Gamified Smart Grid Implementation Through Pico, Nano, and Microgrids in a Sustainable Campus

Citlaly Pérez[1](✉), Juana Isabel Méndez[1], Antonio Rivera[1], Pedro Ponce[1], Sergio Castellanos[2], Therese Peffer[3], Alan Meier[4], and Arturo Molina[1]

[1] Institute of Advanced Materials for Sustainable Manufacturing, Tecnologico de Monterrey, Monterrey, MX 64849, USA
{A01336766,isabelmendez,A01337294,pedro.ponce,armolina}@tec.mx

[2] Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX, USA
sergioc@utexas.edu

[3] Institute for Energy and Environment, University of California, Berkeley, CA 94720, USA
tpeffer@berkeley.edu

[4] Energy and Efficiency Institute, University of California, Davis, CA 95616, USA
akmeier@ucdavis.edu

Abstract. Deploying a smart city is becoming a trend toward achieving sustainability and enabling a better lifestyle for its inhabitants. Energy plays a leading role in smart cities, as most of our everyday activities and environment are related to energy sources. Integrating renewable energy into the electric power system is also challenging due to the intermittency and security of supply; a solution to this challenge is a decentralized system, which integrates renewable energies, reduces fossil fuel usage, and increases eco-efficiency. Furthermore, research suggests including social interaction between the inhabitants and the smart grid through interfaces with game elements that motivate and educate individuals about the smart grid. Thus, smart grids require including new distributed entities that have not existed previously, such as picogrids, nanogrids, and microgrids. In addition, the internet of things (IoT) applications provide advanced monitoring and control in the smart grid in case of an outage or disturbances. Therefore, this paper presents a microgrid, nanogrid, and picogrid integration using a building facility at Tecnologico de Monterrey, Mexico City Campus. Besides, a solar photovoltaic array was analyzed to understand the energy consumption and its interaction with the Campus microgrid. The building considers three groups: specialized laboratories, computer rooms, and classrooms. Additionally, a gamified platform was deployed to teach the Campus community the differences between these grids and how each picogrid had different consumption.

Keywords: Sustainable Campus · IoT Campus · Microgrid · Picogrid · Nanogrid · Renewable sources · Gamified platform

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1 Introduction

Non-renewable sources such as fossil fuels, including coal, oil, and natural gas, have been powering economies for over a century and a half by supplying about 80% of the world's energy [1]. Nonetheless, they require millions of years to regenerate; thus, they negatively impact the environment [2]. Moreover, the atmosphere's carbon dioxide and other greenhouse gases come from burning fossil fuels to generate energy [1]. Consequently, those gases are the primary cause of climate change and reduce the quality of life (QoL).

On the other hand, renewable sources, including solar, wind, hydro, biofuels, and others, help transition into a less carbon-intensive and more sustainable energy ecosystem [2]. Table 1 depicts the characteristics of some renewable sources and their technology type categorization. There are two categories of renewable energy technologies [3]:

- Dispatchable.
- Non-dispatchable or Variable Renewable Energy requires meeting the following characteristics for their integration into the current power system:
  - Variability is due to the temporal availability of resources.
  - Uncertainty is due to unexpected changes in resource availability.
  - Local specific properties due to the geographical availability of resources
  - Low marginal costs since the resources are freely available.

Furthermore, due to the Paris Agreement, over 700 cities worldwide have shifted to renewable energy [4]. These shiftings conceptualize and target their transition through decarbonized projects, net-zero energy buildings, or carbon-neutral outlines to move towards more renewable and sustainable cities [5].

By 2050, New York expects an 80% reduction in CO_2 emissions [6]. Copenhagen released an official plan to target CO_2 neutrality by 2025 [7]. In 2013, Vejle, Denmark, became part of the 100 Resilient Cities and proposed four pillars [8]:

- A Co-creating City: Multidisciplinary collaborations between public and private sectors to address the city's challenges.
- A Climate Resilient City: Their future development uses sustainable resources, renewable energy, and green transport by taking water and climate change as their drivers for their development.
- A Socially Resilient City: Future generations are the key to social and economic cohesion. Urban spaces and social housing aim to strengthen social resilience and community adherence.
- A Smart City: An efficient society is a product of smart technologies that promote social interactions and social inclusivity. The multiple collaborations, public accessibility, and digital technologies support youth education to create a digital society.

