linguistics (400 students in 4 years) Maritime & Logistics Management (400 students in 4 years)	
School area Total area: 12,700 m^2 on 4 floors	**Library** Total area: 4,900 m^2 on 4 floors

optimize the building variables like e.g., construction materials, insulation, use of reflective paints, or green roofs. Although the focus was on design principles and construction materials, attention was also paid to the construction process and timetable, local sourcing of materials, and transportation to minimize environmental impacts. Concerning the local climatic conditions, VTT experts have used the information provided for Alexandria by Energy Plus, a widely known and accepted source among professionals in the field.

Finally, the results were presented, discussed, and validated during the project's Final Event for key local stakeholders and a Final Seminar organized for a selected group of students from the University of Alexandria. The results have also been disseminated in several international conferences.

4.3. Approach

As already mentioned, TRNSYS software was used for estimating the energy demand of NST. Three different building models were generated according to the building typologies defined by the Master Plan, namely, commercial, educational, and residential. Fig. 5 shows the layout of a typical residential building in New Borg El Arab based on the findings of the expert team. All information in the tables that follow is partly coming from the specifications in the Master Plan, partly from the "inputs bills" already mentioned, and partly from the workshops held together with the local partner, KFHSD, and the international experts that worked in the project.

Table 3 shows the total area of the different building typologies included in the Master Plan and the paired building model used to simulate the corresponding energy behaviors, as well as the thermal properties of the construction materials used in the models for a typical wall section.

In addition to the previous, VTT experts made the following assumptions:

4.3.1. Buildings

- Low-e windows (tinted double glazed 4/12/4 mm Glass/air/Glass, U = 1.69 W/m$^{2\circ}$C) as provided by the local experts.
- 20 °C and 26 °C as heating and cooling indoor temperature set points respectively.
- Energy efficient practices, such as natural ventilation (free cooling) and external shading devices applied.
- Different internal gains and energy consumption of electrical appliances estimated according to the provided occupancy patterns for each of the abovementioned building models.

Based on these assumptions, eight different building cases were defined as shown in Table 4.

4.3.2. District

- Very efficient buildings, building-to-building transaction.
- Synergies between buildings.

Fig. 4. NST Master Plan: Building heights. (Image: UPSCALE/Atkins).

