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Article

Urban Lighting Project for a Small Town: Comparing Citizens and Authority Benefits

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Abstract: The smart and resilient city evolves by slow procedures of mutation without radical changes, increasing the livability of its territory. The value of the city center in a Smart City can increase through urban lighting systems: its elements on the territory can collect and convey data to increase services to city users; the electrical system becomes the so-called Smart Grid. This paper presents a study of smart lighting for a small town, a touristic location inside a nature reserve on the Italian coast. Three different approaches have been proposed, from minimal to more invasive interventions, and their effect on the territory has been investigated. Based on street typology and its surroundings, the work analyzes the opportunity to introduce smart and useful services for the citizens starting from a retrofitting intervention. Smart city capabilities are examined, showing how it is possible to provide new services to the cities through ICT (Information and Communication Technology) without deep changes and simplifying the control of basic city functions. The results evidence an important impact on annual energy costs, suggesting smart grid planning not only for metropolis applications, but also in smaller towns, such as the examined one.

Keywords: smart city; smart lighting; road lighting; LED; energy consumption; smart grid

1. Introduction

Energy demands represent a global issue that calls for innovative local energy solutions, such as the ones generally proposed in Sustainable Energy Action Plans (SEAP). EU Countries have set up goals to reduce greenhouse gas emissions by 20%, to increase energy efficiency by 20% and to increase the share of renewable energy sources to 20% by 2020. Public Administrations are called to reduce CO_2 levels and the impact of energy production on the environment. For this reason, Municipalities can join the Covenant of Mayors [1], the most important global movement on a local level, and receive support during the transition period to find the appropriate resources. By the end of February 2015, more than 6000 cities around Europe (3000 in Italy) signed the agreement and started working on their SEAPs [2].

This research focuses on energy efficiency development in urban areas, combining public lighting management and city resources. Cities around the world proceed in projects like energy efficient public lighting and CHP (combined heat and power) projects as well as energy efficient buildings, satisfying high thermal standards and using eco-materials. The rapid development of renewable energy technologies represents a great future potential [3,4], and gives the possibility of public and private buildings becoming energy producers [5]. Cities around the globe could become important players in the future CO_2 trading market, as they emit large quantities of greenhouse gases caused by public lighting, urban transportation and public building energy usage.

The public lighting systems in our cities are basic and vital services for city users and public administrations. Citizens demand high-quality services but urban lighting is a significant consumer of energy. The maintenance cost of street lighting is a challenging energy and financial burden for governments around the world [6].

In Italy as well as across the EU, urban and street lighting systems are old, obsolete and inefficient, not complying with regulations [7], sometimes damaged, and they represent to all municipalities a potential source in terms of energy efficiency and CO_2 reduction. The need to meet targets for Energy saving and reduction of CO_2 production perfectly matches with the need for the renovation of urban lighting.

A recent study carried out by the European Commission [8] has shown that between 30% and 50% of electricity used for lighting could be saved by investing in energy-efficient lighting systems. In many cases, such investments are not only profitable and sustainable but also improve lighting quality [9]. However, urban lighting is an issue consisting of several balanced aspects: standards, minimum requirements, valorization of the city, structure and composition of the urban environment, and requalification of urban spaces.

This paper shows a study for a new lighting system of a small town on the Italian coast, an attractive touristic location inside a nature reserve. Three different approaches, from minimal to more invasive actions are described, and their results on the town are investigated by comparing energy consumption and lighting quality. Technical characteristics and energy consumption data regarding the existing system have been provided by the municipality. The streets considered in this case study are not currently complying with law requirements. The proposed systems were modeled using commercial software and it was set as a minimum requirement to comply the standards. The first level is lamp retrofitting to achieve the minimum required illumination by current standards. The second level approach, introducing deeper changes than the first one, is the design of a new system to comply with the laws, to maximize energy savings and to obtain the requalification of urban spaces that could become more attractive [10]. The third approach studies the lighting system as a smart grid opportunity; therefore, the systems are improved with more contextualized services for city users, making the lighting system a multi-service system and therefore a "smart" infrastructure [11]. The new lighting system, designed following the definition of Smart Cities, achieve better results from an economic, social and environmental point of view [12].

This approach can be considered a model for other cities to develop a comparison among different public lighting solutions and opportunities. The sensors can be distributed over the territory installing them on existing urban infrastructures; in the case study, the grid is the lighting system, which has widespread coverage in the town. The distribution of the sensors was studied basing on the analysis of the urban characteristics and needs [13]. Furthermore, in this paper, the main advantages of the proposed smart grid, including quantifiable and non-quantifiable benefits, are discussed [14].