Therefore, a smart city improves citizens' QoL by providing them with services, technologies, and products that react more quickly and efficiently to their needs [5].

Furthermore, these services require a structure that provides solutions to the following challenges: healthcare, public safety, traffic and mobility, education, transportation, security, and energy [9–13].

Table 1. Non-dispatchable and dispatchable renewable energy sources.

Renewable energy	Characteristics	Category
Solar [14]	Photovoltaic (PV) panels convert solar energy into direct current electricity using semiconducting materials. Solar PV combines two advantages: module manufacturing in large plants, which allows economies of scale, and modular technology that deploys fewer PV panels	Non-dispatchable
Wind [15]	Wind turbines extract power from an airflow to produce mechanical or electrical power. Eolic energy is a mature technology with various system sizes, producing cheap energy at the utility scale. However, such technology is expensive on a small scale. In addition, due to wind's high unpredictability, turbines are commonly accompanied by other energy sources or storage systems when used in small applications	Non-dispatchable
Biomass [16]	Biomass is mainly a stored source of solar energy. Plants produce biomass through photosynthesis. Biomass can be burned directly for heat or converted to renewable liquid and gaseous fuels through various processes	Dispatchable
Hydropower [17]	Hydropower relies on the typically fast-moving water in a large river or rapidly descending water from a high point. This source converts the force of that water into electricity by spinning a generator's turbine blades	Dispatchable
Geothermal [18]	Geothermal energy derives from the thermal energy flux from the earth's center and is used only for thermal production or cogeneration. Geothermal electricity is very cheap when the proper ground conditions are met, although not many places have the suitable soil characteristics	Dispatchable

In this regard, smart renewable energy systems positively affect urban environments and citizens by influencing their well-being and increasing their QoL [5]. Thus, these systems are critical in generating clean energy and producing zero emissions as they require the integration of the power grid to ensure stability, protection, and operational restrictions. However, the power grid interaction with renewable sources must ensure stable operation after fault, load changes, and other network disturbances within a smart city [19].

As a result, decentralized power systems help solve relevant tasks such as optimizing and stabilizing power systems due to their flexibility in integrating renewable energy sources and intelligent control centers in power production and distribution [19]. Furthermore, a decentralized energy system seeks to put power sources closer to the end-user; thus, renewable sources, combined heat, and power can interact with the grid and help reduce fossil fuel use to increase eco-efficiency [19].

1.1 Smart Grid

Although there is a variety of smart grid definitions, the Electric Power Research Institute defines it as [20]:

- *The Smart Grid incorporates information and communications technology into every aspect of electricity generation, delivery, and consumption to minimize environmental impact, enhance markets, improve reliability and service, and reduce costs and improve efficiency.*

Thus, Smart Grids requires to fulfill the following [19, 21]:

- Enhance the operation of the legacy high voltage grid, for instance, by using synchrophasors.
- Improve grid-customer interaction by providing smart metering or real-time pricing.
- Include the new distributed entities that have not existed previously. Consider the picogrids, nanogrids, microgrids, and active distribution networks.

Furthermore, the common goals of power management in smart grids include minimizing electricity costs, reducing the peak to optimal ratio, maximizing user comfort, minimizing consolidated energy consumption, and integrating renewable energy [19]. Besides, the smart grid needs to provide a dynamically interactive real-item infrastructure encompassing the many visions of diverse power system stakeholders [21].

Consequently, citizens play a relevant role in the smart grid interaction, as they need to be aware of the importance of changing the ancient electric delivery methods for a sustainable one and the benefits it has to their economy [19, 21]. Furthermore, the feedback between the power plant and the customer is possible thanks to the two-way communication implemented around the smart grid.

