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# Planning & Open-Air Demonstrating Smart City Sustainable Districts

**Stefano Bracco [1], Federico Delfino [1,2], Paola Laiolo [1,*] and Andrea Morini [1]**

1 DITEN—Department of Naval, Electrical, Electronic and Telecommunication Engineering, University of Genoa, 16126 Genova, Italy; stefano.bracco@unige.it (S.B.); federico.delfino@unige.it (F.D.); andrea.morini@unige.it (A.M.)
2 CENS—Management Center of Savona Campus, University of Genoa-Savona Campus, 17100 Savona, Italy
* Correspondence: paola.laiolo@edu.unige.it

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**Abstract:** The article is focused on the "demonstration" activities carried out by the University of Genoa at Savona Campus facilities in order to implement the "Living Lab Smart City". The idea is to transform the Savona Campus in a Living Lab of the City of the Future: smart technologies in Information and Communication Technology (ICT) and energy sectors were installed in order to show a real application of the Smart City concept to population and external stakeholders. Moreover, special attention was given to the environment, personal wellbeing, and social equalities. The sustainable energy Research Infrastructures (RIs) of Savona Campus allowed enhancement of the applied research in degree programs and the collaboration with several companies. In particular, an important partnership with the Italian electric Distribution System Operator (DSO), ENEL S.p.A., started in 2017 to test the capability of these RIs to operate disconnected from the National Grid, relying only on the supply of renewables and storage systems. The "Living Lab Smart City" is an important action to reduce the carbon footprint of the Savona Campus and to increase the awareness of students, teachers and researchers towards Sustainable Development in Higher Education Institutes.

**Keywords:** smart city; living lab; sustainability; sustainable energy; sustainable environment; wellbeing

## 1. Introduction

During the last two decades, many cities around the world started to improve their urban infrastructures and services by resorting to the opportunities offered by state-of-the-art innovative technologies and according to the "sustainability" paradigm in order to offer higher life quality conditions to their citizens [1–5]. These efforts have been generally focused both on specific redevelopment operations on underused or decaying suburban areas and on the redesign of city centers from a traditional urban core, very often overcrowded, to a more environmentally sustainable and comfortable space, where the public community can work and spend free time, even experiencing a healthy lifestyle. This is the concept of the new sustainable smart cities [6–9], intended as urban spaces highly permeated by the contribution of a citizen and society oriented technology [10]. The so called "smartization process" includes interventions on different sectors of everyday life, based on a wide application of Information and Communication Technology (ICT) to both monitoring how the city is evolving and to connect, protect and enhance the lives of citizens [6,11,12]. Consequently, IoT (Internet of Things) sensors, video cameras, social media, and smart devices act as an urban nervous system, providing a constant information to local institutions and to the community. In particular, they allow, at any time, to manage, optimize and control all the urban activities according to people need [13–15].

Smart cities today stand for a multidisciplinary subject of interest with several sectors of development, namely energy [16], intelligent buildings, mobility, environment, low-impact infrastructures, participated governance, education, healthcare and wellbeing, and sustainable tourism. As a result, these intelligent and sustainable urban areas have been studied not only by scholars in architecture and urban planning, but also by other disciplines, such as the social sciences (economy, geography), and the technical ones (computer science, electrical and civil engineering) [17,18].

It should be noticed that universities can play an active role in facilitating the deployment at a wide scale of the smart city concept, strictly cooperating with government and local institutions [19–21]. Academic players, indeed, can address innovation projects to the real experimentation at the campus level of smart city "pilots" in order to show "open-air" innovative technologies and increase the public awareness about the topic [20]. Following this path, university campuses can become Living Labs [22–24], open-innovation environments typically characterized by private—public partnerships (research institutions, industry, SMEs) aimed at implementing and demonstrating new services, products and systems for urban applications [24]. In this context, the University of Genoa (UNIGE), Italy, recognizes, in its Charter, sustainability as one of the main pillars for its future evolution, in strict connection with the development lines of the surrounding territory (Liguria Region, the North West Italian district), such as tourism, green & blue economies, hi-tech/hi-skills industries and health, wellbeing & sport activities. In particular, UNIGE is strongly committed in following an innovation path towards the paradigms of "Zero Emission Campus" and "Smart City Living Lab" at its premises located in the city of Savona (about 45 km from Genoa) [21,25–27]. UNIGE idea is to make the Savona Campus a model of sustainable district for local society and institutions through the real demonstration of the best available technologies in the environmental, energy and wellbeing sectors.

The present paper describes the projects and activities conceived by the University of Genoa with the specific intention to transform the Savona Campus into a demo site of a sustainable smart urban district, namely the "Living Lab Smart City", characterized by the most relevant city features, such as residences, offices, green/recreational areas, food service, and educational activities.