2. Current Regulations

Road lighting requirements are described in the standards UNI 11248-2012 [15] and UNI EN 13201-2004 [16]; classification of these requirements is put in relation to the road type category defined by *Codice della strada* (Highway Code) [17]. UNI 11248 defines the range of lighting classes based on main user type (motorized traffic, cyclists and pedestrians) for each road type; a group of variable parameters, such as the traffic flux, defines the selection of the lighting class; UNI EN 13201-2004 lists the lighting standards for each class. One or more lighting classes of the range could be attributed to the same road depending on the condition parameters; for example, the class changes moving from rush hour to later evening hours, when there are fewer users (see Figure 1); in this case, dimming control is important to satisfy the different lighting needs and to maintain an appropriate illuminance and/or luminance for the users [18]. Furthermore, in Italy, regional laws control the emissions towards the sky and lighting pollution that implement lighting restrictions for energy savings. The next revision of the Italian standard will introduce adaptive installation and control strategies to satisfy the European standard requirements [19]. The case studies presented in this paper satisfy the standards.

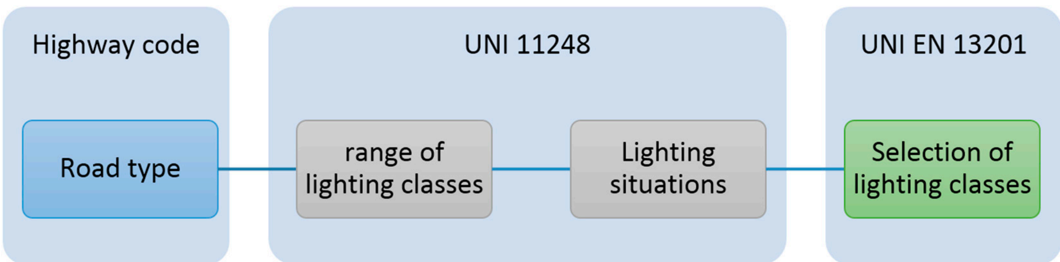

Figure 1. How to select the lighting classes.

3. New Technology: Source and Control System

The designer is asked to choose the suitable lighting technology considering the surroundings of the installation. New optics technologies are designed to reduce the dispersion of light flux; light pollution causes unnecessary energy consumption and has environmental impacts. Moreover, recent research proves the role and effect of light on humans [20], especially related to spectrum and exposure to high levels of illumination [21,22]. For example, Light Emitting Diode (LED) spectrum has a spike in the blue region, which today, appears to be acting on human beings, both their circadian and attentive systems.

From previous considerations, an environmentally friendly lighting system should minimize the lighting levels and at the same time guarantee safety conditions for drivers and pedestrians; it should also be energy efficient and respectful of humans, the environment, and all kinds of living beings.

Another aspect of design concerns the selection of the lighting source based on their characteristics; LED lights are able to maintain their characteristics, even with 50% dimmed flux and have very long life cycles; metal halide lamps have a high color rendering index but they present a high CCT; and high pressure sodium lamps have high luminous efficiency but a very low color render index. Adding control systems to the design can assure a point by point control, switching and managing the fluxes at preset times, assuring the control of the lighting power utilized and dimming it. Market offers different types of regulators; the basic bi-power system has a preset power regulation set by the hour. Another possible solution is the use of remote control systems that automatically adapt the luminous flux and manage the entire lighting grid. Additional control sensors included in the panel board or in each light point send data to the remote control system, the software analyzes the information (for example how many users are in the area) and adjusts the luminous flux. Furthermore, the aging of dimmed lamp is slower than a continuously operated lamp [23].

However, technology may go further; the poles can be transformed in nodes of a smart grid transmitting information about users, weather and diagnosis operation data; automation saves energy and decreases costs, dimming lighting flux when the street is not used. Studies show [24] that it is important to encourage the installation of smart dimmable electronic ballasts, as well as receiving switching and dimming commands from a streetlight lane, so the controller can also be used to auto-detect lamp and electrical failures. The advantage for municipalities is to apply devices and sensors to the lighting system, which is an existing network grid. The main advantage of implementing a lighting system is reflected in the amount of energy saving and the reduction in both operational and capital cost. Lighting Smart systems can help the maintenance and management of the systems itself.

4. Case Study

This work considered four streets in a little town with 10,000 citizens (data from Italian National Institute of Statistics) in the north of Italy; it is a seaside town with seasonal tourism. The lighting class is designed for the evaluated quantity of users but during the summer the population increases because of tourism. Therefore, the lighting systems have to supply an appropriate service. The town is an attractive touristic location inside a nature reserve where lighting legislation is more restrictive to preserve the natural environment.

The study is divided in three main phases: analysis, design and comparison. In the first phase, the authors analyzed the streets, their surroundings and the existing lighting systems. The second phase concerns the three level lighting design approaches and in the third part the results are evaluated and compared to define which is the most suitable solution (see details in Table 1).

Table 1. Methodology.