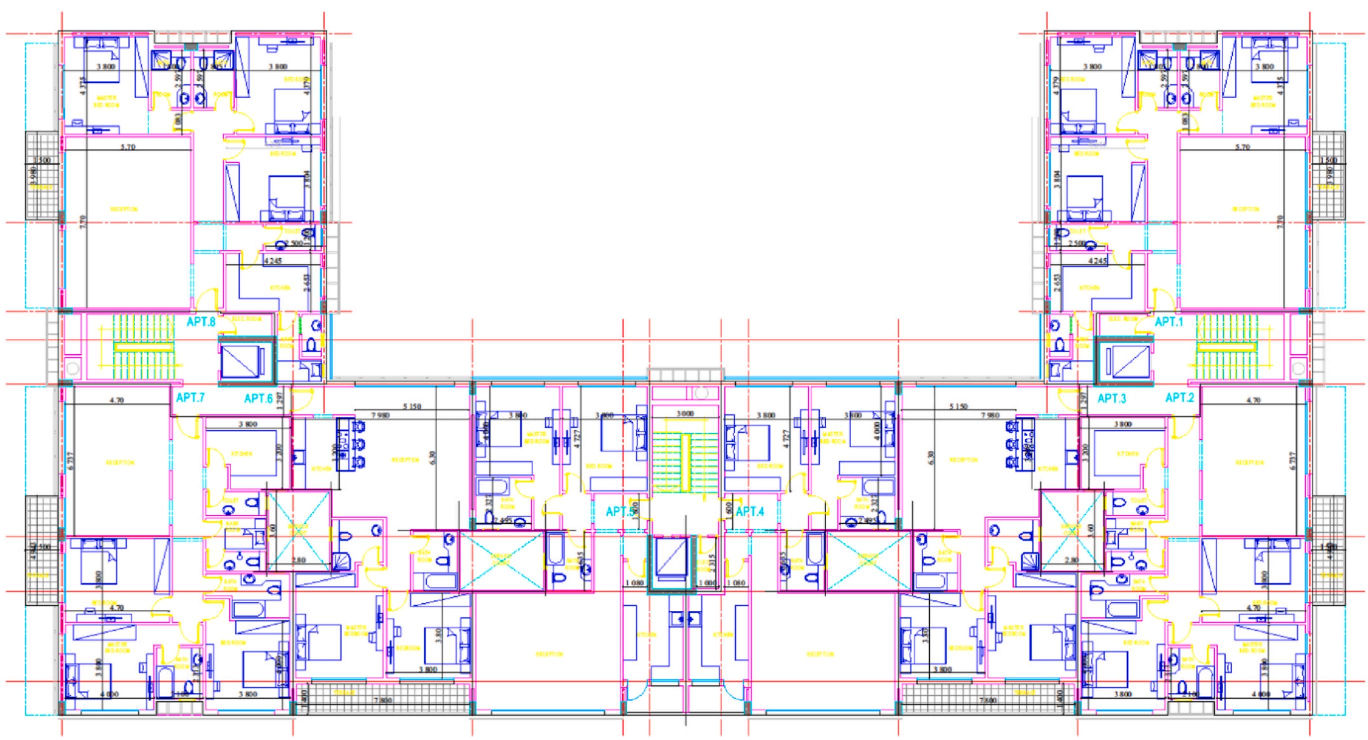


Fig. 5. Residential building floor layout. (Image: Francesco Reda, VTT).

- Different configuration of RES for supplying energy to NST were assessed using a system model and considering both solar PV integrated on building roofs and decentralized ground-mounted wind turbines.
- PV distribution in different buildings optimized to minimize energy export and maximize self-consumption.
- District heat pump in use.

Table 5 shows the cases defined based on the previous assumptions, while Table 6 summarizes the five scenarios considered for the total RES capacity installed. In the light of the results obtained, NST offers a real opportunity for the realization of Egypt's EE potential, even for the residential sector, since NST buildings are not lacking rooftop space, which typically hinders solar PV installation on old and renovated buildings (World Bank, 2017).

Table 3
Total area of building typologies, paired building model and thermal properties of the wall section.

Master Plan			
Total area (m^2)	**Building typology**	***Paired building model***	
101 465	University Neighbourhood	*Educational*	
51 970	Business	*Office*	
46 565	Cultural	*Educational*	
180 471	Family	*Residential*	
23 490	Hotel	*Residential*	
20 223	Commercial	*Office*	
16 240	Schools	*Educational*	

Material	**Specific Heat [J/kg. °C]**	**Density [kg/m^3]**	**Conductivity [W/m. °C]**	**Width [mm]**
Cement Plaster	1 000	2 000	1.4	25
Red bricks	1 000	1 200	0.5	125
Insulation	900	80	0.04	50
Red bricks	1 000	1 200	0.5	125
Cement Plaster	1 000	2 000	1.4	25
			[W/m^2°C] U (Transmittance)	**0.526**

Table 4
Cases defined for building energy performance simulation.

Reference	Tset, heating-cooling (20–22 °C)
Case 1	Tset, heating-cooling (23 °C)
Case 2	Tset, heating-cooling (20–26 °C)
Case 3	Tset, heating-cooling (20–26 °C), Natural Ventilation
Case 4	Tset, heating-cooling (20–26 °C), Natural Ventilation, Shading
Case 5	Tset, heating-cooling (20–26 °C), Natural Ventilation, Shading, Egyptian Stone
Case 6	Tset, heating-cooling (20–26 °C), Natural Ventilation, Shading, Wall Insulation
Case 7*	Tset, heating-cooling (20–26 °C), Natural Ventilation, Shading, Wall Insulation, HR48%
Case 8*	Tset, heating-cooling (20–26 °C), Natural Ventilation, Shading, Wall Insulation, HR80%

* Only for Educational and Offices.

5. Results

5.1. Buildings

Fig. 6 shows the results corresponding to the Residential, Office and Educational building models defined as described in Section 4.3. For the Residential model, the Reference case is shown at the bottom (BaU: cooling and heating 60 kWh/m^2 and 39.64 kWh/m^2). As could be expected in a country like Egypt, the cooling demand constitutes the biggest share, whereas the heating load appears negligible in all cases, except Case 1 (around 10 kWh/m^2, still a low value). Looking more closely, the temperature set point alone can have a significant effect on the demand. Best case: Cooling 36 kWh/m^2 and 13.59 kWh/m^2 heating (50% reduction).

