Digitalization and Smart islands in the Kvarner archipelago

Marko Mimica*, Goran Krajačić *, Damir Medved**, Darko Jardas***
* Faculty of Mechanical Engineering and Naval Architecture, Zagreb. Croatia
** Ericsson Nikola Tesla d.d., Zagreb, Croatia
*** Regionalna energetska agencija Kvarner, Rijeka, Croatia
e-mail adresa: mmimica@fsb.hr

Abstract **- Currently, in the European Union there are two major initiatives that address the issue of sustainable development of the islands. Top-down initiative coming from the Declaration on Clean energy for EU islands and bottom-up Smart Islands initiative. Both initiatives consider islands as living labs that can host innovative pilot projects and lead Europe's transition into a sustainable and low carbon environment. Following objectives of both initiatives, the Croatian government passes a law on islands that support the development of smart islands. The paper presents a comprehensive review of studies, projects, policy documents and scientific publications related to Smart Islands development in Kvarner archipelago which can be used as a model for implementing new sustainable technology on the islands. It also provides expert recommendations for digitalization in several sectors crucial for the development of islands and an integrated approach to management of island resources.**

Ključne riječi – Smart island; Kvarner archipelago; digitalization; blockchain; information and communication technology

I. INTRODUCTION

Current ongoing digitalization is penetrating every sector of society. Its impacts are visible in energy, transport, social, economy and many more sectors. Even more, digitalization has enabled new communication pathways between these sectors. Implementation of advanced information and communication technology (ICT) created a more interconnected world with the highest possibility of a collaboration of different stakeholders than ever before. As in every technological and industrial revolution, there are technologies which can be first applied to the islands, so they could feel the first impact of these positive changes. Islands can be living labs for implementation of new technology and therefore be leaders of change. Although isolation and poor connection with the mainland create difficulties for the island population, these constraints can be beneficial for the execution of some pilot projects and implementation of new sustainable technologies. If successful on the islands, these projects could most probably be implemented in some rural areas on the mainland. The European Union (EU) acted on this issue and supported two initiatives that will create the framework for future development of the islands. Top-down initiative Clean Energy for EU Islands [1] provides a pathway for islands to create low carbon and sustainable environment with low energy prices. The initiative will result with the implementation of advanced technologies for energy storage, less dependence on import of energy, improvement of air quality and preservation of island natural heritages. Another framework is Smart Islands Initiative [2], which is a bottom-up initiative. Smart Islands Initiative sets ten action points for creating a smart and inclusive society on islands. It seeks to present islands as the test – beds for hosting projects that stress optimal usage of local resources for purpose of creating sustainable communities. With Smart Island Initiative, the role of islands is no longer to follow, but to lead Europe's transition towards a more sustainable community.

Many kinds of research have been made in order to investigate the possibilities for smart technology integration on islands. One of the first methods developed was RenewIslands method presented in [3]. RenewIslands provided a qualitative indicator for evaluation of islands' needs and resources on many different sectors including energy, water, waste, and wastewater needs as well as energy import infrastructure and wind, solar, biomass, geothermal and hydro potential. This method was foundation for modelling energy systems of different islands as for example in [4], where authors modeled energy system of several interconnected islands in tool EnergyPLAN showing that interconnected islands have decline of Critical Excess Electricity Production (CEEP) up to 22% in comparison with scenario when islands are not connected in common system.

The main problem regarding renewable energy sources (RES) integration is balancing between production and consumption as described in [5]. Many researchers suggest that integration of different flows substantially increase system possibility to integrate RES. Dominković et. al [6] combines smart charging, reverse osmosis technology and an ice storage for increasing the possibility for RES integration. In another work, Segurado et al. [7] present analysis of integrated water and energy supply where excess electricity production from the wind power plant is used by desalination units for covering water demand of the population or where

desalinated water is used as energy storage in a pumped hydro system.

