Integration of transport and renewable energy sectors in 100% renewable islands communities – Case study Lastovo

Conference Paper · October 2015

3 authors:

Antun Pfeifer
University of Zagreb

Goran Gasparovic
University of Split

Goran Krajacic
University of Zagreb

Integration of transport and renewable energy sectors in 100% renewable islands communities – Case study Lastovo

Antun Pfeifer*
International centre for sustainable development of energy, water and environment systems – SDEWES Centre, Zagreb, Croatia
E–mail: antun@sdewes.org

Goran Gašparović
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Zagreb, Croatia
e–mail: Goran.Gasparovic@fsb.hr

Goran Krajačić
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Zagreb, Croatia
e–mail: Goran.Krajacic@fsb.hr

ABSTRACT

This paper examines the integration of transport and energy production sectors for isolated islands communities. Present energy supply on Croatian islands relies on fossil fuels and electricity from the mainland. Exploitation of renewable energy sources, for which there is great potential on Croatian islands due to their geographic location and climate, leads towards self-sufficiency and sustainable development. In order to design a self-sufficient and sustainable island, integration of renewable energy sources alongside with energy savings is needed, with attention to be given to energy storage. In this paper, use of electric vehicles as energy storage for energy from RES is examined. Case study of island of Lastovo shows how transport and electricity needs can be accommodated through integration of energy flows to help communities to achieve energy self-sufficiency. Through scenario approach using H2RES and HOMER software, case study examines how integration of renewable energy sources and increase in penetration of electric vehicles to islands transport sector help integration of transport and energy production sectors in order to make Lastovo, which currently imports all of transport fuels and electricity supply from the mainland, a 100% energy self-sufficient island. The results show, through two different scenarios for the year 2020 with various degrees of EV integration in transport sector of Lastovo, the amount of RES penetration which can be implemented and how this affects the energy costs on the island. Also, an index of sustainable RES penetration is introduced to show the influence of environment preservation constraints on efforts to achieve 100% renewable supply of energy on the island.Scenarios present ambitious goal of 100% renewable energy system with 25% penetration of EV in islands transport sector in first scenario and 50% penetration of EV in second scenario. In first case energy consumption in transport was also decreased from 12 TJ (without EV) to 9.89 TJ, and with 50% EV there was further decrease to 7.85 TJ of primary energy consumption in transport sector. Electricity consumed by EV was supplied from RES and reached 235 MWh in first scenario and 470 MWh in second scenario.Index calculations show significant difference between maximal renewable energy sources penetration and renewable energy penetration under influence of environment protection constraints.

* Corresponding author

KEYWORDS

RES integration, 100% renewable islands, electric vehicles, energy storage

INTRODUCTION

Significant problem of island communities has traditionally been energy import and transport of fuel supply. Introduction Renewable Energy Sources (RES) in Micro grids (MG) and integrating energy demand of few systems such as domestic heating, cooling, fuels for transport or larger, commercial demand is becoming one of the most investigated ways of making local island communities more energy self-sufficient. Lately, scientific research in this has made a lot of effort to develop methodologies [1] and tools in [2] and [3] in order to help transition of island communities into post-carbon, energy secure and self-sufficient ones. Apart from using already developed models, new algorithms have also being examined [4], [5] to describe the integration of transport and energy production systems better [6]. Impact that this integration has on the electricity demand curve and energy demand of the system have also been examined in [7], [8] and [9]. In this paper, case study of island of Lastovo will be presented. Lastovo islands energy system has been modelled in HOMER and H2RES, to determine how much RES penetration can islands system accept and how far can this take the islands community on the path to energy self-sufficiency.This is discussed through two scenarios with different amount of plug-in electric vehicles (EV) introduced into islands transport in the year 2020 and by comparing environmental constraints given by local regulations and environmental protection strategies. HOMER was so far used for small micro-grid applications such as in cases of [10] and [11] but also in [12] for large island communities. H2RES was used for analyses in already mentioned cases of renewable islands and others, such as Malta [13], Porto Santo[14], San Vincente and Cape Verde[15]. Since Lastovo is an island with almost all of its area protected as park of nature, it implies significant constraints on any new projects which involve large construction areas and introduction of changes into nature. Other islands in Croatia also have areas which are protected in some similar way, either only through NATURA 2000, or being Croatian National Parks or Parks of nature. This paper argues that it makes sense to investigate how much new capacity installation and measures that aim to integrate systems in order to achieve energy self-sufficiency depend on environmental constraints in their chances to succeed as a starting point in future discussions on adequate locations for the future RES projects. Similar research was conducted for wind energy in Europe [16] and for Croatia, using GIS [17], but in this paper, integrated approach was applied to take into account all available technologies in planning the island energy systems and then to compare possibilities through scenarios. For smaller island, and with different approach, penetration of RES into fragile environment was examined in [18]. In this paper, more complex location was examined with aggregated modelling.

