Electrification of Transportation in Islands

Subjects: Engineering, Electrical & Electronic | Transportation
Contributor: Efraín O'Neill-Carrillo, Matthew Lave, Thad Haines

Electric vehicles (EVs) represent an important socio-economic development opportunity for islands and remote locations because they can lead to reduced fuel imports, electricity storage, grid services, and environmental and health benefits. This entry presents an overview of opportunities, challenges, and examples of EVs in islanded power systems, and is meant to provide background to researchers, utilities, energy offices, and other stakeholders interested in the impacts of electrification of transportation. The impact of uncontrolled EV charging on the electric grid operation is discussed, as well as several mitigation strategies.

Keywords: electric vehicles ; charging stations ; vehicle-to-grid

1. Introduction

In remote and island areas, the benefits of EVs can be even more significant than on mainland systems. For example, fuel supply chains for island and remote communities are particularly volatile in both price and availability, so the higher efficiency and fuel flexibility of EVs (EVs can charge using electricity generated from any fuel) present an opportunity to stabilize and reduce transportation costs. EVs represent an important socio-economic development opportunity for remote and island locations because they hold the promise of reduced fuel imports, are an electricity storage resource, can provide grid services, and can result in improved environmental and health conditions. To directly show the cost savings achievable through electrification of transportation, **Figure 1** shows the comparison of the cost of a gallon of gasoline to an equivalent value for EVs. In nearly all cases, EVs have a reduced cost of operation when compared to gasoline vehicles. A modified eGallon was used [1] for this comparison, based on miles per gallon and kWh/100 miles for 2019 Hyundai Kona gasoline and electric vehicles.

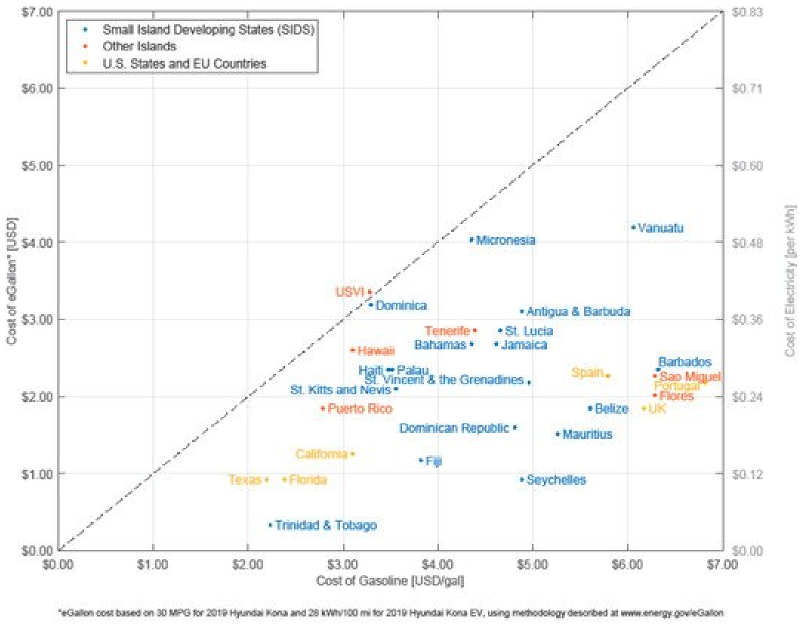

Figure 1. Cost of a gallon of gasoline versus an EV “eGallon” (most data from [2][3]).

Beyond direct cost savings, the potential abilities to (a) control EV charging as a form of demand response to support the centralized electric grid, and (b) couple EV charging with distributed energy resources (DERs) such as rooftop solar photovoltaics (PV) are particularly valuable features of the electrification of transportation in island and remote systems. Coupling with PV can not only lessen grid impacts (dampen positive or negative ramps in net load), but can also be used in emergency-response applications to charge EVs directly from the PV when the centralized electric grid is out [4].

Yet, in the smaller electric grids of remote and island areas, relatively modest amounts of EVs can result in significant increases in total electric load, which could pose challenges to grid operations. Technical obstacles include grid reliability issues, increased generation capacity needs due to shifts in daily peak demand, and grid upgrade and maintenance costs [5]. High EV penetration (percentage of total load due to EVs) in remote and island systems may require large grid and charging infrastructure investments and supportive policies, which might not currently exist in small islands with uncertain regulatory/policy environments [4].