These papers made a significant contribution regarding increasing smart technology integration in island systems by combining different flows, but they don't investigate the role of information and communication technology (ICT) in this process. Importance of ICT in RES integration is described at [8] where the author emphasizes that with smart meters and tracking of generation and consumption in real time it is possible to effectively balance the energy system. Bibri S. E. et al. [9] emphasizes the Internet of Things (IoT) concept as one of the key components for implementing ICT in smart systems. According to him, IoT has great potential to improve energy efficiency and, in combination with big data applications, to accelerate sustainable development. In [10] the authors provide a concept for achieving automatic control by using IoT and cloud computing. They suggest that opportunities and challenges that emerge from big data implementation will be the driving force for the development of smart cities. Gubbi et al. [11] present user-centric cloud model based on an interaction of private and public clouds and indicates the importance of integration of IoT and cloud computing in order to provide reliable support to users using services offered by multiple stakeholders.

Several studies and action plans were completed regarding islands in the Adriatic Sea, mostly focused on mapping and suggesting measures for the implementation of sustainable technology for achieving a low carbon and sustainable environment. Most advanced islands in this aspect are Kvarner archipelago islands. The biggest islands of Kvarner archipelago are Krk, Cres, Lošinj, and Rab while some of smaller ones are Unije, Susak, and Plavnik. Pag is in the geographic area of Kvarner archipelago, but administratively is not part of it and therefore is not considered as part of Kvarner archipelago. The available data about these islands from studies [12], [13], [14], [15] is presented in Table I.

II. METHODS

This paper's objective is to offer a path for islands to mitigate towards more sustainable and low carbon environments. Framework for development of Smart islands in Croatia is given in Table II. It is consisted out of five phases (P1 – P5) and for every phase, there is an estimated duration as well as required actions and desirable results. It is worth noting that it is not desirable to try to implement this concept on the whole area, such as the Adriatic Sea, but to rather implement Smart island concept on a single island and then expand it further (Figure 1). Islands that have similar characteristics or that are located in the same area such as Kvarner archipelago have a better chance that technological solutions implemented on one island will be suitable on other islands as well. One of the key aspects in setting up the right framework for the development of Smart islands is to do a quality mapping. RenewIslands is a method that will is mostly used for this purpose. It is used for the creation of several alternative scenarios for energy planning based on islands needs and resources. Mapping of islands needs is assessed with electric energy consumption, heat and cold energy consumption, transport energy consumption, waste and wastewater treatment and water demand, while islands resources are assessed with the wind, solar, hydro, biomass and geothermal potential. In addition to this, there are also parameters for the islands' energy import infrastructure and water infrastructure.

TABLE II. FRAMEWORK FOR DEVELOPMENT OF SMART ISLANDS IN CROATIA

Phase	**Framework**		
	Duration	***Actions***	***Results***
P1	1991 – 2003	Generating ideas, setting up frameworks	National Island Development Programme, Law on Islands
P2	2004 – 2016	Advocacy, Mobilization, Screening, Mapping	IEE projects STORIES [16], Meshartility [17], BEAST [18], SEAPs, SECAPs
P3	2017 – 2030	Experimentation with top – down and bottom – up frameworks, ICT expansion	Smart Islands Declaration [2], Clean energy for EU islands [1], Horizon 2020, Pilot islands, ICT/ Digitalization, National Legal framework for Islands
P4	2030 – 2040	Society assisted acceptance and full commercialization (self-sustained) of Smart Island approach	Smart energy, Smart transport, Smart water management, Smart waste management, Smart Governance, Smart economy, Climate change adoption
P5	2040 – 2050	New innovation and business model	Innovation, Business models, Resilience

TABLE I. DATA ABOUT KVARNER ARCHIPELAGO ISLANDS FROM SELECTED STUDIES

Island	**Population**	**Area [m^2]**	**Nr. Of tourists**	**Final Energy Consumption [MWh]**	**Energy Consumption [MWh/cap]**
Krk	19 383	405,8	682 200	190 842	9,846
Cres	3 184	405,8	114 800	54 323	17,06
Lošinj	10 141	74,36	293 400	145 320	14,33
Unije	88	16.9	6 783	1 209	13.741