METHODOLOGY

Using currently developed models, HOMER and H2RES, scenarios aimed to make the island 100% energy self-sufficient are investigated. Apart from comparing the way these models approach the problem of using plug-in electric vehicles (EV's) batteries as storage for the excess electricity produced by RES, specific factor of environment protection is taken into account. This is investigated through comparison between scenario which would achieve highest share of RES in the islands system and the scenario which presents only installed capacity of power plants which are in accordance to local environment protection regulations, policies and strategies. "Environmentally friendly" scenarios are actually more cautious scenarios which avoid taking into account RES or any other source of energy if it is not accepted in local and/or regional environment protection strategies and regulations. In each scenario, present state of art of electricity distribution systems is compared to the desirable distribution system which could accommodate the increase in EV number on the island. Financial expenses for this transition are then added to the investment cost of scenarios, calculated in HOMER. In HOMER, batteries are simulated without load curve (only with HOMER's own method for simulation of batteries), while in H2RES batteries are coupled with load curve. Such approach enables for research to define an **index of sustainable RES penetration**, comparing highest possible local RES penetration, which is a function of local resources, energy infrastructure and cost, with sustainable RES penetration, which is a function of mentioned parameters, but with introduced Environmental Protection Constraints (EPC). Such index is presented in Eq.1:

$$I = f(\sum \frac{\text{Esust}}{\text{Eacc}}) \tag{1}$$

Where E_{sust} [kWh] is the penetration of energy from RES which is sustainable for the system with EPC, E_{acc} [kWh] is maximal penetration of energy from RES which can be accepted by the system without taking into account EPC.
When introducing integration of systems, where one system has storage capacities, E_{sust} is calculated as presented in Eq. 2

$$E_{sust} = \Sigma E_{IT} + \Sigma E_{stor} \tag{2}$$

Where E_{IT} [kWh] stands for intermittent energy taken by the system and E_{stor} [kWh] represents energy that was first stored in storage capacities, such as electric vehicle batteries or static battery banks.
After introducing index of sustainable RES penetration, it is possible to see which island systems are able to achieve more RES penetration without danger to their ecosystems and also further investigate why some islands cannot fully profit from their resources. It can be a starting point for better planning of locations for RES power plants and for possible reconsideration of regional environment protection policies.

CASE STUDY - LASTOVO

Lastovo is an island municipality in the Dubrovnik-Neretva County in Croatia. Map of Lastovo is given on Fig.1. The municipality consists of 46 islands with a total population of 792 (2011.) peopleand a land area of approximately 53 square kilometres. The biggest island in the municipality is also named Lastovo, as is the largest town. Settlements on the island include the villages of Ubli (also known as Sveti Petar), Zaklopatica, Skrivena Luka and Pasadur. The majority of the population lives on the 46 square kilometres island of Lastovo. The island largely relies on its natural beauty and preservation to attract tourists each season. In the year 2006 the Croatian Government made the island and its archipelago a nature park.