This entry documents previous research and implementation efforts for EVs in islands. The works described focus on island or remote energy systems and their grid impacts as well as mitigation approaches for high EV penetrations. Key topics include: (1) the impact and potential mitigation options of integrating EVs into remote and island electric grids and, (2) the need for an overarching energy policy that can serve as a framework or guide to EV adoption strategies. The importance of a holistic energy policy is illustrated through case studies on the impact differing policies have had on EV adoption and operation.

2. Grid Impact Concerns of Uncontrolled EV Charging

Two interrelated studies modeled the impact of EV charging in the island grid of São Miguel, Azores, Portugal for a group of residential customers [6] and for an industrial customer allowing employee workplace charging [7]. São Miguel has a total system load of 140 MW [8], though the residential load considered in [7] was 292 dwellings totaling 140 kW at peak load, and the industrial load in [6] also peaked around 140 kW. Despite the similar peak load values, the transformer serving the residential customers (630 kVA) was much larger than the one serving the industrial customer (250 kVA), as the residential transformer was sized based on expected seasonal increases in the residential load. Due to all EVs beginning to charge at the same time and the transformer size differences, overloading was found through simulations at 75% EV penetration in the residential scenario but at only 40% EV penetration for the workplace charging scenario. Both studies additionally estimated a shorter transformer lifecycle when EV penetrations led to transformer overloading. In the residential case, 3 h of daily transformer overloading due to 100% EV penetration would result in approximately 6 h of transformer life reduction each day. The industrial transformer was particularly stressed by fast-charging scenarios (regular charging rates were up to 7.4 kW, fast-charging rates were up to 50 kW), with approximately 58.5 h of service life lost for every one day of fast-charging operation at 35% penetration. This was heavily influenced by the transformer size and 3 daily overload peaks caused by all EVs starting to charge at the beginning of each work shift.

An example of line overloading comes from a study modeling an actual distribution feeder in the island of Trinidad [9]. While Trinidad has an installed capacity of about 2200 MW [10], the feeder studied had about 5 MW of load. An increased amount of line overloading was observed when EV penetration levels reached 10%, though it should be noted that some line overloading is found to occur even before EVs are added. Consistent with the note in the previous paragraph, the authors comment that, "…known issues such as pole-mounted transformer overloading were intentionally neglected due to the understanding that it is inevitable that overloading will occur and can be addressed by simply resizing to a higher transformer capacity" [9].

As EV penetrations become significant, increased loads due to EV charging may cause voltages on distribution grids to drop below acceptable voltage limits. A common range of acceptable voltages is + /−5% (e.g., ANSI C84.1 Range A [11]) , such that at a 120 V customer, for example, the centralized grid must deliver voltage between 114 V and 126 V. Having too low or too high of a voltage on a distribution feeder can result in adverse impacts including unscheduled maintenance, early equipment replacement, damage to customer equipment, and in extreme cases, increased grid outages resulting in lost revenue [12]. Several studies of island systems have simulated that voltages will decrease below allowable limits during the simultaneous charging of many EVs.

The study using the feeder model from Trinidad described earlier found that voltages dropped below acceptable limits at several feeder nodes when EV penetrations of as little as 5% were implemented [9]. Voltages were already very close to lower limits before any EVs were connected, a state which may be common in island and remote systems due to grid design and operation considerations.

3. Mitigation of EV Impacts

The challenges of EV integration motivate research on the impact, mitigation, and effective controls of EV charging. This research will immediately benefit remote and island systems and will also be valuable to larger mainland systems in coming years as EV penetrations become significant on larger mainland electric grids, which will take longer.

It is very important to reduce the negative impacts to the electric grid from the early stages of EV adoption to avoid limits on further EV adoption [3]. While upgrades to electric grid infrastructure, such as increasing the size of conductors (to avoid line overloading), increasing the size of transformers (to avoid transformer overloading), or adding voltage control devices (to keep voltage in allowable ranges), can directly mitigate most concerns, they typically are high-cost and require significant installation efforts. Cheaper and easier to implement mitigation strategies will involve the EVs in grid operations, including simple control strategies for EV charging (e.g., use of timers), controlled EV charging in response to the state of the electric grid, EV chargers providing grid services to assist with grid operations, and integration of EVs with DERs.

EVs can provide grid support services (also known as "ancillary services") to reduce their impact and support electric grid operations. For example, EVs can be used as a form of demand response, reducing their charging during periods when the electric grid is stressed, such as if a generator fails or when load is unexpectedly high. EV chargers can also be configured to provide voltage support, such as through volt-var control schemes which have become common in PV inverters [3].