It is important to underline that planning and implementing a smart city is not simple because cities are made up of multitudes of individuals and entities that are difficult to coordinate. However, this process inside Savona Campus has been carried out with the active involvement and empowerment of all the Campus community components (students, faculty, and employees).

This article is organized as follows. Section 2 gives an overview about the Campus, while Section 3 describes the material and methods used to implement the "Living Lab Smart City" in different sectors. The performance evaluation metrics and the results of the projects are described in Section 4. Finally, Section 5 presents our discussion and conclusions.

## 2. Savona Campus Overview

From 1930 to 1990, the whole area, of about 55,000 sqm (Figure 1), hosted a military compound of the Italian Army. The barracks were delimited by a high wall, still present outside the current university campus. Afterwards, in the 1990s, an urban regeneration accommodated the University facilities into the pre-existing seventeen buildings. Nowadays, more than 2000 students attend here both B.Sc./M.Sc. programs and professional masters in Engineering (environment and energy sectors), Health & Sport Sciences, Nursing, Media Sciences, and Sustainable Tourism. About 185 persons (15 employees and 170 academics) are part of the University staff located inside the Savona Campus. Moreover, the area includes 15 SMEs (Small and Medium Enterprises) with about 130 workers. Many services for both students and workers are present as well: a library, a cafeteria, a canteen, study halls, sports facilities, green areas and student accommodations. Therefore, the Campus can be compared to a small city district since the most relevant city features are represented. For this reason, the University of Genoa decided to focus the research inside Savona Campus on Sustainability and Smart City topics in order to create a "Sustainable and Innovative Campus" able to increase the private and public awareness about the aforementioned themes. Great efforts were made to enhance green areas, increase sustainable mobility, and implement a waste-recycling program. Since 2011, an innovation project, named "Energia 2020" [21,26,28], allowed to create two important Research Infrastructures

(RIs) integrating renewable energy sources and system automation in order to reduce the carbon footprint and to create a high-comfort environment for the Campus: the "Smart Polygeneration Microgrid" (SPM) and the "Smart Energy Building" (SEB) [21,28,29]. These RIs allowed, in 2017, to start a collaboration with a multinational energy company, Enel S.p.A. This brought to the creation of an "Open Innovation Lab" aimed to test the Smart City technologies in ICT and energy sectors [21]. Moreover, UNIGE is developing projects and programs related to sport in order to improve health and wellbeing of students and Campus users. In particular, a cooperation with Savona Municipality was put in place to design and create a National Sport Hub for sea and water activities.

The many actions developed on sustainability and smart city topics at Savona Campus, allowed to join, in 2016 and 2017, two important global networks about "Sustainable University Campuses". The first is the International Sustainable Campus Network (ISCN), a non-profit association of globally leading colleges and universities working together to holistically integrate sustainability into campus operations, research and teaching [30]. The second is the UI Greenmetric, a university ranking platform established with the aim to evaluate and rank universities all over the world according to their current condition and policies related to green campus and sustainability activities [31].


**Figure 1.** Satellite map of Savona Campus area from Google Earth 2018 (Google Earth V 7.3.2.5491. (23 July 2018). Savona Campus—University of Genoa, Savona, Italy. 44°17′54′′ N, 8°27′01′′ E, Eye Alt 215 m. Available online: https://earth.google.com/web/). The yellow line represents the Campus wall.

## 3. Materials and Methods

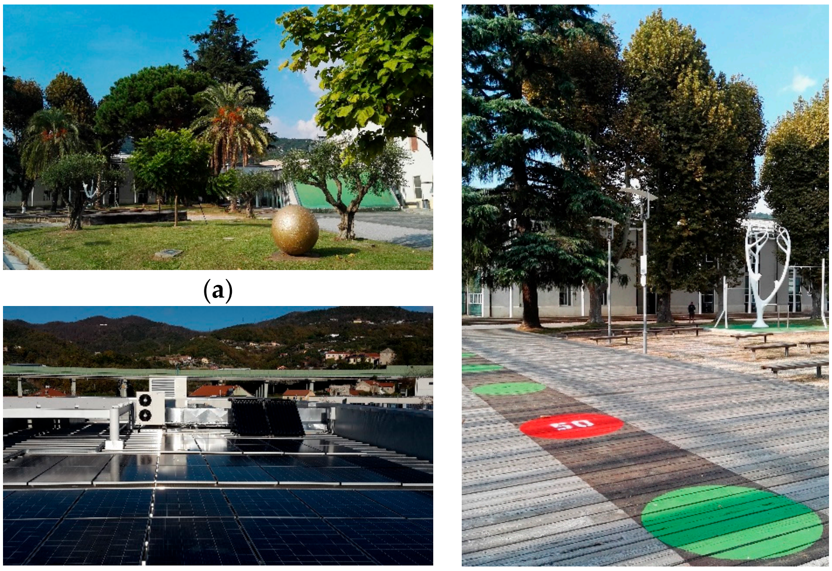
In the recent years, the research of the University of Genoa inside Savona Campus has been devoted to engineering topics such as sustainable energy & environment, smart buildings and electric mobility. Recently, health and sport sciences studies on wellbeing and healthy ageing have been developed as well, making the Campus an example of a healthy and innovative district inside the city of Savona.