Fig. 1 Map of Lastovo

The island of Lastovo belongs to the central Dalmatian archipelago. Thirteen kilometres south of Korčula, the island is one of the most remote inhabited islands in the Adriatic Sea. Other islands in this group include Vis, Brač, Hvar, Korčula and Mljet. The dimensions of the island are approximately 9.8 kilometres long by up to 5.8 kilometres wide. The Lastovo archipelago contains a total of 46 islands, including the larger islands Sušac, Prežba, Mrčara and an island group called Lastovnjaci on the eastern side. The island has a daily hydrofoil service and ferry service linking it to the mainland at Split and stopping along the way at Korčula and Hvar. Despite major fires in 1971, 1998 and 2003, about 60% of Lastovo is covered with forest, mostly Holm Oaks and Aleppo Pines and Mediterranean underbrush. Lastovo possesses all the basic characteristics of the Mediterranean climate, dominated by mild, moist winters and warm, long, and dry summers. The island receives around 2700 sun hours per year, ranking it among one of the sunniest in the Adriatic and pleasant for tourists. This produces a water temperature around 27 °C in summer. Annual rainfall is 622 millimetres. Since there are no permanent surface water streams, residents rely on bores, dams and wells. Recently, undersea water piping was introduced in order to secure fresh water supply.In 2012 total consumption of electricity was 2,975 MWh with peak load of 1,123 kW, while total energy consumption was 10,861 MWh. The island is connected to the electric grid by two undersea cables at each side of the island. The annual increase of consumption for all calcualtions was set to 3.5%, which takes into account development of turism sector, which employs majority of islands inhabitants. In 2020 total calculated consumption of electricity is 3,769 MWh with peak load of 1,423 kW.

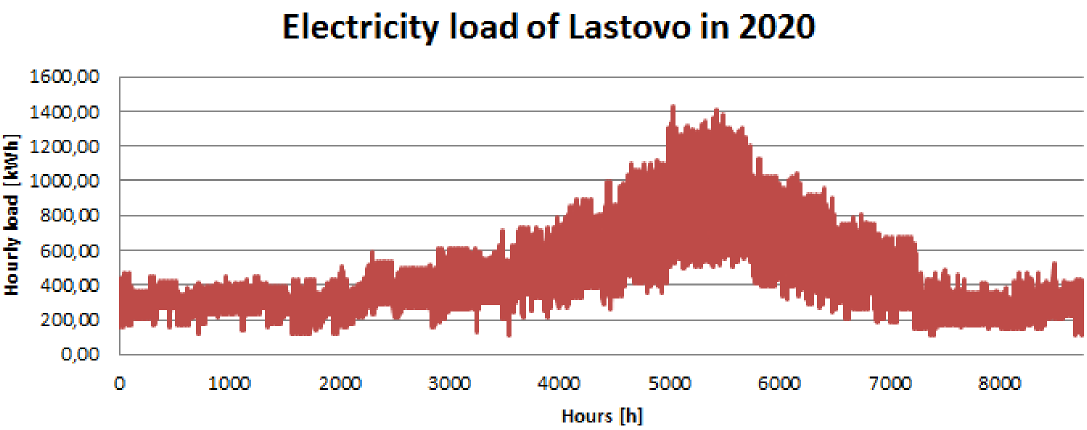

Fig. 2 Electricity load of Lastovo in 2020

Wind and solar radiation represent most promising renewable resources on the island.

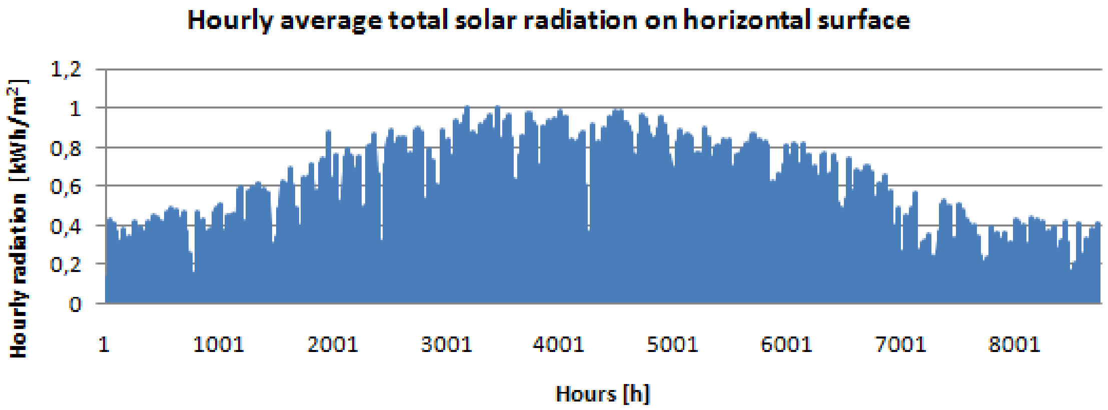

Fig. 3 Hourly average total solar radiation on horizontal surface

The island is in the most promising region for solar radiation technologies use in Croatia, while wind power on islands was until recently prohibited by law, but this obstacle is now removed.