A study in São Miguel looked at how EVs could support an increase in the use of renewable energy and presented possible grid-related revenues for EV owners [13]. The study assumed bi-directional EV charging, that is, EVs could be used as dispatchable storage devices. When EV owners were compensated financially for providing ancillary services, EVs had lower total costs of ownership than conventional vehicles, even though EV purchase costs were significantly higher than conventional vehicles. However, as EV penetration increased, revenues from providing grid services decreased for individual EV owners. An important finding was if high EV penetrations are achieved and controlled effectively, nearly all of the variability in the total system's electric demand curve can be eliminated, which would simplify and reduce the cost of electric generation needed.

4. Strategically Locating EV Chargers

Another way to mitigate the impact of EV charging is to place chargers at robust nodes in the electric grid such that large numbers of chargers can be installed without overloading system components or causing voltage issues.

EV chargers are already prolific on the island of Jeju, South Korea, with 1103 express charging points and 344 slow charging points (full recharge overnight) [14]. The voltage and loading challenges highlighted in [15] are being addressed through strategic placement of new chargers [16], among other strategies (e.g., encouraging EV charging stations powered from renewable stations [17]).

EVs can be strategically controlled to enable higher penetrations of variable renewable energy resources by increasing charging during times of high renewable generation and decreasing charging during periods of low renewable energy generation. An example is shown for the Portuguese island of São Miguel where charging strategies were examined [18]. The EVs were able to help flatten the island's daily demand curve for different scenarios up to 32% EV penetration. Similarly, a study for the Portuguese island of Flores (peak load of approximately 2 MW [19]) looked at how EVs could increase the use of renewable energy [19]. Optimal charging strategies were studied using a dynamic programming algorithm, and the main result was that controlled charging of EVs reduced both the need for backup generation and the amount of wind energy curtailed.

Overall, the works presented in this section demonstrate that EVs charging from renewable DERs can be mutually beneficial. EVs benefit from cheaper electricity with lower emissions, while renewable DERs can increase utilization and even allow for new installations as EVs utilize power which may have previously been curtailed due to a lack of demand or a concern over high penetrations of renewable energy resources.

5. Coordinated Policy and Economic Decisions

There are policy and economic considerations, beyond the technical feasibility, that are essential for successful EV deployment in remote and island locations. Many remote and island locations have good potential for EVs because they typically have short driving distances and often have available renewable resources that can be leveraged to generate power locally, often at lower cost than centralized grid power. However, it is important to develop holistic energy policies and consider the local context when addressing policy and economic challenges and to adapt implementation strategies accordingly.

In the Caribbean, for example, the long-term impacts of an EV transition need careful consideration due to limits on electrical and business infrastructures[20]. The Caribbean Community (CARICOM) Regional Electric Vehicle Strategy (REVS) Framework provides the foundation for a transition to EVs in the Caribbean[19]. The REVS acknowledge the importance of changing transportation systems at the local level, as well as accounting for driving behaviors and transportation preferences of individuals. The framework provides guidelines in the following areas: Policy and regulation; technology and infrastructure; capacity development and awareness; finance, market development and innovation. It has a strong emphasis in a market approach, inclusion of relevant stakeholders, capacity building, prioritization of public and commercial transportation, and the key role of technology and infrastructure improvements. Other important regional references for the Caribbean are the position paper “The Future of E-Mobility in the Caribbean” from the Caribbean Centre for Renewable Energy & Energy Efficiency (CCREEE) [21] and the report “Electrified Islands: The Road to E-Mobility in the Caribbean”[22].

6. Cost Issues and Utility Business Changes

EVs represent a new business opportunity for utilities in remote and island areas around the world through increased electric demand. To facilitate this, some utilities, such as those in the Bahamas, Turks and Caicos, and St. Lucia are installing EV chargers to encourage EV adoption [23]. However, there may be significant additional electric grid infrastructure investments required to accommodate this new load. Financing these infrastructure upgrades can be challenging, and utility rate structures may need to be revised. The mitigation strategies listed in Section 3 and Section 4 can help defer or eliminate infrastructure upgrades.