In this context, it is worth mentioning the "Energia 2020" project of the University of Genoa, an important Research and Development (R&D) project related to the concepts of Sustainable Energy and Smart City [21,26,28]. The project, designed in 2011 and developed thanks to public financing, planned to install within the Savona Campus innovative energy systems aimed at both reducing operating costs and $CO_2$ emissions. Additionally, particular attention has been paid to create a comfortable environment for the Campus users. Energia 2020 consists of three different actions:

(i) Smart Polygeneration Microgrid (acronym: SPM); (ii) Smart Energy Building (acronym: SEB); (iii) Energy Efficiency Measures (acronym: EEM). The SPM, an "intelligent" and sustainable microgrid providing electricity and thermal energy to the Campus [21,26], started to operate in 2014. In 2017 both the SEB and the EEM were implemented; the first is an "intelligent" and active ZEB (Zero Emission Building) interacting in real-time with the Energy Management System of the SPM, while the second deals with a series of actions aimed at reducing the consumptions and the energy dispersions at the building level. These three interventions contributed to start, at the end of 2017, an important collaboration with the Italian electric Distribution System Operator (DSO), Enel S.p.A. The purpose of this public-industrial partnership is to develop research projects in the fields of sustainable energy, smart mobility and islanded microgrids. For that reason, the "Living Lab Microgrid" national laboratory was created [21].

Over the last three years, health & wellbeing topics are strengthening inside Savona Campus. From an educational point of view, one B.Sc. in Sport and Health Sciences and one Master's of Rehabilitation of Musculoskeletal Disorders are present. These programs benefit from several sport infrastructures within the Campus to practice what taught during the lessons. In particular, inside the area of the Campus it is possible to train specific sports as tennis and football or to practice a total-body training inside a smart Gym (U-Gym) or outdoors over a 1 km open-air fitness trail, named U-Trail. U-Gym and U-Trail were specifically designed to be used for individual wellbeing of students, university staff and personnel of the SMEs located inside the Campus, but also as Sport and Health Laboratories to performance studies on sport and rehabilitation programs.

Figure 2 shows some photos of the Savona Campus about green areas, renewable energy technology and outdoor sport infrastructures.




(b) (c)

**Figure 2.** The figure shows some photos of Savona Campus: (**a**) the garden near the canteen and students accommodations; (**b**) the photovoltaic plant and the solar thermal collectors above the Smart Energy Building; (**c**) part of U-trail, a 1 km outdoor fitness trail, with one training station at the top right of the photo.

The following sub-sections describe in detail the Smart City sectors developed inside the "Living Lab Smart City" of Savona Campus. Moreover, Table 1 summarizes all the achievements obtained inside Savona Campus in the main Smart city sectors.

**Table 1.** Smart City achievements of Savona Campus—University of Genoa.

| Smart City Sector | Achievements of Savona Campus |
|---|---|
| Sustainable Energy | • Creation of a Smart Microgrid managed by an Energy Management System<br>• Energy production from renewable sources and cogenerating units<br>• Energy-efficiency interventions in public buildings |
| Smart Mobility | • 4 charging stations (2 Grid to Vehicle and 2 Vehicle to Grid)<br>• 4 electric vehicles (2 bikes and 2 cars)<br>• 73 bike parking lots |
| Smart Buildings | • Construction of a Smart Energy Building managed by a Building Management System<br>• Automatic light and presence sensor systems in all the buildings |
| Sustainable Environment | • Improvement of green areas and biodiversity<br>• Vertical hydroponic garden<br>• Smart garden irrigation system<br>• Rainwater collection<br>• Improvement of waste collection |
| Health, Wellbeing and Social Integration | • Creation of a technological gym with some instruments able to produce electricity<br>• Creation of an outdoor fitness trail<br>• Projects, at the design phase, to enhance the actual football field and to create a National Sport Hub for sea and water activities<br>• Planning for special programs for the sport training of disabled people |