1° Phase—Analysis		**2° Phase—Design**	**3° Phase—Comparison**	
1.1 Streets analysis	Geometry	2.1 First level approach	3.1 Results comparison	Energy consumption
	Users flux			Costs
	Road type category	2.2 Second level approach		Benefits
1.2 Surroundings analysis			3.2 Level selection	
1.3 Actual lighting system analysis	Lighting classes	2.3 Third level approach	3.3 Possible services to adopt	
	Laws requirement			
	Energy consumption			

The streets selection was based on their different characteristics (see Tables 2 and 3 and Figure 2): S1 is a seafront street and S2 connects the seafront with the town center, whereas S3 and S4 are residential streets with a peak of users only during the rush hours.

S1 consists of a two way street, with two sidewalks and a cycle path. The speed limit is 50 km/h and the traffic flow is constant during the whole day, with a reduction late at night. The carriage is 7 m, the sidewalks section varies from 1.5 m to 5 m, and the cycle path is 2 m wide; the lighting has a single sided disposition, with 7 m high poles, 15 m distant to each other and the source is high pressure sodium (HPS) lamps with a power of 150 W.

The weak features of the existing system are the inadequate color rendering index, and the lack of luminous uniformity caused by the extreme distance between poles, resulting in a violation of the standard UNI EN 13201-2004.

S2 is a town center street. It is a two way traffic street with on-street parking and two sidewalks that are shadowed with small trees. The carriage, parking zones included, is 13 m and the sidewalks are 1.5 m wide; an opposite lighting disposition is realized with poles 4.5 m high placed at a distance of 15 m and with HPS lamps having a power of 100 W. The speed limit is 50 km/h and the traffic flow is constant during the whole day.

S2 lighting system has the same problems as S1 but this street also has trees foliage obstructing the luminous flux, producing shadows on both the road and the sidewalks.

Even if it is located in the central part of the town, S3 is used only by cars, it has no sidewalks along the road; moreover, the vehicular traffic flow is never intense, both during the whole day and all night. It is a two way street 9 m in width; the single sided lighting is provided with HPS 150 W lamps on 8.3 m high poles with a 1.3 m bracket arms and a distance of 30 m.

The use of HPS lamps with a low color rendering index cause a bad perception of the environment and the poles distribution cause a low luminance uniformity value with zones in complete darkness.

S4 is a residential street that is mainly used by local traffic and the flow is scarce during the day as well as during the night. It is a one way street with on street parking area, and two sidewalks. The whole carriageway is 8 m wide, sidewalks are 2.5 m in width, and the two lanes measure 2.5 m each. The lighting poles are only in the left side of the street, at a mean distance of 25 m; many of them are 8.2 m high and the HPS 150 W lamps are mounted on bracket arms of 1.4 m length.

Table 2 shows the lighting classes and Table 3 synthetically describes all the characteristics of the four selected streets and the energy consumption; total consumption has been calculated summing lamp power, devices consumption and hours of use. A 150 W HPS lamp consumes approximately 750 kWh per year, a 100 W lamp consumes approximately 500 kWh.

Table 2. Lighting classes (UNI EN 13201-2004).

	Speed Limit (km/h)	Road Classes	Lighting Classes (UNI 11248)	Luminance of the Road Surface (minimum)			Disability Glare %	Lighting of Surroundings
				L [cd/m²]	Uo	Ul	TI (max.)	SR (min.)
S1	50	E	ME3c	1	0.4	0.5	15	0.5
S2	50	E	ME3c	1	0.4	0.5	15	0.5
S3	50	F	ME4b	0.75	0.4	0.6	15	0.5
S4	50	F	ME4b	0.75	0.4	0.6	15	0.5

Table 3. Dimensions of the four streets.

Characteristics	S1	S2	S3	S4
Total width of the street (m)	13.5	15	9	8
Poles distance (m)	15	15	30	25
Pole high (m)	7	4.5	8.3	8.2
Pole bracket arms length (m)	-	-	1.3	1.4
Light source	HPS	HPS	HPS	HPS
Lamp power (W)	150	100	150	150
Devices energy consumption	19%	20%	19%	19%
Annual energy consumption (kWh)	750	500	750	750