Production cost impacts for different levels of EV penetration were considered for Barbados. Barbados has 240 MW installed capacity, a peak demand about 170 MW and 287,000 inhabitants. A daily average driving distance of 40 km (≈25 mi) was assumed. The results showed that production costs increase the most with uncontrolled charging at night. Once controlled charging strategies are used, costs begin to decrease. The least cost is achieved when controlled charging occurs during the day and there is close coordination with the grid (i.e., vehicle-to-grid services) [24]. When EVs can provide ancillary services, production costs from charging EVs can be limited, more renewable energy can be integrated, curtailment is reduced, and the investments needed for grid-connected storage are reduced [24].

The 49 inhabited Croatian islands may be able to meet their energy needs from locally available renewable energy sources [25]. Researchers from the University of Zagreb completed studies for the islands of Krk, Unije, and Losinj in the North Adriatic Sea, and Mljet, Lastovo, and Korcula in the South Adriatic Sea. Building smart energy systems on these islands has become a key strategy to increase penetration of renewable sources and make local transport more sustainable. The island of Vis (pop. 3600) was used as a case study to integrate renewable energy sources, demand response, and EVs in a harmonized planning effort. The main recommendation was to use alternative financial mechanisms, such as energy cooperatives and energy service company business models including PV in the Croatian islands’ energy transition [26].

7. Lessons Learned

The key challenges for the electrification of transportation and potential solutions in remote and island locations are summarized below:

- Technical challenges associated with high levels of EV penetration include added stress on electric infrastructure.
    - Uncontrolled EV charging could affect reliability, security, efficiency, and economy at a faster rate in small, isolated grids, even in early EV stages [3].
    - Increased peak loading and costs to the utility in upgrading and maintaining infrastructure [5].
- Mitigation strategies for addressing these challenges include:
    - Rate-based incentives such as demand charges, time-of-use rates and dynamic pricing [3][27].
    - Smart charging technologies to reduce grid costs, provide grid services, and increase renewable energy utilization [5][28][19][29][24].
- Examples of policy, regulatory, and user-related challenges in remote and island locations include:

- Lack of long-term policy vision [30] which impedes understanding the far-reaching impacts of EV transitions [21].

- High import duties, high initial costs, and limited availability of EVs [21][30][31], the difficulty of offering incentives due to limited government budgets [23], and uncertain regulatory/policy environment [31].

- Consumer expectations must be managed [21][31] including aversion to new technology and lack of familiarity [31][32].

- To address these challenges, there is a broad spectrum of policy and economic strategies to support EV deployment including:

  - Coordinate policy and economic goals through a comprehensive energy policy framework or strategy [21][33][29].

  - Highlight the crucial role of incentives policies on EVs [34][32] and adapt best practices [5].

  - A supportive government and buy-in from and partnerships with stakeholders across different sectors and communities [5][23][35][36][31][32].

  - Leverage transportation modes that are familiar locally and meet local needs [37][38] (e.g., motor bikes instead of cars).

  - Cost and business strategies: Diversify utility business, for example through EV services market and filling EV market voids [23][32]; explore alternative financial mechanisms such as energy cooperatives and ESCOs [25]; focus on solutions for short driving distances and use of local energy resources [34], and identify business arrangements for reusing EV batteries (as an incentive for new owners while stimulating local economies) [3][39][31].