### *3.1. Sustainable Energy*

The need for a more efficient, reliable and sustainable energy production inside the Savona Campus paved the way for the design of a smart microgrid. Smart Grids are modern "active" grids designed to gather and exchange both information and energy. Among Smart Grid solutions, Microgrids are considered to be ones of the most interesting applications of this concept. They can be defined as localized aggregations of generating units (from renewable or traditional sources), loads as well as storage systems (electrical and thermal) related to a restricted area. The aforesaid infrastructures need to be daily managed by a so called EMS (Energy Management System) that usually aims at minimizing operating costs and/or emissions, also considering the possibility to apply demand response strategies [32,33]. In this context, the SPM pilot project has been developed by the University of Genoa with the purpose to efficiently and economically manage the energy produced and distributed within the Campus, optimizing the contributions coming from renewable sources and thus reducing the pollutants emissions [25–27]. The SPM is composed of an electrical and a thermal grid, both managed by a central brain, the Energy Management System (EMS), in charge of real-time checking the functional status of all the grid's elements and informing in case of problems or breakdowns [34]. The EMS allows also to forecast the energy consumptions to optimally schedule the operation of dispatchable sources, also planning the exchange with the public grid, with the goal of minimizing operational costs and reducing carbon dioxide emissions [28].

The main energy components of the SPM are: two photovoltaic plants (PV), three solar thermodynamics dishes, two cogenerating micro-turbines, two gas boilers, two absorption chillers and one electrochemical storage system. Furthermore, an additional PV plant, two solar thermal collectors and a geothermal heat pump are present in the new Smart Energy Building of the Campus.

Most of the electricity needs of the Savona Campus are satisfied by the generation from both solar power and cogenerating micro-turbines fed by natural gas. These high efficiency cogeneration units allow to exploit the primary energy to produce simultaneously two types of energy: electrical energy, injected into the distribution grid, and thermal energy, used to integrate the boilers' production during coldest months and as feeding source for the absorption chillers (in order to produce cooling energy) during warmer months. It is important to underline that the electrical energy generated by PV fields can be stored inside the electrical storage system, under the supervision of the EMS developed by the University of Genoa. The following table (Table 2) summarizes the sizes of the plants present inside the Savona Campus.

**Table 2.** Size of the energy production plants inside Savona Campus.

| Energy Production/Storage | Installed Power/Storage Capacity |
|---|---|
| Electricity | 120 kW (PV plants)<br>130 kW (Cogeneration units) |
| Thermal energy | 900 kW (Boilers)<br>224 kW (Thermal power – cogeneration units)<br>220 kW (Cooling power– absorption chillers)<br>45 kW (Geothermal heat pump)<br>2 kW (Solar Thermal collectors) |
| Electrical storage | 140 kWh |

Due to the EEM project, the Campus end-user consumptions and the energy dispersions at the building level have been reduced. In particular, new window fixtures have been installed the air conditioning system has been improved and led lamps have been included in both the internal and external light systems.

### 3.2. Smart Mobility

UNIGE owns two electric bikes and two Li-ion batteries cars, whose technology guarantee a long life cycle, high performances, high efficiency, and no toxic components. The benefits given from the usage of electric vehicles are first of all environmental: indeed, there is no emission of local atmospheric pollutants and no acoustic noise.

Electric vehicles can be recharged inside the Campus since four charging stations, connected to an E-car Operation Center platform, are present. Two of them allow the Grid to Vehicle (G2V) technology, while the other two are also Vehicle to Grid (V2G). The latter, installed in 2017, use the batteries of the electric cars as support storages to the electric grid. Indeed, V2G is a technology that allows a full integration of electric vehicles into the electricity grid and a more efficient management of renewable energy. Through a V2G station, drivers can charge their batteries during off-pick periods (low demand), with the option to use the energy stored in the vehicles' batteries at home/office or even feed back to the grid during peak hours, when the costs are higher, becoming therefore "prosumers" (producer and consumer).

Another type of zero emission vehicle enhanced inside the Campus is the bike. Nowadays, about 73 bike parking lots are available for free inside the area; moreover, bicycles are available, upon request, for students staying at the Campus accommodations.

### 3.3. Smart Buildings

Several technological and smart devices are present within the buildings of Savona Campus in order to improve both safety and life quality of students and workers. Some examples are automatic lights, presence sensor systems, video surveillance system and automatic door sensor system to enter into the Library. Moreover, the entrance into the U-Gym is guaranteed by using a RFID (Radio Frequency Identification) bracelet or a specific smartphone app (Virtual Badge) and the environmental comfort inside the Smart Energy Building has been increased thanks to a controlled mechanical ventilation system.

In 2017, the SEB was built to be an innovative and high performance smart construction to meet goals of zero carbon emissions, energy and water efficiency, and automation [25–27]. It acts as the first smart city urban infrastructure in Italy as it is directly connected to the SPM. This connection, guaranteed by the BMS (Building Management System) of the SEB and the EMS of the SPM, allows the SEB to be an "Energy Prosumer" able to produce energy (thermal and electrical) for its own and, in case of need, to recall it from the SPM. Moreover, the BMS can optimally manage the electrical and thermal performances of the SEB, but also the led lamps intensity, the indoor temperature, the building blinds and the water consumptions.