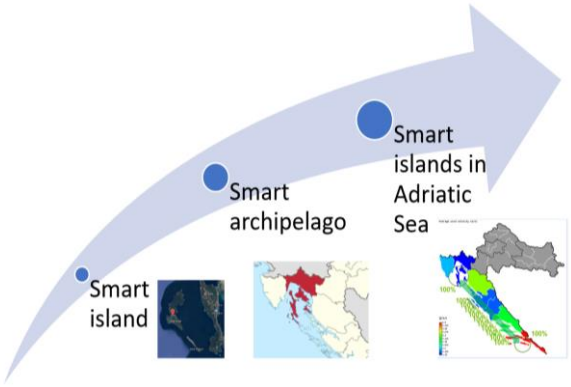

Figure 1. Development of Smart Island in the Adriatic Sea

One of the most important expected results of phase P3 of the presented framework is digitalization. Integration of digital processes is crucial for the development of Smart islands. Key role in this process will have advanced information and communication technology (ICT). Implementation of ICT will provide new management strategies and open new flexibility opportunities. Energy systems are currently going through the digitalization process with a final goal of developing a sustainable and low carbon energy system. This is particularly important for electric power systems since the electrification of different sectors such as transport or heating will play an essential role in achieving this goal. Because of this electric power systems need to become smart grids which will consist of not only smart devices such as smart meters, but that will also have the possibility of automated and remote control. Also, a change of end users' role will be needed. Today's passive consumers will need to be transformed into active components of the energy system or prosumers. Prosumers will be able to consume and produce energy. Ideally, prosumers will be able to satisfy their needs and export the rest of the energy to the electric grid or store it in energy storages. This concept will be beneficial when there will be high demand for electricity in the system and DSO will be able to easily send a signal to activate batteries from prosumers to satisfy the demand. This could lead to a huge amount of distributed energy resources and create concepts known as virtual power plants. Furthermore, this will require that the distribution system operator (DSO) become an active operator like transmission system operator (TSO). Data manipulation will become more important as information collected from smart devices will need to be processed and used properly.

This kind of progress in the energy system will not be possible without adequate communication. Concepts such as the Internet of Things (IoT) where different devices are connected in the network and communicate together will be needed. Such communication will have to be executed through a fast and secure communication network and a 5G network that is already being implemented. 5G network will enable a huge implementation of IoT in every aspect of everyday life providing faster communication able to transfer a huge amount of data in a short time thus creating a more connected world. All data will need to be gathered in a cloud which will process and manipulate the data. Clouds will be organized according to themes defined in [2]:

1. Energy
2. Transport
3. Waste
4. Water
5. Governance
6. Information and communication technologies
7. Economy
8. Education
9. Environment

These clouds will be connected so that they create a synergy between different themes. Special emphasis will be placed on the energy area for an efficient and low carbon energy system is the main issue to deal with to create not only Smart island but also Smart city.

By using currently available top-down studies and also bottom-up studies it is possible to propose a new concept of Smart Island according to Figure 2.

III. RESULTS

According to the presented framework, development of Smart Islands in Croatia is currently in phase P3. During the past twenty years many studies and projects were completed in order to investigate Croatian islands' possibilities for sustainable development. The island that was most detailed investigated is Korčula. In the study [19], the authors presented a case with a 100% intermittent RES for the island of Korčula. The authors investigate which is the best combination of wind and solar power in order the achieve low-cost solution and the combination with the least export and import of electric energy. Figure 3. presents energy planning scenario until 2030. together with energy import and export, RES share in primary energy supply (PES), RES share in total electricity production and CO_2 emissions on the island Korčula.