References

1. Hares, S. Caribbean Islands Plug into Electric Car Revolution. 2018. Available online: https://www.reuters.com/article/us-islands-caribbean-transportation-elec/caribbean-islands-plug-into-electric-car-revolution-idUSKBN1KF1O5 (accessed on 1 October 2019).
2. Innovation Outlook: Smart Charging for Electric Vehicles; International Renewable Energy Agency (IRENA): Abu Dhabi, United Arab Emirates, 2019.
3. Chargepoint. Level Up Your EV Charging Knowledge. Available online: https://www.chargepoint.com/blog/level-your-ev-charging-knowledge/ (accessed on 6 August 2020).
4. Gay, D.; Rogers, T.; Shirley, R. Small island developing states and their suitability for electric vehicles and vehicle-to-grid services. Util. Policy 2018, 55, 69–78. [Google Scholar] [CrossRef]
5. Godina, R.; Paterakis, N.G.; Erdinç, O.; Rodrigues, E.M.G.; Catalão, J.P.S. Impact of EV charging-at-work on an industrial client distribution transformer in a Portuguese Island. In Proceedings of the Australasian Universities Power Engineering Conference (AUPEC), Wollongong, Australia, 27–30 September 2015. [Google Scholar]
6. Electric Power, Ministry of Energy and Energy Industries, Government of the Republic of Trinidad and Tobago. 2020. Available online: https://www.energy.gov.tt/our-business/electric-power/ (accessed on 10 July 2020).
7. P.G.E. Voltage Tolerance Boundary. Available online: https://www.pge.com/includes/docs/pdfs/mybusiness/customerservice/energystatus/powerquality/voltage_tolerance.pdf (accessed on 5 August 2020).
8. Park, Y.; Kim, D.; Huh, J.; Kim, Y. New and renewable energy policies of Jeju Island in Korea. In Proceedings of the World Renewable Energy Congress, Linköping, Sweden, 8–13 May 2011. [Google Scholar]
9. Kim, S.; Kim, H.; Lee, H.; Lee, J.; Lee, B.; Jang, G.; Lan, X.; Kim, T.; Jeon, D.; Kim, Y.; et al. Expanding power systems in the Republic of Korea: Feasibility studies and future challenges. IEEE Power Energy Mag. 2019, 17, 61–72. [Google Scholar] [CrossRef]
10. Chang, M.; Bae, S.; Yoon, G.; Park, S.; Choy, Y. Impact of electric vehicle charging demand on a Jeju Island radial distribution network. In Proceedings of the IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT), Washington, DC, USA, 17–20 February 2019. [Google Scholar]
11. Ehsani, M.; Falahi, M.; Lotfifard, S. Vehicle to grid services: Potential and applications. Energies 2012, 5, 4076–4090. [Google Scholar] [CrossRef]
12. N.M. Corporation. Powering Resilience: How EVs Can Help Communities Bounce Back after a Disaster. Available online: https://global.nissannews.com/en/releases/release-b8a1567ee6066d582c91ef8f1d0b47ad-190920-00-e (accessed o

n 10 July 2021).

13. Terna. Terna in Sardinia. Available online: https://download.terna.it/terna/0000/0859/94.PDF (accessed on 5 August 20 20).

14. Porru, M.; Serpi, A.; Mureddu, M.; Damiano, A. A Combined planning and design approach of a public charging infrastr ucture for electric vehicles. In Proceedings of the IEEE Vehicle Power and Propulsion Conference (VPPC), Chicago, IL, USA, 27–30 August 2018. [Google Scholar]

15. Kadurek, P.; Ioakimidis, C.; Ferrao, P. Electric Vehicles and their impact to the electric grid in isolated systems. In Proce edings of the International Conference on Power Engineering, Energy and Electrical Drives, Lisbon, Portugal, 18–20 M arch 2009. [Google Scholar]

16. Askja. Energy. Available online: https://askjaenergy.com/iceland-introduction/energy-data/ (accessed on 5 August 202 0).

17. Wappelhorst, S. Iceland Is One the World’s Most Interesting Electric Vehicle Markets. 9 July 2018. Available online: http s://theicct.org/blog/staff/iceland-ev-market-201807 (accessed on 25 October 2019).

18. Viscidi, L.; Graham, N.; Madrigal, M.; Masson, M.; Prado, V.; Monticelli, J. Electrified Islands: The Road to E-Mobility in the Caribbean. Report from the Inter-American Development Bank and the Organization of American States, and the In ter-American Dialogue. 2020. Available online: http://www.ecpamericas.org/assets/Site_18/files/Resources/2020/Electri fied%20Islands%20Final.pdf (accessed on 1 July 2021).

19. CARICOM; The Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE). CARICOM Regional Electr ic Vehicle Strategy (Revs) Framework. 2020. Available online: https://ccreee.org/document/regional-electric-vehicle-stra tegy-revs-framework (accessed on 12 July 2021).

20. T. Rogers, D. Gay and R. Shirley, "Zero-carbon electric transport already reach small islands" . GreenBiz. Retrieved 20 21-8-13

21. The Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE). The Future of E-Mobility in the Caribb ean. 2020. Available online: https://ccreee.org/sites/default/files/documents/files/ccreee_brief_future_of_emobility_final. pdf (accessed on 11 July 2021).