For the Office and Educational models, again the Reference case appears at the bottom (BaU: 202 kWh/m^2 p.a. as total energy use and 162 kWh/m^2 for HVAC). As it turns out in both cases and unlike the Residential example, here the cooling demand is not always the biggest

Table 6
Scenarios for total RES installed.

S1	25% of the district's power peak	2.40 MW
S2	50% of the district's power peak	4.81 MW
S3	75% of the district's power peak	7.21 MW
S4	100% of the district's power peak	9.61 MW
S5	Enough RES capacity to achieve Net Zero Energy District (NZED) > energy produced = energy consumed	

Table 5
Cases defined for district energy performance simulation.

CASES	Portion of roof covered by PV			[MW]		
	Residential	Educational	Office	PV capacity	Wind capacity	Total RES
Case 1	17%	14%	8%	2.4		2.40
Case 1*	12%	14%	8%	2.02	0.38	2.40
Case 2	34%	27%	16%	4.81		4.81
Case 2*	19%	27%	16%	3.70	1.11	4.81
Case 3	59%	32%	21%	7.21		7.21
Case 3*	25%	41%	24%	5.24	1.96	7.21
Case 4	77%	45%	30%	9.61		9.61
Case 4*	25%	54%	32%	6.43	3.18	9.61
NZED	78%	49%	37%	10.21		10.21
NZED*	25%	58%	34%	6.69	3.57	10.26
NZED**	0%	0%	0%		10.36	10.36
Reference 1	Absorption chiller supplies the 60% of the cooling demand and district heat pump the remaining 40%, heat supplied by gas burner efficiency 70%					
Reference 2	District heat pump					

* PV and Wind combined; ** Only Wind.

share, and the heating load is not negligible. Three best cases: ~67 kWh/m^2 (67% reduction).

The "best cases" highlighted in the previous paragraphs refer to the combination of factors that provides the greatest potential for energy savings based on the simulation results. Specifically in relation to the Office building model, the results obtained are very much in line with the research by Elharidi et al. which indicates that an increased efficiency of the systems installed (HVAC, lighting, equipment, and appliances) combined with a more energy conscious occupant behavior, offer a good potential for energy saving (Elharidi et al., 2018).

5.2. District

Fig. 7 shows an overview of the results obtained at district level indicating the final energy consumption (equal to imported electricity in Fig. 7 for cases from 1 to 4 and NZED), and Onsite Energy Matching (OEM) and Onsite Energy Fraction (OEF) of the different cases (see Table 3). OEM shows the part of the electricity generated onsite used for the onsite demand, rather than exported to the grid, whereas OEF shows the part of the onsite demand covered by onsite electricity generation (Cao et al., 2013). The system performance is better if the values of OEM and OEF are higher (approaching value of 1), resulting in high matching characteristics (Rehman et al., 2019).

The share of the use of Renewable Energy Systems (RES) increases towards Net Zero Energy District (NZED) cases where the OEF reaches the OEM. The objective is to have high RES with low OEF. In an NZED scenario, the amount of energy exported equals the amount of energy imported. However, the optimization goal is to minimize the import-