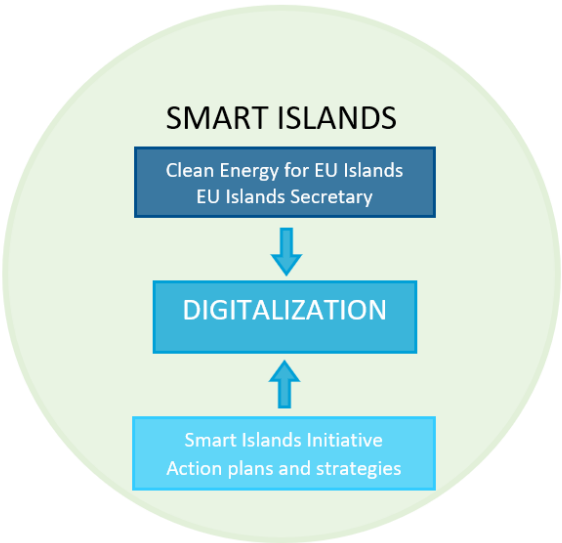

Figure 2. Combining top-down with a bottom-up approach to develop Smart islands

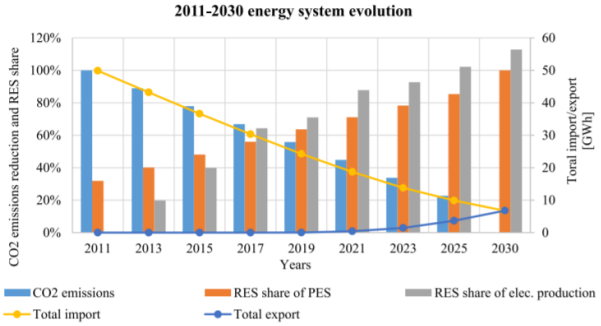

Figure 3. Energy system characteristics of island Korčula by 2030.

The study clearly shows huge potential for achieving low carbon energy system, but in order to balance energy system with 100% intermittent RES, advanced ICT is a necessity that must be implemented or otherwise this kind of energy system would not be possible.

Many ideas and methods were generated during this period such as RenewIslands method. As mentioned, RenewIslands is based on qualitative indicators. During phase P3, this method will be transformed into advanced RenewIslands methods which will be called Smart Islands method. Smart Islands method will consist of more accurate, quantitative indicators for mapping islands need and resources such as energy consumption per capita, load factor, available reserve, and similar indicators. Based on these indicators, Smart Islands method will optimate and suggest several energy planning scenarios that will set the framework for the development of the islands' energy sector.

In addition, some frameworks have been set up and the government passed a law on islands [20]. Nevertheless, real progress is yet expected to be made in this phase of the presented framework. The technological breakthrough which is currently happening will make possible to create the first smart islands in the Adriatic Sea. Islands of Kvarner archipelago are especially interesting to researchers since islands of this archipelago already implemented some advanced sustainable technologies. Chargers for EV are installed on Krk, Cres and Lošinj [21], desalination plant, two photovoltaics systems of 100 kW and a 500 m^2 of solar thermal collectors at a public hospital [22] are installed on Unije and solar power plant was installed on Krk. Krk has also modern public lightning with connected optical cables which open the opportunity for easy implementation of smart monitoring. Further planned projects are solar power plant on Unije and anaerobic digestion plant for biogenic waste, an optical network, and Energy Academy on Krk [22] and the biggest 6,5 MW solar power plant in Croatia on Cres.

Substantial improvement is made in the waste management sector of islands of Kvarner archipelago in comparison with other islands of Adriatic Sea. Waste management possibilities of Cres and Lošinj are presented in [23]. The study presents current waste management problems such as disposal and transfer to the mainland and suggest an integral solution to the problems. The best example of waste management is on island Krk, where 53,6% of waste was separated in 2017. [24]

The number of tourists is especially important for the islands because during their stay need for waste treatment, water, and energy increase substantially. It is possible to notice from Table I. that the number of tourists is several times higher than the islands' population. This can completely exhaust the islands' resources during the summer months. Because of that, islands often have problems with balancing of the electric power system during these periods. Electric vehicles (EVs) are one of the possible solutions to this problem because they can serve as storage solutions. EVs can be in charge or discharge mode depending on power system requirements. Another option for power system balancing improvement is the implementation of demand response technologies. Demand response is ancillary service that enables activation od deactivation of larger loads in the system depending on when the power system requires it. This service can change the daily demand curve and increase the flexibility of the system. Full implementation of demand response will not be possible without advanced technology such as smart meters and advanced ICT. Smart metering systems monitor electricity consumption, measure the quality of electricity and detect faults [25]. Thus, smart meters increase the security of the system and provide prosumers an opportunity to act on market prices in real time. Data collected from smart meters and smart sensors will need to be quickly and securely transferred to the cloud. As mentioned before, the 5G network will play a crucial role in this process together with IoT and cloud computing (Figure 3.).

