Sustainability Comparison of Campus and Community Micro grids through SDEWES Index and H2RES Introduction and...

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Sustainability Comparison of Campus and Community Micro grids through SDEWES Index and H2RES

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Abstract

A micro grid is by definition of USA Department of Energy "A group of interconnected loads and distributed energy resources with clearly defined boundaries that act as a single controllable entity with respect to the grid, and can connect and disconnect from the grid to enable it to operate in both connected or island mode." [1] The optimized design and control of micro grids can increase energy independence and diversify energy sources in the energy system. At the same time, micro grid applications need to be taken together with other dimensions of sustainable development for better integrated planning and assessment.

The paper proposes assessing through the SDEWES (Sustainable Development of Energy, Water and Environmental Systems) Index a variety of communities targeted for sustainable development. The two communities are a residential neighbourhood and the campus of University of Split. Comparison with the conglomeration of the city of Split is studied in areas of energy consumption, renewable resources generation, and water management along with integration of power generation, mobility and other socio-economic and environmental factors, such as air quality and greenhouse gasses (GHG) emissions. Potential new micro grid operations are proposed within the conglomeration. New installations of renewable energy sources (RES) in urban areas, such as Building Integrated Photo Voltaic (BIPV) are explored. Integration of RES is examined to provide optimal conditions for predicted electrical loads within a 24-hour period. All indicators are assessed with the Index, with proposals for further extension of Index dimensions and parameters for micro grid applications. Energy planning case studies for decentralized generation of renewable energy and electrification of transportation are conducted in H2RES energy planning software for hourly energy balances. Other modes of transport are proposed in terms of higher share of public transport utilization and self-mobility options.

The paper will conclude with the lessons from the use of a hybrid approach for conducting sustainability comparisons of various communities that have micro grid applications based on the SDEWES Index adapted for micro grid purposes and H2RES energy planning software. The results will

also be useful for proposing future directions for the various communities targeting sustainable development.

Keywords

Sustainability, Micro grid, H2RES, PV, SDEWES Index, Campus, Residential building, smart grid

Introduction and Literature Review

The paper deals with the options of installing BIPV to the case study communities of University of Split campus and the neighbouring residential district of Split 3. Two options for BIPV are examined. First, façade integrated PV retrofitted into the existing residential high-rises of the district, and second, roof mounted PV on the roofs of public buildings on the campus buildings.

SDEWES Index is a comprehensive list of parameters defined to benchmark sustainability of cities [2] and [3], campuses , airports and communities [4], [5]. The dimensions covered by the Index provide quantitative and qualitative information about energy consumption, climate, water, environment, GHG emissions, urbanism and city planning, welfare, R&D and innovation policies.

H2RES or Highways 2 Renewable Systems is a software model designed primarily on the University of Zagreb, Faculty of Mechanical Engineering to provide optimal generation of energy based on optimising the individual components of the energy system. Firstly, the model was used for island regime simulations, with emphasis on large-scale integration of RES into the system [6], [7]. From there research moved on to test various other energy vectors and storage systems [8], [9]. Finally, grid storage was introduced for 100% RES scenarios [10], [11]. New versions of H2RES continue to be developed, with further emphasis on optimisation [12], [13].

This work is among the first to study electrical energy consumption with the purpose of potentially creating a 100% RES powered campus in Croatia. Previous work was conducted by University of Zagreb, Faculty of Electrical and Computer Engineering with the goal of load forecasting for optimising building energy usage [14].

The scope of this paper extends to multiple areas of energy planning, micro grid operation, smart grid and systems, electricity distribution operation, introduction of RES into existing energy systems, sustainability assessments, and connects to areas such as urbanism, city planning, water supply, waste and wastewater management to provide an overview of all systems included to create an urban micro grid operation with RES input.

Multiple tools, software programs and methods are available for energy planning. One of the most useful oversights of 43 such resources was presented by Connolly et al. [15], with specific insight into integrated multiple energy vector operations in urban areas by Mendes et al. [16]. In order to properly estimate what is the long-term need for energy generation of an energy system, detailed time-wise resolution needs to be employed, on the order of one hour or less [17]. In cases that potentially require even higher resolution, such as electric vehicle operation and interaction with the grid, Vehicle to Grid (V2G), intervals of 15 min or less are also investigated [18]. Optimization of micro grid systems refers mainly to forecasting loads in the system while keeping track of multiple goals of emissions reduction, supply security or quality of supply [19]. While not investigated for this paper, multiple energy vector optimization, spanning electrical, heating and cooling demands provides multiple options to shift loads, influence demand side management and affect overall pricing of the system [20]. Another energy vector is introduced with the hydrogen as grid storage in fuel cells [21]. While micro grid operation and RES generation improves robustness of an energy system, it brings costs that should be addressed properly. One example is the use of game theory and Nash bargaining to reduce the cost of energy transfers [22]. Smart grid assumes a mean of two-way exchange of information between the participants within an energy system. The simplest device for such use would be a smart meter or automated meter reader (AMR) that feeds consumption information back to the grid operator. Along with the proposal of BIPV installations, a system such as the one proposed by Al-Ali et al.[23]. It is important to stress that there is at no time any additional demand on the distribution network that may cause capacity issues, which may be mitigated by a smart scheduling system taking technical constraints into account [24]. Impacts of uncoordinated micro grid operations such as charging or discharging of electric vehicles investigated by Clement-Nyns et al. [25] and [26] can have negative effects on the local distribution network in terms of lack of installed capacity in the transformer substations, voltage drops during high-load operations and frequency deterioration. Sustainability of a system is based on data collection from various data sources such as national statistics bureaus and aggregated data by sector of activity (transport, housing, etc.) [27]. General overview of the methods is presented by Banos et al. [28]. A particularly large consumer of energy is the building and housing sector, and as such possess the cheapest way of tackling the reduction of energy use through efficiency and use of renewable technologies to implement a Zero Energy Building (ZEB) [29]. On the urbanism side, an ever increasing need for sustainability attracts more and more studies into decentralised energy initiatives. Nine such cases are presented by Chmutina et al in [30]. Rollout of such novel RES and smart grid projects is often hindered by many involved sides in the process, from distribution operators, to local authorities, through businesses and finally the state. Mah et al. investigate the role of government in pilot smart grid cases in Japan [31]. One of the areas with most potential for integration of RES is the water supply system. Integrated small hydro power plants can be implemented into existing major water supply lines as well as wastewater systems. [32].

Case Study

The case presented in this paper focuses on the urban agglomeration area of Split as defined by the recently signed contract [33] and several specific locations within the city itself. General facts about the location are presented in the following chapter.

Urban agglomeration of Split has a population of approximately 325000 determined by 2011 census [34], divided into six cities (Split, Kaštela, Omiš, Solin, Trogir, Sinj) and seven municipalities (Dicmo, Dugi Rat, Dugopolje, Klis, Lećevica, Muć, Podstrana) with the total area covered of 1270 km^2.

Table 1 - Demographic and geographic data of Split agglomeration

Agglomeration Split	Residents	Area (km^2)	Residents/km^2
Cities			
• Split	178192	79.33	2246
• Kaštela	38474	57.67	667
• Omiš	14872	266.2	56
• Solin	23965	18.37	1305
• Trogir	13260	39.1	339
• Sinj	24832	181	137
TOTAL Cities	**293595**	**642**	**458**
Municipalities			
• Dugi Rat	7,091	10.8	657
• Klis	4,739	176.1	27
• Podstrana	9103	11,52	790
• Seget	4863	77.9	62
• Dicmo	2820	68	41
• Dugopolje	3465	63.5	55
• Lećevica	588	87.66	7
• Muć	3835	210.8	18
TOTAL Municipalities	**31641**	**628**	**50**
TOTAL Agglomeration	**325236**	**1270**	**256**

The composition of the agglomeration varies widely from heavily urbanised areas of central part of Split, with high density of living (2246 residents/km^2), to just 27 residents/km^2 in Klis, a municipality only 13 km distance by road from the city centre (9 km air distance). Average density is calculated at 256 residents/km^2 [35]. See

Table 1 and Figure 1. Overall geographical shape of the agglomeration is determined by significant geographical features of the area, defining a long 48 km north-east to south-west by no more than 5 km wide stretch of land confined by the sea and the surrounding mountains of Kozjak, Mosor and Omiška Dinara. The eastern end is encompassed by the estuary of river Cetina, while the western ends on the local foothills near the administrative border of city of Trogir.

While not strictly part of the geographical agglomeration, another three cities (Sinj and Trilj inland, Supetar on the island of Brač) and ten other municipalities (Milna, Bol, Nerežišća, Postira, Pučišća, Selca, Sutivan on Brač, island of Šolta, Marina and Okrug) with over 33000 residents and 907 km^2 gravitate heavily towards the agglomeration, as Split is the regional capital of Split-Dalmatia County and a major administrative centre. See Table 2 and Figure 2.

Major economic activities of the agglomeration focus primarily on the tourism sector, with port of Split being a major cruise ship destination, as well as a major passenger and ferry port, third by passenger volume on the Mediterranean. Previous activities involved a significant share of heavy industry in the bay of Kaštela area, with chemical, plastic, textile and steelwork factories. Remaining operating ones are three cement factories (two under prolonged shutdown) and two shipyards in Split and Trogir. University of Split is a major national institution, with approximately 25000 enrolled students on 12 departments [36].