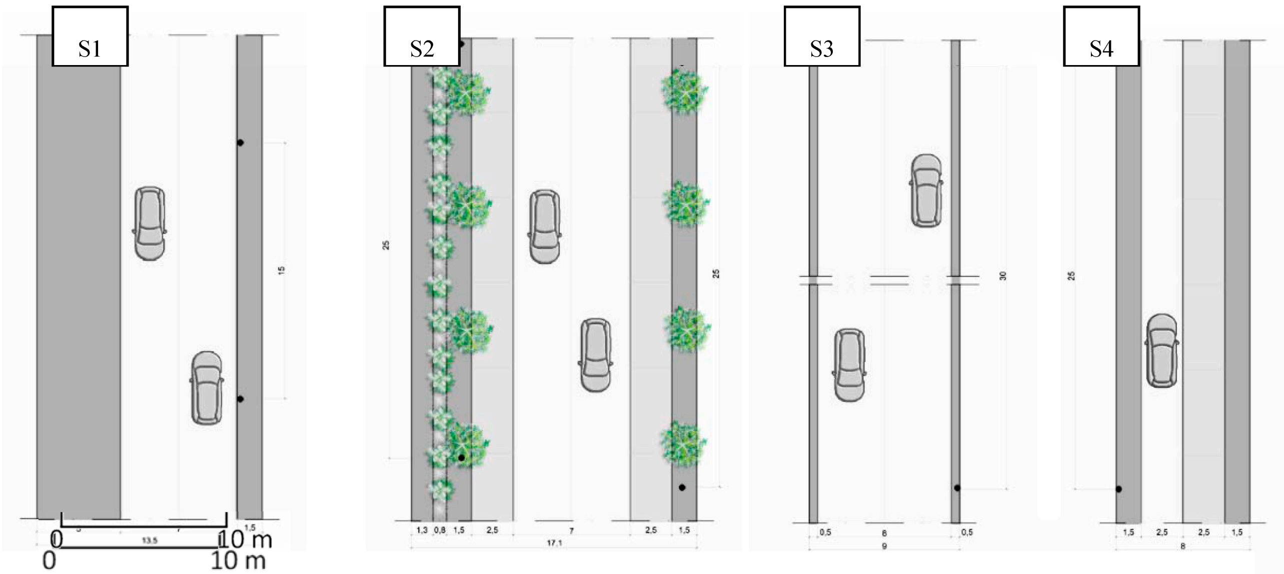

Figure 2. *Cont.*

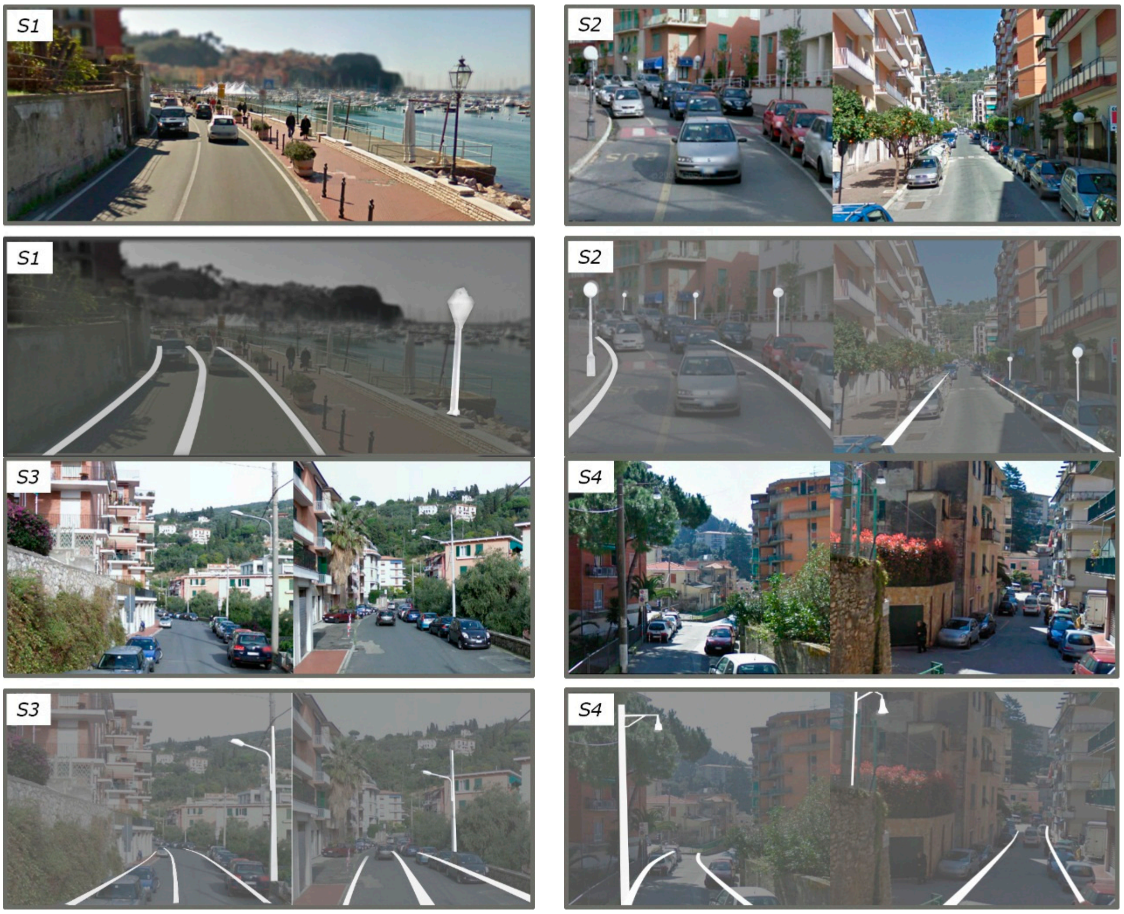

Figure 2. Case study streets maps and pictures (S1, S2, S3, and S4).