Advanced technology such as 5G, IoT and cloud computing open new opportunities for integrating different energy flows. A good example of that is the integration of energy, waste and wastewater sector. Similar concept to this is presented in [26] where authors present the methodology for integration of waste, water, and energy sector in Smart city concept. Intermittent RES production brings new insecurities into the energy system. Since waste and wastewater processing consume a substantial amount of energy, by adjusting the time of processing it is possible to increase system flexibility. For example, if the data collected from smart meters and processed in cloud indicates an increase in consumption on the island the system sends the signal to deactivate processing in waste or wastewater plant in order to reduce the total consumption. Another way of integrating these flows is by using residual heat that comes from waste and wastewater plants. Heat from these plants could be used and therefore increase the efficiency of the heating system.

Similar flow integration can be achieved by combining the energy and water sector with desalination plants. Desalination plants are used for separating mineral components from saline water to produce water for irrigation or human consumption. By timing the work of

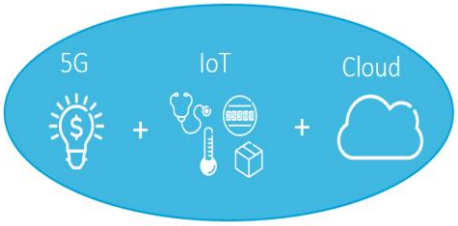

Figure 3. The synergy between 5G, IoT, and Cloud [27]

desalination plant it is possible to support the energy system same way the waste management plants supports it. Such flow integration was investigated in [28], where the desalination plant was powered by microgrid. Fast communication and transfer of data is achieved with wireless communication and the authors present cost – efficient desalination management with desalination plant participating in demand response market which is possible with the implementation of advanced ICT. Furthermore, since desalination systems increase the possibility of RES integration in energy systems they also have an impact on reducing the production from fossil fuels plants as implicated in [29].

Social acceptance is crucial for implementing changes such as island transition to Smart island. Digitalization opens new opportunities for informing and including people. One of the most influential ways of using digitalization is through social networks which offer a possibility to inform a wide range of people as well as ask them for feedback on any matter. Digitalization enables easier multi-stakeholder collaboration and increases the possibilities for creating a circular economy as emphasized in [30]. It empowers citizens and provides an opportunity for local ownership and participation of citizens in financing projects like solar power plants. Such citizen participation is planned on Krk where local citizens will have the opportunity to become a stakeholder in solar power plant Barbičin. Nominal power of solar power plant Barbičin will be 5 MW and it should be in operation until the end of 2019.

Additionally, with digitalization, it will be possible to make effective education strategies. Islands will be living labs that will secure the knowledge transition and projects implemented on the islands will serve as a starting point for other energy transition projects in cities.

The smart grid will enable the development of new energy market that will be based on peer to peer trading. The technology that will allow this to happen is blockchain and there are already pilot projects that will test this technology such as IMPACT [31]. The blockchain is a technology that stores records or transactions in a growing and continuous list of transactions that are called blocks. Every block is linked to another block and secured with a cryptographic hash key. The electricity trading is done from one peer or producer to another peer or consumer through an encrypted transaction. The encrypted transaction is in the form of a smart contract that is activated when a specific term is satisfied or when there is a signal from the system to execute the transaction. Many benefits can emerge from this kind of electricity markets such as lower market price, better voltage control, improved balancing of a power system and better quality of electric energy. Simplified diagram of this kind of market is shown in Figure 4.

Buyers and sellers submit their offers on blockchain platform while DSO coordinates preservation of power system balance with buyers and sellers and approves transactions on the blockchain platform.