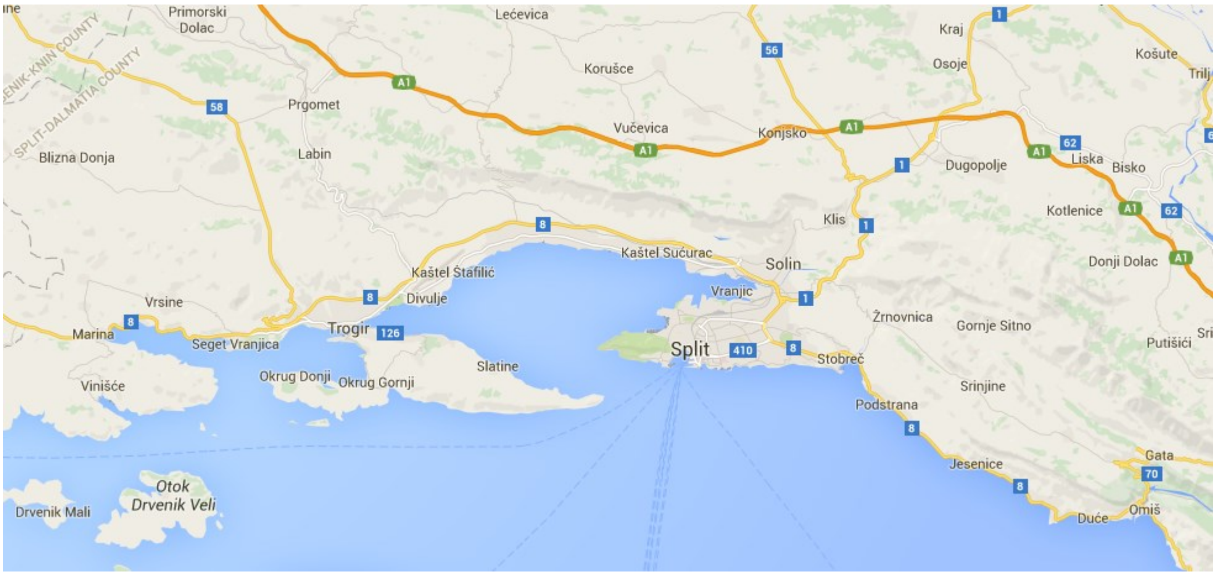


Figure 1- Split agglomeration territory

Table 2 – Extended agglomeration data

Extended Agglomeration	Residents	Area (km^2)	Density per km^2
Cities			
• Trilj	9417	267	35
• Supetar	4096	30	137
TOTAL Cities	**13513**	**297**	**45**
Municipalities			
• Milna	1009	35	29

• Bol	1645	23	72
• Nerežišća	864	79	11
• Postira	1554	47	33
• Pučišća	2189	106	21
• Selca	1804	53	34
• Sutivan	826	22	38
• Šolta	1675	58	29
• Marina	4597	108.8	42
• Okrug	3458	9.8	42
TOTAL Municipalities	**19621**	**542**	**36**
TOTAL Extended	**33134**	**839**	**40**

Energy generation of the region is favourable towards RES. There is a large hydropower generating river basin of Cetina, in Figure 3 and

Table 4 [37], with 960 MW of installed capacity and several large accumulations, totalling 1380.6 million m^3. The Hydro Electric System (HES) is connected to 110 kV and 220 kV transmission lines supplying all of Dalmatia and parts of neighbouring Bosnia and Hercegovina. From transformer station (TS) Konjsko near Dugopolje, the system is connected to 400 kV transmission lines to other parts of Croatia. Also from TS Konjsko, two 110 kV branches are routed towards Split agglomeration over different physical routes. The input points for the 110 kV voltage level are several transformer stations in the city of Split itself and other cities Table 3.

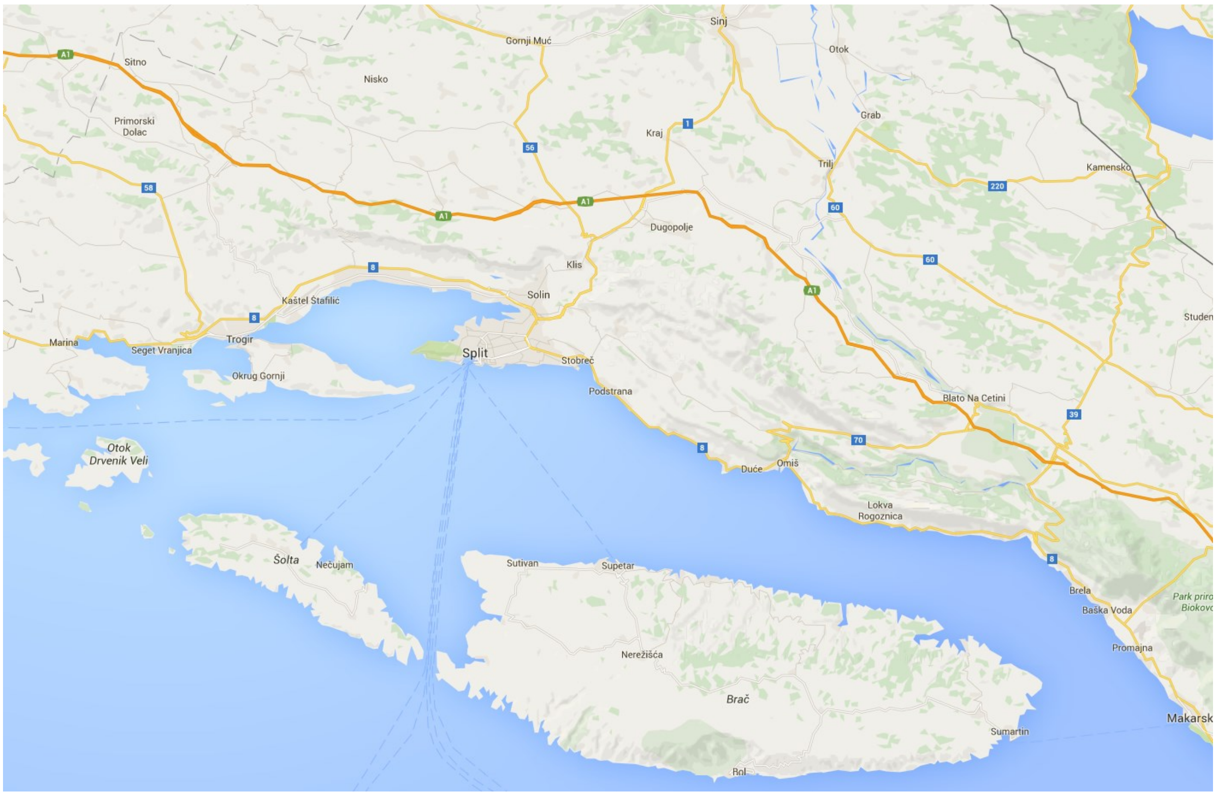


Figure 2 - Extended agglomeration including inland areas and islands

Table 3 – 110 kV substations in Split agglomeration

Substation name	Operating level (kV)
• **Vrboran**	110/35/10
• **Meterize**	110/35
• **Dujmovača**	110/10
• **Visoka**	110/10
• **Gripe**	110/10
• **Dobri**	110/10
• **Sućidar**	110/10
• **Trogir**	110/35
• **Dugi Rat**	110/35/10
• **Kaštela**	110/35
• **Dugopolje**	110/10

Table 4– Overview of hydro power capacity installations, Cetina Hydro Electric System

Hydro Power Plant	Installed Power (MW)	Generators
• **Peruča**	60	2 x 30
• **Orlovac**	237	3 x 79
• **Đale**	40.8	2 x 20.4
• **Kraljevac**	46.4	2 x 20.8 + 1x 4.8
• **Zakučac**	576	4 x 144
TOTAL	**960.2**	

Other RES sources include wind power plants (WPP) and small hydro power plants (SHPP), along with limited installations of PV panels. Installations regulated through Feed-in-Tariffs (FIT) are included in the overview via Ministry of Economy web [38], and for the details of installations outside of the FIT system through national electricity utilities' annual Distribution System Operator (DSO) report in Table 5.

Table 5– FIT system installations and status

RES FIT System	Number of installations (active installations)	Planned installed power (MW)	Realised installed power (MW)
PV	30 (29)	11.5	1.192
SHPP	3 (1)	5.33	1.2
WPP	14 (3)	445.5	76
CHP	2 (0)	11	0
TOTAL	49 (4)	473.33	78.392

Only publicly available data regarding non-FIT installations in Split-Dalmatia County are a 300 kW PV installation in a quarry of a local cement factory [39], and a 2 MW PV installation on the island of Vis, currently under construction [40]. Additionally, a 30 kW PV installation is in operation on the roof of the local University of Split Engineering Department, also for research purposes, with plans for further extensions [41].

Energy planning for the ElektroDalmacija distribution area is determined by the characteristic Wednesday method, with the third Wednesday in January and July taken into account Table 6. In addition, the maximum day is also taken into account, in Table 7, as taken from the DSO yearly report for 2013 [42].