The building has two floors covering a total area of 1000 $m^2$. The heating and the air-conditioning are provided only by a geothermal heat pump and solar thermal collectors, while the electricity is supplied by the photovoltaic panels mounted on its roof and by SPM storage batteries. In addition, the energy efficiency performance of the SEB are improved thanks to the high performance thermal insulation materials (cladding and ventilated facades) of the external walls and the low consumption led lamps.

### *3.4. Sustainable Environment*

Environmental protection is one of the main pillars of sustainability. The technological development should protect ecosystems, air quality, and sustainability of natural resources. Following this direction, it becomes very important to enhance the surrounding environment to make it clean and livable. For this reason, UNIGE decided to improve the green areas of Savona Campus, obtaining a covering of about the 23% of the global area. The biodiversity is preserved since different trees species can be found: pine, palm, olive, cedar, and plane trees. In addition, a vertical hydroponic garden, fed only by water, is present inside the SEB. Lawns and gardens inside Savona Campus are irrigated by a smart irrigation system which runs automatically but can be optimally managed by the use of a web application also available on smartphones. The web application allows to monitor the garden irrigation status, to set different irrigation programs, to detect problems in the system, to see the irrigation schedule in a selected period, and to generate reports about the use of water. Moreover, the gardens near the SEB are irrigated by the use of recycled rain water. The water collected from the roof, conveniently filtered, is stored inside an underground 5000 liters storage tank and it is used, in case of need, for garden irrigation and toilet flushing. This system allows to have both economic and environmental benefits. Other examples of water saving technologies are the dual-flush toilets and low flow taps and showers in the buildings.

Great efforts were also made in relation to urban waste and recycling. The Savona Campus wants to raise awareness on the issue of urban waste and to be a model of environmental impact reduction for population and institutional stakeholders (e.g., municipalities) in the surrounding area. For this reason, appropriate waste containers were located into all the buildings and in the main external areas. It is possible to recycle paper and cardboard, plastic, glass, cans, organic waste, used electrical batteries, toners and cartridges, and also street sweepings. All the waste fractions, including the street sweepings, are collected and sent to different treatment plants.

### *3.5. Health, Wellbeing, and Social Integration*

Many more people today are living healthier lives than in the past decade. Nevertheless, the economic growth and high workloads can often cause health diseases and psychological disorders [35]. A possible way to increase the personal wellbeing is to practice regular sport. Sport activities, together with technological innovation, can facilitate a transition to a world of reduced environmental stress and enhanced human wellbeing. For these reasons, the University of Genoa decided to invest some of its funds, not only in the energy and environment sectors, but also in the sport one, improving and creating new facilities inside the Savona Campus following the smart city concept.

From 2017, the Smart Energy Building hosts a digital and technological Sport Science Lab, named U-Gym, available for students and Campus workers. It is a cutting-edge gym with particular equipment for indoor training with LCD displays for the interaction with a virtual coach by the use of a Cloud platform. Each sport equipment allows the user to access a personal account in which historical training program results, favorite websites, and social networks are present. Moreover, some of these instruments (bikes, tapis roulant, and elliptical machines) are able to produce electricity thanks to the "human movement"; this energy is injected into the Smart Energy Building and used inside offices, laboratories and also into the gym. The access to U-Gym is automatically controlled by a virtual gap: the door can be opened by the use of a special bracelet (the same used for sport equipment) or by using Android or iOS Apps.

In 2018, a 1 km fitness trail, named U-Trail, was created. The path includes three different workout stations for a total body outdoor training. The exercise options can be learned on a smartphone App available both on IOS and Android platforms.

In the near future, two other projects will be put in place. The first one, U-Field, is devoted to roof the existing football field to create an indoor multi-purpose field to train football, volleyball and basketball. The second is aimed to establish, in collaboration with Savona Municipality, a National Sport Hub for sea and water activities (e.g., open water swimming, surf, rowing, sailing, stand up paddle, beach volley, beach soccer) on the beach in front of the Campus (about 800 m far from the University). This water sport center could be used by the Campus population (students and workers) but also by the Olympic athletes for their training.

Finally, special attention was given to the generation of a comfortable environment for people with disabilities. In particular, wheelchairs ramps were built outside the buildings and suitable lifts were inserted inside. Moreover, a recent project, named "Sportability", planned special programs for the sport training of disabled people (also for Paralympic athletes) by the use of Savona Campus facilities.

## 4. Results

The "Living Lab Smart City" of Savona Campus allowed to implement several projects in different smart city sectors such as energy, smart buildings, sustainable mobility, and wellbeing. These activities produced many benefits both from educational and government/industrial perspectives. All the developed infrastructures and facilities helped the University to fill the gap between theoretical lessons and the real world applications, allowing the students both to make an experience of applicative research during their degree programs and to have a direct insight of what explained during the lessons.

The following sub-sections are related to the results obtained, respectively, in the energy sector, in the waste management area and about the health and sport facilities use.

