SOCIAL, ENVIRONMENTAL AND ENERGY CONTEXT OF THE GALÁPAGOS ISLANDS

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August 2020

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EXECUTIVE SUMMARY

The Galápagos Islands are administered as a Special Regime, primarily in order to fulfil national and international commitments to conserve the biodiversity and natural environment in this World Heritage site. Political debates in the province have arisen from the loss of rights of local citizens associated with these conservation goals, compared to citizens of mainland Ecuador, and the various attempts to compensate for this in the province's laws and subsequent reforms. In addition, current policies around sustainable development advocate for the need to consider the province no longer as simply a natural system to be protected, from which humans are excluded, but as a social ecosystem in which resolving social issues will lead to achieving '*buen vivir*' for local communities as well as helping to address conservation challenges. A clear issue that must be urgently addressed is the economic dependence of local communities on the booming tourism industry, which is putting pressure on local ecosystems, as well as on the limited basic services. The collapse of the tourism industry associated with the 2020 outbreak of Covid-19 has forced local communities to revert to forms of economic activity that were previously more dominant, such as agriculture and fishing, heralding a possible future that is more economically diverse and more sustainable. Overall, however, there has been a dearth of social and economic studies compared to research focusing on the natural ecosystem and conservation policies, resulting in knowledge gaps around the needs of local communities, their perceptions of conservation measures and the impact these have on their well-being and prosperity. The 2008 national constitution and subsequent provincial policies also highlight that local citizens are now expected to play an important role in governance; however, questions remain as to the best way to involve communities in these nascent participative processes and give them ownership over issues of sustainable development and conservation.

The challenge of reformulating the Galápagos economy to encompass more diverse livelihoods and more equitable growth must be accomplished without expanding the urban footprint and the reliance on products shipped from the mainland. Researchers have suggested that traditional practices in relation to tourism and urban development in the province must be modified to achieve a model based on adaptive-resilience and co-management, with a more comprehensive approach to territorial planning, more participative processes and stronger institutional networks. A change in strategy from high-volume/low-value tourism, to more limited numbers of tourists with experiences that are designed to maximise the economic value with a lower environmental impact has been called for, accompanied by stronger technical and administrative capacities to enact these changes. The provincial sustainable development plan highlights the political will towards promoting eco-tourism and nature-based tourism, incorporating more participative processes. More broadly, researchers have suggested that if local communities are able to take control of the business opportunities that the tourism boom represents, this could provide an impetus for a transition to more satisfying livelihoods for a greater proportion of residents with lower environmental impacts. In addition, if local residents can identify opportunities that are specific to the local context and create their own specific knowledge around these solutions to issues that affect them, they could reduce their dependency on imports and build a path towards self-sufficiency and sustainability. The potential for local Galápagos people themselves to influence a transition to sustainable development, which intimately concerns them and their way of life, might be encouraged through community self-organisation and transition management, lasting beyond political cycles, bringing together representatives of communities, conservationists and government. To achieve a more participative governance model, the agency of the local population, in balance with conservation and sustainable tourism, will be important, as well as more equitable development to facilitate local access to education, culture and medical services, amongst others.

This literature review is intentionally broad, seeking to identify future research avenues based around local challenges and opportunities. For example, rapid population growth due to migration from mainland Ecuador, driven by access to subsidies and the tourism market, raises questions around the social, cultural, economic and environmental issues associated with this migration. As the prioritisation of conservation policies gives way to a focus on more integrated policies promoting the sustainable development of the socio-ecosystem, what are community perceptions around the issues of productivity and conservation in the context of a tourism-intensive economy? Is there a sense of disenfranchisement due to top-down political interests in conservation and tourism, and is this evolving? What relationships exist between poverty, inequality and local development? What is the nature of asymmetrical power relations between stakeholders? Policies and regulations for conservation aimed at mitigating environmental degradation can alter socio-ecological dynamics and power relations. How can conservation be leveraged to encompass the needs of both nature and community? How is conservationism at odds with the economic development of locals? What are the socioeconomic effects behind the commodification of protected areas? How is the co-management of the Galápagos Marine Reserve perceived by stakeholders? What types of decisions are taken, and is consensus or a lack thereof common beyond political settings? What role can education play, not only to train locals for the tourism industry, but also for other economic activities? Is education an effective tool for conservation?

In terms of local infrastructure and services, there is an opportunity to rethink urbanism and avoid further expansion of the urban space into protected areas. Other potential issues revolve around the management and disposal of wastewater and solid waste. There is also an urgent need to better understand both the status and nature of aquifers in the islands, as well as the water consumption patterns and uses. Researchers have called for watershed analyses to be performed, which could be connected with a food-water-energy nexus approach to promote food and energy self-sufficiency, contributing to the UN sustainable development goals as well as the fight against invasive species. Prior to the Covid-19 crisis, the local population gave little value to local agricultural produce, however these perceptions have evolved as a result of the crisis. The freshwater resources of the island are also little valued, as they are viewed as contaminated, and the flat rate charge for usage does not discourage wasteful practices. How can a combination of policy changes and education around the nature of the fragile and unique resource systems of the archipelago promote appreciation for local products, thus helping to achieve self-sufficiency and supporting conservation goals?

In regard to the energy context of Galapagos, it is important to take into consideration that achieving the Ecuadorian government's goal of zero fossil fuel use in the archipelago will require major technological changes. Prior to addressing these investment-intensive changes, less technology-intensive approaches, such as energy efficiency measures, should be considered in order to reduce the energy demand. When considering alternatives to the current energy scenario, it is relevant to consider the different contexts on the inhabited islands of the province. However, it is also necessary to consider that some technologies could only make technical or economic sense if implemented across the archipelago and across different energy uses. It is also important to maintain a systems perspective when analysing the different alternatives, identifying their interactions with other systems, such as the food and water production and supply, community behaviour, and ecosystem conservation.

Marine transport is the largest fuel consumer in the archipelago. Solar-electric vessels could represent an alternative option for some of these services, such as short ferry crossings, short tours, and water taxis. An alternative for the fossil fuel used by rapid inter-island speedboats could be to use biofuels, or potentially hydrogen. Intermittent renewable energy generation, such as from solar PV or wind, represents the cheapest option to generate clean electricity, but this creates a need for additional flexibility in the electric system to deal with the intermittency. Demand shifting could represent a cost-effective measure to meet this flexibility requirement. An alternative for this flexible back-up is the use of energy storage, such as through batteries or the generation of an intermediate energy vector such as hydrogen, which is relatively cheap to store. In terms of land transport, electric vehicles are already a reality in the islands and could represent a solution for most of the land transport, but their limited range and high charging times (compared with fossil fuels) require behavioural changes in users. Hydrogen could also represent a viable alternative for land transport decarbonisation, but its use would require a shift to this energy vector in other energy-consuming sectors in order to maximise the use of the new infrastructure required for its implementation.

INTRODUCTION

The goal of this summary of the social, environmental and energy context of the Galápagos Islands is to provide a concise account of the opportunities and challenges associated with the Ecuadorian Government's stated goal of achieving zero fossil fuel use in the islands by 2040. This goal is an acknowledgement of the need for societies to transition to cleaner forms of energy to support more equitable and sustainable development. The goal also acknowledges the risks to human populations and the unique Galápagos ecosystem from climate change and the associated extreme weather effects, sea level rise and ocean acidification. Further risks to the islands come in the form of the introduction of foreign species, pollution from the use of fossil fuels and from local waste, as well as plastics from local use or brought to local waters by ocean currents.

As tourism is the main economic activity in the islands, a clear conflict exists between the conservation of the main source of income, stemming from the unique local ecosystem, and economic growth from developing the tourism industry. The unique environment of the islands comes partially from its geological setting, a series of islands produced by hot spot volcanic activity akin to that of the Hawaiian and Canary Islands. This active geological setting comes with a suite of natural hazards and risks, arising from the active volcanism and seismicity. Kvan & Karaciewicz (2019) note that the Galápagos Islands constitute a living laboratory for analysing the impact of human settlements, questioning their future trajectory and offering more equitable and sustainable alternatives. To that end, this review summarises the overall social, environmental and energy context of the Galápagos and the associated relevant policies. Potential avenues for future research are highlighted in *purple*.

SOCIAL & URBAN CONTEXT

SETTLEMENT & POPULATION GROWTH

Although many scientific studies of the Galápagos Islands have been conducted under the impetus of the Galápagos National Park (GNP) and the Charles Darwin Foundation, the economic and social aspects of the island have only been studied since the late 1980s/1990s[1]. In terms of the human history of the archipelago, there is evidence for temporary occupation of the islands by indigenous people[2], followed by the use of the islands by pirates and whalers after the later discovery of the archipelago by Europeans. Ecuador annexed the islands in 1832, marking the beginning of colonisation attempts[3]. The first successful settlement was the establishment of a hacienda in El Progreso on San Cristóbal Island in the 1880s, followed by a similar settlement on Isabela Island (Fig. 1). Waves of European settlers then arrived in the 1920s and 30s.

Fig. 1: Map and names of the Galápagos Islands (Image attribution: Wikipedia Commons)

The economy of the islands thus began around agriculture, shifting to fishing in the 1950s[3]. Tourism began to grow as an economic sector in the 1960s and the crash in the sea cucumber market in the 1990s meant that tourism became the dominant economic activity. The progressively more rapid increase in tourism has driven urbanisation and population growth in the islands[3]. The population of the Galápagos Islands has grown at an average annual rate of 4.83% over the last two decades, whilst that of Ecuador has grown at a rate of 2.03%[4]. This rapid growth has been attributed to the migration of people from mainland Ecuador seeking employment in the tourism industry (accounting for 3.5–4% of growth, balanced by 1–2% emigration), especially in the context of the national economic crisis of the 1980s and 1990s[4]. The employment rate in the province (90%) has consistently been measured as higher than that of mainland Ecuador (46%), and average salaries are also higher (average monthly salaries of USD 772 compared to USD 252 in 2010), which offsets the higher living costs[4]. Migration has also been driven by subsidies available for Galápagos residents, including for energy, airfares and shipping, which has aided in raising the standard of living above that of the mainland[4]. Although the poverty rates are lower in the islands than the average across Ecuador, 11% of the population is estimated to be living in extreme poverty (defined as lacking two or more basic needs) and a further 40% are estimated to be living in poverty (lacking one basic need), as measured using the Unsatisfied Basic Needs Index[5].

GEOGRAPHIC CONTEXT

Only five of the 18 main Galápagos islands are permanently inhabited[6]. The population of 25,124 residents is distributed in three urban and five rural settlements[1]. The three main urban settlements in the archipelago are Puerto Ayora (Santa Cruz Island), Puerto Villamil (Isabela Island) and Puerto Baquerizo Moreno (San Cristóbal Island). The other settlements are widely distributed, resulting in a greater need for infrastructure and transport than if the population were more concentrated[1]. In general, in the inhabited islands of the Galápagos, farmlands are located in the highlands whereas the urban settlements are located on the coast[1]. Situated in the centre of the archipelago, Santa Cruz Island has the highest population (in the urban area of Puerto Ayora and the rural settlements of Santa Rosa and Bellavista) as well as the highest on-land tourism[1] (Fig. 2). A highway connects the airport on nearby Baltra Island to Puerto Ayora. Two ports exist on Santa Cruz, one on Baltra (Itabaca Canal)

Fig. 2: Map of Santa Cruz Island, the most populated island in the Galápagos archipelago (Image attribution: creative commons)

Fig. 3: Map of San Cristóbal Island, the second most populated island and home of the capital of the Galápagos region, Puerto Baquerizo Moreno (Image attribution: creative commons).

and one in Puerto Ayora (Academy Bay)[1], receiving tourism boats and boats from other islands. Baltra island hosts the main airport of the archipelago, receiving 201,000 passengers per year, and was a US Army base during the second world war[1]. Santa Cruz was settled in the 1940s by Europeans, North Americans and Ecuadorians.