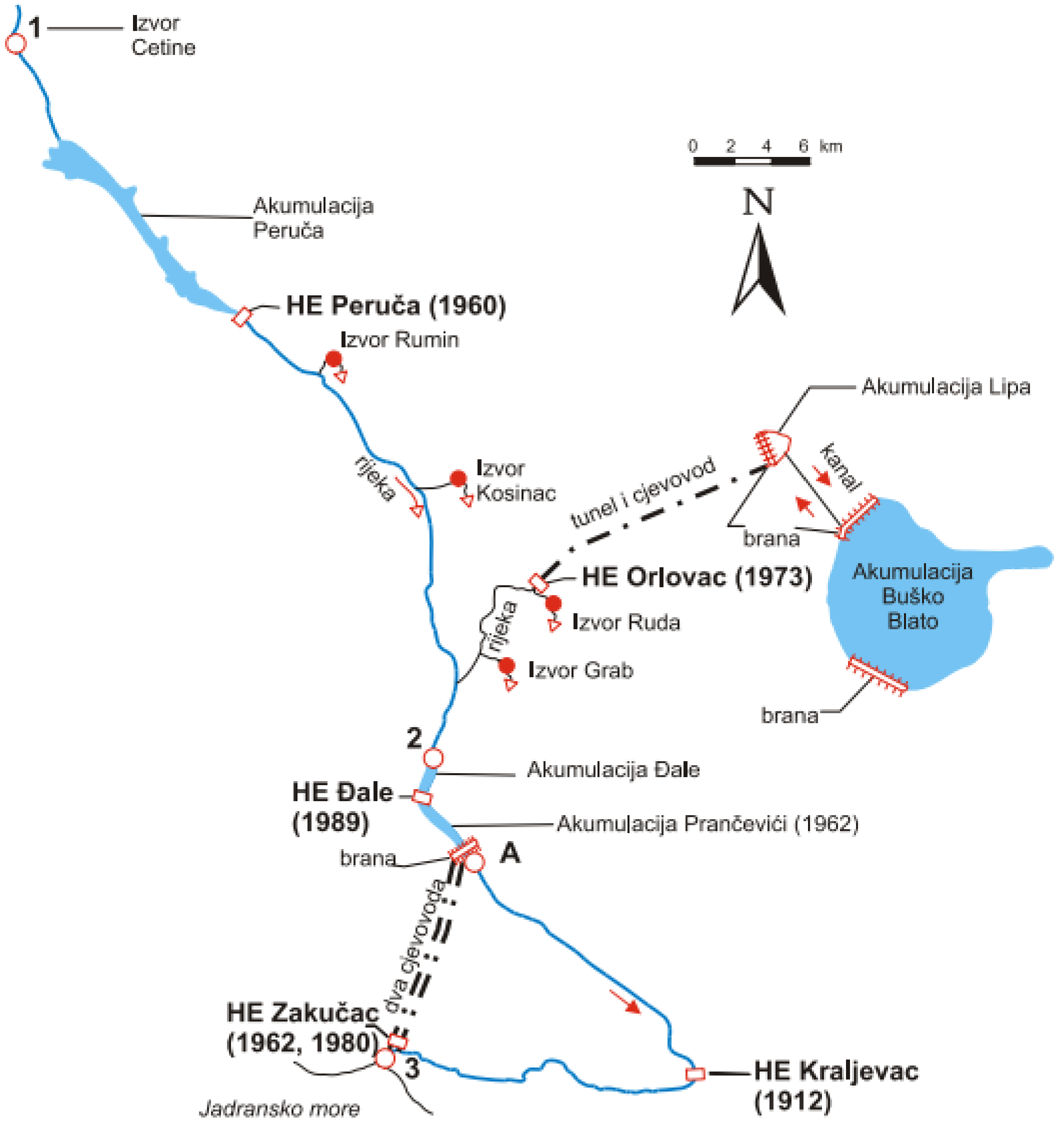


Figure 3 – HES Cetina graphic display

Table 6– Characteristic Wednesdays power readings

Characteristic Wednesday					
3rd Wed. In January			3rd Wed. In July		
Power (MW)	Date	Time	Power (MW)	Date	Time
343.13	16.01.	22:30	309.85	17.07.	22:30

Table 7 – Maximum Day power readings

	Maximum Day		
Distribution Area	Power (MW)	Date	Time
Split	435.29	11.02.	19:45

Estimated power losses in the distribution network for 2013 are 10.92%, for a total of 212.658 GWh. Sales of electrical energy on low voltage level are stated in Table 8, Table 9, Table 10 and Table 11.

Table 8 - Gross consumption of electrical energy (GWh)

Distribution Area	From TSO	From other DSO	From cross-border trade	From small power plants	To other DSO	To cross-border trade	TOTAL
Split	1951.72	0.60	0.79	1.00	0.00	7.22	1946.88

Table 9 - Structure of electrical energy consumption (GWh)

Distribution Area	Tariff buyers and buyers without suppliers	Privileged buyers	DSO consumption	Other subjects	Own + other consumption	TOTAL
Split	1104.50	629.73	4.03	0.70	4.73	1734.22

Table 10 - Sales of electrical energy (GWh)

Distribution Area	High Voltage	Medium Voltage	Commercial	Public lighting	Residential	TOTAL	TOTAL SALES
Split	9.25	190.18	560.83	50.10	923.87	1534.79	1734.22

Table 11 - Sale structure at low voltage (GWh)

	Commercial Tariffs						Residential Tariffs					
Distribution Area	Blue	White	Red	Orange	Yellow-public lighting	TOTAL Commercial	Blue	White	Orange	Black	TOTAL Residential	TOTAL Low Voltage
Split	24.52	200.00	336.30	0,00	50.10	610.92	128.66	795.21	0.00	0.00	923.87	1534.79

For the micro grid case study, several sections of the grid and associated transformer substations were detected and used. The principal 110/10 kV TS is the TS Sućidar, which uses five of its 10 kV fields to power the area, and TS Visoka, with six 10 kV field. There are total of 46 10 kV substations connected to the two 110 kV substations. The installed power is delivered through 51 transformers combining 30.08 MVA total. Table 12 lists the 10 kV fields of both TS Sućidar and Visoka, while

Table 13 lists all the substations connected to the 10 kV fields.

Table 12 – Transformer 10 kV fields feeding micro grid areas

TS	VISOKA	TS	SUĆIDAR
TS Field	Name	TS Field	Name
K38	SMRDEČAC 16	K02	SUĆIDAR 14
K55	SMRDEČAC 34	K09	SUĆIDAR 13
K56	SUĆIDAR 31	K17	G.Š.C. 1
K71	SMRDEČAC 15	K19	SUĆIDAR 15
K72	SUĆIDAR 27	K33	SUĆIDAR 16
K73	LIDL		

The designated area is surrounded by several major city streets, arranged in a rectangular shape, forming two city blocks. The northern block houses the University of Split urban campus, while the southern block forms the district of Split 3, as provided in Figure 4.

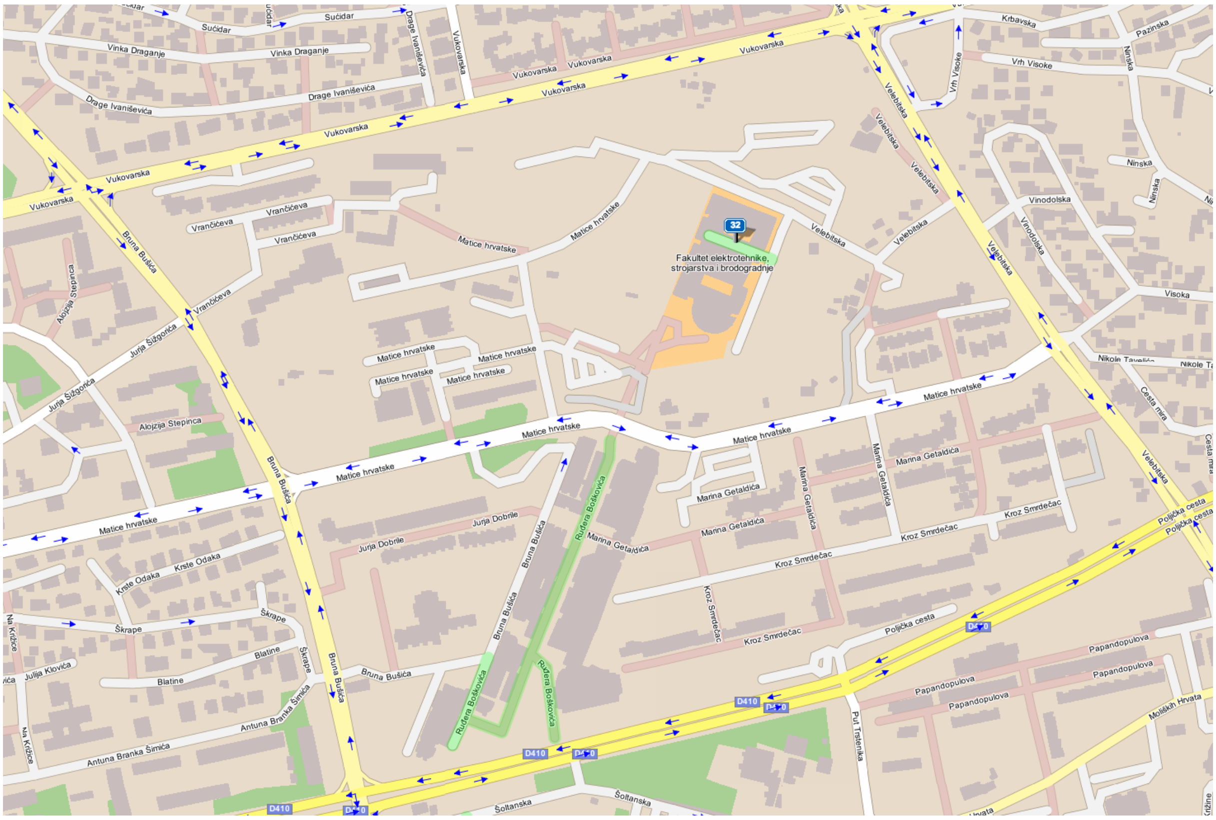


Figure 4 – map of the case study area

The campus portion, along with the departments contains three blocks of housing, high school complex and several smaller houses, while Split 3 contains four major streets with high-rise residential buildings, along with an elementary school, market and a row of commercial buildings (shopping mall, office buildings, supermarket, post office) along the southern row, facing the D410 road. Overall population is close to 13000, based on 2011 census.