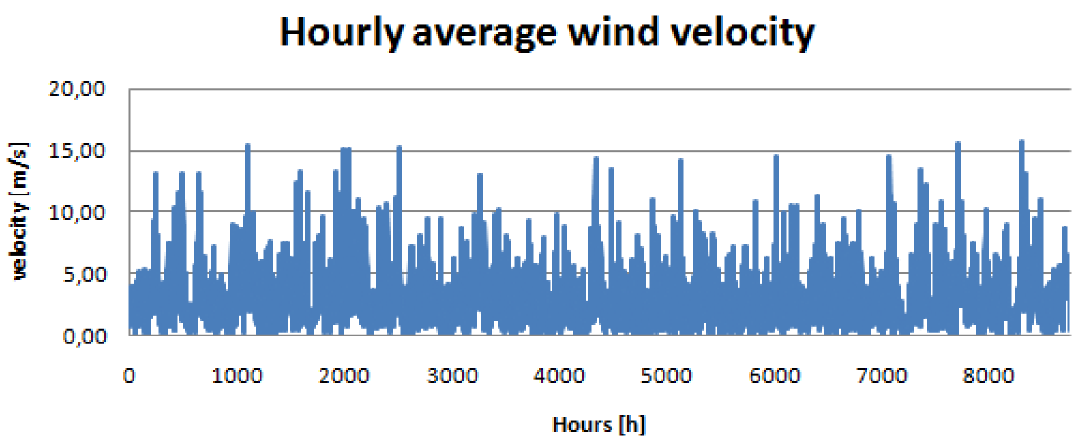

Fig. 4 Hourly average wind velocity

Since majority of the island is under protection as the "Park of nature", and due to current constraint in Croatian laws on building in the area of 1 km from the very coast and the considerations of the recent *Strategic environmental impact study of the Plan of renewable energy sources in the area of Dubrovnik-Neretva county* (2015) [19], Lastovo is a relevant example of the island community with considerable environmental restrictions which have great influence on the possibility to transform islands energy system into a 100% energy self-sufficient one.

Through scenario approach, integration of energy production system from the RES and transport system on the island was investigated as a solution for supply for the island community energy demand.

Input data for scenarios is obtained through survey of rooftops at the island, depending on their azimuth. Rooftops facing South were taken into account as suitable for solar PV systems. Area of such rooftops was 8085 m^2, which, with assumed 7.4 m^2/kW_einstalled capacity of PV systems, suffices for 1,091 kW of PV systems installed. Only one potential location for PV solar power plant out of four named locations is recommended to remain in plans according to [12]. On the mentioned location, Vrsi, power plant with 1 MW installed capacity can be constructed, for the EPC scenario. Other locations, Velji pod, Vrsje dolac and Žegovo polje have no less then 20 ha of area, and could have capacity of at least aditional 4.5

MW. Lacking more detailed information, locations were measured using Google Earth tools to obtain this estimations by the rule of tumb.
Also, EPC consider building windturbines on the island unacceptable at this time, which is taken into account in EPC scenarios, while in 100% RES scenarios 1 wind turbine with installed capacity of 1.5 MW is considered feasible.
Prices that were used in HOMER Pro, are listed in the Table 1:

Table 1 Prices of technologies and energy in HOMER Pro

Technology	Investment	O&M	Energy	Electricity
Solar PV (€/kW)	1,578.95	157.89	Daily rate (€/kWh)	0.112
Wind turbine (€/kW)	1,754.39	17.54	Nightly rate (€/kWh)	0.055
Novel battery for EV (€/unit)	4,605.26	197.37	Sale capacity (kW)	1,000
Converter (€/kW)	46.05	0.46	Purchase capacity (kW)	2,000

Also, new batteries for the vehicles on the island are modelled in scenarios. Novel batteries are in the same class as most used ones at present for passanger cars, but also transport mileage on Lastovo is taken into account – how many kms a vehicle actually needs to travel around Lastovo. Route that connects all major towns on the island is calculated by Google tools, and the batteries were modelled to enable round-trip of the island, from Uble to Skrivena Luka, via Lastovo.