San Cristóbal (Fig. 3) is the second most populated island, with a rural settlement (El Progreso) and an urban settlement (Puerto Baquerizo Moreno). The island also has an airport receiving 70,000 passengers per year[1], and one port. Isabela Island is the largest in size (Fig. 1), with a small population divided between the urban

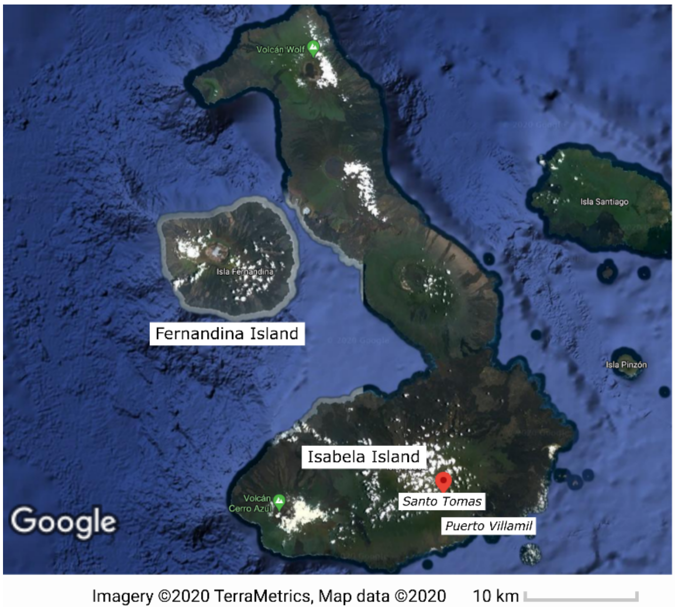

Fig. 4: Map of Isabela Island, the third most populated island (Image attribution: map edited from Google Maps).

Fig. 5: The town of Puerto Ayora, on Santa Cruz Island, which has developed the new El Mirador neighbourhood on land that previously belonged to the national park (Image attribution: map edited from Google Maps).

settlement of Puerto Villamil and the rural settlement of Santo Tomás (Fig. 4). Floreana Island (Fig. 1) has the smallest population and was colonised in 1833 by Villamil. Floreana hosts one port and can only be reach by sea.

When the Galápagos National Park (GNP) was established in 1959, 97% of the land in the territory was designated for the GNP. Consequently, the current rapid population growth must be accommodated through urban development, due to the restricted land available for inhabitants[6]. Such urban growth also necessitates the provision of consumables and transportation. Visitor numbers to the Galápagos are also increasing, bringing economic opportunities for tourism. According to Kvan & Karakiewicz (2019), a deeper understanding of the islands must include a consideration of the population and environmental systems as co-dependent and interlinked. For example, the GNP cannot exist without the staff to operate and manage it, nor without the unique species and habitat that motivated its creation. Thus, the boundaries between the national park land and the land allocated for inhabitation could be viewed as fictional, and people, species, flora and fauna pass between these spaces.

Lopez Andrade & Quiroga Ferri (2019) note that although the national park has designated official borders for protected areas, negotiations have allowed settlements to grow past these limits, such as the 'El Mirador' neighbourhood in the town of Puerto Ayora, on Santa Cruz Island (Fig. 5). These authors highlight the signs of urban pressure in the towns of Santa Cruz and San Cristóbal and argue that a better understanding of the social and urbanisation processes is essential to mitigate the impacts of population growth, by guiding more sustainable processes.

Fig. 6: The harbour in Puerto Ayora, on Santa Cruz Island (Image attribution: Wikipedia Commons).

Santa Cruz was chosen as the location of the GNP headquarters in the late 1950s[1]. The rapid rise in tourist numbers from 5000 annually in the 1970s to over 200,000 in 2017 resulted in rapid urban growth in Puerto Ayora (Fig. 6), without an urban or socio-economic plan. During this boom, the area around Puerto Ayora densified and settlements appeared in the highlands of the island[1]. The density of Puerto Ayora is listed as 63/ha over 190 ha in the 2010 census. The rural settlement of Bellavista (Fig. 2) is evolving to become a satellite town of Puerto Ayora, with urbanisation developing along the highway in between. Despite the perception of high density in Puerto Ayora, Lopez Andrade & Quiroga Ferri (2019) note that the occupation ratio of the buildable surface is only 41%. Most housing in Puerto Ayora consists of single-family units, and multi-unit buildings are rare. The 'El Mirador' extension of Puerto Ayora was built to accommodate this rapid urban growth, but Lopez Andrade & Quiroga Ferri (2019) argue that it was unnecessary given the inefficient use of existing urban space in Puerto Ayora. These authors note that this inefficient occupation of space represents an *opportunity to rethink urbanism in Puerto Ayora and avoid further expansion of the urban space into protected areas.*

San Cristóbal Island was colonised earlier than Santa Cruz, in the late 19th century, and a large sugar and coffee plantation and cattle farm were established there[1]. The island evolved to be centred on fishing and agricultural production. The rural settlement El Progreso (Fig. 3 & 7) saw a population decrease between 2010 and 2015 and as a result, is surrounded by abandoned farmland. Puerto Baquerizo Moreno (Fig. 3 & 8) is the historical capital of the islands and the base of government institutions and civil servants. It is smaller than Puerto Ayora on Santa Cruz Island, but has grown in recent decades through government investment[1]. Several NGOs have also established a base in Baquerizo Moreno, as well as the Galápagos Science Centre, and the Universidad San Francisco de Quito (USFQ) has a campus in the capital[1]. Land-based tourism is also becoming an important industry on San Cristóbal. Only one fifth of the area of Puerto Baquerizo is occupied, as the rest belongs to the Navy and is unoccupied[1]. The population density is 44 inhabitants/ha and the occupation ratio of the buildable surface in the occupied part of the town calculated by Lopez Andrade & Quiroga Ferri (2019) is 43%. One- and two-story buildings are the most common type of structures in Puerto Baquerizo (Fig. 8).

Fig. 7: The rural settlement of El Progreso, on San Cristóbal Island (Image attribution: Local government of San Cristóbal)

The declaration of the national park limited fishing activity in the region and tourism has displaced fishing as the primary economic driver in the islands[6]. Until recently, most tourists took part in boat-based tours, resulting in a reduced environmental impact on land, but also in less equitable access to revenue from industry for land-based residents compared to boat owners. *One challenge is therefore developing the tourism industry for more equitable growth without expanding the urban footprint and the reliance on products shipped from the mainland*[6]. The interaction between mainland Ecuador and the islands occurs dominantly through Santa Cruz and San Cristóbal, which comprise most of the population, receive all the air passengers and 95% of the products and goods shipped from the port of Guayaquil [1]. Santa Cruz is the main hub of tourist activity, with 40 taxi and tour boats, all relying on diesel. *As the inter-island transportation relies mainly on diesel, another important challenge is to reduce this dependence on fossil fuels.*

Fig. 8: A typical street in Puerto Baquerizo Moreno, on San Cristóbal Island (Image attribution: Wikipedia Commons).

According to Batty et al. (2019), the Galápagos represents the best example of a natural ecosystem where human settlement has been relatively low and controlled since the first sustained human contact over 500 years ago. However, as the tourism revenue has become more important for Ecuador, tourism numbers have increased dramatically as well as driving local population growth, bringing with it environmental pressures associated with the introduction of new materials and consumption.

TOURISM

The growth in the tourism sector has exceeded all expectations of local residents, conservationists and local authorities[4]. Official guidelines in 1980 recommended that visitors be limited to 12,000 per year, and this was later raised to 25,000 per year, but visitor numbers are now around 250,000 per year[4].

The tourism sector supplies close to 70% of jobs in Galápagos and forms the dominant part of the economy[3]. People drawn to Galápagos to work in the tourism industry come mainly from Ecuador, including the cities of Quito, Guayaquil, Ambato and Loja. Temporary migrants also come increasingly from the United States, United Kingdom and Germany[3]. De Haan et al (2019) note that the tourist numbers increased 138% between 2001 and 2011, and 1473% compared to 1979, therefore the human dimension in the region has changed dramatically over recent decades.

Fig. 9: A typical tourism boat in the Galápagos Islands, often owned by outside companies (Image attribution: Galapagosislands.com)

Boat-based tourism includes day-trips and island hopping on small speedboats ('fibras'), which are locally owned and operated and carry up to 16 people. These boats are also used to move products between islands[3]. These locally-owned vessels now allow the local community to reap some benefits from tourism as the boats historically operating in the islands were owned by external parties[8]. Yachts and cruise ships also offer multi-day trips and may carry up to 100 people (Fig. 9). In the latter, tourists remain aboard the boats apart from short trips on land, leading to tensions with local people who perceive this tourism as "detached" and not contributing to the local communities[3]. Most tourism in the Galápagos is boat-based, but there is a growing trend for land-based activities and this sector is growing rapidly (Fig. 10). For example, in 2001 30% of Ecuadorian tourists and 86% of international tourists slept on boats at night, whereas only 9% Ecuadorian and 66% of international tourists slept on boats in 2010[8]. Land-based tourism is growing through activities such as eco-tourism sites in the agricultural highlands of Santa Cruz and San Cristóbal, such as endemic forests and natural geological formations (e.g. lava tubes) [3]. This rise in land-based tourism has led to a rise in the construction of hotels and the provision of land-based jobs in the tourism industry[8]. Surfing and sports fishing are also recent activities being developed. Environmentally, boat-based tourism puts less pressure on public services on land, but creates hazards related to oil spills, legal or illegal dumping of waste, and the effects of propellers on marine wildlife[8].

As the agriculture and fishing industries are in decline, it is common for those working in those sectors to also hold a second job in the tourism industry[3]. A survey of 167 people working in the fishing industry in 2012 showed that the majority were not hopeful about future prospects and most full-time personnel wished to leave the industry[8]. However, many people working in this industry have a low level of education and lack desirable skills that would be required to work in tourism. In addition, social discontent has arisen over the unfair distribution of benefits from tourism, as most profits have ended up in the hands of outside companies[8]. According to Walsh et al (2019), tourism may remain the perceived source of social inequalities if outside companies retain control of the market and if local communities are unable to develop the skills needed for high-level tourism jobs, such a multilingualism. In contrast*, if local communities are able to take control of the*

Fig. 10: Tourism is booming in the Galápagos Islands, and developing from mainly boat-based to also include land-based, putting additional pressure on local resources and services (Image attribution: EturboNews)

business opportunities that the tourism boom represents, this could provide an impetus for a transition to more satisfying livelihoods for a greater proportion of residents with lower environmental impacts[8].

ISLAND ECONOMICS & EMPLOYMENT

According to Walsh et al. (2019), the economy of the islands includes four main sectors: agriculture, fisheries, tourism, and the public sector. The agriculture sector has been declining since the 1970s, and in 2009 employed only 8.4% of the workforce[8]. Although the fisheries sector is in decline and now represents a small portion of the economy (<4% of the total income in the islands), the transition of livelihoods from fishing to tourism is an important issue in the Galápagos, and has fuelled multiple strikes in recent decades[8]. The Galápagos region is also a semi-autonomous province of Ecuador and makes a significant contribution in terms of taxes from the tourism industry to the central government (the demands for products from the mainland also boosts the national economy[4]). As a result, the municipal and provincial governments have grown to represent important employers in the islands, with 12.8% of the overall workforce in 2009 (and 22.8% on San Cristóbal)[8], compared to 4% employment in the public sector in mainland Ecuador.

The economic development of the islands is now dominantly driven by tourism, with at least 40% of the workforce estimated to be employed in this sector in the 1990s[8]. The GDP of the islands grew by 78% (from a base of USD 41 million) between 1999 and 2005, which represents an annual growth of 10%, and tourism explains 74% of this growth[4]. However, *despite the rapid economic growth, per capita income has only risen 1.8% annually and local residents feel that they receive unfair access to the tourism revenue*[4]*.* Indeed, due to the rapid increase in the revenue from tourism, and despite efforts to design the tourism industry to benefit the local population, outside interests have been drawn to the region and profits have gradually been skewed towards non-residents and outside companies[8]. For example, Walsh et al. (2019) indicate that the licencing system for tourism vessels, originally designed so that these could not be sold and were only given to local residents, represents a system that now benefits mostly outside companies, who have bought up the rights to these licenses and now reap most of the revenue from the boat-based tourist trade[8]. Another example consists of the rights to sports fishing activities, which have also been subverted so that local fishermen only reap a small proportion of the revenue. *The low growth of the GDP per capita has created pressures on the local government to allow commercial fishing in the Marine Reserve or increase the number of visitors per year, despite clear implications for sustainability in any of those scenarios*[4]*.*

In another example of efforts to benefit local residents from the tourism industry, from 1998 only Galápagos residents could be employed as naturalist guides. However, the initially high quality of the guides declined gradually as those seeking employment in the tourism sector lacked desirable skills such as multilingualism, salesmanship and customer service, due to a lack of educational opportunities[8].