5. A 3—Levels Approach

5.1. Level 1: Retrofitting

The first level approach aims to improve the urban street lighting. Retrofitting suggests the replacement of existing luminaries with new ones chosen for their technological properties; light sources and optics are replaced but the geometry of the existing system (distance and height) remains the same. This is the most common action since it requires less financial resources. Results, though, remain less successful than the other approaches.

LED lamps are used to replace HPS lamps in the four streets because of their easy luminous flux control. Seasonal traffic influences S1 and S2 during the summer when they get crowded with both vehicles and pedestrians; respect to the other light sources for street application, LED allows designing a lighting level for rush hours and then to dim the light emission in the winter period when the number of users is lower. Moreover, they are located in the city center where a high chromatic quality is required for heritage places: even if both LED and MH lamps have high CRI, LED was preferred for the large variety of CCT available; MH lamps have the same power consumption of the existing HPS but a lower luminous efficacy. On the contrary, S3 and S4 are streets with low vehicular traffic all year long and the choice of LED allows for easy dimming during the late night hours.

Table 4 shows the possible retrofitting intervention proposed in the four studied streets, presenting the main features of the new road lighting.

Table 4. Dimensions of the new lamps.

Characteristics	S1	S2	S3	S4
Light source	LED	LED	LED	LED
Power (W)	117	70	122	60
Devices energy consumption	14.00%	12.50%	14.00%	12.00%
Correlated Color Temperature (K)	6000	6000	4000	4000
Luminous flux (Lm)	7743	4332	13030	6050
Device Length (mm)	684	617	807	758
Device Width (mm)	448	333	505	412
Device Height (mm)	370	175	359	354

With respect to the current lighting system, the use of LED technology represents an improvement of the light quality, particularly of the color rendering; economically, the durability of LED, higher than the other lighting sources, allows the reduction of maintenance costs, even if the HPS are considerably energy efficient lamps.

The annual energy saving in terms of absorbed power, after lamps substitution replacing HPS with LED, in all the four streets is shown in Table 5; results show that the retrofit produces a sensible reduction of about 33% of the energy consumption for the street lighting.

Table 5. Annual energy consumption before and after the intervention of lamp substitution.

Source	S1	S2	S3	S4
HPS	750 kWh	500 kWh	750 kWh	750 kWh
MH	750 kWh	500 kWh	750 kWh	750 kWh
LED	560 kWh	330 kWh	580 kWh	280 kWh

The compliance to the Standards on street lighting (UNI EN 13201-2004) was verified using commercial lighting software using photometric data provided by the manufactures; a virtual 3D model of the street has been realized, and lamp geometry has been reproduced along the road. The software calculates luminous flux deriving from the photometric data. The lighting systems are designed to comply with the standards for carriageways, sidewalks and cycle paths. The use of asymmetrical optics has improved the luminance uniformity, even while maintaining the poles distance and facilitating a reduction in light pollution. This intervention causes a positive effect on the environment, decreasing the undesired light on buildings and towards the sky.

5.2. Level 2: New Lighting System

The second level approach consists of a new lighting system proposing different high and distance of the light points. Fixtures choice depends on the surroundings: the presence of trees along the S2, cycle path in S1 or the sidewalks were taken into account in the lighting design. Lighting levels and luminous distribution affect the pedestrian sensations [25] feeling less safe in lower lighting conditions [26]. A dynamic road lighting is proposed that could adapt lighting conditions on the street only when and where it is needed [27]: studies examine appropriate lighting level designed to meet the pedestrians need for sense of security [28].

The LED lamps proposed for all four streets consume less power compared to the first level approach, between 80 W and 100 W in S1 and S2, respectively, and 50 W and 38 W in S3 and S4, respectively. The annual consumption is 480 kWh in S1 and is 25% lower compared to the existing system, in S2 it is 230 kWh with a savings of 53%, in S3 the consumption is 400 kWh and the saving is 47%, and in S4 it is a 76% reduction. Savings in S4 is 62% and is higher compared to both the existing and the first level approach; the results of the analysis highlight that the actual system is unsuitable, especially in S3 and S4 where the proposes could achieve more energy savings; S1 comparison shows a low difference, but, in these results, the different control system that can increase savings is not considered.

The poles are 6 m high in S1 because of the trees. In S2 the position of the poles is bilateral with 6 m height. In S3 and S4, the poles are 8 m high. The on–off switch could be traditional and economic device or automatic equipment could be installed. In a new lighting system, it is possible to manage the luminous flux level as well as the on–off switch mode; therefore new road lighting could be more efficient and less pollutant. The solution considers a remote control with sensors on each pole to satisfy the different lighting needs during winter and summer in S1 and S2, which are main roads with sidewalks, S2 connects schools, public spaces and theater with S1 the seafront road. This control manages the flux level, maximizes the service with energy and human capital savings but it is an expensive system; therefore, S3 and S4 roads have no remote control but a new generation ballast, which dims the power at a specific time. The solution considers four power slots (see Table 6). Standards recommend choosing a different lighting class when the users are less than 25% or 50% (UNI 11248), and sometimes the road has three different classes, as it is in S3 and S4. Both actions consider LED but in the second approach the lamp power is lower. In this case, the energy efficiency and the longitudinal uniformity are higher than the retrofitting solution (see Figure 3 and Table 7) and energy efficiency also improves by means of system control.