Relevant data on the batteries are given in Table 2.

Table 2 Properties of battery model

HOMER battery model	
Nominal Voltage (V)	36.00
Nominal Capacity (Ah)	720
Nominal Capacity (kWh)	25.92
Round Trip Efficiency (%)	90.00
Maximum Capacity (Ah)	3,570.06
Max. Charge rate (A/Ah)	36.667
Max. Charge Current (A)	916.667
Max. Discharge Current(A)	500
Capacity Ratio, c	0.317
Weight (kg)	68
H2RES battery model	
Charge efficiency(%)	95.00
Charge power (kW)	11
Discharge efficiency(%)	95.00
Discharge power (kW)	26
Max. Capacity (kWh)	26
Min. Capacity (kWh)	11

Also, in Fig.5, the schematic of energy system of Lastovo is given:

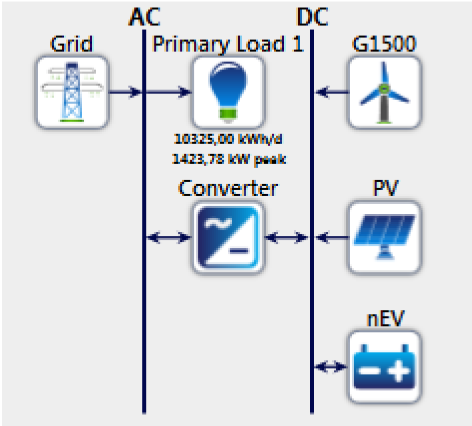

Fig. 5 Schematic of the system modelled in HOMER Pro

Overall schematic includes all components that exist in some scenario, although HOMER Pro calculates all scenarios at once, and some components do not form parts of all scenarios. Therefore in Fig. 5 there is no exact numbers for converter, nEV, PV or wind turbine. For converter, scenarios discuss the size of converter between 1,000 and 4,000 kW, for PV installed capacity, sizes are between 1,091 kW and 10,000 kW, installed capacity of wind turbines reaches from 1,500 kW to 7,500 kW and batteries from 100 to 200 pieces.

Data for most important scenarios that are considered is given in Table 3:

Table 3 Data sheet for all scenarios

	Installed PV capacity (kW)	Installed wind turbine capacity (kW)	Electric vehicles share in transport (%/no.)
Low EPC scenario 1	1,091	0	25% / 102
Low EPC scenario 2	1,091	0	50% / 200
High EPC scenario 1	2,091	0	25% / 102
High EPC scenario 2	2,091	0	50% / 200
Low 100% RES scenario 1	6,497	1,500	25% / 102
Low 100% RES scenario 2	6,497	1,500	50% / 200
High 100% RES scenario 1	10,000	7,500	25% / 102
High 100% RES scenario 2	10,000	7,500	50% / 200

For simulation of EV batteries in H2RES, aggregated battery load curve is used in order to simulate the use of batteries for the vehicles while travelling. This load curve is shown on fig. 6, both for 25% and 50% EV penetration, and represents scaled load curve from the nearby city of Dubrovnik. Load curve for the island of Lastovo has not yet been developed.