22. L. Viscidi, N. Graham, M. Madrigal, M. Masson, V. Prado and J. Monticelli, "Electrified Islands: The Road to E-Mobility i n the Caribbean. Report from the Inter-American Development Bank and the Organization of American States, and the Inter-American Dialogue" . Energy & Climate Partnership of the Americas. Retrieved 2021-8-13

23. Godina, R.; Rodrigues, E.M.G.; Matias, J.C.O.; Catalão, J.P.S. Weekend charging impact of EVs on a residential distrib ution transformer in a Portuguese Island. In Proceedings of the 51st International Universities Power Engineering Conf erence (UPEC), Coimbra, Portugal, 6–9 September 2016. [Google Scholar]

24. Tarek, R.; Anjum, A.; Hoque, M.A.; Azad, A. Solar electric ambulance van unfolding medical emergencies of rural Bangl adesh. In Proceedings of the IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 29 August 2016. [Google Scholar]

25. Groupe Renault and EEM Create First Smart Island in Porto Santo. 2018. Available online: https://media.group.renault. com/global/en-gb/groupe-renault/media/pressreleases/21204577/le-groupe-renault-et-eem-creent-la-premiere-ile-intelli gente-a-p (accessed on 15 October 2019).

26. Groupe Renault and EEM Create First Smart Island in Porto Santo. 2018. Available online: https://media.group.renault. com/global/en-gb/groupe-renault/media/pressreleases/21204577/le-groupe-renault-et-eem-creent-la-premiere-ile-intelli gente-a-p (accessed on 15 October 2019).

27. Jeong-yeo, J. Jeju strives to be global benchmark with carbon-free project. The Korea Herald, 8 May 2019. [Google Sc holar]

28. Baatarbileg, A.; Otgongerel, Z.; Lee, G. Recent status of electric vehicle charging infrastructure in Jeju Island. In Proce edings of the IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Seogwipo-si, K orea, 8–10 May 2019. [Google Scholar]

29. Thoma, K. Electric Vehicles in the Pacific Islands? An Investigation of the Possibilities of Electro-mobility in Samoa. Ma ster’s Thesis, Victoria University of Wellington, Wellington, New Zealand, 2014. [Google Scholar]

30. Ellsmoor, J. The Electric Vehicle Revolution is Alive in Barbados. 2018. Available online: https://www.forbes.com/sites/j amesellsmoor/2018/12/20/the-electric-vehicle-revolution-is-alive-in-barbados/#25749ec05ff8 (accessed on 1 October 2 019).

31. Camacho Alcocer, D.; Krams, B.; Körner, M.; Hantsch, F.; Martin, U.; Herzwurm, G. Electric vehicles in rural demand-re sponsive systems: Findings of two demand responsive transport projects for the improvement of service provision. Wor ld Electr. Veh. J. 2018, 9, 32. [Google Scholar] [CrossRef]

32. Pfeifer, A.; Bošković, F.; Dobravec, V.; Matak, N.; Krajačić, G.; Duić, N.; Pukšec, T. Building smart energy systems on Croatian islands by increasing integration of renewable energy sources and electric vehicles. In Proceedings of the IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Milan, Italy, 6–9 June 2017. [Google Scholar]

33. Selosse, S.; Ricci, O.; Garabedian, S.; Maïzi, N. Exploring sustainable energy future in Reunion Island. Util. Policy 2018, 55, 158–166. [Google Scholar] [CrossRef]

34. Jennings, R. How One Pollution-Weary Asian Island Adopted Electric Vehicles. 2019. Available online: https://www.voanews.com/east-asia/how-one-pollution-weary-asian-island-adopted-electric-vehicles (accessed on 29 October 2019).

35. City Population. Labuan Bajo. Available online: https://www.citypopulation.de/php/indonesia-nusatenggaratimur.php?cityid=5315010025 (accessed on 10 July 2021).

36. The Electric Car and the Caribbean. Available online: https://www.caribbean-council.org/electric-car-caribbean/ (accessed on 30 October 2019).

37. Haakana, J.; Haapaniemi, J.; Lassila, J.; Partanen, J.; Niska, H.; Rautiainen, A. Effects of electric vehicles and heat pumps on long-term electricity consumption scenarios for rural areas in the nordic environment. In Proceedings of the 15th International Conference on the European Energy Market (EEM), Lodz, Poland, 27–29 June 2018. [Google Scholar]

38. Bremner, R. The fossil-free quest: How Renault is revolutionising a Portuguese island. AutoCar, 24 June 2019. [Google Scholar]

39. Clairand, J.M.; Arriaga, M.; Cañizares, C.A.; Álvarez-Bel, C. Power generation planning of Galapagos' microgrid considering electric vehicles and induction stoves. IEEE Trans. Sustain. Energy 2019, 10, 1916–1926. [Google Scholar] [CrossRef]

40. Innovation Outlook: Smart Charging for Electric Vehicles; International Renewable Energy Agency (IRENA): Abu Dhabi, United Arab Emirates, 2019.