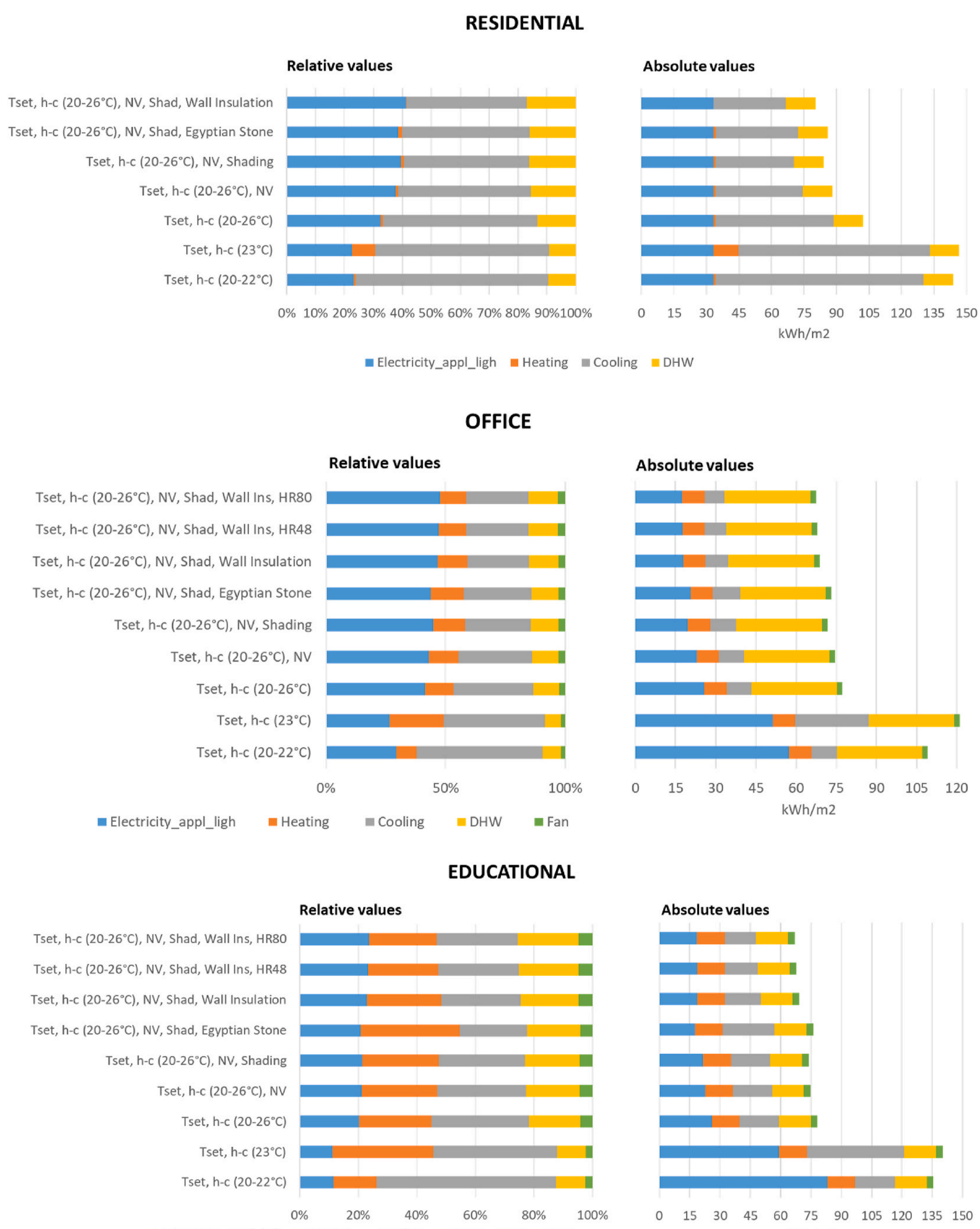


Fig. 6. Energy demand in relative and absolute values obtained for the Residential, Office and Educational building models. (Image: Francesco Reda, VTT)

export, and to provide the energy needed in operation by means of the RES existing in the district.

In Fig. 8, the results shown have a special focus on heat pump and RES. The image on the left depicts the final energy demand showing production shares and import (import = final energy consumption of Fig. 7 for cases 1 to 4 and NZED); while the image on the right shows the common chart for defining NZE target (exported vs. imported energy) (Sartori et al., 2012).

As it can be seen, the mixed use of PV and wind (NZED*) combined with heat pump exports less with almost the same import. Only PV or only wind (NZED**) options import more. NZED cases export more than the other cases. Energy storages are needed to decrease import.

As mentioned, the methodology and approach of the energy assessment work, already discussed in the previous section, were designed to produce results that could contribute to additional objectives 5 (scalability and replicability) and 6 (possible synergistic effects). A more detailed discussion on how to contextualize the results obtained and what next steps to take based on the gaps identified and potential discovered can be found in section 6.

6. Discussion

In the view of the authors of this article, this type of project has a clear potential to add to the realization of the goals of the above-mentioned Egypt Vision 2030 and World Bank report on EE, but only if it can provide truly inclusive solutions and an adequate integration to the existing urban fabric of NBC. Otherwise, there is a risk of deepening the current social divide by creating an island of wealth and technological advancement surrounded by much poorer living conditions. This is in line not only with Graham & Marvin's thesis of "splintering urbanism" (Graham & Marvin, 2001), but also with many other critical voices of certain smart city models over relying on new technologies, networks, and business development to attract global investments, and often leading to "social polarization" and exclusion (Hollands, 2008). Instead, addressing local needs with the help of available technology as means to achieve *"socio-economic stability and urban livability"* should be at the centre of the smart city (or rather citizenship) agenda as formulated by authors such as Sadoway & Shekhar (Sadoway & Shekhar, 2014).