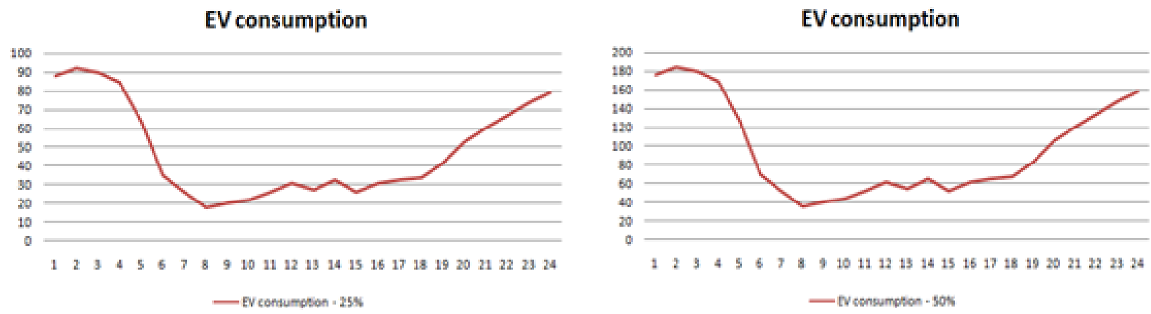

Fig. 6 Load curves of EV batteries

RESULTS AND DISCUSSION

Scenarios were calculated both in HOMER Pro and H2RES, to obtain better insight in economic feasibility and modelling of EV as storage mechanism for energy from RES. Important data includes intermittent energy taken, energy from batteries and overall renewable fraction for each scenario. Results for each scenario are given in Table 4:

Table 4 Results of relevant scenarios

	Intermittent taken H2RES [kWh]	Storage H2RES [kWh]	RES share H2RES [%]	Intermittent taken HOMER [kWh]	Storage HOMER [kWh]	RES share HOMER [%]
Low EPC scenario 1	1,386,118.58	293,974.90	44.58%	1,554,781.00	114,355.00	34.60%
Low EPC scenario 2	1,386,118.58	437.604.74	48.39%	1,554,781.00	142,146.00	34.40%
High EPC scenario 1	1,638,554.77	401,160.89	54.12%	2,979,886.00	309,987.00	51.40%
High EPC scenario 2	1,638,554.77	830,256.48	65.51%	2,979,886.00	411,399.00	49.30%
Low 100%RES scenario 1	2,145,640.10	316,984.56	65.35%	10,699,014.00	976,719.00	78.90%
Low 100%RES scenario 2	2,145,640.10	698,610.34	75.47%	10,699,014.00	1,730,950.00	84.30%
High 100%RESscenario 1	2,420,791.55	317,310.71	72.65%	21,451,671.00	1,343,945.00	87.80%
High 100%RES scenario 2	2,420,791.55	562,248.92	79.15%	21,451,671.00	2,361,171.00	92.70%

Value of the index of sustainable RES penetration is obtained by comparing each scenarios value of the sum of intermittent energy taken and stored to the intermittent energy taken and stored in the High 100% RES scenario, which represents the largest possible penetration of RES in the given conditions. This comparison, and the price of energy calculated in HOMER Pro, is given in Table 5:

Table 5 Values of index I and cost of energy

	COE [kn/kWh]	*Value of index I - HOMER*	*Value of index I - H2RES*
Low EPC scenario 1	1,194	0.07	0.61
Low EPC scenario 2	1,344	0.07	0.61
High EPC scenario 1	1,347	0.14	0.75
High EPC scenario 2	1,561	0.14	0.83
Low 100%RES scenario 1	2,901	0.51	0.90
Low 100%RES scenario 2	2,877	0.52	0.95
High 100% RESscenario 1	4,824	1.00	1.00
High 100%RES scenario 2	4,621	1.00	1.00

To illustrate better the difference between possible RES fraction, due to locations natural resources, and amount of energy from RES that can be taken into system, due to EPC, Fig.6 shows graphically the values of index *I*.