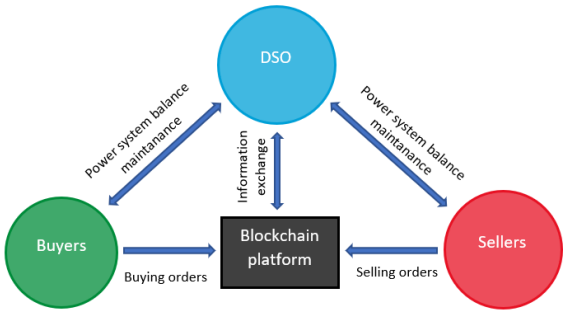

Figure 4. Diagram of the electric energy market based on blockchain

Another blockchain implementation could be insecurity of the data saved in the cloud [32]. As data is becoming a more important factor in decision making and regulation, the significance of data security is one of the most important issues. This is especially true when users don't have access to physical data storage as in cloud computing. Due to encryption and high security, blockchain appears to be a suitable solution to this problem. The problem of blockchain is that it still isn't enough stable technology and therefore, more research will have to be done in order to achieve full implementation of blockchain for the security of the data.

IV. CONCLUSION

Kvarner archipelago represents one of the best places in the Adriatic Sea for the implementation of advance sustainable technology. Framework for developing Smart islands in Croatia suggests that the results of the current phase should be a development of top – down and bottom – up strategies, which is achieved, and implementation of ICT and overall digitalization of existing processes on the islands. Smart Islands Initiative differences nine sectors in which digitalization has to be implemented. The energy sector is the key to developing a low carbon sustainable environment. However, integration of intermittent RES in electric power system brings insecurity in energy system balancing. This paper presents several studies that offer solutions to this problem. Furthermore, this paper suggests several models of digitalization and the integration of different sectors in order to increase energy system flexibility. Combination of IoT with fast and secure 5G network and with cloud computing is crucial for successful digitalization. This combination is applied to all nine sectors with special emphasis on the energy sector. The paper underlines the importance of advanced technologies such as smart meters and sensors and describes the possibilities of

demand response and EVs. These technologies cannot be fully used unless they are connected through advanced ICT. Furthermore, this paper presents a model of future decentralized energy market based on blockchain technology. Decentralized energy market will bring lower electricity prices as well as improved power system control. However, decentralized energy market will not be possible unless advanced ICT such as IoT, 5G, and cloud are implemented because this technology is vital for DSO to preserve the stability of the power system. Islands of Kvarner archipelago are ready for integration of advanced sustainable technology and have already implemented some of the sustainable technology. If implemented, future plans for islands of Kvarner archipelago described in this paper will take these islands significantly closer to completing the task of phase P3 and becoming Smart islands.

Acknowledgments

This work has been financially supported by the Croatian Science Foundation and this support is gratefully acknowledged.

REFERENCES

[1] European Commission, “Clean Energy for EU Islands launch,” *European Commission Energy News*, 2017.

[2] Smart Island Initiative, “Smart Islands Declaration,” 2017.

[3] N. Duić, G. Krajačić, and M. da Graça Carvalho, “RenewIslands methodology for sustainable energy and resource planning for islands,” *Renew. Sustain. Energy Rev.*, vol. 12, no. 4, pp. 1032–1062, 2008.

[4] A. Pfeifer, V. Dobravec, L. Pavlinek, and G. Krajačić, "Integration of renewable energy and demand response technologies in connected island systems – Case study of islands of Vis, Lastovo, Korčula, Mljet and Pelješac."

[5] P. D. Lund, J. Lindgren, J. Mikkola, and J. Salpakari, “Review of energy system flexibility measures to enable high levels of variable renewable electricity,” *Renewable and Sustainable Energy Reviews*. 2015.

[6] D. F. Dominkovic, G. Stark, B. M. Hodge, and A. S. Pedersen, “Integrated energy planning with a high share of variable renewable energy sources for a Caribbean Island,” *Energies*, 2018.

[7] R. Segurado, M. Costa, N. Duić, and M. G. Carvalho, “Integrated analysis of energy and water supply in islands. Case study of S. Vicente, Cape Verde,” *Energy*, vol. 92, pp. 639–648, 2015.