The tourism industry also drives most of the migration towards Galápagos, with many people arriving from mainland Ecuador to work in jobs catering to tourists and in government jobs that have grown as a result of the burgeoning resident and tourist populations[8]. Immigration control measures were implemented in the Galapagos Special Law in 1998[9].

INFRASTRUCTURE & SERVICES

The development of infrastructure has not kept pace with the boom in tourism and local population growth, resulting in negative consequences for local services (power, water, sanitation, healthcare) and commerce, although improvements are being made in the two main islands (Santa Cruz and San Cristóbal)[3]. De Haan et al (2019) note that Galápagos residents have been historically underserved in terms of access to education, water, sanitation and healthcare. The Galápagos has registered a 68% increase in housing units over the last 10 years. However, the percentage of homes with a network sewer service decreased from 30% in 2001 to 26% in 2010, and is even lower on the most inhabited island, Santa Cruz, at 4%[3]. Many homes use septic tank systems that were constructed with no regulations and may leach contaminated material into the environment[10].

Fig. 11: Water purification plant in Galápagos (Image attribution: Josselin Guyot-Tephany, Galápagos Report 2011-2012).

Issues relating to wastewater and sewerage are multi-fold. Firstly, the island nature of the region necessarily implies a restricted amount of fresh water available for human use. The lack of adequate infrastructure also results in frequent disposal of waste water into the ocean or injection into the porous volcanic rocks that make up the islands[3]. This poses a threat of contamination to the already overstretched freshwater resources used for human consumption (Fig. 11*). In 2009, 70% of illnesses in Puerto Villamil were estimated to originate from the consumption of contaminated water*[10]*. In addition, excessive pumping from wells leads to the ingress of salt water into fresh water aquifers, increasing the salinity of the fresh water*[3]*.*

Petroleum products are transported by sea over 1000 km from mainland Ecuador, to fulfil the increasing demand for touring, fishing and transportation boats, as well as diesel for electricity generation[3]. Numerous oil spills have resulted from this activity, which are detrimental for the environment, including that from an oil tanker for the supply of marine vessels that ran aground in 2001, and from a recent sunken barge in the harbour at Puerto Baquerizo Moreno on San Cristóbal Island, in 2019.

Solid waste disposal was identified as an issue by many of the island communities and *the management and disposal of solid waste has been identified as a key priority for the Government*[10]*.* Recycling plants have been set up on three of the main inhabited islands (Santa Cruz, San Cristóbal and Floreana)[5]. However, only a percentage of the waste generated on the islands is currently recycled. For example, San Cristóbal currently produces 4.17 tons per day and only 10% is recycled[5]. There are currently no provisions for recycling computing equipment, white goods, electronics and scrap metal. Although a portion of this waste is sent to mainland Ecuador, these items can still be found dumped on unoccupied land in the islands[5].

More generally, urban growth has taken the form of lateral expansion, internal infilling and, more recently, the construction of additional levels vertically[3]. Policy shifts have allowed land swaps between the national park and the community lands, so that expansion was possible onto land that was formerly excluded from community use[3]. However, de Haan et al (2019) note that the current urban development in the region lacks an integrative vision with the goal of achieving sustainability in this island socio-ecosystem. These authors draw attention to the need for a unifying strategy linking infrastructure, people and land development dynamics through the management of the social, terrestrial and marine sub-systems with a view to supporting tourism and protecting the environment[3]. Karakiewicz (2019) argues *that if residents in Galápagos can identify opportunities that are specific to their local context and create their own specific knowledge around these solutions to issues that affect them, they could reduce their dependency on imports and build a path towards self-sufficiency and sustainability*[5].

INSTITUTIONAL CONTEXT

The management of Galápagos is conducted through various institutions, including the Galápagos Government Council or CGREG (Consejo de Gobierno del Régimen Especial de Galápagos)[11], which represents the provincial government. The president of the CGREG (Currently Mr Norman Wray) has the status of a minister and is appointed by the national government. The CGREG president reports directly to the President of Ecuador and to the director of the GNP[11]. The director of the GNP (currently Dr Jorge Carrión) is under the Department of Natural Resources (Ministerio de Energía y Recursos Naturales No Renovables). Other central government departments deal in various aspects of life in the province (Table 1), including the ministries of tourism, education, agriculture, health, electricity and renewable energy[11]. Certain of these institutions have overlapping responsibilities, for example the GNP and the Ministry of Tourism, who are both responsible for monitoring and regulating the use of small boats in the Galápagos Marine Reserve.

Central Government	Ministerio del Ambiente (Ministry of the Environment) Ministerio de Turismo (Ministry of Tourism) Ministerio de Sectores Estratégicos (Ministry of Strategic Sectors) Ministerio de Defensa (Ministry of Defence) Ministerio del Interior (Ministry of the Interior) Ministerio de Educación (Ministry of Education) Ministerio de Salud Pública (Ministry of Public Health)
Regional Government	Consejo de Gobierno del Régimen Especial de Galápagos (Government Council for the Special Regime of the Galapagos) Agencia de Regulación y Control de Bioseguridad y Cuarentena para Galápagos (Biosecurity and Quarantine Regulation and Control Agency for Galapagos) Dirección Regional de Espacios Acuáticos de Galápagos (Regional Direction of Aquatic Spaces of Galapagos)
Local Government	Gobiernos Autónomos Descentralizados de San Cristóbal, Santa Cruz e Isabela (Decentralised Autonomous Governments of San Cristóbal, Santa Cruz and Isabela) Gobiernos Autónomos Descentralizados Parroquiales de El Progreso, Floreana, Santa Rosa, Bellavista y Tomás de Berlanga (Decentralised Autonomous Parish Governments of El Progreso, Floreana, Santa Rosa, Bellavista and Tomás de Berlanga)

Table 1: Main entities with influence in the governance of the province of Galápagos[12].

In addition to the provincial government, there are also elected local governments (Gobiernos Autonomos Decentralizados), including three municipalities and several rural parishes (Juntas Parroquiales), as well as mayors for the three main towns on Santa Cruz, San Cristóbal and Isabela[11] (Table 2).

Canton	Principal islands	Cantonal capital	Area (km^2)	Area (%)	Rural parishes
Isabela	Isabela, Darwin, Wolf, Fernandina	Puerto Villamil	5.367.5	80.9	Tomás de Berlanga
San Cristóbal	San Cristóbal, Española, Genovesa, Santa Fe, Floreana	Puerto Baquerizo Moreno	848.5	12.8	El Progreso, Santa Maria
Santa Cruz	Santa Cruz, Marchena, Pinta, Pinzón, Santiago, Seymour, Baltra	Puerto Ayora	5 415.5	6.3	Bellavista, Santa Rosa

Table 2: Political divisions of the Galápagos Province[12].

The GNP manages 97% of the land as well as the Galápagos Marine Reserve, and creates regulations to restrict human activities that infringe upon the park (such as fishing, hunting, gathering and construction)[11]. The Galápagos Marine Reserve was created in 1998, as a result of concerted efforts from fishers and conservationists to prevent the overexploitation of marine resources and the entrance of industrial national and international fishing fleets into the region[11]. According to Quiroga (2019), this was a participatory process that forced different stakeholders to discuss and negotiate around their needs[11], and included 74 meetings of the Grupo Núcleo, a multi-stakeholder planning group, as well as two fisheries summits and three community workshops[13]. The Marine Reserve was then co-managed by the Galapagos National Park, the Inter-Institutional Management Authority (IMA), and the Participatory Management Board (PMB)[14], until this co-management arrangement was dismantled in the 2015 reform of provincial laws. The PMB was composed of primary local stakeholders, and operated through members making specific management proposals (e.g. regarding fishing or tourism), which were analysed, negotiated and finally agreed upon by consensus[13]. These proposals were then passed for approval to the IMA, which comprised representatives of ministers and local stakeholders, and then on to the GNP for implementation and control[13]. If consensus could be reached in the PMB, the different stakeholder positions were communicated to the IMA, where decisions were then made. Most consensus-based proposals from the PMB were approved without modification by the IMA, demonstrating the effectiveness of the co-management approach, which resulted from strong incentives among local stakeholders to agree upon viable proposals[13]. The PMB has now been replaced by a Participatory Management Advisory Council (Consejo Consultivo de Manejo Participativo), which provides non-binding advice on the management of the Marine Reserve.

The GNP has the greatest responsibility in terms of enforcing conservation regulations given that they manage 97% of the land surface in the province, however a lack of resources has proven problematic in the past, for example in terms of successfully limiting visitor numbers and the introduction of foreign species[14]. The Charles Darwin Foundation and the World Wildlife Fund also play an important role in influencing policy in the province, and many international non-governmental organisations, such as the UN, monitor conservation in the islands[14].

ENVIRONMENTAL CONTEXT

SUSTAINABILITY IN THE GALÁPAGOS

LAWS AND PLANNING INSTRUMENTS

The Ecuadorian constitution was re-written and ratified in 2008, with pioneering recognition of the inalienable rights of Nature, including the management and regeneration of its natural cycles, structures, functions and evolutionary processes. In this national vision, the governments of successive generations of Ecuadorians will therefore bear a responsibility for the management of biodiversity. Ecuadorian citizens have the legal authority to sue on behalf of Nature[15]. The National Plan for Good Living (Plan Nacional del Buen Vivir - PNBV) for the periods 2013–2017 and 2017–2021 outlines the guidelines for long-term public planning and investment in the Ecuadorian territory, incorporating the notion of '*buen vivir*', which is defined as follows: "*Good Living is the style of life that enables happiness and the permanency of cultural and environmental diversity; it is harmony, equality, equity and solidarity. It is not the quest for opulence or infinite economic growth.*"[16]. The plan promotes a redistribution of wealth and a gradual exit from an export-focussed economy to one where the means of production are more democratically accessed. This is the approach to be adopted in order to change the country's productive model and mitigate the impacts of climate change. The PNBV also includes policies promoting climate change adaptation and mitigation, energy-efficiency, the use of renewable energies and energy self-sufficiency. Further relevant policies include the sustainable development and conservation of natural heritage, sustainable water management, pollution prevention, and the incorporation of an environmental focus in public policies.

In terms of goals relevant to the Galápagos, the PNBV 2017–2021 includes policies to:

- encourage productive diversification and access to public services according to the special conditions of the province;

- strengthen biosecurity and quarantine measures, including local participation, for the prevention, early detection, monitoring, control, and eradication of invasive species;
- consolidate human settlements and limit urban and rural expansion in Galapagos, considering the biophysical limits of the ecosystems, and managing their natural resources sustainably;
- encourage multimodal transport at the national level, with an emphasis on the Galapagos;
- increase access to public telecommunications services and information technologies, especially in the Galápagos sector; and
- promote sustainable consumption and production according to the particularities of the local ecosystems, particularly in the Galapagos Islands.

The Galápagos province is administered as a Special Regime, in order to fulfil the national and international commitments to conserve the unique biodiversity. The government of Ecuador introduced the Special Law for the Galápagos (Ley de Regimen Especial para la Conservacion y Desarollo Sustentable de la Provincia de Galápagos) in 1998, with the aim of promoting both conservation and economic development in the province[14]. The planning and management authority for the Special Regime indicated by the 1998 law was the (now-defunct) INGALA (Instituto Nacional Galápagos). The Special Law created the Marine Reserve, limited the ability for immigrants arriving from mainland Ecuador to secure employment in the province in order to control immigration, restricted fishing rights to include only local residents, strengthened institutions such as the GNP, and gave privileged access to permanent residents for economic activities, such as the tourism industry. Following changes in the national constitution in 2008, the planning and management authority for the Galápagos special regime became the CGREG (Regional Government Council for the Special Regime of Galápagos), which required a reform to the Special Law. The new law came into force in 2015 (Ley Orgánica de Régimen Especial de la Provincia de Galápagos) and further tightened immigration measures. In addition, the new law now gave preferential access via affirmative action (rather than exclusive access) for permanent residents to the fishing and tourism industries, and a presidential veto changed the way that wages in the islands would be calculated. The latter triggered a wave of demonstrations in the province and calls to scrap the law entirely and bring in a completely new one. A new process of reform began in 2018 and is still underway.