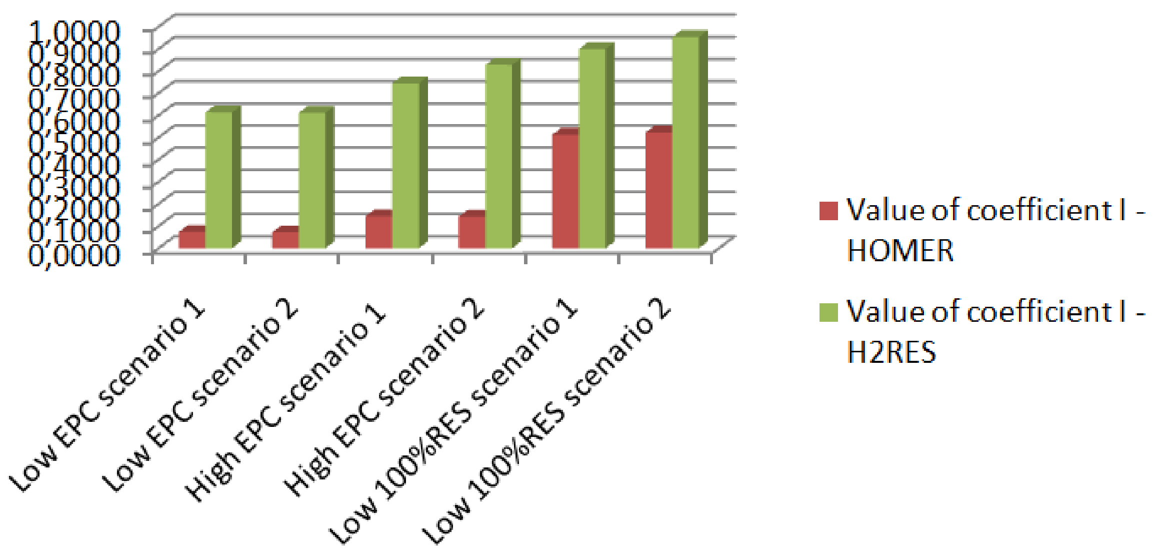

Fig. 7 Values of index I

CONCLUSION

Although there is a lot of work being done in order to research the possibilities of isolated communities becoming 100% energy independent, some island communities face specific barriers in their efforts. Such communities are often blessed with richness of nature and therefore belong to Nature protected areas and areas with protected cultural heritage. In such cases, there are environmental protection constraints which limit possibilities of new RES installations to provide energy production on location and contribute to community's energy independence. In this paper, index was proposed to determine the difference between energy systems sustainability potential with EPC's and without them. The reasoning behind this proposal is not to subjugate the environmental protection in favour of building new facilities without constraints, but rather to start debate about specific constraints, their scientific viability and planning of local sustainable energy systems while protection the environment in most reasonable way. In the case of Lastovo, integration of transport and RES sector was introduced with aim to achieve 100% renewable island community, but with all constraints taken into account, this ended up to be unachievable. Value of proposed index was only 0.145 for High EPC scenario 1, which illustrates how much more potential the location has, in terms of local renewable energy potential. When EV batteries are simulated with load curve, the value of index becomes higher, due to EV's own consumption and availability. Therefore a way to optimize RES penetration could be to combine stationary and EV batteries, with economic feasibility constraints.

Because of this, local legislation and environmental protection constraints should be re-evaluated, which would in turn might help to lower the consumption of fossil fuels on islands and achieve environmental benefits in more efficient way.

Other issue that was discussed in the paper was the difference between two energy planning models, HOMER Pro and H2RES. Since HOMER Pro simulates batteries without load curve and with battery competition, it shows larger possible penetration of RES, while H2RES, with battery load curve, shows possibly more realistic results.

Further work in the field should include detailed analyses of constraints, comparison between similar sites around the world and local legislation on environment protection, with goal to find the optimal limits and constraints that still give enough space to local development, which in turn helps to global environment protection struggle, namely mitigation of global warming through use of renewable, low or post-carbon technologies. Also, further research should be conducted to see if optimization of realistic number of stationary batteries and EV batteries can be conducted in such a way that system exploits as much of the location's RES potential as it is possible while remaining cost-effective and economically feasible.

ACKNOWLEDGEMENT

This work has been supported by the *Intelligent Energy Europe Programme* (IEE, 2007-2013) under Grant agreement no: IEE-13-839 (BEAST project), and by the Croatian Science Foundation through projects i-RESEV and MICROGRID. This support is gratefully acknowledged.