[8] Y. Kuang *et al.*, “A review of renewable energy utilization in islands,” *Renewable and Sustainable Energy Reviews*. 2016.

[9] S. E. Bibri, “The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability,” *Sustain. Cities Soc.*, 2018.

[10] D. Li, J. Cao, and Y. Yao, “Big data in smart cities,” *Sci. China Inf. Sci.*, 2015.

[11] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, “Internet of Things (IoT): A vision, architectural elements, and future directions,” *Futur. Gener. Comput. Syst.*, 2013.

[12] igr d.o.o.,igr AG, IInstitut für angewandtes Stoffstrommanagement Umwelt-Campus Birkenfeld, “Interdisciplinarna strategija nulte emisije stakleni kih plinova za integrirani održivi razvoj otoka Krka,” Zagreb, 2012.

[13] Sensum, “Akcijski plan energetski održivog razvitka grada Cresa.” 2016.

[14] B. Hermetek, “Energy system planning on Island Lošinj with use of RenewIslands metodology,” Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, 2007.

[15] S. Bratić, “Planning of development for the energy self-sufficient Island Unije,” Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, 2011.

[16] Intelligent Energy Europe - European Commission, “STORIES Addressing barriers to storage technologies for increasing the penetration of intermittent energy sources.” [Online]. Available: https://ec.europa.eu/energy/intelligent/projects/en/projects/stories.

[17] “MESHARTILITY - Measure and share data with utilities for the Covenant of Mayors.” [Online]. Available: http://www.meshartility.eu/en/about-meshartility.

[18] “BEAST - Beyond Energy Action Strategies.” [Online]. Available: http://www.beastproject.eu/.

[19] H. Dorotić, B. Doračić, V. Dobravec, T. Pukšec, G. Krajačić, and N. Duić, “Integration of transport and energy sectors in island communities with 100% intermittent renewable energy sources,” *Renewable and Sustainable Energy Reviews*. 2019.

[20] Republic of Croatia, “Law on Islands.” 2018.

[21] “www.puni.hr.” .

[22] DAFNI, “Smart Island Projects and Strategies.” .

[23] H. Grofelnik, “Mogućnosti gospodarenja otpadom na otocima Cresu i Lošinju Possibilities of Waste Management on the Islands of Cres and Lošinj,” pp. 118–124, 2012.

[24] Ponikve usluga d.o.o., Ponikve voda d.o.o., and Ponikve eko otok Krk d.o.o., “Yearly report 2017.,” 2017.

[25] V. Høynes and J. Berntzen, “The second wave of smart meters: a win–win situation for consumers and energy companies.” [Online]. Available: https://perspectives.tieto.com/blog/2016/10/the-second-wave-of-smart-meters-a-winwin-situation-for-consumers-and-energy-companies/.

[26] A. Strzelecka, B. Ulanicki, S. Koop, L. Koetsier, K. Van Leeuwen, and R. Elelman, “Integrating Water, Waste, Energy, Transport and ICT Aspects into the Smart City Concept,” in *Procedia Engineering*, 2017.

[27] D. Medved, “5G network.” 2019.

[28] S. W. Lee, S. Sarp, D. J. Jeon, and J. H. Kim, “Smart water grid: the future water management platform,” *Desalin. Water Treat.*, 2015.

[29] A. Corsini and E. Tortora, “The influence of water desalination systems on load levelling of gen-set in small off-grid islands,” in *Energy Procedia*, 2017.

[30] M. Antikainen, T. Uusitalo, and P. Kivikytö-Reponen, “Digitalisation as an Enabler of Circular Economy,” in *Procedia CIRP*, 2018.

[31] S. Ilak, Perica; Rajšl, Ivan; Zmijarević, Zlatko; Herenčić, Lin; Krajcar, “Decentralised electricity trading in the microgrid Implementation of decentralized Peer-to-Peer Concept for Electricity Trading (P2PCET).” 2018.

[32] E. Gaetani, L. Aniello, R. Baldoni, F. Lombardi, A. Margheri, and V. Sassone, “Blockchain-based database to ensure data integrity in cloud computing environments,” in *CEUR Workshop Proceedings*, 2017.