On the other hand, the results presented in section 5 are very much in line with other similar evaluations conducted in Egypt and even in other parts of the world sharing somewhat similar conditions as seen in the Introduction. The case of NST was addressed using VTT's own methodology and previous experience in the country further improved for this application (main objective 1; additional objective 4), as already explained. All these contributions are adding to a growing body of knowledge, which in turn is leading to a deeper understanding of how different energy systems perform in the local conditions of Egypt enabling the development of replicable and scalable solutions (main objectives 2 and 3) that are feasible and affordable in that context.

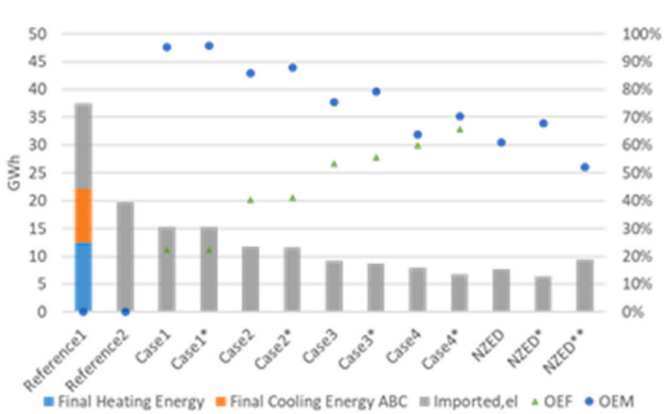


Fig. 7. Results obtained at district level. (Image: Francesco Reda, VTT)

Consequently, the authors believe that the next step is to complement the insight gained so far with good implementation cases that can be monitored and analyzed to advance the body of practice. More pilot projects are needed to test, validate, and further refine the evidence and the solutions resulting from the simulations and calculations carried out within numerous studies concerning the region as seen above. Predictably, these pilots would contribute to inform (and improve) future practice. Additionally, the potential for scalability (additional objective 5) and for increasing the efficiency and decreasing CO_2 emissions when moving from "building" to "district" scale should be further explored, while considering aspects like e.g., the positive effects of green infrastructure (trees, green roofs, façades) to decrease urban heat island (Susca et al., 2011) or more in general, of Nature Based Solutions (NBS). All this contributes to the practical realization of SDG11 - Sustainable Cities and Communities. To this end, the public sector can support the process by e.g., helping to disseminate international, regional, and national best practices, and even more importantly, leading by example. Egypt's New Administrative Capital currently under development east of Cairo (Lewis & Abdellah, 2019) (Midolo, 2019) offers a very good opportunity for scaling up the solutions developed by smaller projects around the country and the findings made by numerous studies, as well as for growing the local expertise. Perhaps a word of caution is due against the proliferation of heavily marketed flagship "ecocity" or "smart city" projects across the Global South that too often focus on the deployment of high-tech solutions and urban practices originating in very different contexts. These are typically supported by pre-existing structures that are not necessarily in place in this part of the world (Myllylä & Kuvaja, 2005). Frequently over relying on technology, they fail to engage the community and to generate a true sense of place (Piew & Neo, 2013). Lack of community engagement can easily lead to these projects not being properly understood by the local citizens and consequently, never fully appropriated (Yu, 2014).

In the authors' view, equally recommendable is to develop deeper understanding in relation to the energy-water-food nexus to discover the potential benefits of multi-level actions (additional objective 6). This is particularly important for Egypt since as Al-Saidi et al. point out, the country faces major security challenges in relation to those three axes, situation that is aggravated by complex regional geopolitics, political instability, and insufficient economic growth (Al-Saidi et al., 2016). Some authors like Fahmi and Sutton warn about the unexpected consequences that the privatization of municipal solid waste (MSW) management can bring for traditional communities of waste collectors, whose livelihood will be threatened by the *"technology-intensive multinational companies"* hired to provide MSW services (Fahmi & Sutton, 2010). However, such situations offer the opportunity to develop innovative business models that will secure the livelihoods of vulnerable communities and yet deliver a sustainable and efficient service. The previously mentioned study of Emirati villas showed that trees would become net carbon sinks if solar-powered reverse osmosis desalination (energy-water nexus in this instance) was to be implemented. Likewise, Egypt should encourage the study of the effects of combined solutions to e.g., reduce water consumption and improve water management, recycle grey and black water for irrigation, introduce aquaponics, increase the efficiency of food production, and strengthen its supply chain. Moreover, considering the gaps identified as well as the need to develop affordable and yet highly functional solutions that can be made available to most of the population, including the poor, Frugal/Grassroots Innovation can "deliver" low-cost robust products and services (Knorringa et al., 2016). Therefore, it may be worth the while to conduct empirical studies on how such innovations can contribute to a more inclusive development in a resource-constrained environment as that of Egypt, and concomitantly, to decrease the risk of splintering urbanism while having a positive impact on several SDGs (Khan, 2016), particularly on SDG10 - Reduced inequalities, by placing citizens at the centre of the process.