Decentralized Energy System. Decentralized energy system conceptualization led to new grid proposals of arrangements based on size and configuration. Therefore, three sizes of grids based on small to medium off-grid or grid-connected systems are picogrid, nanogrid, and microgrid [19]. These grids use renewable energy sources and can operate independently of grid-supplied power. The pico, nano, and micrograms are easily installed, flexible, and can, in time, be connected to main power grids if and when such networks expand [22].

1.2 Picogrid, Nanogrid, and Microgrid

Picogrid's size is around 1 kW, and its key components are generation plus single-phase distribution [19]. Therefore, picogrids imply an appliance-level power distribution network with an ultra-low-power demand [22]. For instance, a powered USB hub becomes its nanogrid, independent (for power) from the upstream computer. Laptops, smartphones, tablets, or sensor networks fall into this category of picogrid [22].

Nanogrids can be interconnected with each other and with microgrids or macrogrids and include a controller, loads, gateways, and storage possibility; they are limited to a single building structure considered a primary load. It is also limited to a network of off-grid loads below 5 kW. This category includes: distributed generators, batteries, electric vehicles, and smart loads capable of islanding with some level of intelligent distributed energy resource management controls [19].

Microgrids have well-defined electrical boundaries and interconnected loads and distributed energy resources [23]. Their purpose is to harness distributed and renewable energy sources in medium and low voltage environments [23]; hence, customers have access to use them directly [19]. Furthermore, microgrids can connect and disconnect from the grid to allow both grid-connected or island modes. Microgrids have a generation capacity of 1–50 kW that serves consumers and uses distribution lines [19].

Microgrids comprise power converters, battery energy storage systems, control and protection systems [23]. In addition, these configurations involve small-scale electricity generation, which serves a limited number of consumers via a distribution grid that can operate in isolation from the national transmission network [23]. Microgrids are appearing on campuses, such as universities, hospitals, military establishments, and business parks in urban environments [19].

Notwithstanding, deploying a smart grid is a complex process requiring all its components to work together as a whole [21]. To achieve this, communication between all the elements is crucial and must be resilient [8]; thus, available Internet of Things (IoT) technologies can gather data by sensing and monitoring citizens and their environment to understand and propose solutions to their needs. Moreover, these grids interact with the power grids and IoT services to accomplish high-functional grid operation and effective electricity usage [24].

Picogrid, nanogrid, and microgrid involved in a Sustainable Campus. An example of a microgrid on Campus is the University of California, San Diego [25], which serves a campus community of more than 45,000 people, 13 million ft2 in 450 buildings, and 1200 acres. The Campus can be seen as a microgrid, each building represents a nanogrid, and each floor's building represents a picogrid. It generates 80% of the electricity used on Campus annually. It has gas turbines that generate 213.5 MW, a 3 MW steam turbine, PV panels that generate 1.2 MW, and a Power Purchase Agreement for fuel cell power that uses methane from a wastewater treatment plant. The microgrid can connect to the larger electric grid and work independently.

1.3 Internet of Things

A smart grid involves transportation and delivery of electricity; every system must be thoroughly efficient and reliable in all its steps [21]. Internet of things (IoT) applications are used to reach this goal because those technologies allow advanced monitoring and control in case of an outage or disturbances, among other issues [24].

The IoT has encouraged the development of devices connected to the internet that allow monitoring and control services. IoT devices are in charge of measuring specific parameters according to their application; those application areas include healthcare, smart building, smart home, and smart grids [21].

In every area where IoT is present, there are essential requirements that the devices must accomplish: low power consumption, small size, low cost, and durability [24]. Alongside those requirements, network features must be considered: low latency, enough bandwidth, resilience, and scalability [24]. Also, crucial security issues must be prevented, such as DoS, DDoS, malware, and phishing.