Table 6. Annual energy consumption of the new systems lamps.

Characteristics	S1	S2	S3	S4
Total width of the street (m)	13.5	15	9	8
Poles distance (m)	15	20	30	25
Pole high (m)	6	6	8	8
Light source	LED	LED	LED	LED
Lamp power (W)	100	50	84	38
Devices energy consumption	14%	12%	12.50%	11%
Correlated Color Temperature (K)	4000	4000	4000	4000
Annual energy consumption (kWh)	480	235	400	175

Table 7. S3 and S4 regulation example.

HOUR	USERS	Lighting classes	
Till 10:00 p.m.	100%	ME4b	Design class
10:01 p.m.–12:30 a.m.	<50%	ME5	One lower class
12:21 a.m.–05:00 a.m.	<25%	ME6	Two lower classes
05:01 a.m.–07:00 a.m.	<50%	ME4b	Design class

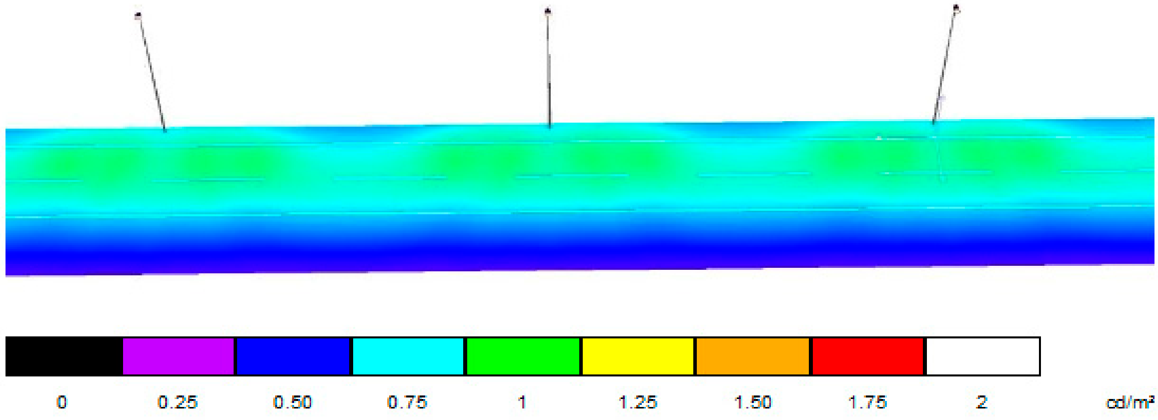

Figure 3. S1 new lighting system luminance value rendering in false color.

5.3. Level 3: Smart Lighting

The third level approach considers the same lighting system of the second level but equipped with a complete remote control. Each pole has sensors detecting users flow, weather and the real flux emitted by the system; a pole, the "head", sends signals to the others and manages the flux and real time control malfunctions. Especially in S1 and S2, this management greatly increases energy savings and extends the average life of the lighting systems since they work at full power only during summer rush hours when the users are both citizens and seasonal tourists. The system management, based on the presence of users, also controls the traffic lights or the crosswalk lightings with additional energy savings. Different manufactures promote integrated systems of lamps, users' detection sensors, wireless communication and lighting control. Lighting management can be reached controlling each single lamp point or an electrical line. The most common are passive infrared sensors (PIR sensor) or camera. Lighting control device is a luxmeter, which verify the amount of light and sends a simple message when the illuminance detected does not reach the expected value because of a natural decade of the lamp that could be old, or dirty, otherwise could detect line dysfunctions.

This grid could also convey information about the city, monitoring and/or managing the environment in several ways useful for citizens (for example real time traffic flow news or waiting time for buses) and for public administration (buildings energy consumption) [29]. The lighting system becomes a smart grid, the infrastructure for a Smart City in which the nodes are the poles with the integrated functions. Other accessories/functions can be added as microphones for gunshot identification or dB sensor for loud noises informing directly the local law enforcement; a parking meter could be installed realizing data, about free parking lots information and also to control the users flux. Most of the information to users could be sent to public screens, other information collected by the remote control software could be sent to municipality. Countless are the possibilities and operations that could be achieved by the smart lighting grid on demand of the local authorities and the context services provided differ by street. S1 is a seafront road, users are citizens and tourists therefore the supplied services are a free Wi-Fi Internet connection and a set of easy access information about weather, public transportation and neighborhood information. The benefits for street users are focused on touristic services but, on the other hand, the municipality can gain useful information about waiting time of public transportation and authorities can take prompt actions or collect data to plan a more functional service. S2 is a citizen's road; the system distributes data about the theater schedule and traffic information. There are also public schools, the municipality can use the new grid to activate a buildings control systems that manage and check the energy consumption and verify the buildings security during the night hours. In addition, teachers and headmasters can use the same database and easily promote and manage, for example, the interschool books and documents exchange. S3 and S4 pass through a residential district; the services are general information about city life (see Figure 4). Traffic information is useful for citizens that can choose the best route, information on the available parking or any recommendations by the authorities as a work in progress or holidays. The management system dims the luminous flux based on the presence of users, not only for lighting control, but also for demand systems.