Table 13 – Field substations connecting to upper voltage level TS

10 kV TS name	kVA	Amount	TOTAL	10 kV TS name	kVA	Amount	TOTAL
FESB	1000	2	2000	**Smrdečac**			
Ekonomski	1000	1	1000	**2**	500	1	500
Monter	630	1	630	**4**	630	1	630
Lidl	630	1	630	**5**	630	1	630
GSC				**6**	630	1	630
1	500	1	500	**7**	400	1	400
2	630	2	1260	**8**	500	1	500
Sućidar				**9**	500	1	500
15	630	1	630	**10**	500	1	500
16	630	1	630	**11**	500	1	500
25	630	1	630	**12**	400	1	400
26	400	1	400	**13**	500	1	500
27	400	1	400	**14**	400	1	400
31	1000	2	2000	**15**	500	1	500
32	1000	1	1000	**16**	1000	1	1000
				17	1000	1	1000
				21	500	1	500
				22	500	1	500
				23	500	1	500
				24	500	1	500
				25	630	2	1260
				26	400	1	400
				27	630	1	630
				28	400	1	400
				29	400	1	400
				30	400	1	400
				31	630	1	630
				32	400	1	400
				33	400	2	800
				34	400	1	400
				35	400	1	400
				37	400	1	400
				38	630	1	630
				39	630	1	630

Methodology

Hypothesis of the work is that through detailed mapping of renewable resources and existing potential at the location of the case study it is possible to offset a part of the energy production by employing local generating potential with minimum interference in the existing state.

For the mapping portion of the methodology, three of the streets are positioned in an almost exact east-west orientation (for the purposes of the study it will be considered to face south at 180°

azimuth), making it optimal to implement BIPV on southern-facing vertical façades. Fourth street, running south-west to north-east was not considered due to the unevenness in the façade structure and large areas of shade caused by the unevenness. Roof area is also not considered due to the small footprint of the building, locations of elevator machine rooms and various telecommunications equipment on roof surfaces. Commercial row is also not considered for the same reasons. Elementary school along with high school building is considered for installation only on the roof section, due to the larger footprint and the fact that there is a 30 x 15 m gym adjacent to the elementary school.

Estimate for BIPV total area of coverage is given as 40% of all south-facing surfaces above the second floor. The estimate is based on the fact that approximately 40% of the area is covered in glass surfaces, and the rest of 20% is discarded area due to shading caused by the uneven surfaces of the facades and technical unfeasibility of covering smaller or inadequate surfaces. Average number of floors for all streets is 12 and average external height of one floor is 3.5 m. Houses on the south side of each street are not considered due to low height average of 2 floors and potential shading from the green growth close to the ground. As the buildings are laid out as monolithic units, it was estimated that the average length of one façade is equal to the average length on the online map service, Google Maps.

Therefore, in Table 14, the layout of all streets with number of buildings, lengths and estimated areas of BIPV surfaces is given.

Table 14 – Available surfaces for BIPV installation

Street	Building	Length (m)	Street	Building	Length (m)
Getaldićeva	1	50	Kroz Smrdećac	1	55
(east-west)	2	80	(east-west)	2	70
	3	60		3	150
	4	120		4	120
Dobrilina	1	180		5	110
Vrančićeva	1	100	Jeretova	1	100
			Matice Hrvatske	1	90
Elementary School			High School		
Overall surface	2100	m2	Overall surface	2600	m2

Following the measuring, all façade lengths are added (total sum 1285 m) and multiplied by 35 m, the average height of 10 floors. The total area covered by BIPV is estimated to be 34825 m2. Given the average efficiency of a solar panel of 135 Wp/m2, the installed power is projected at 6.072 MW. Additionally, another 3700 m2 may be installed on the roofs of the elementary and high school, giving further 0.499 MW installed, for a total of 6.5715 MW.

For measurement of the campus part, three streets with BIPV were added to the residential sector sum, along with the roof of the high school. All other campus buildings will be calculated towards the campus micro grid operation. For the calculation, the same methodology of 40% usable surface has been kept. Several buildings on the campus have glass facades, and these will have to have transparent BIPV installations, increasing the overall investment. The average height for these buildings is 4 floors at 3.5 m each. Table 15 lists all campus buildings and their surface area, either façade or roof.

Final calculation puts the available area for BIPV on the campus at 2940 m2 of façade BIPV and 6600 m2 of roof mounted PV. That amounts to 0.397 MW BIPV and 0.891 MW of roof PV, for a total of 1.288 MW.

Overall installation sums up to 6.469 MW BIPV and 1.787 MW roof PV and a total of 8.256 MW.

For PV production PV-GIS tool [43] was used to calculate average monthly production of 1 kWp of installed PV panels, both on façade (vertical, 90° inclination) and optimally inclined slope (36° for Split area). The production results are displayed further below.

Table 15 – University of Split Campus buildings

Building	Area (m^2)	Length (m)
Student Dormitory		70
Economy Main		55
Economy Annex		30
Library		55
Civil Eng., Arch., Urbanism	1800	
Elec., Mech. Eng., Naval Arch.	1800	
Natural Sciences	3000	

Data Acquisition of Electricity Demand

The electricity data consumption from DSO HEP ElektroDalmacija was obtained from their SCADA system and covers a timespan of one year, from 01.01.2013 until 31.12.2013 [44]. The data has been provided in one hour time steps as direct measurements of electrical current in Ampere on the low voltage side of the transformer substation. Since the measurement was conducted on a three-phase system, to convert it into units of energy, the formula is given in Equation 1:

$$E\ (Wh) = SQRT\ (3) * U\ (V) * I\ (A) * PF \quad (1)$$

where U is the nominal voltage of the low voltage grid network (10 kV), I is the actual power reading for a given time period and PF stands for Power Factor of the grid, determined by measurements to be on average 0.99. Minimum and maximum values were 0.95 and 1.00, respectively Figure 5. The measurements for PF were conducted in the period from 23.09.2014 to 30.09.2014 in 10 minute intervals.

After running the raw power readings through the formula, a complete set of all results was available for analysis. The data included all 110 kV and lower voltage level substations for the agglomeration of Split. Dataset consisted of data from 14 substations and 266 10 kV fields. This allowed for the combined electrical demand of Split agglomeration to be presented during one year in one hour intervals, as provided in Figure 6.