Three main parts are involved in a general IoT implementation: IoT embedded devices, gateways, and clouds [24]. The first one is related to all the sensors and actuators included in the application, which must be connected by short-distance communication technologies such as Bluetooth Low Energy (BLE), ZigBee, or WiFi. Secondly, the gateways or routers are the linkages between the devices and the cloud service. These routers have different technologies depending on the connection conditions or the distance between devices. Finally, all the data gathered from the IoT devices is sent to the cloud using long-distance communication technologies (WAN) such as NB-IoT, LoraWAN, and Sigfox. In the cloud infrastructure, the data is stored, processed, and made logical decisions [24].

1.4 Gamification in Smart Grids

Gamification uses game elements to enhance user experience and user engagement in real contexts and applications [26]. Gamification motivates and increases user activity and retention by adding gaming elements, enticing users, and encouraging specific types of behavior, creating a significant driving force to induce desirable user behavior. Gamification has been widely used in different fields, such as productivity, finance, health, and sustainability [26].

Marques and Nixon [27] suggested that Smart Grids need to ease the interaction between the users and the grid to communicate load adjustment and understand human motivational psychology. They outlined that the gamified applications should promote and motivate continual change in individuals' behavior regarding the smart grid through three cores: energy education, social interaction, and energy conservation.

Konstantakopoulos et al. [28] proposed an HMI for a social game that encourages energy-efficient behavior among smart building occupants. The social game was employed for residential housing single-room apartments at the Nanyang Technological University campus. This interface deployed IoT sensors to monitor real-time room lighting systems and HVAC usage. The interface included feedback, points, rewards, random rewards through coins and daily energy usage. Besides, they suggested incorporating game applications in smart grid management.

Common gamification design principles include goals and challenges, personalization, rapid feedback, visible feedback, freedom of choice, freedom to fail, and social engagement. Gamification elements include points, scoring, leaderboards, progress bars, ranks, rewards, or incentives [26].

The goal of an interface is to make users feel in control of their experience. Graphical interfaces for gamification purposes allow for specifying goals, rules, settings, context, and types of interactions. The basic mechanics of gamification interfaces are closely related to game design: addressing the human desire for socializing, learning, mastery, competition, achievement, status, self-expression, altruism, or closure [26].

Smart grids appeared to respond to human energy needs and improve electric energy conditions [21]. However, as human energy needs are involved, it requires understanding how humans behave to understand their pattern's consumption. It is complex to know in a smart grid about the type of users; therefore, gamification is a way to teach the community [13]. Thus, this paper proposes to employ gamification techniques to provide an interactive interface about the different types of grids involved in a Campus facility. The microgrid, nanogrid, and picogrid are better explained in a Campus, as it is similar to understanding a community or how a city behaves [12, 13].

2 Proposal

Following UC San Diego's proposal, a great example of a microgrid is a university campus and its application into the Mexico City context. In 2018, Tecnologico de Monterrey, Mexico City Campus (Tec CCM) began its reconstruction due to the 2017 earthquake. The new Sustainable Campus considers renewable sources as photovoltaic arrays, including urban parks and plazas, the mitigation of annual flooding with bioclimatic considerations such as naturally ventilated buildings, pergola for heat gain reduction, and reduction of carbon footprint [12, 13]. Currently, there are six constructed buildings.

This paper focuses on nanogrid and picogrid using CEDETEC building as a case study. Besides, a solar PV array is analyzed to understand better the energy consumption and its interaction with the Campus microgrid. Thus, Table 2 sections CEDETEC by room type, floor, and grid type. Each floor column presents the grid type as picogrid, whereas the nanogrid is presented as a merged row of the four floors. Due to the privacy of the building consumption, estimated energy consumption was proposed using templates that accepted energy simulators have, such as EnergyPlus software [29]. Thus, the equipment density in Watts per meter considered for each room type was as follows: Specialized laboratory (Open lab): 43.1 W/m^2; Computer Room: 20 W/m^2; and Classroom: 10 W/m^2. The estimated occupancy hours considered 12 daily hours during 43 weeks at 80% of occupancy (2064 h) and nine weeks with 20% occupancy (108 h), giving a total annual equipment usage of 2172 h.