REFERENCES

1. Duić, N.; Krajačić, G.; Carvalho, M.G.;"RenewIslands methodology for sustainable energyand resource planning for islands"; Renewable and Sustainable Energy Reviews12 (2008) 1032–1062
2. Krajačić, G.;Duić, N.; Carvalho, MG.; "H2RES, Energy planning tool for island energysystems – The case of the Island of Mljet";International journal of hydrogen energy34 (2009) 7015 – 7026
3. Bačelić Medić, Z.; Ćosić, B.; Duić, N.; "Sustainability of remote communities: 100% renewable island of Hvar", Journalofrenewableandsustainableenergy 5, 041806 (2013)
4. Gašparović, G., Krajačić, G., Šare, A., Duić, N., "Advanced modelling of an electric vehicle module in the H2RES energy planning software", 8th SDEWES Conference, Dubrovnik, Croatia, 2013.
5. Škugor, B.; Deur, J.;"A Novel Model of Electric Vehicle Fleet Aggregate Battery for Energy Planning Studies"International Electric Vehicle Conference (IEVC), Florence, Italy, 2014.
6. Škugor, B.; Deur, J.;"Dynamic Programming-based Optimisation of Charging an Electric Vehicle Fleet System Represented by an Aggregate Battery Model"9th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Venice-Istanbul, 2014.

7. Šare, A., Krajačić, G., Pukšec, T., Duić, N., "The Impact of Electrification in the Transport Sector on the Power Curve, and the Integration of Renewable Energy Sources in to the Power Systems of the Dubrovnik Region", 8th SDEWES Conference, Dubrovnik, Croatia, 2013.
8. Novosel, T., Perković, L., Ban, M., Keko, H., Pukšec, T., Krajačić, G., Duić, N., "Hourly transport energy demand modelling – Impact of EVs on the Croatian electricity grid", 1st SEE SDEWES Conference, Ohrid, Macedonia, 2014.
9. Novosel, T., Perković, L., Ban, M., Pukšec, T., Krajačić, G., Duić, N., "Utilization of agent based modelling for energy planning – Transport energy demand modelling" 21th Forum organized by the Croatian Energy Association, Zagreb, Croatia, 2014.
10. Dalton G.J., Lockington D.A., Baldock T.E, "Feasibility analysis of renewable energy supply options for a grid-connected large hotel" Renewable Energy 34 (2009) 955–964
11. Dalton G.J., Lockington D.A., Baldock T.E, "Case study feasibility analysis of renewable energy supply options for small to medium-sized tourist accommodations" Renewable Energy 34 (2009) 1134–1144
12. Sadrul IslamA.K.M., RahmanMustafizur, MondalAlam H., AlamFiroz, „Hybrid energy system for St. Martin Island, Bangladesh: An optimized model" Procedia Engineering, Volume 49, 2012, Pages 179–188, International Energy Congress 2012
13. Busuttil, A.; Krajačić, G.; Duić, N.;"Energy scenarios for Malta", International Journal of Hydrogen Energy (0360-3199) 33 (2008), 16; 4235-4246
14. Martins, R.; Krajačić, G.; Alves, L.M.; Duić, N.; Azevedo, T.; Carvalho, M.G.; „Energy Storage in Islands - Modelling Porto Santo' s Hydrogen System", Chemical Engineering Transactions (1974-9791) 18 (2009); 367-372
15. Segurado, R.; Krajačić, G.; Duić, N.; Alves, LM; „Increasing the penetration of renewable energy resources in S. Vicente, Cape Verde", Applied energy (0306-2619) 88 (2011), 2; 466-472
16. European Environment Agency. Europe's onshore and offshore wind energy potential - EEA Technical Report. Luxembourg : European Environment Agency, 2009.
17. Međimorec, D., Knežević, S., Vorkapić, V., Škrlec, D., Wind Energy and Environmental Protection: Using GIS to Evaluate the Compatibility of Croatian Strategies, 2011 8th International Conference on the European Energy Market (EEM) • 25-27 May 2011 • Zagreb, Croatia
18. Katsaprakakis, D.A.,Papadakis, N., Kozirakis, G., Minadakis,Y., Christakis,D., Kondaxakis, K., Electricity supply on the island of Dia based on renewable energysources (R.E.S.) Applie d Energy 86(2009) : 4. 516-527
19. Strategic environmental impact study of the Plan of renewable energy sources in the area of Dubrovnik-Neretva county(2015), IRES Ekologija