### *4.1. Energia 2020 Project's Results*

The Energia 2020 actions, that is the SPM, the SEB, and the EEM, allowed to reduce, in 2017, the energy bill (electricity and thermal energy) of the Campus of about the 30% (81,000 € saved in one year). Moreover, different companies are developing Research and Development (R&D) activities in collaboration with the University researchers with the goal of creating innovative hardware and software products for smart microgrids and smart buildings. In particular, the "Living Lab Microgrid" has been conceived by the University of Genoa, in collaboration with the Italian DSO, Enel S.p.A, to develop research projects in the fields of sustainable energy, smart mobility, and islanded microgrids (electrical networks which are able to work only by the use of renewable sources and storage systems, without being connected to the national grid). Enel S.p.A. works together with Savona Campus researchers on SPM and SEB infrastructures to test smart city technologies in order to create a springboard for their development and widespread implementation. Moreover, research activities focused on innovative technical solutions for the residential sector will be also build up, in the domain of smart electrical homes/ appliances and devices related to the Internet of Things. The results derived from the Living Lab Microgrid will be used to develop guidelines for the implementation of the smart city concept in urban areas; besides, the Savona Campus will become a demo site where the technologies of the smart city will be available to the community. The sustainable energy research team operating at the Campus is heavily committed in sharing results, field experiences, techniques and strategies with researchers operating in energy and sustainability topics around the world, through bilateral cooperation, framework agreements between Universities, participation in European projects, etc. This because the University firmly believes that, in a world characterized by tight economic constraints and technical complexity, important results can be achieved only by sharing different experiences and joining research efforts. It is also for this reason that both the SPM and the SEB were conceived as test-beds for the Smart City paradigm, open to research activities carried out by industries and other Universities.

The implementation and the study of the SPM and SEB infrastructures at the Savona Campus defined several sustainability best practices to be reproduced at the city level designing residential, tertiary and industrial districts characterized by distributed generation units and efficient buildings. The best practices are the following ones:

- production of sustainable energy to satisfy the Campus needs;
- use of Combined Cooling, Heating and Power (CCHP) systems to reduce primary energy consumptions and $CO_2$;
- implementation of Energy Management Systems to optimally manage the energy production and distribution;
- use of electrical storage systems to compensate the fluctuations of power production from renewable sources;
- promotion of the use of sustainable mobility by enhancing the electrical vehicle charging stations with two different technologies (G2V and V2G);
- creation of a sustainable urban energy island with buildings fed only by renewables with no connection to the public electric grid;
- use of energy efficient appliances such as LED lamps automatically controlled according to available natural light and occupancy levels;
- use of water efficient appliances and water recycling programs to reduce the waste of water;
- use of ventilated facades and high thermal/acoustic insulation systems to reduce thermal dispersions;
- implementation of Building Management Systems to optimally manage building consumptions and performances to guarantee both a maximum comfort level and high efficiency.

In order to better analyze the energy performance of the "Living Lab Smart City", that is the combination of SPM and SEB, six Key Performance Indicators (KPIs) were considered. Three of them evaluate the electric performance (Electrical self-production—ESP, Electrical production from renewable sources-EP_R and Electrical production from CCHP—EP_CCHP), while the other three consider the thermal ones (Thermal self-production-TSP, Thermal production from boilers-TP_B and Thermal production from CCHP—TP_CCHP). The equations used to calculate these indexes are the following ones.

$$\mathrm{ESP} = \frac{\text{Electrical energy production}}{\text{Total electrical demand}} \cdot 100 \tag{1}$$

$$\mathrm{EP\_R} = \frac{\text{Electrical energy production from renewables}}{\text{Electrical energy production}} \cdot 100 \tag{2}$$

$$\mathrm{EP\_CCHP} = \frac{\text{Electrical energy production from CCHP}}{\text{Electrical energy production}} \cdot 100 \tag{3}$$

$$\mathrm{TSP} = \frac{\text{Thermal energy production}}{\text{Total Thermal demand}} \cdot 100 \tag{4}$$

$$\mathrm{TP\_B} = \frac{\text{Thermal energy production from boilers}}{\text{Total Thermal demand}} \cdot 100 \tag{5}$$

$$\mathrm{TP\_CCHP} = \frac{\text{Thermal energy production from CCHP}}{\text{Total Thermal demand}} \cdot 100 \tag{6}$$

The following spider graph (Figure 3) summarizes the energy KPIs of Savona Campus from 2015 to 2017. It can be noticed that both the electrical self-production, taking into account the electricity produced by the cogenerating micro-turbines and the PV plants, and the electrical production from renewables have been increased from 2015 to 2017 (the electrical self-production in 2015 was about

36%, while in 2017 it was 49%). This is due, basically, to the new PV fields installed over two buildings: in 2015 only one PV field was present, now they are three. The Electrical production from CCHP remained almost constant at about 60%. As per the thermal performance, it is important to underline that all the energy needed to heat or cool the buildings is produced inside the Campus by the geothermal plant in the SEB and by cogenerating micro-turbines with absorption chillers and, when necessary, by the boilers. In 2016, a very cold winter caused a bigger use of the boilers with respect to years 2015 and 2017. The thermal production from renewables in 2015 and 2016 was 0%, while in 2017 it was 5% since the geothermal plant of the Smart Energy Building started to operate.