Table 2. CEDETEC room type by floor.

Room type	First floor	Second floor	Third floor	Fourth floor
Specialized laboratory	11	1	0	2
Computer room	3	6	3	3

(*continued*)

Table 2. (*continued*)

Room type	First floor	Second floor	Third floor	Fourth floor
Classroom	4	6	12	9
Grid type	Picogrid	Picogrid	Picogrid	Picogrid
	Nanogrid			

Figure 1 shows the microgrid, picogrid, and nanogrid applied into the Sustainable Campus Tec CCM. These are the grid distribution:

- Microgrid: Interconnected loads from each building.
- Nanogrid: A single building capable of being self-sufficient through PV arrays and smart loads.
- Picogrid: Each building level is composed of lighting, appliances, security, and HVAC systems, among others.

In addition to the PV array for the nanogrid, this paper also proposes to integrate solar energy into other applications within the university campus, such as:

- E-bikes with a motor powered by solar energy for the mobility of students and personnel within the Campus.
- Solar lamps.
- Solar chargers for low electricity consumption devices.
- Greenhouses powered by solar energy produce food for consumption within the Campus.

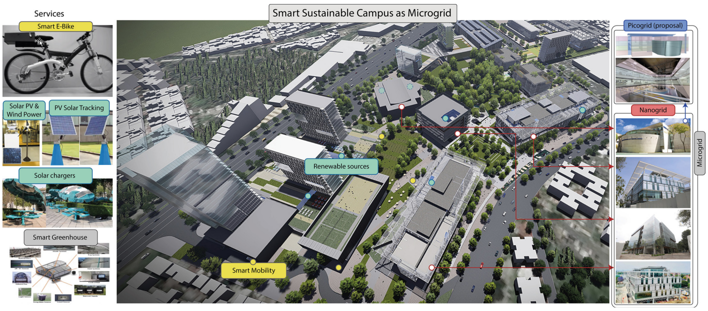

Fig. 1. Sustainable Campus as an example of Smart City using microgrid, nanogrid, and picogrid (Tec CCM).

Besides, Fig. 2 describes the gamification elements required in each grid type. For the microgrid, exploratory tasks and unlockable content are displayed because the community has access to the general level and visualizes the levels available for each building (or nanogrid). Then, the second level is the nanogrid, where the students learn the consumption on each floor and how the four levels of the CEDETEC building represent the nanogrid. Finally, on the third level, each floor represents the picogrid; the community has access to random rewards, social competition, feedback, and challenges. In [12, 13], they proposed for the picogrid level and specifically in each classroom how to provide gamified elements that engage students and teachers in a dynamic for becoming energy aware.

The main specifications of the modules and the inverters used for the PVsyst program simulation are described in Table 2 [30]. The location of the building is (19.28°N, -99.14°W). The roof considered was the east and west sides with a roof area of (800 m^2), and the inclination and azimuth for the PV modules (19°/0°) were considered for the PV modeling proposal of the nanogrid building (CEDETEC, Table 3).

3 Results

Table 4 estimates the annual energy consumption of each floor based on the type of room and equipment density described in the previous section. The annual consumption of this nanogrid building is estimated to be 2220 MWh. With an estimated usage by floor of 65.5%, 10.2%, 12.4%, and 11.9%.

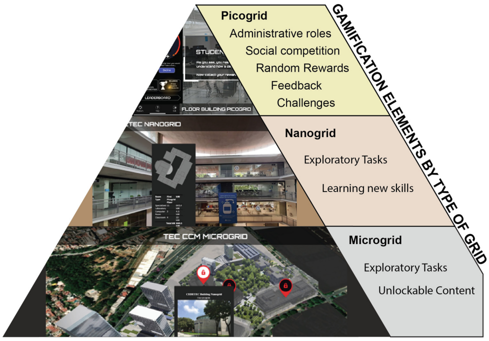

Fig. 2. Pyramid of types of grids involved in the Campus. Microgrid, nanogrid, and picogrid have different gamification elements.