The sustainable development plans for the region must be aligned with national and international commitments. A consultative process led to the elaboration of the most recent 2015–2020 Galápagos Plan (Plan de Desarollo Sustentable y Ordenamiento Territorial del Regimen Especial de Galápagos) by the CGREG (the following development plan up to 2030 is currently in the final stages of development), outlining the regional vision for sustainable development and territorial planning over that period[10]: "*Galápagos is a territory of peace with inhabitants committed to the conservation of their natural heritage; the exercise of the constitutional rights to buen vivir of citizenship and nature is guaranteed; interculturality is favoured and fair and equitable access to the use and exploitation of its natural resources is possible according to the biophysical limits of the archipelago, becoming a national and international reference in the management and governance of a sustainable territorial development model*". This document replaces the previous regional plan (Regional Plan for the Conservation and Sustainable Development of Galapagos, 2002) as the main instrument for provincial policy planning with the goal of sustainable development of the islands[17].

The plan represents the primary coordinating instrument of the CGREG, and unites national, provincial and cantonal planning tools within the framework of the Special Law, along with international commitments relating to the World Heritage and conservation status of the islands[17]. Conceptually, the plan strengthens the approaches laid out in the preceding planning processes, and was developed by identifying the specific opportunities and challenges in the province[17]. The development of the plan included a participatory phase, including local citizens and public/private institutions, as well as the collection of technical information, including information generated specifically for that purpose. Teams from SENPLADES (the Ministry for Planning and

Development), the National Institute for Higher Learning, and the Centre for Strategic Planning developed a flow analysis for the province and elaborated several development scenarios before outlining the chosen strategy.

As part of the participative process, workshops were held on each of the four inhabited islands, and representatives of the local communities were elected to form a Provincial Assembly, which met on Santa Cruz to outline problems and opportunities[17]. The conservation of biodiversity was identified as essential for the achievement of *buen vivir*, as well as the development of local skills and the diversification and adaptation of production to local conditions[17]. Additional workshops included the involvement of local and national government to contribute to the final management and planning tool.

The results of this process highlighted that the current development model of the Galapagos is unsustainable, both in terms of biodiversity conservation and human development[17]. The main causes of the failings of this model were identified to be an overdependence on the mainland for energy, a low diversification of economic opportunities, poor access to internet, unplanned urban expansion, a shortage of recreational space for the local population, limited coverage and poor quality of basic services, and a weak governance model ill-suited to the dynamic situation of the territory[17]. The direct consequences of these issues include an over-reliance on tourism, the introduction of alien species, biodiversity loss, negative land use changes, habitat fragmentation, water quality issues and the general degradation of the living conditions of the communities[17]. However, the human, economic, institutional and natural resources of the islands represent opportunities that could be properly articulated to form a sustainable model of territorial management for the islands[17].

Fig. 12: Methodology for the elaboration of Plan Galapagos[17].

The plan summarises the nature of and the challenges associated with the biophysical, human, productive, sociocultural, transport and institutional components of the Galápagos region, and proposes a set of objectives in line with the various national development plans (the National Plan for Good Living, National Strategy for Changing the Productive Matrix, National Strategy for Equality and Poverty Eradication) and the special nature of the region (international treaties qualifying the Marine Reserve and the World Heritage status). The five strategic objectives outlined in this plan are:

1. To consolidate a comprehensive model of sustainable development for the Galapagos socio-ecosystem;
2. To promote the *buen vivir* of the residents of Galapagos, as well as a quality of life and a lifestyle that is typical "of the islands";

3. To promote a society based around knowledge and the diversification of the productive matrix;
4. To reduce the energy dependence on the continent, optimizing renewable electricity generation, transport and connectivity;
5. To strengthen the governance model of the Galapagos Special Regime.

1. Consolidate a comprehensive model of sustainable development for the Galápagos socio-ecosystem	• Implement a comprehensive model of land management, considering biophysical limits and aimed at halting the expansion of human settlements • Promote the sustainable use of ecosystems and their natural resources • Promote forms of consumption and production that reduce the flow of energy and materials from the continent • Regulate population growth based on scientific constraints regarding the biophysical limits of the island ecosystems
2. Promote the *buen vivir* of Galápagos residents, within the context of island life	• Promote the cultural identity of the Galapagos population based on its unique surroundings and with a gender perspective • Improve social cohesion through the exercise of the rights of buen vivir or good living • Ensure adequate drinking water supply and environmental sanitation systems in ways that are appropriate for the insular ecosystem • Ensure access to quality public health services according to the geographical conditions of the Islands • Increase awareness of Ecuadorians in other provinces of the country regarding the natural and scientific values of Galapagos, its commitment to preserving this heritage for the future, and the buen vivir of its population
3. Promote a knowledge society and diversification of the production matrix	• Foster basic and applied research applicable to sustainable development of the territory and promote technology transfer • Promote the development of human talent according to labour demand in the territory • Consolidate a sustainable and solidarity-based socioeconomic system that favours artisan, agricultural, and fishing sectors
4. Reduce energy dependence on the continent, optimizing the generation of renewable electricity, transport, and connectivity	• Optimise air, land, and maritime transport systems, and the connectivity of the province • Promote the transformation of the energy matrix to a reliance on renewable resources
5. Strengthen the governance model of the Special Regime of Galápagos	• Consolidate the model of participatory management for planning for sustainable development to improve the governance of the province • Strengthen transparency and tax collection systems to enhance the equitable redistribution of income, and the economic and financial sustainability of the Special Regime • Consolidate a risk management system according to the characteristics of the territory • Strengthen and expand inter-institutional coordination capabilities among all government and private entities

Table 3: The five major objectives of Plan Galapagos along with the corresponding regional public policies[17].

The plan outlines a set of goals, policies, targets and indicators (46 targets and 59 indicators) associated with each of these objectives (Table 3), as well as a list of regional programs to be implemented. The goal is the creation of a more sustainable island socio-ecosystem, which represents an eco-tourism destination as well as a pioneer territory for bioagriculture[17]. Key to this vision is the reconfiguration of the province's economy as centred around the knowledge and skills of local people, reducing wealth generation to within the biophysical limits of local resources (e.g., fisheries), and prioritizing technology transfer and innovation. The land use planning incorporated into Plan Galapagos includes: protected zones (e.g. the marine reserve and national park); urban zones; rural zones; and special zones (e.g. areas of natural interest, of special public services or of natural hazards)[17].

The following is a list of goals associated with the above objectives:

Goal 1: Consolidate a comprehensive model of sustainable development for the Galápagos socio-ecosystem

- Reduce the area of vacant land in the urban and rural areas by at least 15% by 2020;
- Reduce the Unsatisfied Basic Needs percentage to 12% by 2020;
- Increase recreational areas by at least 15% by 2020;
- Increase the number of dwellings with sustainability parameters to 20 per 1000 by 2020;
- Achieve no increase in the critical status of marine and terrestrial species in the archipelago;
- Increase dock user satisfaction in relation to the fulfilment of the purpose of quarantine control in cargo ports to 90% by 2020;
- Increase to 100% the quarries that have an environmental license and environmental audits approved by the environmental authority by 2020;
- Increase the percentage of contracted local suppliers to 15% by 2020;
- Reduce by 20% (from 800 kg to 640kg per capita) the per capita consumption of perishable basic goods that enter the islands by 2020;
- Increase by 50% the amount of credit granted by public banks for productive activities by 2020;
- Reduce the annual growth rate of permanent residents to 2.5% per year by 2020;
- Reduce the number of people who stay in the Galapagos province in an irregular state to less than 2 in every 1000 identified visitors who enter the islands by 2018;
- Reduce the annual growth rate of temporary residents in the province to 4% by 2020.

Goal 2: Promote the *buen vivir* of Galápagos residents, within the context of island life

- Increase the active participation of the community in social, political, cultural and physical activities to 20% by 2018;
- Reduce the gap between men and women in unpaid work for permanent residents by 10% by 2020;
- Increase citizen security to 98% by 2018;
- Increase access to drinking water within homes to 100% by 2018;
- Increase the perception of drinking water quality on the islands to 81% by 2018;
- Increase to 100% the coverage of the public sewer network on the populated islands by 2018;
- Increase to 90% the homes connected to a wastewater treatment system by 2020;
- Increase to 100% the landfills that have an environmental license and environmental audits approved by the environmental authority by 2018;
- Reduce per capita solid waste generation by 15% by 2020;
- Increase citizen satisfaction in reference to public health services in the province to 81% by 2020;
- Reduce the hospital discharge rate to 40 in every 1,000 residents by 2020.

Goal 3: Promote a knowledge society and diversification of the production matrix

- Increase to 100% the number of research projects carried out that are disseminated among the population and decision-makers by 2020;
- Increase to 33% the research carried out in the areas of social sciences and economics/productive sector by 2020;
- Increase to 40% the percentage of students who complete a higher education career by 2020;

- Increase by 100% the number of scholarships for training programs by 2018;
- Increase per capita production of agricultural crops by 30% by 2020;
- Increase to at least three the number of sustainable fishery certifications by 2020;
- Increase to 10% the number of civil organisations that have sustainable production certifications by 2020;
- Increase to at least 85% the perception of the island visitors of the quality of the services offered by 2018;
- Increase to 25% the number of establishments with environmental and sustainable tourism certifications by 2020;
- Reduce to 3.5% the annual growth rate of tourists entering the islands by 2020.

Goal 4: Reduce energy dependence on the continent, optimising the generation of renewable electricity, transport, and connectivity

- Increase to 75% the (flexible) paving of the existing road network in rural areas by 2020, trying to use environmentally friendly materials;
- Increase to 100% the port facilities for the management of maritime cargo transport in and to the Galapagos Islands by 2020;
- Increase to 100% the airport facilities for helicopters on populated islands for the management of inter-island passenger air transport and transport to the Galapagos Islands by 2020;
- Increase the coverage of collective passenger transport between urban and rural areas of the islands to 60% by 2018;
- Increase user satisfaction in reference to the quality of internet service to 81% by 2020;
- Reduce per capita fossil fuel consumption by 10% in the province by 2020;
- Reduce the annual growth rate of fossil fuel consumption for electricity generation to 3% by 2020;
- Increase electricity generation from renewable energy sources to 40% by 2020.

Goal 5: Strengthen the governance model of the Special Regime of Galápagos

- Increase to 20% the percentage of the population that attends a citizen participation event organised by the institutions of the province by 2018;
- Increase by 50% the average investment from projects that are executed in the territory with total or partial financing from international cooperation by 2020;
- Increase the tax revenue of public institutions on the islands by 50% by 2020;
- Reduce the income inequality of the inhabitants of the Galápagos to 35% by 2020, as measured by the Gini coefficient;
- Reduce by 8% the percentage of the population living in a situation of vulnerability to natural hazards by 2020;
- Increase to 100% the number of public institutions that have risk management plans by 2018;
- Increase by 50% the percentage of institutions that work with at least one intersectoral intervention by 2018;
- Increase to 81% the satisfaction of citizens in reference to public services in the province by 2020.

In 2015, Ecuador adopted the UN's Agenda 2030, centred around the 17 Sustainable Development Goals (SDGs) and recommendations from the UN's 3rd Habitat conference that local authorities should take a central role in achieving these goals[18]. The objectives of the national development plan to 2030 must therefore be aligned with the global and local goals of Agenda 2030. As part of the preparation for the new development plan, the planning secretariat of Ecuador issued guides for each province, canton, and for the Galápagos region[18,19]. These guides outline how the local and provincial development and land use plans must be aligned with the national development plan and the SDGs over the short (1–2 years), medium (5 years) and long term (10–20 years). According to this guide[19], the procedure for updating the plan consists of a strategic diagnosis of the present situation, including problems and opportunities, an outline of the desired territorial model, and a management plan for achieving the desired outcomes, including explicit targets and indicators. This is the same approach as was adopted in the current Plan Galápagos (2015-2020) and will be applied to the new development plan to 2030.

SUSTAINABILITY ISSUES

There has been an increasing recognition of the environmental issues surrounding population growth in the islands, and the need to approach conservation and management in a holistic way, rather than focussing on management within different compartments, namely within the GNP, the Marine Reserve, and the inhabited land areas[4]. More generally, approaches to human sustainable development have moved from more general considerations of the linkages between human systems and global ecosystems, to a recognition of the importance of towns and cities and their particular socioeconomic contexts for resource use and consequences on the natural environment[7]. Batty et al. (2019) argue that urban spaces should be viewed as complex adaptive systems, meaning that places are embedded in connected networks around the exchange of goods, services, energy and information. According to these authors, these characteristics mean that urban spaces are typically difficult to influence through traditional policy approaches, and attempts to influence them can lead to a number of unintended consequences. In addition, the rapid timescale of urban growth and the global reach of its networks (e.g. global flows of goods, energy and information) lead to an intense forcing over local ecosystems, which typically cannot respond in real time[7]. Once disturbed, ecosystems tend to recover at a slower pace than that of human adaptation, and may not recover to the original state prior to human contact. Batty et al. (2019) conclude that some degree of top-down governance of 'commons' is therefore necessary for sustainable development.