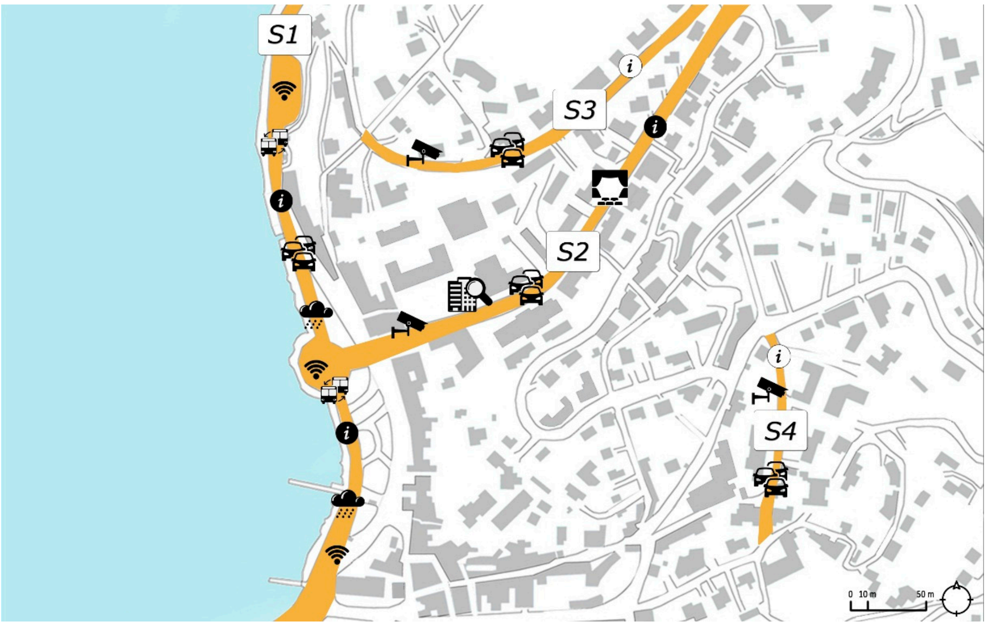

Figure 4. New supplied services.

The smart city approach has the aim of improving the life quality in urban areas; the ICT considerably stimulates the way of enjoying the city. This set of technologies increases the interconnection between networks. The innovative multi-functional system manages the city in a more sustainable way from different points of view: energy, environmental, functional and social. The approach analyzes the city and the territory as a nodes grid. The goal is a multilevel approach for the urban lighting as a smart grid. The smart lighting becomes the infrastructure of the city, a Smart City.

6. Discussion

Approaches show different energy savings depending on the level of action (see Figure 5), but each action presents a lower energy consumption regarding the existing lighting system.

S1 third level approach has the highest energy savings compared to the existing system that does not achieve the standards and has old fixtures. The new smart lighting system can manage the seasonal tourist flux and achieves higher energy savings providing services to the users at the same time.

S2 is a touristic road too, and for this reason, the third level approach with the remote control system is advisable to manage the seasonal flux.

S3 needs new infrastructure but can achieve energy savings and lighting pollution decrease installing bi-power regulators.

For S4, the existing system has a geometry that allows retrofitting achieving all the established aims.

The third level approach is chosen in S1 and S2, which are main roads with numerous users; in S3 and S4, the second and the first, respectively, improve the service. The lighting system becomes a smart grid with new services for users in S1 and S2, whereas in S3 and S4 the new management technologies have higher energy savings (see Table 8). The choice of the level of intervention depends on the characteristics of the environment and the choice of the various, relevant and applicable services of the third level have to be considered in any case.