Table 3. PV models and inverters suggested for the CEDETEC's nanogrid.

PV modules		Inverters	
Manufacturer	Generic PVsyst	Manufacturer	PVsyst
Model	Poly 30 Wp 36 cells	Model	3 kWac inverter
Module size	0.360 × 0.650 m^2	**Input characteristics (PV array side)**	

(*continued*)

Table 3. (*continued*)

PV modules		Inverters	
TRef	25 °C	Vmin	125 V
GRef	1000 W/m^2	Vmax	440 V
Voc	21.70 V	Vmax array	550 V
Isc	2.40 A	Vmin@Pnom	188 V
Vmpp	17.30 V	Pnom DC	4.0 kW
Impp	1.74 A	**Output characteristics (AC grid side)**	
Pmpp	30.10 W	Grid voltage Monophased	230 V
ISC temperature coefficient	1.40 mA/°C	Grid frequency	50/60 Hz
Pnom	30 Wp	Pnom AC	3.0 kWac
		Pmax AC	3.0 kWac
		Inom AC	13.0 A
		Imax AC	16.0 A
		Max. Efficiency	97.0%

Table 4. CEDETEC annual energy consumption for the equipment.

Room type	First floor	Second floor	Third floor	Fourth floor
Specialized laboratory	643.4 kW	2 kW	0 kW	7.9 kW
Computer room	4.1 kW	60.1 kW	14.8 kW	14.4 kW
Classroom	22 kW	42.4 kW	112 kW	99.2 kW
Total picogrid	669.5 kW	104.5 kW	126.8 kW	121.5 kW
Total nanogrid	1022.3 kW × 2172 h = **2220.4 MWh/year**			

Table 5 shows the results from the PVSyst simulation. The produced energy by the proposed PV array will be 204.4 MWh/year with a specific production of 2003 kWh/kWp/year and a performance ratio of 88.21%.

Table 5. PV Array Characteristics suggested for the CEDETEC's nanogrid [30].

PV modules		Inverters	
Number of PV modules	3402 units	Number of inverters	27 units
Nominal (STC)	102 kWp	Total power	81.0 kWac

(*continued*)

Table 5. (*continued*)

PV modules		Inverters	
Module	162 strings × 21 in series	Operating voltage	125–440 V
At operating conditions (50 °C)		Pnom ratio (DC:AC)	1.26
Pmpp	99.8 kWp		
Vmpp	293 V		
Impp	340 A		
Total PV power		**Total inverter power**	
Nominal (STC)	102 kWp	Total power	81 kWac
Total	3402 modules	Number of inverters	27 units
Module area	796 m^2	Pnom ratio	1.26

Considering CEDETEC's energy consumption (2220.4 MWh/year), the proposed PV array will be able to feed 9.2% of this demand. The proposal is that this nanogrid feeds picogrids located in the floors that do not have a large energy consumption, such as the second, third or fourth floor; another proposal would be feeding picogrids located in computer rooms and classrooms with low energy demand. For instance, this PV array will provide power for the computer rooms located on the third and fourth floors and the classrooms on the first and second floors entirely, which represent a demand of (203.3 MWh/year).

Figure 3 shows the IoT implementation applied to Sustainable Campus. First, the sensors and actuators collect and sense the data from the buildings, renewable sources, laboratories, utilities, transportation, and services. Then, the gateway links these devices with the cloud service. Thus, the collected data is sent to the cloud using WAN technologies. In addition, the end-users become active participatory sensors that send information to the cloud, sensors, and actuators. In other words, the first group marked represents all the sensors installed in the classrooms, laboratories, and computer rooms. All those small spaces are the local area networks (LAN), so technologies like Bluetooth, Zigbee, or even WiFi fit correctly.