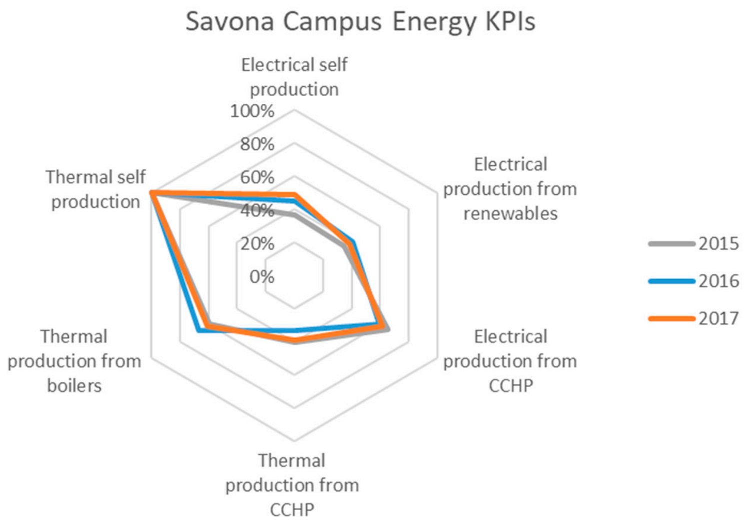



**Figure 3.** The spider diagram summarizes the values of the six Energy Key Performance Indicators of Savona Campus RIs. The performances were evaluated for three different years: 2015 (grey line), 2016 (blue line) and 2017 (orange line).

### *4.2. Results about the Recycling Program*

The implementation of the recycling program inside the Savona Campus generated benefits for the environment because the recycling rate reached the 75%. The total amount of waste produced inside Savona Campus is about 100 tons per year. The recycling plants guarantee a 100% recycling for paper, plastic, batteries, and toners; 98% for glass & cans; and 75% for the street sweepings. The unsorted waste part is finally taken off to a landfill. The following pie chart (Figure 4) shows the types and the corresponding percentage of production of the waste produced inside the Savona Campus. In particular, it underlines that the street sweepings represent the biggest part of waste (48%), while the unsorted waste is only the 14%.

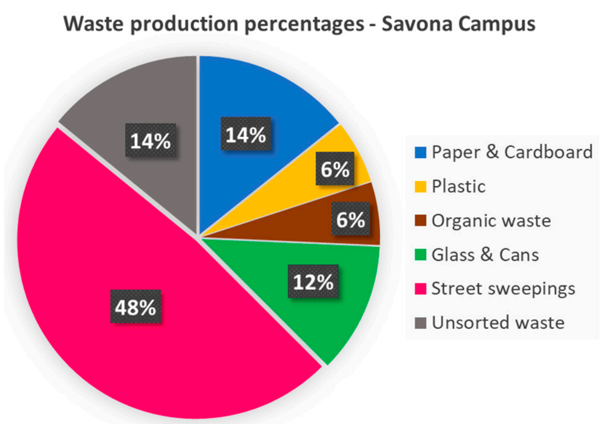



**Figure 4.** The pie chart shows the percentages of production relative to different types of waste: paper & cardboard, plastic, organic waste, glass & cans, street sweepings and unsorted waste.

### 4.3. Results about the Use of Sport Infrastructures

The outdoor sport infrastructures of Savona Campus, namely the U-Trail, the football field and the tennis court are generally used during the warmest months, namely from May to October. In the near future (second semester 2019), the football field will be roofed (U-Field project) allowing the training also during the colder months. It is important to highlight that such infrastructures are freely accessible from 8.00 a.m. to 8.00 p.m., not only for the University people, but also for the population, due to the public nature of the Savona Campus area.

Data are available since May 2018, when the U-Trail was completed and unveiled. On average about 50 persons per month practiced football and tennis, except in August since, due to summer holidays, the training is stopped. The U-Trail gained a growing importance during the summer because several students, and workers as well, started to learn the exercises and enjoyed the open-air training in their free time. Moreover, some local high schools in the nearby brought their students to practice open air sport during their sport sciences lessons. The following graph (Figure 5) highlights this growing trend.