In the Galápagos, the four or five main centres of population concentrate the demand for energy, construction materials and food[7]. To understand the relationships between the urban and natural systems, it is necessary to investigate the specificities of the local population, employment, development, transport and land- and boat-based tourist populations, their relationships with the local ecosystems and how these relations may change given different future development scenarios[7]. In a study of the tourism sustainability of the islands, Espin et al. (2019) found that the cyclical nature of the relationship between tourism and population growth degrades the natural capital of the archipelago, which in turn threatens the potential for the province to attract sufficient visitor numbers to maintain social wealth[4]. These authors recommend that tourism strategies for the islands attempt to curb the tourism and demographic growth loop, to avoid for example the expansion of urban areas into the GNP[4]. They recommend that *a change in strategy from high-volume/low-value tourism, to more limited numbers of tourists with experiences that are designed to maximise the economic value with a lower environmental impact is needed, accompanied by stronger technical and administrative capacities to enact these changes*[4].

Due to the rapid population growth and rapid increase in the standard of living of Galápagos residents, the province has one of the highest levels of consumption per capita in Ecuador[11]. This level of consumption, accompanied by a decrease in local production from agriculture and fishing, means that a large amount of products must be imported, resulting in one ship arriving from the mainland every week as well as around ten flights bringing visitors and products[11]. This increase in connections with the mainland leads to an increase in the risk of oil spills, invasive species (intended, e.g. ornamental plants, as well as unintended) and new diseases[11]. There has been an attendant increase in the use of fossil fuels for marine transportation, as well as for air conditioning, refrigeration and transport on land.

In the archipelago, important biological threats to the islands' unique ecosystems come from uncontrolled farming, the introduction of foreign plants (raspberry, the guava, and the quinine tree) and animal species (wasps, ants, mosquitoes, birds, frogs, geckos, goats, pigs, donkeys, cats, and dogs), as well as pathogenic micro-organisms[1]. Invasive plant species are now estimated to outnumber native species[8]. Invasive species may also be responsible for transforming the landscape of the islands and reducing land productivity, leading to the abandonment of fields and farming for preferred jobs in the tourism industry, and increasing pressure on overstretched urban services[8]*. Further reduction in the fishing and agriculture sectors could also threaten food security in the archipelago*[4]*, due to the heavy reliance on imports.*

According to Quiroga (2019), regulations have been put in place to shape the relationship between Galápagos residents and their environment, in order to protect and monitor the changes in native species[11]. However, these interventions represent top-down control mechanisms that have had mixed results and have generated conflicts[11]. The government regulates the use of common resources through the GNP, but this has led to conflicts with residents, with some resorting to illegal, unsustainable use of those resources. For example, the failure of regulations to manage protected areas is clear in the effects of invasive species, illegal fishing, the overexploitation of resources, and the urban expansion into the GNP[11]. In addition to these top-down processes, bottom-up, community-led actions also exist. For example, local people working in the tourism sector, such as those who have obtained day passes to take tourists to certain sites of interest, monitor each other's activities to ensure the conservation of the common resources[11]. In addition, fishers working in sports fishing are acting to further conservation efforts by limiting their catches, or operating on a catch-and-release basis[11].

However, many examples of top-down regulation with no community participation also exist[11]. One of these examples is the creation of the Marine Sanctuary in 2016 (not to be confused with the Marine Reserve, which was created in 1998), purportedly to protect sharks on the northern side of the islands[11]. According to Quiroga (2019), sharks were already under protection from the Marine Reserve, therefore the creation of the Sanctuary by the Charles Darwin Station, National Geographic and the Presidency of Ecuador, with no consultation of local fishers, was viewed as an effort to shore up the poor environmental record of President Correa. An alternative interpretation was that the Sanctuary was intended to boost tourism in an area where mostly external companies operate, and the concurrent permission for fishers to use previously banned long-lines was viewed as a measure to placate them following the creation of the Sanctuary, which impinged on their fishing activities[11].

Despite conservation policies, the establishment of protected areas in the islands, migration control and restrictions on land development, environmental degradation is accelerating[5] and UNESCO added the Galápagos to the list of Natural Heritage Sites in Danger in 2007[9] (it was removed from the list in 2010, to recognise the effort by the Ecuadorian Government to preserve the Galápagos biodiversity, despite ongoing concern from conservationists[20]). Gonzalez et al. (2008) defined four cycles of development of the islands separated by transitions brought about by human factors:

- Extractive exploitation (1525–1832), e.g., pirates and whalers re-stocking food supplies;
- Colonisation (1832–1959), e.g., from single settlements to towns and villages;
- Wilderness conservation (1959–1998), e.g., establishment of the GNP and protected areas;
- Conservation-development balance (1998–present).

The transition in 1832 was defined by the permanent settlement of the islands, as previously described. The transition in 1959 was due to the declaration of the National Park, motivated by the centenary of the publication of Darwin's "On the Origin of Species" (the limits of the national park were then defined in 1979 and finally ratified in 1998 through the Galapagos Special Law). The transition in 1998 from wilderness conservation to a conservation-development balance was brought about by the introduction of the Galápagos Special Law, due to the realisation that the development of the islands was incompatible with sustainability. Through this law, the Ecuadorian Government granted permission for the Galápagos to be run by a special regime, where the rights of free residence, property, and commerce could be restricted for its protection. In particular, the Marine Reserve was created through this law to eliminate commercial and illegal fishing, allowing only small-scale artisanal fishing by local residents. The law also incorporated social policies for the betterment of local residents and solidified the cooperation between the public and non-profit sectors (Table 4)[14]. *However, Hoyman & McCall (2013), found that despite strong support for the law among community leaders in the Galápagos, there was also a strong sense that it has not been effectively implemented, due to weak institutions, a lack of leadership and failure to enforce unpopular elements of the law*[14].

Policies from the Galapagos Special Law	Other Federal policies
Fishing licence availability: restricted to local residents only	Super wage: requires all wages to be 140% over Ecuador mainland minimum wage
Job restrictions: temporary residents may not hold a job until they have resided on the island for more than 1 year	Teachers wages: teachers on the Islands are required to be paid a minimum wage higher than super wage policy
Promotion of entrepreneurship: encourages selling of indigenous crafts	Subsidies for Island residents: 12 annual subsidised flights to mainland Ecuador
Research: supports academic research on how to better utilise natural resources, promote sustainable development and environmental conservation	
Quarantine: requires enforcement and use of quarantines	
Conservation efforts: promotes collaboration among resident communities to promote sustainable development	
Affirmative action: provides tax credit to support hiring native residents	

Table 4: Summary of eco-tourism policies, from Hoyman & McCall (2013)[14].

Gonzalez et al. (2008) conclude that the current tourism model in the Galápagos is unsustainable and has important links with population growth, jobs, resources consumption, invasive species and the lifestyle of the local population. In order to ensure a transition towards sustainable development, these authors argue that *traditional practices in relation to tourism and urban development in the Galápagos must be modified to achieve a model based on adaptive-resilience and co-management, with a more comprehensive approach to territorial planning, more participative processes and stronger institutional networks.* They advocate for more inter-disciplinary research at the frontiers of social and biophysical sciences.

de Haan et al (2019) note that socioeconomic transitions such as those described above represent a shift in how local needs are being met, even though the force causing the change may not be local. However, these authors see a *potential for local Galápagos people to influence a transition to sustainable development which intimately concerns them and their way of life – a 'Galapageña' transition.* Some characteristics of the Galápagos human system include a bottom-up, informal structure of human occupation, as immigration was driven by perceived economic gain from higher paying jobs in the tourism industry and a weak economy in mainland Ecuador[3]. Often, immigrants from mainland Ecuador became illegal immigrants in their own country due to settling in the Special Regime despite population control. In addition, adaptive behaviour can be seen in the creation of fishing co-operatives, the co-management of the marine reserve and job diversification into the tourism industry, as a result of challenges to the fishing industry such as from shifts in external markets, conservation regulations and climate-ocean system factors related to ENSO (El Niño Southern Oscillation).

According to de Haan et al (2019), some aspects that might encourage a successful 'Galapageña' transition include community self-organisation (geographically dispersed, systemically connected, sustainable and sensitive to local needs) and co-evolution of the island's social and natural systems (which are intrinsically intertwined as one provides the economic basis for the other)[3]. A challenge for the notion of co-evolution is to ensure that the dynamics of the process are mutually beneficial, and towards increased sustainability. De Haan et al (2019) argue that there is scope for transition management, lasting beyond political cycles, bringing together representatives of communities, conservationists and government.

RESOURCES

FRESH WATER

Fresh water is a limited resource in the archipelago, and the availability varies greatly depending on whether it is an El Niño year (rainy) or La Niña (drought)[21]. Water resources that recharge the hydrological system include rain and 'garúa', a mist that forms in the highlands during the cool season, whereas the natural outlets that deplete the system include evaporation (high in the winter), infiltration (the rocks and soils in the Galápagos are very porous due to their volcanic origin) and springs[21].

The fresh water resources in the Galápagos can be summarised as belonging to the following categories[21]:

- Coastal lagoons & ocean outlets (vulnerable to changes in watersheds);
- Aquifers (vulnerable to contamination and depletion by over-exploitation);
- Ponds, lakes & wetlands (important resources, for humans as well as fauna);
- Springs & streams (very limited in the Galápagos except temporary flows, & vulnerable to contamination);
- Underground water (e.g., San Cristóbal).

d'Ozouville (2007) noted that the issues surrounding fresh water in the Galápagos stem from colonisation and the ensuing population growth occurring without an integrated water management plan taking into account rainfall/runoff, brackish water, exploitation, contamination, the national park and the agricultural zone[21]. *The most serious issues relate to the use of contaminated water for domestic use, the scarcity of fresh water resulting from leakages, and the use of brackish water for agriculture due to this scarcity[21].* The population is also mostly located in the arid coastal areas, compared to the highlands where more rainfall occurs[22]. Guyot-Téphany et al. (2013) also highlighted that the importation of a continental water distribution model is ill-adapted for the specific Galápagos context, and increases the disconnect between residents and the reality of water resources in an island context[22].

The water that is consumed in the Galápagos comes mainly from the public water network (83% of households)[10]. A small percentage of households also obtain water from springs, wells or by delivery (Table 4). The traditional practice of collecting rainwater also occurs, mostly in rural areas where no municipal piped water is available. However, this practice is not widespread and has decreased in port areas following the introduction of the municipal water network, and has also acquired negative connotations for residents[22]. An estimated 15–20 litres of water per person per day are required to meet the need for consumption, preparing food, basic hygiene and washing clothes[10]. Considering the resident and tourist population, this equates to a daily need for 257 million litres in 2020[10]. There is a current effort to measure the actual consumption in each municipality as there is a dearth of data related to the lack of water meterage.

USE	Santa Cruz	San Cristóbal	Isabela	Floreana
Domestic in urban zones	Municipal system – water from crevices and deep wells (not contaminated)	Municipal system - water from a stream (not El Junco Lake)	Municipal system – water from wells	Rainwater, spring
	Contaminated source (salt and fecal coliform)	Contamination beginning; leakage causes scarcity	Brackish, contaminated	Drought – lack of rain, the spring dries up
Domestic in rural zones	Rainwater	Rainwater, streams	Rainwater	Spring, rainwater
	Drought	Some streambeds are affected by drought	Drought	Drought
Potable Water	Private desalination plants; rainwater	Private desalination plants; rainwater	Imported drinking water; rainwater	Imported drinking water; rainwater
Water for agriculture	Rainwater, tank trucks – salty, contaminated water	Rainwater, streams	Rainwater, tank trucks – brackish, contaminated water	Rainwater - drought

Table 5: Freshwater uses on inhabited islands in the Galápagos (from d'Ozouville, 2007[21]).

Type of water	Unit price
Contaminated water from the Municipal system, domestic use	\$3.00 per month
Contaminated water from the Municipal system, commercial use	\$8.00 per month
Water from the deep well supplied to Bellavista with meters	\$1.21 per m^3
Contaminated water supplied by tank trucks, highlands	\$10 - \$30 per m^3
Desalinated water	\$100 (in jugs) per m^3 \$25 (from a hose) per m^3

Table 6: Prices of water on Santa Cruz (from d'Ozouville, 2007[21]).