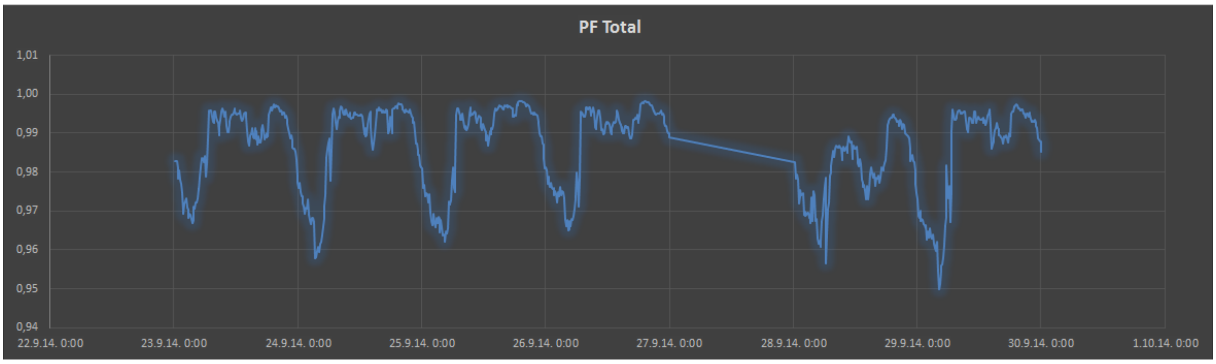


Figure 5 – PF readings from DSO SCADA system

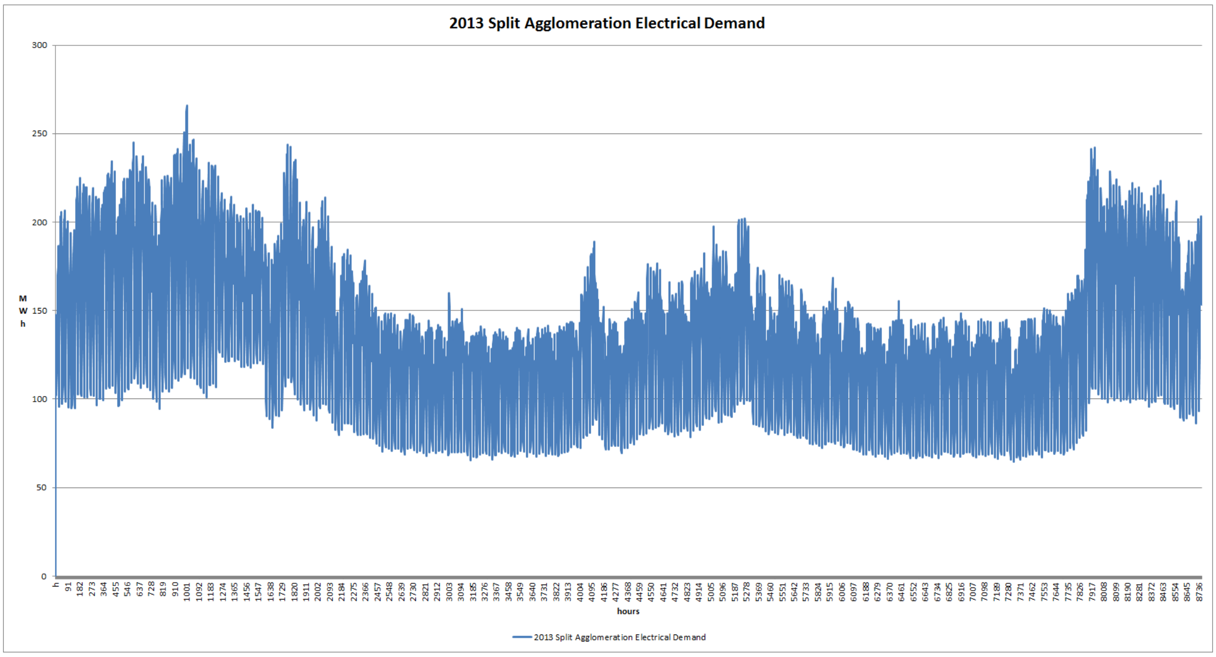


Figure 6 – yearly electrical demand

Table 16 presents basic statistical data about the demand for 2013. The data correlates with the official DSO report for the same year, with minor differences since the DSO covers a larger area then the data obtained.

Table 16 – Agglomeration Split Electrical Demand

Maximum Demand	265.95	MWh
Minimum Demand	64.68	MWh
Average Demand	137.86	MWh
Consumption	1207.68	GWh

Next, 3 more graphs in Figure 7, Figure 8, Figure 9, represent first the combined residential and campus demand, and then separate demands, to establish what are the differences in the pattern of demand for each of the entities. Table 17 summarizes the basic electrical demand for the combined and separate summations.

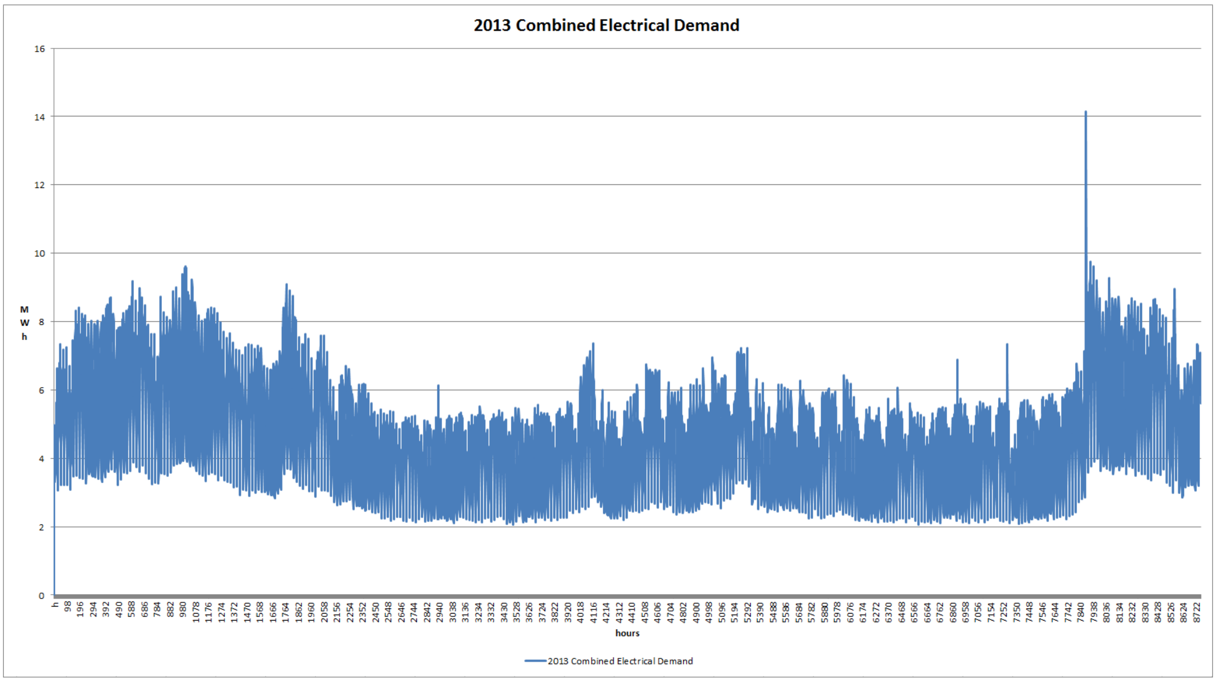


Figure 7 – 2013 Combined Electrical Demand Split 3 + Campus

Table 17 - 2013 Combined Electrical Demand Split 3 + Campus

Combined Electrical Demand		
Maximum Demand	14.14	MWh
Minimum Demand	2.05	MWh
Average Demand	4.92	MWh
Consumption	43.13	GWh

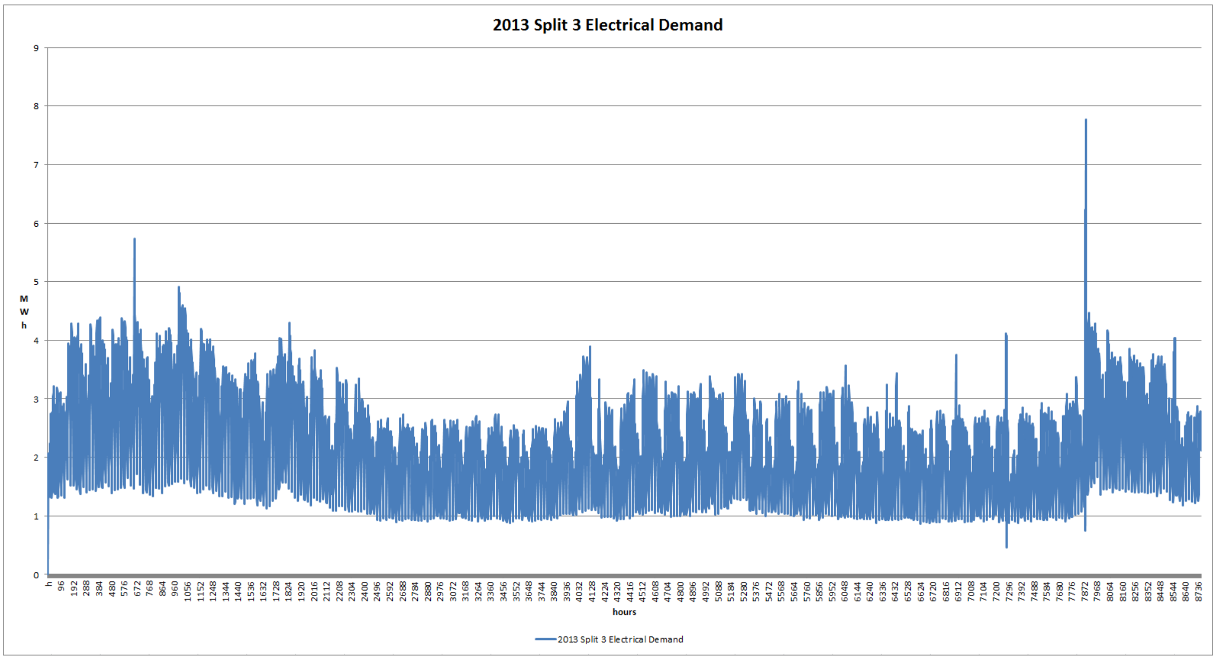


Figure 8 – 2013 Electrical Demand Split 3

The data for Figure 8 was obtained from substation field related to the locality of TS Visoka, with fields K38, K17, K71, and K73. This data represents the residential part of the micro grid Table 18.