Very likely, this discussion would not be complete without

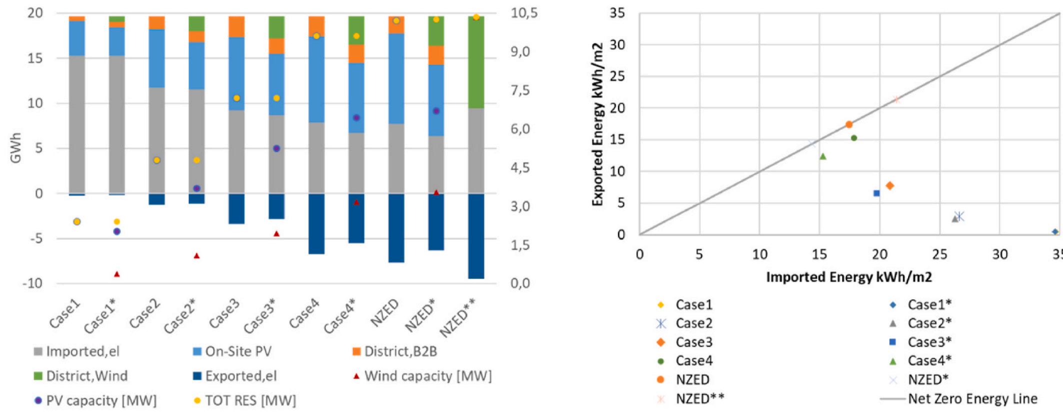


Fig. 8. Results obtained at district level. Focus on heat pump and RES. (Images: Francesco Reda, VTT)

highlighting the importance of capacity building as a fundamental component for the successful development of solutions adapted to local conditions based on the transfer of processes, technology, and good practices. However, in the authors' project experience, capacity is (and probably should be) built on both sides, although it may initially appear that the need for capacity development is only on the local side, in support of the development of better contextualized solutions. More information on this topic can be found in a couple of previous articles by two of the authors of this text (Antuña-Rozado et al., 2018; Antuña-Rozado et al., 2019b).

One of the limitations of this type of research is precisely that it remains at the planning level, which is not necessarily a decision of the researchers but the result of many other circumstances. Therefore, the authors would like to emphasize the importance of monitoring such projects from planning and design to construction, operation, and maintenance to get a more accurate and comprehensive picture.

7. Conclusions

As explained, what has been done in practice is to virtually connect the largest possible number of building models based on the different typologies included in the Master Plan to district energy production. The crucial importance of developing an adequate baseline built on the most accurate possible local data became clear during the assessment process. As equally important is to interpret the data gathered correctly and to make the right assumptions. Another realization was the need to complete the energy assessment with a cost analysis like the one carried out (also by VTT) for EcoNBC project, or the recently concluded study on the feasibility of a hybrid photovoltaic-fuel-cell-battery (PV/FC/B) to supply a small community in the planned city of NEOM in Saudi Arabia (Rezk et al., 2020). Likewise, the need to proceed with the next phases of the study to cover other aspects like water, waste, material resources, taking the same approach and trying to find potential synergistic effects, also became apparent. However, these additional studies have not been carried out yet due to lack of funding.