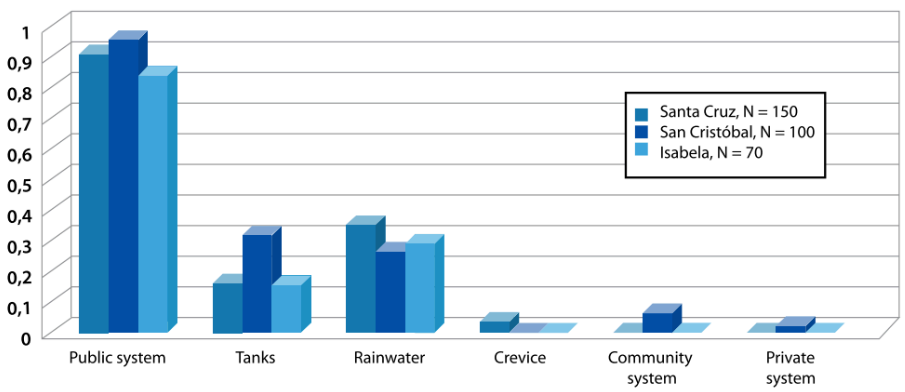

Fig. 13: Water use proportions for Galápagos households, from the study of Guyot-Téphany et al. (2013)[22]

The situation on each island can be summarised as follows:

- Contamination of aquifers in the coastal area is a big issue in **Santa Cruz**, affecting water quality. The state of the aquifer is not well understood, which limits exploitation. Farmers lack a source of fresh water for irrigation. Viable alternatives need to be sought[21].

- There are more abundant water resources in the highlands of **San Cristóbal**, however the distribution system is inadequate therefore the water does not reach the population[21]. The only perennial stream exists on San Cristóbal but a treatment system is needed for decontamination, as well as a monitoring system to aid in planning in the event of a drought.
- On **Isabela**, there are limited fresh water resources in the highlands and coastal resources suffer from contamination and salt water ingress[21].
- **Floreana** has a complete lack of water due to the depletion of resources[21]. People rely on rainwater collection and water importation.

The municipal water distribution systems are well advanced, especially in the port areas (88% of households on Santa Cruz, 93% on San Cristóbal and 81% on Isabela), where access to piped water is affordable (generally <10 USD/month) and viewed by residents as synonymous of comfort and development[22]. However, the quality of the piped water remains a significant issue, partly due to a lack of community involvement in water conservation[21]. In the three main inhabited islands, both the piped water and water distributed by tankers has been found to contain pathogens due to contamination from sewage[22]. Water stagnation in municipal pipes and poor conditions in residences is thought to amplify this problem, especially on Santa Cruz, where the supply is intermittent with an average of three hours supply per day[23]. Water treatment plants were launched in 2013 in both San Cristóbal and Floreana[10]. There are currently no plants in operation on Santa Cruz and Isabela, although a plant servicing the urban area of Santa Cruz is currently under construction. In addition, some homes are not connected to the public water network and consume pumped brackish water[10]. Overall, only 27% of homes in the Galápagos have access to potable water.

Guyot-Téphany et al. (2013) highlight a paradox in the water supply model in the Galápagos. The supply to coastal communities of freshwater via the municipal piped system and water tankers has enabled urban and population growth. However this expansion and the increase in tourism has put this system under pressure, resulting in water rationing[22]. This situation has resulted in the lack of piped water to households on the margins of the port communities, especially in Puerto Baquerizo Moreno. In addition, rainwater collection is no longer sufficient to cover the needs of communities in the highlands, especially for agriculture[22].

There are also major issues around water wastage, and it has been estimated that more water is wasted than is consumed[22]. Waste comes partially from leaks in the system due to ageing infrastructure and lack of maintenance[23], as well as on the side of users as there are no water meters in place and tariffs are fixed. Guyot-Téphany et al. (2013) surveyed residents and found that many people reported wasteful water practices, such as allowing their household water tanks to overflow. The lack of care related to piped water is explained by the awareness of residents with respect to its contamination, resulting in a perceived lack of value. Where possible, residents tend to buy purified water, collect water, or boil water at home for consumption and cooking, and use this contaminated water for other domestic uses[22]. These necessary practices have led to a distinction in the minds of residents regarding water for consumption and for other uses, with differences between islands resulting from their distinct situations (the distinction is made between freshwater and brackish water on Santa Cruz and Isabela, and between drinking water and piped water on San Cristóbal)[22].

Guyot-Téphany et al. (2013) note that there has been a change in perception relating to water over time. Historically, water scarcity and the search for water was foremost in the consciousness of early Galápagos settlers. Nowadays, residents tend to view the water as easily available and accessible, but with problems relating to the necessity of using brackish and contaminated water[22]. In other words, surveyed residents did not view the situation as one of scarcity, and responded that they could use as much water as a resident in mainland Ecuador, but not in the same way[22]. *There is therefore a disconnect between the concern of residents around the quality of water, and the unmeasured, easy access to water, which leads to a perceived lack of value of the piped water and wasteful practices[22].*

d'Ozouville (2007) recommended water management by watershed in the Galápagos, as is increasingly applied worldwide, with the involvement of all the authorities relevant to the watershed area[21]. Ongoing efforts should focus on the scientific characterisation of the water resources (e.g., understanding what resources exist and how the resources change seasonally and with climate change), public engagement and participation (e.g., highlighting the origin of the resource and engaging residents in its conservation) and political advocacy. There is also a need for further social science studies to understand the relationship between people and water, in order to solve these difficult issues[22]. Guyot-Téphany et al. (2013) recommended that improvement in the situation should come from changing the public perception to valuing water as a resource, as well as limiting water use[22]. Specifically, solutions should include promoting water practices that are appropriate for the island context (such as rain collection), improving the existing municipal distribution system (including the installation of a metering system), and promoting green technologies to deal with sewage appropriately and without using water[22].

Recently, Reyes et al. (2017) modelled the future water demand for Puerto Ayora over a 30-year period, based on various growth scenarios for the tourism industry, including a range of water demand management and supply scenarios (slow growth: 180,000 tourists per year, based on numbers for 2012, preferred by NGOs and the GNP; moderate growth: average annual increase of 4% in visitor numbers, based on figures over the past 20 years; rapid growth: average annual increase of 7%, a figure preferred by the central government to increase tourism revenues; very rapid growth: annual increase of 9%, with eight times as many tourists as residents by 2044)[23]. *These authors found that the current provision and infrastructure are insufficient for any growth scenario and concluded that the rapid and very rapid growth scenarios are unsustainable and unaffordable[23].* A strategy incorporating appropriate water demand reduction measures (leakage reduction, water meter installation, water demand management) and increased supply via desalination (combined with rain water collection and greywater recycling) was found to be the most viable scenario for coping with increased growth, but only in a slow growth scenario[23]. In addition, this strategy would significantly increase the energy demand for the island, as desalination is the most energy intensive method to produce drinking water, which could imply additional fuel importation from the mainland in the absence of an expansion of renewable energy sources. The disposal of brine from the treatment of sea water also represents a potential problem in this scenario[23]. None of the options that these authors explored were able to match demand in the moderate, rapid and very rapid growth scenarios, and the most viable strategy described above would not suffice to meet demand if the preferred rapid growth scenario is encouraged by the central government. Further studies are called for, including for example the use of desalination for drinking and cooking and the use of brackish water for other uses, and considering the possible impact of climate change on rainwater resources.

SOLID WASTE MANAGEMENT

The use of plastic bags was reduced through an initiative driven by the GNP, by distributing reusable canvas shopping bags for local families and charging for plastic bags in grocery stores. The use of plastic bags in the islands was then banned in 2015[5].

	Santa Cruz & Baltra	**San Cristobal & Floreana**	**Isabela**
	18,000 residents	9,500 residents	2,500 residents
	Approx. 14 tons/day	Approx. 6.6 tons/day	Approx. 3.4 tons/day
Residential	Recyclables, organic waste, non-recyclable waste; Main producer of non-recyclable, scrap and special waste		
Commercial	Main producer of recyclable and non-recyclable waste		
Bars & Restaurants	Large producer of recyclable and organic waste		
Tourism: Bars/Hotels	Large producer of recyclable and organic waste		
Marine Transport	Largest producer of fuel oil		

Electricity Generation	Second largest producer of used oil. Producer of special and toxic waste	Second largest producer of used oil. Producer of special and toxic waste	Largest producer of used oil. Producer of special and toxic waste (PCBs)
Fishing	Used oil and rubbish floating in the sea		
Artisanal & Semi-industrial	Large waste producer, including toxic and special waste		No detailed information available
Medical (clinics, hospitals, pharmacies)	Hospital waste, hazardous bio-waste		
Agriculture	Producer of special organic waste		No detailed information available

Table 7: Summary of current waste management practices, from CGREG[10]

ENERGY CONTEXT

ELECTRICITY SYSTEM

The Galapagos electricity system is composed of four isolated networks located in the islands of Santa Cruz–Baltra (connected by an 800 m underwater cable) , San Cristobal, Isabela, and Floreana[24]. Elecgalapagos S.A. is the company responsible for the generation, transmission, distribution and retailing of the electricity[25]. The interconnection of the four islands is not currently economically feasible as they are around 50–80 km apart and the cost of underwater cable is around US$ 15 million per km, considering cost data from of the Santa Cruz–Baltra interconnection[25].

The total installed electricity generation capacity of the islands is presented in Table 8.

Island	Diesel [kW]	Renewable			Total [kW]	Storage	
		Biofuel [kW]	Wind [kW]	Solar [kW]		Power [kW]	Capacity [MWh]
San Cristobal	7,190	-	2,400	13	11,403	-	-
Santa Cruz	11,850	-	2,250	1,600	18,660	Li 500	0,27
						Pb 500	4,03
Isabela	1,000	1,630[a]	-	952	3,582	Li 660	0,33
Floreana	-	290[a]	-	21	311	Pb 63	0,38
Total	24,800	19,200	4,650	2,586	33,856	1,729	5,01

[a] *dual diesel-jatropha oil that works on an 80/20 ratio of jatropha oil and diesel ratio[26]*

Table 8: Installed capacity for electricity generation in Galapagos[27]

With this installed capacity, 84% of the electricity generated in 2018 was produced from diesel, while 12% was produced by wind turbines and 4% by solar photovoltaic (PV)[27]. This demonstrates the heavy reliance of the archipelago's electricity system on diesel imports from the mainland. Fig. 14 displays the detailed energy generation by technology for each island.

On both Isabela and Floreana, the thermal generation runs on biofuel produced from jatropha oil (also referred to as *piñón*), which is extracted from the fruit of a tree cultivated as "living fences" by small farmers, therefore it does not compete with food production and currently does not require extra land use. However, this oil is produced in the Guanabi province of mainland Ecuador, and must be transported to the archipelago at a total cost of 8 US$/gallon in 2014[28].