The sensors should contribute to the correct energy management, including measuring lighting, HVAC, and other loads connected to the energy supply. Also, people's presence, sunlight intensity, and temperature must be detected, among others, to control the systems properly. The data collected on each LAN can be shown to the end-users with an indicator display or a mobile app (fourth group). However, sending the information to the cloud service using WAN protocols is mandatory to use the routers installed along with the Campus (second group). The third group represents the cloud services that will process, store and make decisions depending on the data received, so two-way communication must be established between the end-user and the systems controlling all the actuators.

Furthermore, Fig. 4 depicts a gamified platform deployed in the Genial.ly platform [31]. This gamified platform aims to teach the Campus community the differences

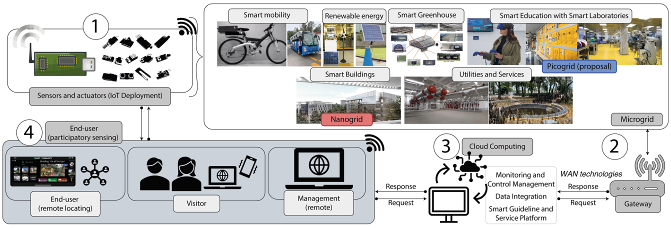

Fig. 3. Sustainable Campus and IoT integration for monitoring and sensing the microgrid, nanogrid, and picogrid at CEDETEC (Tec CCM).

between grids. The game starts with the microgrid level; it depicts a mission and provides exploratory tasks and unlockable content. It allows the community to learn how the four buildings have specific picogrid floors. The players can interact directly with CEDETEC and explore each floor. Besides, the players interact with this building. At the nanogrid level, they can access two new activities to explore the building through a virtual tour that opens a new window.

The other activity belongs to each picogrid, and the community can put the mouse above each floor and learn about the type of rooms available in each picogrid. Thus, information regarding the number of specialized laboratories, computer rooms, and classrooms is depicted. Then, the players select the next step, and a floor building picogrid image is depicted. The objective is to select the connected thermostat and visualize the differences between the professors' and the students' interface.

These interfaces depict how the teacher can send a message to the students by suggesting, for instance, increasing by 1 °C the thermostat setpoint to save energy and how they can save it by increasing it. Literature shows that by increasing 1 °C the setpoint, at least 6% of energy can be saved [13]. Finally, random rewards are deployed so players can select one of the three rewards.

4 Discussion

This paper followed the four pillars that Vejle, Denmark, proposed for Resilient Cities [8]. These pillars applied to the Sustainable Campus include:

- A co-creating City: The proposal provides multidisciplinary collaboration and activities through boot camps with the government or activities that connect the end-users with the Campus [32].
- A Climate Resilient Campus: the services integrate solar energy services in services like mobility, transportation, recreation or leisure, or even in the manufacturing process or agro production as greenhouses powered by solar energy. Empower the local consumption through these greenhouses.

- A Socially Resilient Campus: New educational models that strengthen social resilience and community adherence have been launched since 2019 with the novel Tec-21 model [10, 12, 13].

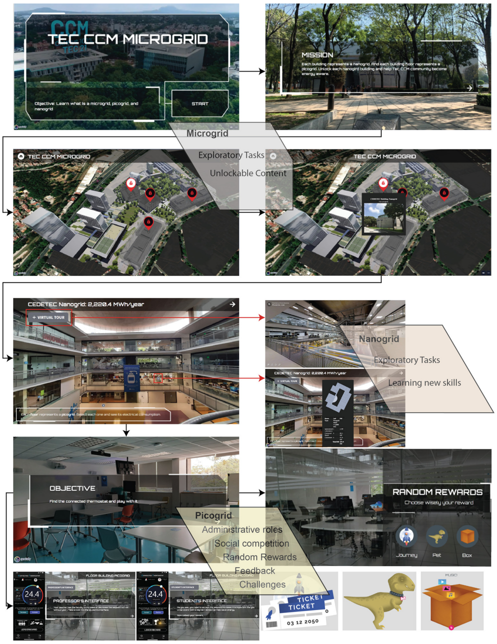

Fig. 4. Gamified platform of Tec CCM microgrid available at [31].