In the light of the results presented, the findings can be summarized as follows:

- The cooling demand does not always represent the biggest share (it did for the Residential model but not for the Office and Educational ones).
- The heating demand is sensitive to temperature set points, internal gains, and fresh air. Consequently, energy behaviors like setting more "energy-rational" set points, use of more efficient home appliances and saving measures such as intelligent lighting, can contribute significantly to decrease the heating demand.
- Natural ventilation is a good energy saving measure (free cooling) for Residential buildings, unlike for Office and Educational ones, mainly due to too high fresh air volumes. This is consistent with VTT's findings from previous experience in Egypt. A citizens' survey conducted on that occasion in New Borg El Arab showed the users' behavior in relation to natural ventilation, either by opening the windows or through vents (Reda et al., 2015).
- Shading has no impact since low-e (tinted) glass is used (infrared wavelength, weak impact on the visible spectrum).
- Replacing the Egyptian stone initially used in the envelope by 5 cm wall insulation, everything else remaining unchanged, slightly improves energy efficiency.
- Unlike cold climates, in this case heat recovery does not have a significant impact.
- Before acting on the system, the energy demand of buildings must be reduced.
- Different energy savings measures should be adopted for different building types.
- Optimizing on-site consumption is highly recommended to reduce the cost of energy infrastructure.
- NZED or Positive Energy District are possible to achieve with conventional RES.

In the authors' view the main objectives (see section 2) have been achieved to a large extent. This is precisely one of the important lessons learned, that it is relatively easy to realize the potential for greater energy efficiency that an early energy assessment that considers local regulations and specific conditions can offer, instead of providing a universal solution often directly transplanted from a completely different context and developed according to different parameters. In terms of additional objectives (see again section 2), the findings and recommendations of the EcoNBC project have also been capitalized on, and even more so since the NST energy assessment provided an opportunity to further refine the methodology developed by VTT during EcoNBC. The potential for replicability (i.e., at building level) is clearly there, provided that specific local conditions are properly considered. While the potential for scalability (i.e., moving from building to district scale) also appears to exist but requires further exploration. Finally, investigating possible beneficial synergistic effects, for example through the energy-water-food nexus, is something that should be addressed more consistently in the future, as this is one of the limitations of current research (see section 6).

Based on the findings presented, the authors believe that it is reasonable to expect that the results of the analyzes and the conclusions derived from them can serve as valuable recommendations to planners regarding feasible RES solutions and corresponding project size, which in turn can contribute to the achievement of SDG7 - Clean and Affordable Energy by 2030 and Egypt Vision 2030.

Author contributions

C.A.-R. and F.R. have been directly involved in the Egyptian case described in this article. They also worked together, back in the day, on the project "EcoNBC Feasibility Study. Transforming New Borg El Arab into an EcoCity", the results of which were capitalized on by this new research. J.G.-N. has coordinated this study, critically reviewed the manuscript, and provided useful recommendations.

Declaration of competing interest

The authors declare no conflict of interest.

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Abbreviations

B	Battery
CAPMAS	Central Agency for Public Mobilization And Statistics (Egypt)
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
EE	Energy Efficiency
EU	European Union
FC	Fuel Cell
FDI	Foreign Direct Investment
GENOPT	GENeral OPTimization
HVAC	Heating, Ventilation and Air Conditioning
ISES	Integrated Sustainable Energy Strategy
KFHSD	Khairy Foundation for Human and Social Development
MED-ENEC	Energy Efficiency in the Construction Sector in the Mediterranean
MENA	Middle East and Northern Africa
MPMAR	Ministry of Planning, Monitoring and Administrative Reform (Egypt)
MSW	Municipal Solid Waste
NBC	New Borg El Arab City
NBS	Nature Based Solutions
NEEAP	National Energy Efficiency Action Plan
NREA	New and Renewable Energy Authority
NST	Nabta Smart Town
NUCA	New Urban Communities Authority (Egypt)
NZEB	Net Zero Energy Buildings
NZED	Net Zero Energy Districts
OEF	Onsite Energy Fraction
OEM	Onsite Energy Matching
PV	Photovoltaic
RE	Renewable Energy
RES	Renewable Energy Source
SBC	Sustainable Buildings and Construction
SBE	Sustainable Built Environment
SDGs	Sustainable Development Goals
SDS	Sustainable Development Strategy
TARES	Technical Assistance to Support the Reform of the Energy Sector
TRNSYS	Transient System Simulation Tool
UAE	United Arab Emirates
UN ESCWA	United Nations Economic and Social Commission for Western Asia
UN-Habitat	United Nations Human Settlements Programme
VTT	Technical Research Centre of Finland Ltd.

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