Table 18 -2013 Electrical Demand Split 3

Split 3 Electrical Demand		
Maximum Demand	7.77	MWh
Minimum Demand	0.46	MWh
Average Demand	2.26	MWh
Consumption	19.80	GWh

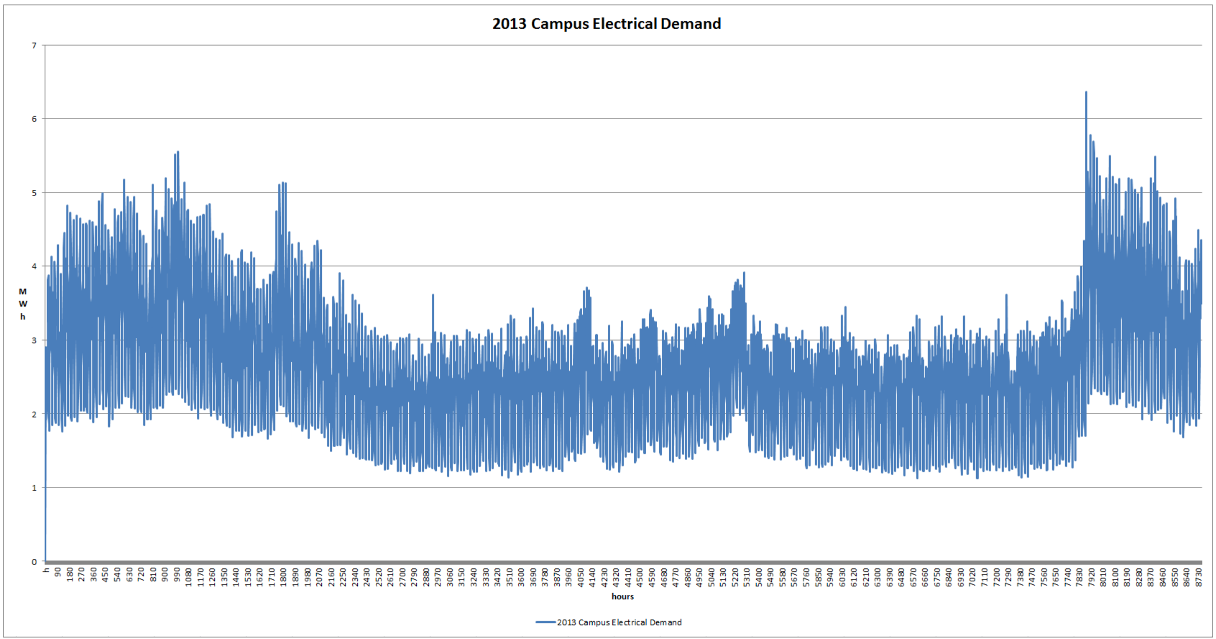


Figure 9 -2013 Electrical Demand Campus

The data for Figure 9 was obtained from substation field related to the locality of TS Sućidar, with fields K02, K09, K19 and K72. This data represents the campus part of the micro grid Table 19.

Table 19 -2013 Electrical Demand Campus

Campus Electrical Demand		
Maximum Demand	6.37	MWh
Minimum Demand	1.12	MWh
Average Demand	2.66	MWh
Consumption	23.34	GWh

Figure 10 provides the Google Earth Pro satellite image of the campus of the University of Split with the 3D building feature and the relative location within the city of Split [45]. The inset of Figure 10 provides the yearly sum of global irradiation on a horizontal plane in Croatia [46]. The area of Split, as marked by the blue circle in the South, receives about 1500 kWh/m^2 of annual global irradiation [46].

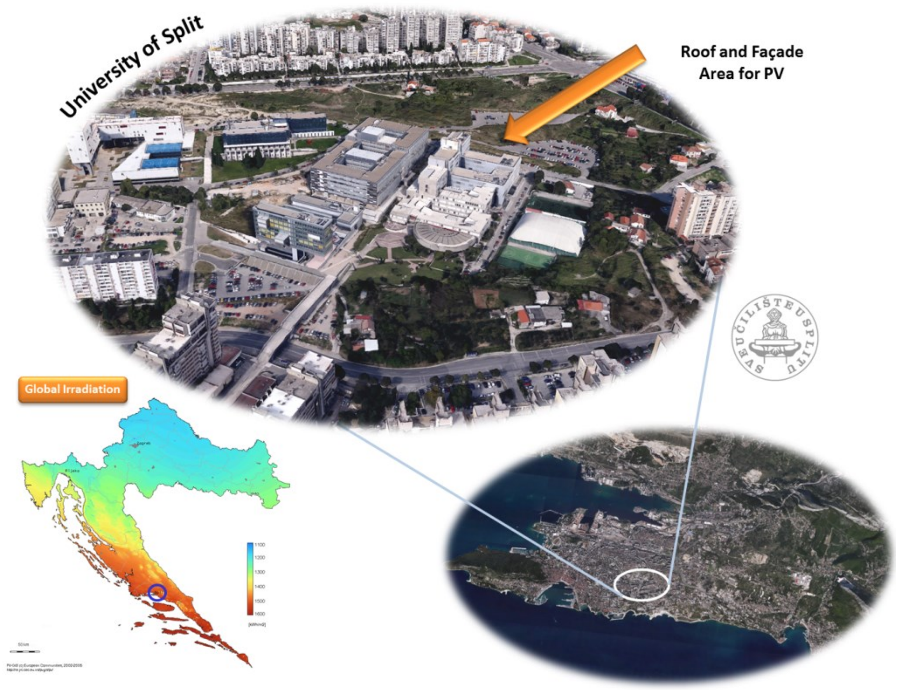


Figure 10 - Location of the Campus of the University of Split and Global Irradiation Map of Croatia

Case Study PV Integration Results

Combining the production data from BIPV and PV for both Split 3 area and Campus area (5.88 GWh and 1.50 GWh)

Table 20 with the recorded electrical demand data (19.8 GWh and 23.34 GWh), on yearly basis BIPV and PV production can cover approximately 29.7% and 6.43%, respectively of each area, or 17.11% of both areas combined Table 21. 75.6% of solar power production is based on façade BIPV and 24.4% on roof PV. The reason for a lower amount of coverage of electrical demand for the campus area lies in the fact there is substantially lower area of possible PV installations, primarily due to the fact campus buildings are significantly lower rises compared to the Split 3 residential district. There is more area available for roof PV, which was taken into account. It would be possible to further extend the coverage of campus demand by installing parking PV on uncovered areas, of which there is a significant area currently in use. This area will be reduced in future with additions of departments to the campus and building of underground garages, however this might be offset in some percentage by roof PV.

There is a noticeable trend of less difference between peak and base usage in the campus demand, most likely due to balancing of the energy needs for campus purposes and less need for daily activities originating from daily living activities. The overall usage of energy is also higher on the campus, suggesting either more intensive energy usage, or more occupants on the assigned substation fields. On both graphs there is a noticeable sharp increase in demand at the beginning of November, coinciding with the beginning of cold weather. For campus demand this might indicate inadequate central heating system that some of the departments use, as users probably uses the air-conditioning units to additionally heat up the space.

Table 20 – BIPV and PV production per area

	BIPV (kWp)	PV (kWp)	Production BIPV (GWh/Year)	Production PV (GWh/Year)	TOTAL per area
Campus	397	891	0.34	1.15	1.50
Split 3	6072	499	5.23	0.65	5.88

Table 21 – Combined BIPV and PV production for both areas

Total Campus + Split 3	BIPV (kWp)	Production (GWh/Year)
BIPV	6469	5.57
PV	1390	1.80
TOTAL SUM	7859	7.38

H2RES results

H2RES was used in the case study to determine whether it is possible to govern the production of solar derived energy to the grid. It was determined that on a yearly basis, there is a 0.025 GWh (0.003% of PV production) surplus of PV production, with a maximum value of 1.2516 MWh in one hour of operation. This suggests that the PV installation has reached the border of potential economical amount of installation and that the next step in the case study should be the installation of grid storage. The ratio of intermittent RES in H2RES was calculated at 17.95%, a 0.84% difference compared to PV-GIS, since H2RES also takes as the input the actual electrical demand of the case study for each of the 8760 hours of the year.

In addition, it is important to consider micro grids in the context of the energy, water, and waste water infrastructures of the urban area in which they operate. The GIS tool the City of Split for which a snapshot is provided in Figure 11 provides a benefit in enabling the inquiry of different urban infrastructure layers and is of particular use for urban planners [47]. Figure 12 provides 3 layers of infrastructure maps for the City of Split based on municipal sources [48], including infrastructure layouts for the electricity grid, water supply pipelines, and the waste water channels. These layers are superimposed on the satellite image of Split to represent the thematic necessity to combine a consideration of contextual aspects that relate to all three elements of energy, water, and waste water systems. As the non-electricity, fuel oil usage component of the campus energy usage, data on the consumption on a daily basis for the building boilers in the University of Split was further obtained as additional data but not used in this research work due to the focus on electrical energy [48]. Other environmental systems, such as coastal water management, protection of forested areas, and green corridors in the city may also be integrated in future analyses of sustainable development.