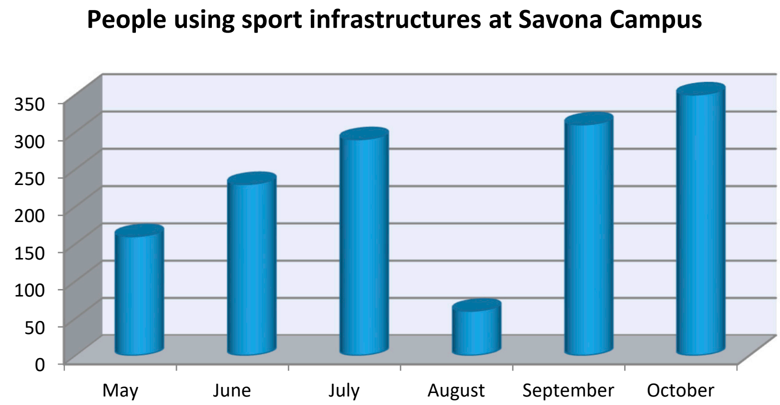



**Figure 5.** The graph shows the number of people (students, workers and local schools) per month, who used the sport facilities of Savona Campus from May to October 2018.

## 5. Discussion & Conclusions

The research activities carried out at the Savona Campus in the sustainability field have permitted to develop important R&D projects in collaboration with industrial companies and foreign universities and research centers. As regards the energy sector, valuable collaborations have been established with Enel SpA, Fiamm SpA, and Siemens SpA to study islanded microgrids, smart electric mobility systems, electrical storage devices, and energy management systems. The aforesaid companies have financed scholarships for PhD students and Assistant Professors in order to strengthen their collaboration with the Savona Campus. Moreover, the main results of the research activities have been published in renowned international journals and presented at international conferences. This has permitted to start joint research programs with notable universities such as ETH Zurich and MIT Boston. Furthermore, the SPM and SEB projects are currently used as examples of smart districts by municipalities that intend to refurbish urban areas with the aim of reducing primary energy consumptions and carbon dioxide emissions. The proposed Living Lab concept can be applied to provide such urban areas with the following facilities and practices: installation of renewable power plants, adoption of energy consumption management systems, and smart mobility, creation of public amenity areas for relaxation and sport activities, as well as social housing areas characterized by the presence of business incubators and innovative 4.0 craft workshops.

In particular, the research activities carried out in the sustainable energy field at the Savona Campus have allowed development of skills and practical expertise on how to develop a smart city project within an urban area [21]. The analysis of the interaction between a smart microgrid and a smart building and the optimal management of the whole infrastructure has permitted to highlight criticalities and potentialities of such innovative facilities. In particular, with regard to energy production technologies, renewable energy power plants, cogeneration units, and storage systems have been deeply investigated in order to evaluate their performance, capital and operating costs, reliability, and availability. It is important to highlight that the optimal design of a smart energy infrastructure based on the aforesaid technologies needs a very detailed energy audit of the end-users, in terms of thermal and electrical loads, in order to choose the best type and size of technologies. Furthermore, the daily management of such complex infrastructures needs the adoption of accurate forecasting tools used to predict thermal and electrical loads, as well as energy carrier prices and energy production from intermittent renewable sources. As described in the result section, the implementation of SPM and SEB projects has determined a huge number of advantages for the daily operation of the Savona Campus in terms of economic savings and emission reduction. Benefitting from the electricity production from the solar source and conveniently exploiting the cogeneration units, in periods characterized by a simultaneous need of electrical and thermal energy, and the storage systems, the energy bill of the Campus has been reduced since a lower amount of electricity has been withdrawn from the public grid and the use of natural gas for boilers has been limited. The resulting economic saving, coupled with the environmental one, has strengthened the sustainability concept within the Campus and has proved the real feasibility of this kind of projects, thus providing an example of a sustainable district for the smart cities of the future.

The activities developed at the Campus from 2014 till now on SPM and SEB infrastructures have also permitted to open new challenging research lines in the smart energy and sustainability field, that specifically refer to smart mobility and demand response. Indeed, in the next years the number of electric vehicles is envisaged to increase and their impact on power grids will be more and more impressive. The testing of V2G technology at the Savona Campus will permit evaluation of the role of electric vehicles within the ancillary service market and interesting analyses could be done in order to compare the performance of vehicle batteries to that of fixed storage batteries. As far as demand response is concerned, the possibility to manage controllable loads and other equipment will be tested and the application of demand response policies will give information on their feasible and profitable adoption in the urban environment.

Good results were obtained also by the implementation of the waste collection program, which allowed Savona Campus to become a public leading guide over Savona Municipality in terms of "smart" and empowered response of the involved community in following environmentally friendly rules.

Finally, health and wellbeing infrastructures contributed to creating a common awareness in Campus population about the benefits carried by the regular practice of sport and outdoor activities, creating as well a strong and positive link with neighboring citizens, who started to spend more and more time inside the Campus living a healthy life.

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