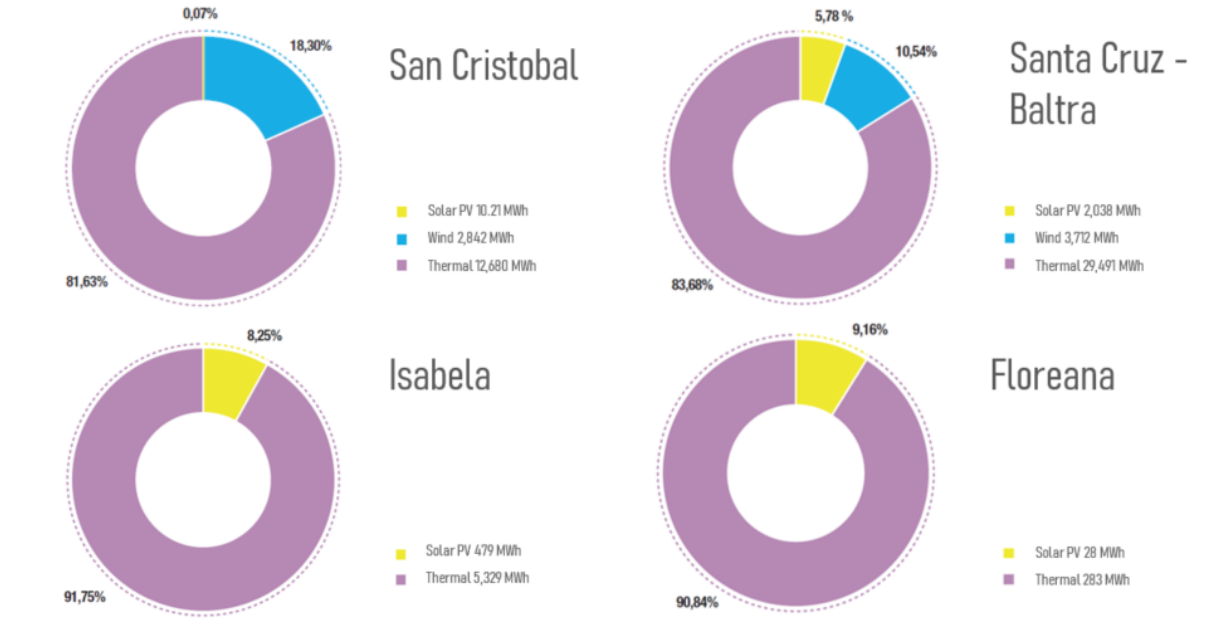

Fig. 14: Electricity generated on each island, subdivided by technology[27]

The electricity system comprises 298 km of medium voltage lines (13.2–34.5 kV), 6 step-up voltage substations (24 transformers), 1 step-down voltage substation (1 transformer). The losses in the system are 8.63%, with 7.29% corresponding to technical losses[29]. The total number of supplied clients is 12484, of which 9729 are residential, 2015 are commercial and only 185 are industrial[30].

The development of renewable generation in Galapagos was aided by a feed in tariff (FIT) system that was in place from 2000–2015 with special tariffs introduced in 2013 for Galapagos, which set the FIT at 12.91 cUS$/kWh for wind generation but did not support solar PV. In 2014, a new resolution maintained the FIT only for biomass, biogas and for hydropower smaller than 30 MW[31]. Additionally, the installation of distributed solar PV systems below 300 kW for residential users and 1000 kW for commercial users is supported by a net-metering scheme[32].

In 2018 the total electricity generated in the islands reached round 56 GWh and a demand of around 90 GWh is forecasted for 2025, with a renewable generation participation projected to reach 56% by that date[27]. To achieve this, a generation capacity expansion plan has been developed by the authorities and considers additional capacity from wind farms and PV generation, as well as new storage and smart grid capabilities, as detailed in Table 9.

Location	Project type	Expected start-up year	Capacity [MW]	Capacity factor	Cost [MUSD]
San Cristobal	Photovoltaic	2020	1	21%	8.5
	Energy storage	2020	1.4	-	
	Automation of hybrid system	2020	-	-	0.5
	Wind	2022	5.6	15%	12.3
	Energy storage	2022	2.2	-	1.3
	Photovoltaic	2024	2.5	19%	5.71
Santa Cruz - Baltra	Second face Baltra wind	2022	6.75	23%	14.8
	Photovoltaic	2022	4	20%	9.14
	Energy storage	2022	30	-	18

	Smart grid	2022	-	-	2.26
	Third face Baltra wind	2025	2.75	18%	6.03
	Photovoltaic	2025	1.5	21%	3.43
	Energy storage	2025	10	-	6
Isabella	Photovoltaic	2021	0.8	20%	1.82
	Energy storage	2021	1	-	1.5
	Photovoltaic	2023	0.5	23%	1.14
	Energy storage	2023	7.1	-	4.26
	Photovoltaic	2025	0.5	23%	1.42
	Energy storage	2025	4.3	-	2.58
Floreana	Photovoltaic	2020	0.09	20%	0.31
	Energy storage	2020	0.384	-	0.33
	Photovoltaic	2023	0.08	20%	1.83
Total					103.16

Table 9: Projects considered in the current expansion plan[27]

ANALYSIS OF BALTRA WIND FARM OPERATION

Baltra wind farm started operating in November 2014. It consists of three Unison U57 wind turbines with a rated capacity of 750 kW each.

There have been reports that this plant has not been operating at its full capacity due to reasons that could be related to insufficient demand in the system or to operational issues. Fig. 15 presents the actual number of hours that the wind far generated 0 kW from January 2016 to May 2017 and compares it to an estimation of how many hours of 0 kW generation there should be. This estimation is based on wind data from Renewables.ninja[33] for Baltra, considering 3 m/s as the minimum generation wind speed.

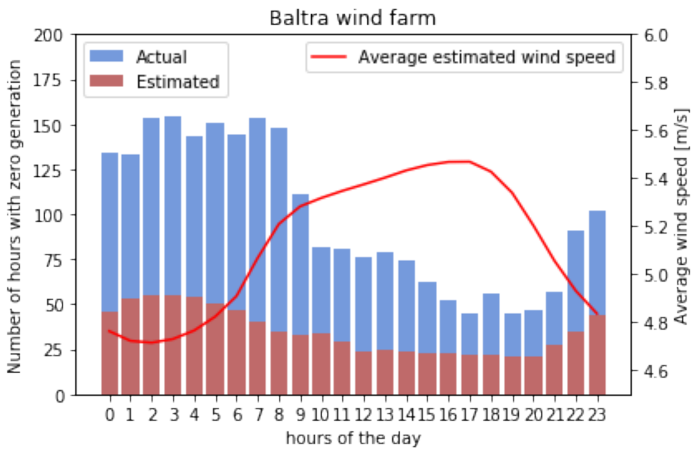

Fig. 15: Total hours with no generation at the Baltra wind farm

It is clear from Fig. 15 that the days when the turbines are not operating relates inversely with the wind speed. The estimated non-operational hours are between 30 and 50% less than the actual observed non-operational hours. However, it is likely that this discrepancy is due to operational issues and not to curtailment due to lack of demand, as Fig. 16 shows that for most of the non-operational hours of the wind farm (hours when the wind farm's output was 0 kW) the total generation in the Santa Cruz–Baltra system was well above 2000 kW.

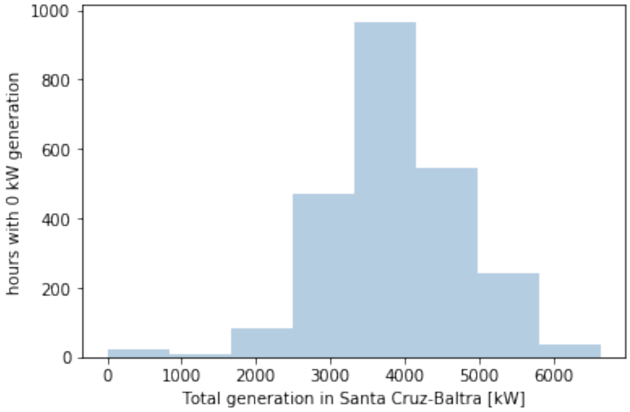

Fig. 16: Histogram of the total generation in the Santa Cruz–Baltra system in the hours when Baltra's wind farm output was 0 kW

ENERGY UTILISATION

The total energy used in the archipelago in 2018 was 329.3 kBEP (barrels of oil equivalent), which equals 539 GWh[34]. As shown in Fig. 17, the main energy consumer in the islands is the transport sector, and the main energy sources are diesel and petrol, used to fuel that transport.

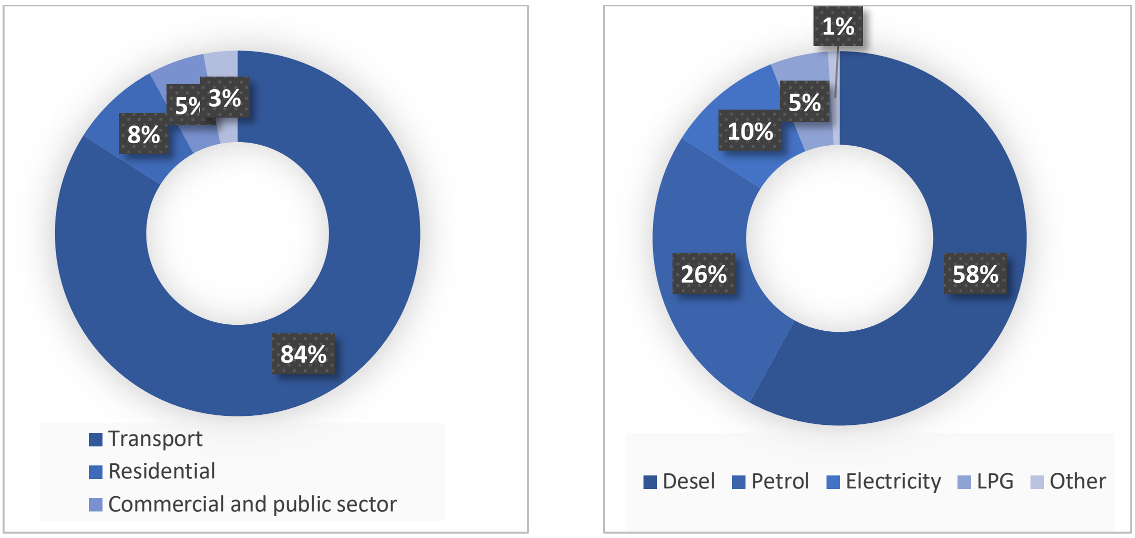

Fig. 17: Energy consumption by sector (left) and by source (right) in Galapagos in 2018[34]

Further details of the energy sources in each sector are presented in Fig. 18:

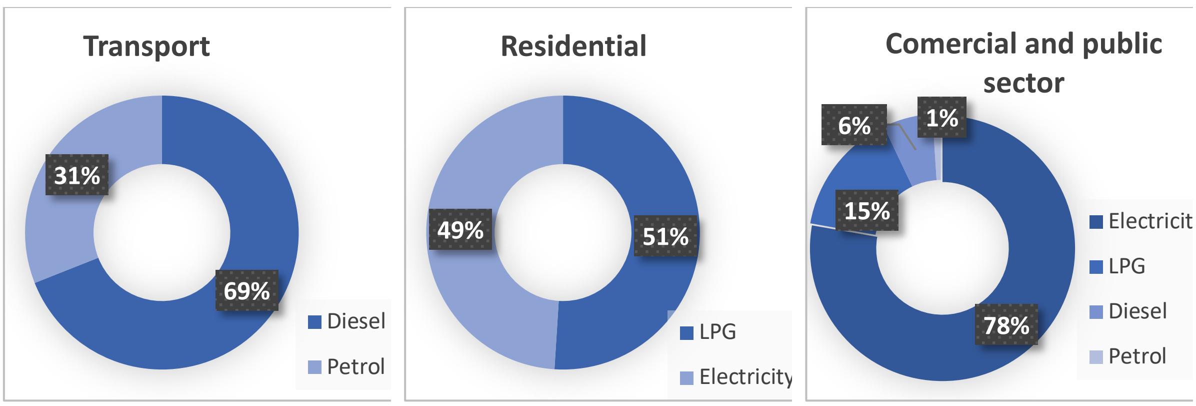

Fig. 18: Energy consumption by energy source, by sector[34]

This summary was developed based on the best publicly available information. However, currently the project "Plan de acción para la transición energética del Archipiélago de las Galápagos – Período 2020–2040" is being carried out by Fundación Bariloche, funded by the Interamerican Development Bank. It is expected that some of the main outcomes will be projections on energy consumption patterns, and most importantly, projections on final energy uses. This report should be available by the end of 2020.

ELECTRICITY UTILISATION

In 2018 the electricity consumption in the islands was 51.3 GWh[34] , which represented an increase of 2.86% with respect to 2017[27].

The per capita electricity demand in the province of Galapagos is the second largest in Ecuador, with 1,558 kWh/inhabitant in 2016[24]. The prices of electricity are around 0.1 US$/kWh for most of the clients, but a subsidy sets the price to 0.04 US$/kWh for clients who use less than 130 kWh/month. The prices for public lighting are higher, at around 0.23 US$/kWh[24]. All of these prices are lower than the real generation cost, which for diesel generation is 0.256 US$/kWh[25].

The share of the electricity demand is 41% residential, 42% commercial, 16% street lighting and other public services, and 1% industrial, according to Eras-Almeida et al. (2020)[32].

Fig. 19 shows the monthly energy consumption in 2018 for each island. It can be noted that there are important seasonal variations, with higher consumption in December–May. This corresponds to the hottest and most touristic season. It is interesting to note that these patterns are similar for the three largest islands, although the variability is less clear for Floreana, probably due to a lower tourist-related consumption and to a lower use of air conditioning on that island.