- A Smart Campus: Dividing the Camus into microgrid, nanogrid, and picogrid provides a decentralized energy system that is easily installed, flexible, and can, in time, be connected to main power grids if and when such networks expand [33]. Besides, the inclusion of IoT allows the community to become an active sensor that continuously senses the daily activities that help predict possible failures or know the students' energy usage patterns through the people's presence, sunlight intensity, temperature setpoints, illumination, or equipment usage [24].

Besides, a gamified platform was deployed following Konstantakopoulos et al. [28] and Marques and Nixon [27] suggestions. Thus, a gamified platform that provides interaction between the users and the grid was deployed to understand the differences between grids. Education through gamification has been used to teach students specific topics. Innovative laboratories in education teach students specific topics like electricity usage [13]. Besides, gamification emerges as a solution to teach students in a ludic manner how to learn particular topics, for example, mathematics [13]. Therefore, there is a potential to apply gamification techniques to teach students the different types of grids and how the consumption reflects in the smart grid. Different game elements are proposed depending on the type of grid because it depends on the level of control the university community has. For example, in the picogrid it is better to use an approach where the student can learn about the use of thermostats and how the setpoint reduces or increases the electrical consumption [12, 13]. The nanogrids are related more to display exploratory tasks to help them become energy aware and identify when they can help reduce electrical consumption. The microgrid enables comparing buildings to teach the community how, depending on the type of building and activity, the type of electrical consumption and learn when they can reduce energy. Teaching the Campus community how to become aware provides them with the knowledge they can apply in their homes to promote these energy reductions.

Future work includes providing real-time interaction in real-time of the microgrid, focusing more on the picogrid, to teach the community how, for instance, managing the thermostat of the setpoint affects the energy and CO_2 consumption directly. Besides, an energy monitor of the Campus could be deployed using the community Villach monitor as a guideline [34].

5 Conclusion

This paper proposes a solar PV array for a building with three types of rooms on each floor: fourteen specialized laboratories, fifteen computer rooms, and thirty-one classrooms. Due to private access to the information, the annual energy consumption was estimated based on templates that energy models' simulators offer, such as EnergyPlus. Hence, the annual energy consumption was estimated at 2220 MWh. The PV array was simulated using the PVSyst software and estimated based on the roof and location at 204.4 MWh/year with a specific production of 2003 kWh/kWp/year and a performance ratio of 88.21%. With this information, the proposed PV array for the nanogrid will be able to feed 9.2% of the building's energy consumption, which can be distributed in the following two options: first, supply power for the second, third, or fourth floor, or second, feed picogrids that will provide energy for the computer rooms of the third and fourth floors and the classrooms of the first and second floors entirely.

To increase the QoL in the sustainable Campus, this paper also proposes the integration of renewable energy sources into services and products in mobility, transportation, recreation, or leisure. These services include E-bikes powered by solar energy, solar lamps and chargers for low electricity consumption devices such as mobile phones, and solar energy greenhouses for personalized food production.

Thus, the communication incorporates information in every grid about electricity generation, delivery, and consumption to improve efficiency and social interaction between each grid and the community members. Consequently, the inclusion of microgrid, picogrid, and nanogrid in a Campus facilitates the monitoring changes after proposing activities or goals such as energy reduction or thermal comfort analysis. As a result, the smart campus community plays a primary role in the smart grid interaction, as they need to be aware of the importance of modifying energy consumption behavior.

Therefore, a gamified platform is deployed to sensitize the community members on the differences between microgrid, nanogrid, and picogrid. This game shows the CEDETEC building as an example of a nanogrid and how the picogrid affects each floor. Likewise, an example of a thermostat display from the student's and the teacher's perspective is deployed to show the community how the teacher can send a message to the student to increase or decrease the setpoint and how its action affects energy consumption.

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