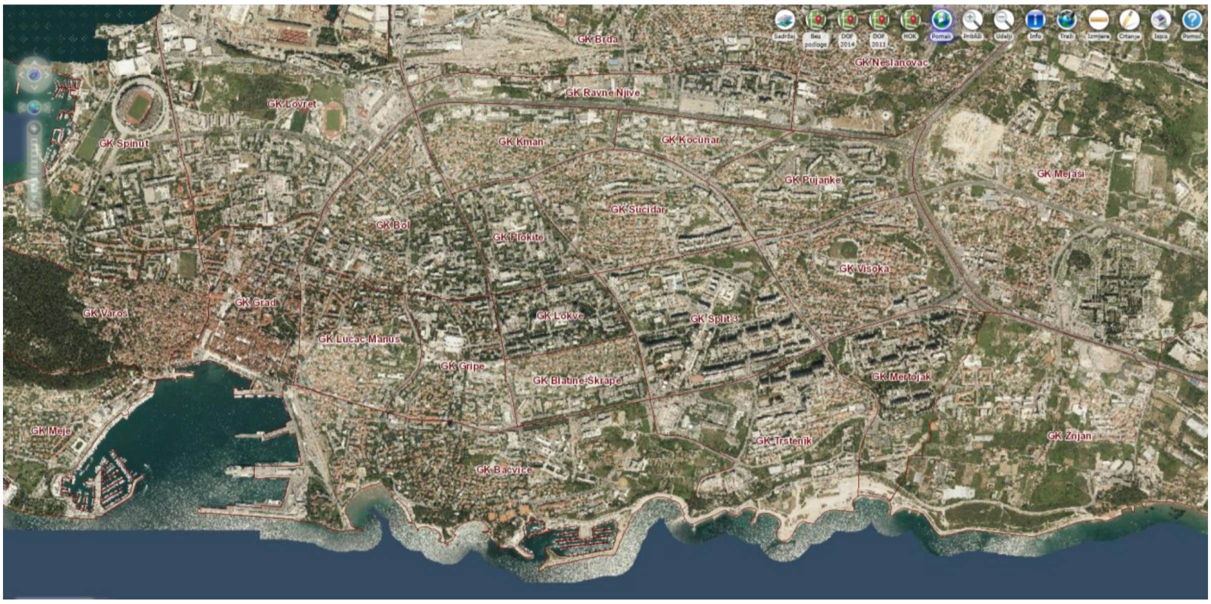


Figure 11 - Urban Infrastructure GIS Tool for the City of Split Based on Municipal Sources

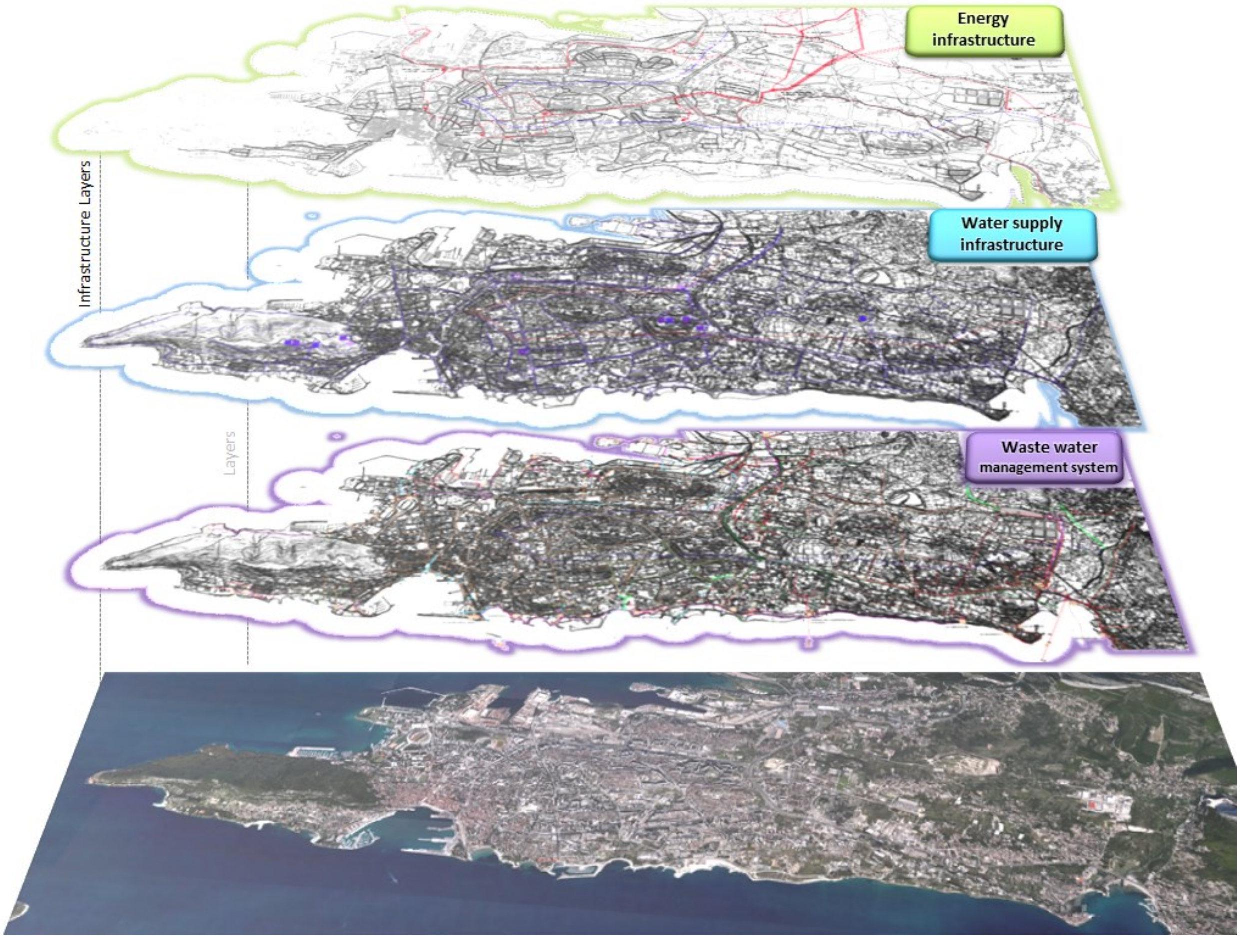
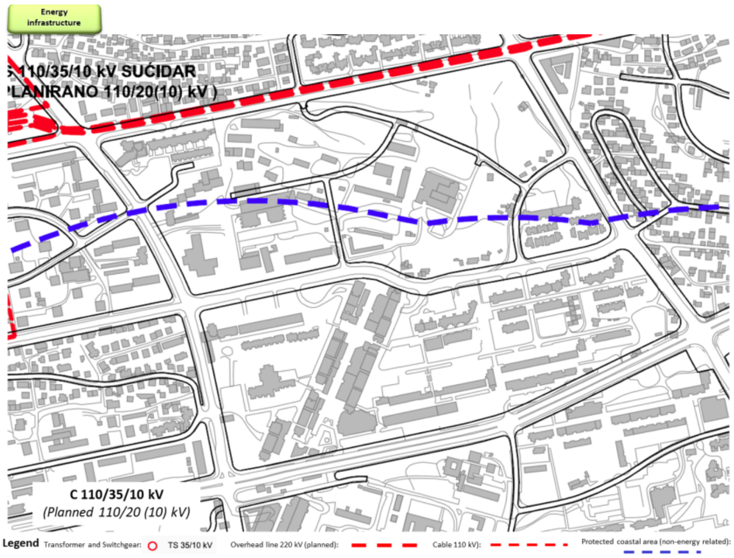
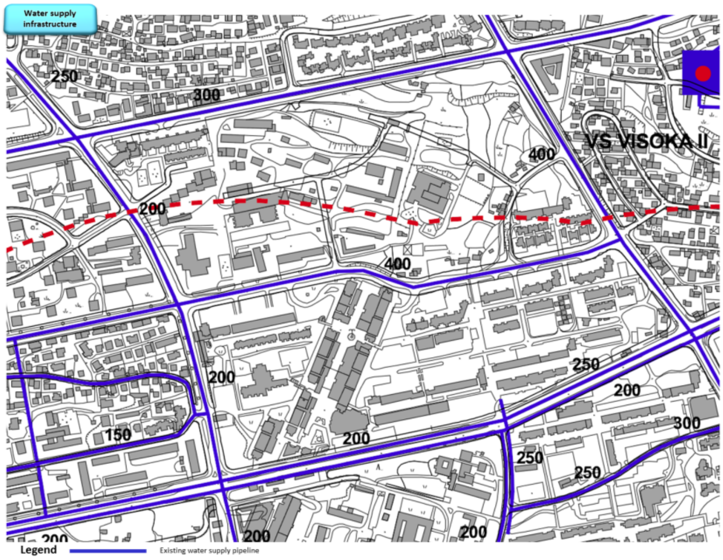
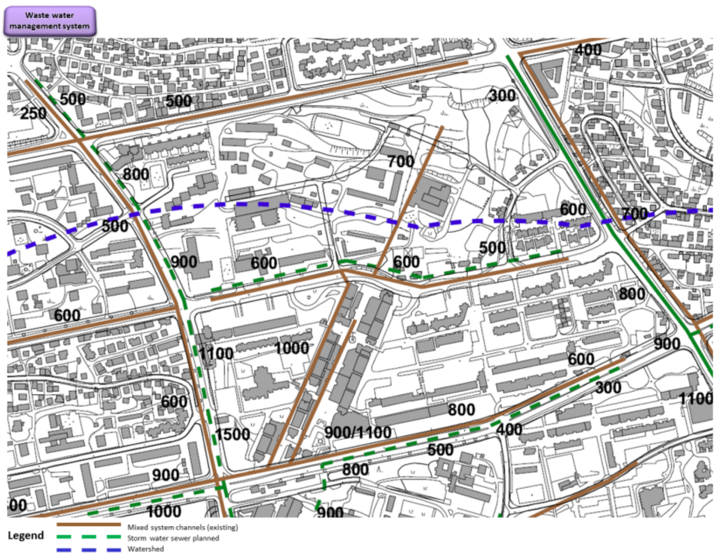