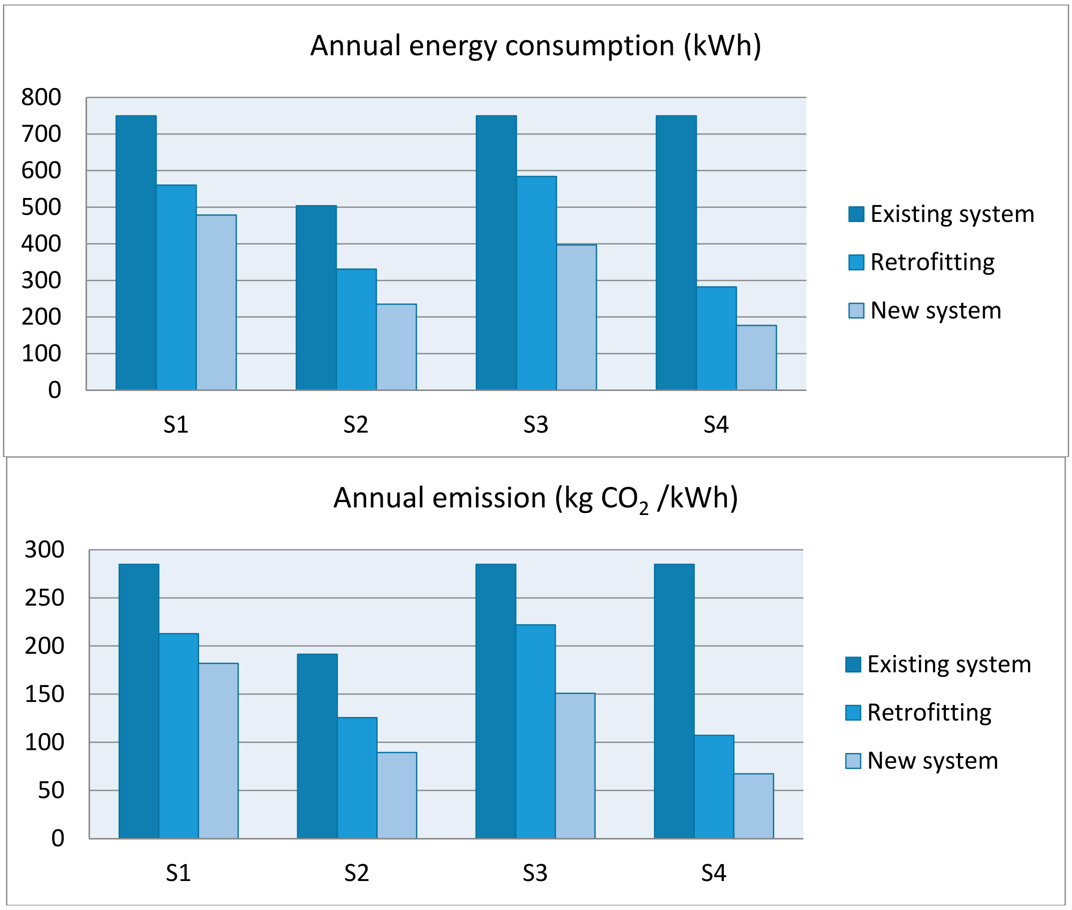

Figure 5. Comparison annual consumption and CO_2 emission per light point (kWh).

Table 8. Projects summary.

Street	Project Level	Dimming	Smart Lighting
S1	Level 3: Smart lighting	Remote control	Users
S2	Level 3: Smart lighting	Remote control	Users
S3	Level 2: New system	Bi-power regulator	Municipality
S4	Level 1: Retrofitting	Bi-power regulator	Municipality

7. Conclusions

Energy demands represent a global issue and Public Administrations should have a role in reducing energy requirements and CO_2 levels. Municipalities joining the Covenant of Mayors receive support during the transition period, while studying and acting for reducing their impact on the environment.

In Italy, urban and street lighting systems are old, obsolete and inefficient; not complying with regulations; sometimes damaged; and they obviously represent an easy and fast way to increase energy efficiency and CO_2 reduction.

The need to meet the targets for Energy saving and reduction of CO_2 production perfectly matches with the need for the renovation of urban lighting. Moreover, urban light appears as the best candidate to make the first step to enter the Smart City concepts.

This paper shows a three level approach applied to a North Italian town sited in a protected area. The approaches, from retrofitting solution to smart city applications, are investigated with the aim of improving energy savings while guaranteeing the full compliance of standards. The different approaches used depending on the background and the choices of which level is proposed to be adopted are explained. In this paper, we have presented methods to improve services for a medium size town through the lighting systems. Every street has its own characteristics and the actions success depend on the primer analysis.

Results, in terms of energy efficiency and lighting quality, show that approaches could be feasible and environmentally friendly at the same time. There are about 5630 Italian towns with less than 5000 habitants where smart lighting can be used to improve services, as shown in the case study.

This approach could be used as a model for others cities to compare different public lighting analyses.

Slowly but firmly all European cities and towns are bound to assume actions in energy management planning in order to guarantee their sustainable development and the road lighting system replacement is an easy and quick solution.

Author Contributions

The study was designed by Lucia Cellucci, Fabio Bisegna, Franco Gugliermetti and Andrea de Lieto Vollaro. The case study was designed by Lucia Cellucci, Chiara Burattini and Dionysia Drakou. Ferdinando Salata and Iacopo Golasi reviewed the literature related to the research. Lucia Cellucci and Fabio Bisegna performed the new lighting systems design projects. The results were then analyzed by Chiara Burattini, Dionysia Drakou, Ferdinando Salata and Iacopo Golasi. English corrections were undertaken by Dionysia Drakou. Franco Gugliermetti and Andrea de Lieto Vollaro, the full professors of the research group, supervised the work related to the paper and the execution of its various phases. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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