Figure 12 - Superimposed Energy, Water, and Waste Water Infrastructure Context of the Micro grid

Table 22 - Details of the Infrastructure Layouts for the Campus Area of the University of Split

<table>
<tr>
<td>Energy Infrastructure</td>
<td>


</td>
</tr>
<tr>
<td>Water Supply Infrastructure</td>
<td>


</td>
</tr>
<tr>
<td>Waste Water Management System</td>
<td>


</td>
</tr>
</table>

For example, Table 22 provides the details of these infrastructure layouts when the municipal level maps are limited to the campus area of the University of Split. These details include the type of electrical cable, transformer and switchgear (energy infrastructure layer) and the path of the existing water supply pipeline (water supply infrastructure layer). In addition, the details include the existing mixed system channels, planned storm water sewer lines, and the watershed (water management system layer). Thematic aspects such as these can be combined in the Sustainable Development of Energy, Water and Environment Systems SDEWES Index as developed in [2].

This Index is a composite indicator to benchmark cities and/or districts based on 35 indicators across 7 dimensions. In addition to an energy consumption and climate dimension that includes the energy consumption of buildings and transport, mostly based on data from CoM Sustainable Energy Action Plans (SEAP), the Index includes a dimension for renewable energy potential and utilization [2]. This dimension requires that cities with a relatively higher renewable energy potential have a higher usage of this potential, particularly to produce electricity. Based on the research work analysis, the usage of a certain percentage of the roof and façade area for PV on the campus buildings in the University of Split would enable the city of Split to perform better in this dimension. Currently, Split does not have SEAP energy data, although plans have been prepared for nearby communities [49].

SDEWES Index Consideration

The role of SDEWES Index was to provide a measurement of sustainability for the case study. Since the Index was not considered for a low-scale application such as a residential district, it was not possible to construct one. Moreover, none of the agglomeration members have SEAP in place and none are signatories of Covenant of Mayors, from which the Index draws on for most of the data. Campuses are covered by the Index, in a previous extension.

With that in mind, an overview of the Index will be given regarding each dimension and parameter and a discussion about the suitability and adaptability of the parameters to campuses will be given. As another alternative, those indicators that are not directly applicable at the campus level may be substituted with the corresponding values for a greater scope, i.e. district, city, and/or country.

provides the parameters that were taken into account from the SDEWES City Index.

Assessment of the Applicable Indicators in the SDEWES City Index to Different Scopes of Community Case Studies

Applicability levels to university campuses:

- **A**: Directly applicable
- **M**: Directly applicable if modified
- **NA**: Not directly applicable

Table 23 – Assessment of the SDEWES City Index indicators and Applicability to Campuses and Communities

SDEWES Index Dimension	Corresponding Indicators [2]	Campus	Community	Explanation *Colour Code: Good indicator candidate (blue); Important indicator that may be redefined (purple); Not significantly relevant for campuses (yellow)*
Energy Consumption and Climate	Energy consumption of buildings (MWh)	A	A	May include High, Low, Medium assessment for electricity, heating, and cooling demand
	Energy consumption of transport (MWh)	A	A	The scope will be defined as campus mobility plus commuting students and staff
	Total energy consumption per capita (MWh)	M	A	Energy consumption per the total of students, academic faculty, researchers, and employees
	Number of heating degree-days (HDD)	A	A	Directly applicable, no modification necessary
	Number of cooling degree-days (CDD)	A	A	Directly applicable, no modification necessary
Penetration of Energy and CO_2 Saving Measures	Sustainable Energy Action Plan (SEAP)	M	A	May include other strategies with sustainability targets. Includes National Energy Efficiency Action Plans (NEEP) and National Renewable Energy Action Plans – (NREAP)
	Combined heat and power based DH/C	A	A	Co-generation and tri-generation may be evaluated under different indicators if the case studies and communities show sufficient diversification to proceed in this direction. As done in the SDEWES Index, the installed capacity should support the scoring method.
	Energy savings in end-usage (buildings)	A	A	The scoring may be diversified with pilot energy efficiency projects and pilot renewable energy projects. University buildings with energy certificates (A-G category) may be scanned.
	Density of public transport network	M	A	Other mobility options on the campus, such as bike paths and mitigation of car plans, especially single occupancy vehicle rate in the central parts of the campus, may be evaluated. Connections to public transit routes may be scored separately to public transport network.
	Efficient public lighting armatures	A	A	Directly applicable, no modification necessary
Renewable Energy Potential and Utilization	Solar energy potential (Wh/m^2/day)	A	A	Directly applicable, no modification necessary (also fits with RenewIslands methodology)
	Wind energy potential (m/s)	A	A	Directly applicable, no modification necessary (also fits with RenewIslands methodology)
	Geothermal energy potential (mW/m^2)	A	A	Directly applicable, no modification necessary (also fits with RenewIslands methodology)
	Renewable energy usage for electricity (%)	A	A	RES based thermal energy may be evaluated if available at the campus level
	Biofuel utilization in transport (%)	A	A	Directly applicable, no modification necessary
Water and Environmental Quality	Per capita domestic water consumption (m^3)	A	A	Directly applicable, no modification necessary
	Drinking water quality index (/100)	A	A	Directly applicable, no modification necessary
	Average air quality PM_{10} (µg/m^3)	A	A	Direct diesel particulate matter (DPM) from transportation may be further assessed
	Ecological footprint (gha)	A	A	Directly applicable, no modification necessary
	Biocapacity (gha)	A	A	Directly applicable, no modification necessary
CO_2 Emissions and Industrial Profile	CO_2 emissions of buildings (t CO_2)	A	A	Directly applicable, no modification necessary
	CO_2 emissions of transport (t CO_2	A	A	Possibility to include $PM_{2.5}$, NO_x, SO_x and other emissions from the energy mix
	Average CO_2 emissions (t CO_2/MWh)	A	A	Directly applicable, no modification necessary

	Number of (nearby) CO_2 intense industries	A	A	Directly applicable, no modification necessary
	Carbon Accreditation of Airport (Levels)	A	A	Directly applicable, no modification necessary
City Planning and Social Welfare	Price of public transport ticket (Euro)	A	A	Directly applicable, no modification necessary
	Urban form and municipal management	M	A	For campuses, may also be used to distinguish separate campus locations, etc. (*) The population density that is assessed under this indicator may be taken separately (see below)
	Community Density and Population	*	*	Campuses and communities may be differentiated based on number of students (number of residents); number of employees; Area m^2 (liveable area); and type (urban, rural, mixed)
	GDP per capita (PPP$ national)	A	A	For the local level, the reporting level may not always correspond to cases (Campus, Split 3)
	Inequality adjusted well-being	M	M	Not directly applicable to the campus or community level
	Tertiary education rate (national)	A	A	Including the university budget. Also reports the R&D budget.
R&D, Innovation & Sustainability Policy	R&D and innovation policy orientation	M	A	For campuses, alternative indicators may be number of researchers
	National patents in clean technologies	A	A	For campuses, alternative indicators may be number of licensed patents
	Number of public/private universities (city)	M	A	For campuses, alternative indicators may be university-industry collaborations
	h-index of scientific publications	A	A	For campuses, alternative indicators may be number of researchers
	Reduction Target for CO_2 Emissions (2020)	M	M	May be updated to CO_2 target at campus and/or community level

Conclusion and further work

Energy planning of micro grids for urban residential and campus areas provided good insight into the differences in operation and abilities of two different urban areas to provide sustainability for itself. PV-GIS supplied data of solar radiation served as an input for H2RES to determine the production of BIPV and roof PV solar panels. The results suggested an average of 17.1% coverage of electrical demand from PV alone. Residential area proved to be more self-sustainable due to higher density of living and lower demand, making it suitable for larger areas of façade BIPV to be installed. Campus areas are a typical representative of urban style academic campus, with large areas covered by low-level buildings and few open spaces, limiting the possibility of implementing more BIPV.

Further work will focus on techno-economic analysis of BIPV installation and integration. Further mapping of potential BIPV locations, such as new building locations and parking spaces, with more detailed measurements are planned. Expansion of the case study area is also possible, since the demand data has been obtained for a far larger area and has already been processed. At that point, the overall production is possible to surpass the demand, and surpluses are expected in the network. Therefore, integration of energy storage to the case is considered, with economic feasibility calculations and overview of current PV legislature in Croatia. H2RES model will be implemented with forward demand projections up to 24h in advance to be able to optimally control the generation side of the system. SDEWES index was not calculated due to the fact that neither participant of the Split agglomeration has a SEAP. This was not the scope of the paper anyway, and suggestions were proposed to expand the index by adding new or replacing existing parameters to better describe the existing situation.

Acknowledgement

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