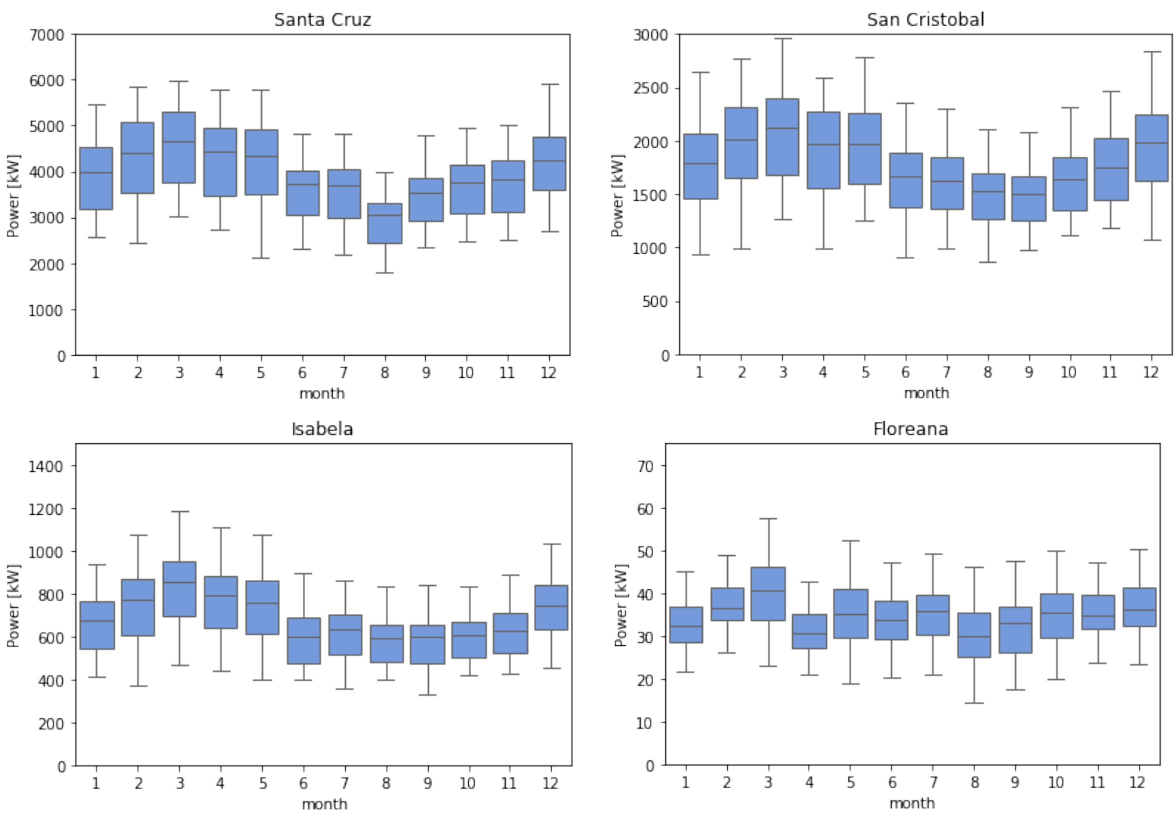

Fig. 19: Power consumption for each island in 2018

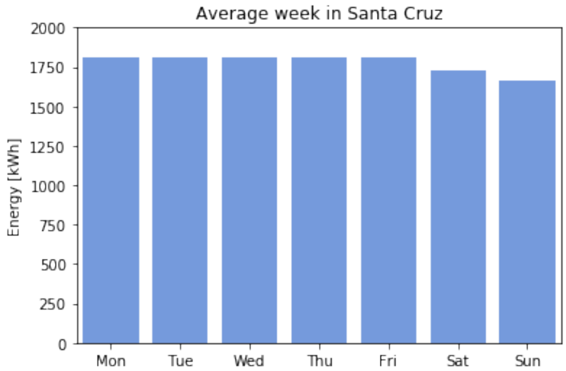

Fig. 20: Energy Consumption during an average week in Santa Cruz in 2018

There are no relevant variations in electricity consumption between the average weekdays, but Fig. 20 shows that on a Sunday there is close to 8% less consumption than during weekdays for an average week in Santa Cruz.

Fig. 21 shows the daily variation in energy consumption for days with high (summer) and a low (winter) consumption in Santa Cruz. While the peak of consumption in both cases is in the evening (at 7 pm), in the summer period there is a high consumption during most of the afternoon, probably due to a higher incidence of air conditioning.

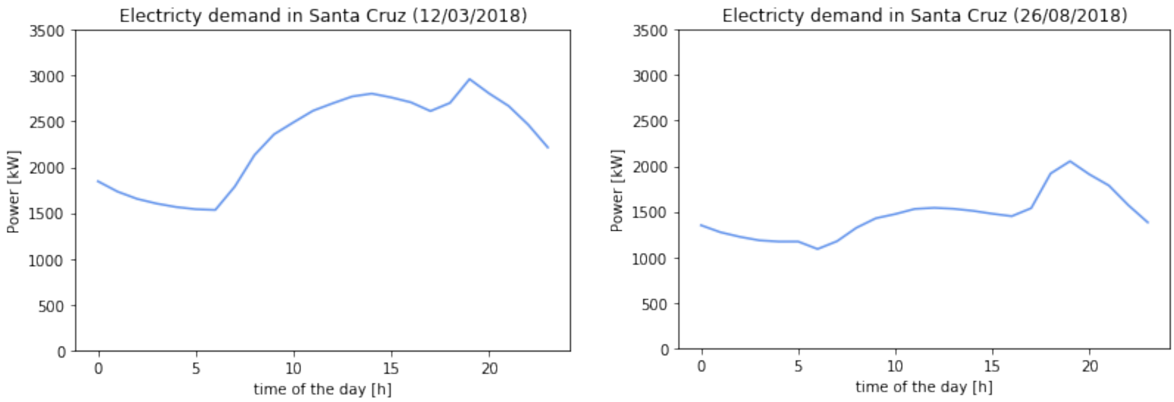

Fig. 21: Seasonal daily electricity demand in Galapagos

Several energy efficiency programs promoted by the central government have been underway in recent years and could have had impacts on the past consumption patterns, and could also potentially have future impacts. Between 2012 and 2016, 1109 inefficient refrigerators were replaced in Galapagos[24], of a total of 3000 expected to be replaced by 2022[35]. It is expected that this program could have an impact of around a 2.4 MWh reduction by 2022[24]. Another program is the PEC program, which aims to replace gas stoves by highly efficient electric induction stoves, and which had replaced 142 stoves by 2015.[24] Eras et al. (2015)[32] assessed the impact of the large scale introduction of induction stoves in Galapagos (8000–9000 in total over the four islands) and concluded that their concurrent use would require the intermittent operation of reserve diesel generators, especially at lunch time. It is important to note that the final energy efficiency of cooking increases from around 50% to close to 90% when replacing a gas stove by an induction stove. However, the fossil fuel consumption may increase if the electricity for cooking is produced with low efficiency fossil fuel-based technologies (such as diesel engine generators with a 35–45% efficiency and 10% transmission losses).

Currently, there are two solar-electric boats operating in the Galapagos. The first is a small 11-passenger boat which has been operating from 2014 for short (7.6 km) touristic trips to the Tintoreras islets (Isabela)[36]. The second is the Genesis Solar catamaran which transports passengers across the Itabaca channel between Baltra and Santa Cruz. This vessel has a 44-passenger capacity and performs around 8 roundtrip crossings per day (600 m each)[37].

According to Plan V (2019)[38], by early 2019 there were 276 electric vehicles in the archipelago. This fleet comprised mostly Chinese Hanteng and Chok brands, as well as 40 Kia Soul vehicles. However, from February 2019, there has been a moratorium on the importation of electric vehicles to Santa Cruz until an assessment of the capacity of the electric system to cope with new electric vehicles is performed[39].

FUEL UTILISATION

The fuels used in the province are diesel, gasoline and liquefied petroleum gas (LPG), which are all imported from the mainland.

The main consumer of fossil fuels is maritime transport, which accounts for almost 60% of the total fuel consumption, as shown in Fig. 22. It is inferred that gasoline is used mainly for terrestrial light vehicle transport and smaller off-board engine boats, while diesel is used for larger maritime transport and for electricity generation. This agrees with Ouvard et al. (2010)[40], who note that 60% of the diesel was used by the tourism sector (transport) and 26% for electricity generation, while 41.5% of gasoline was used for transportation, 21.5% for fishing and 17.5% for electricity generation (most likely in small domestic or commercial generators) in 2010.

In the case of LPG, it is used mostly for cooking and water heating (85% and 15% respectively)[40].

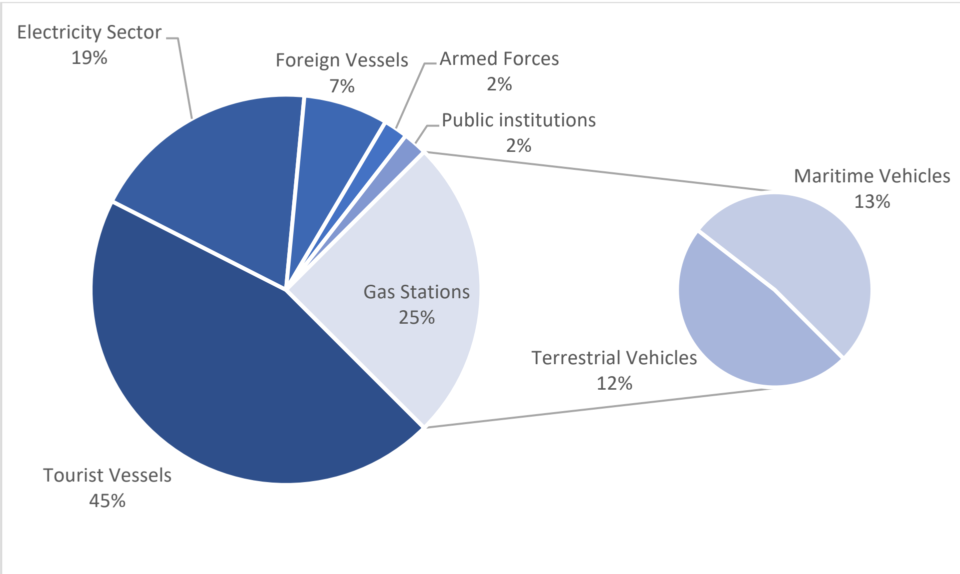

Fig. 22: Fuel consumption by sector in Galapagos in 2010[41]

There appear to exist no more recently-updated data, as Apolo et al. (2019)[25] used the data same source. According to Tyler (2018)[42], in 2010 there were between 40–50 boats (launches) operating as transport between the islands, although Plan Galapagos[9] mentions 31.

For land transport, preliminary information from the project currently being carried out by Fundación Bariloche, indicates an estimated 2871 vehicles in the archipelago in 2019. 210 of these correspond to electric vehicles. Among the remaining vehicles, 213 correspond to lorries of various sizes, 170 to cars, 932 to pickup trucks, 107 to buses and minibuses and 1238 to motorcycles.

In 2018, the consumption of fuel in the province of Galapagos for electricity generation was 11.8 ktoe of diesel (approx. 12,000 m^3)[30].

According to data from a survey conducted in 2013, 5% of the population used an LPG heater for domestic hot water (DHW) and 6% used the stove (also LPG at that time), while 55% used an electric shower and 34% did not use DHW[43]. For cooking, according to 2015 census information, 93.3% of households use LPG, while 2.5% use electricity[44]. It is likely that these figures have changed in the last few years as a result of the programme replacing gas stoves by electric induction systems.

It is important to consider that fuel prices in the archipelago are subsidised, as in the rest of the country. The price for diesel for transport is around 0.4 US$/l and for electricity generation is around 0.24 US$/l, and the price for gasoline (petrol) is between 0.27 and 0.42 US$/l, depending on the final use[42]. These prices include a subsidy for the fuel transport to the islands. According to Tyler (2018)[42] the diesel used in the tourism sector has not been subsidised since 2010.

GALAPAGOS CLEAN ENERGY PROPOSALS AND STUDIES

Several approaches to decrease the carbon footprint of the energy use in Galapagos have been analysed in previous research. Most of these focus on decreasing the carbon footprint of the electricity generation in the archipelago, by means of increasing the generation from renewable energies and improving the grid operation via demand side management and better grid management.

The archipelago has interesting potential for electricity generation via wind and solar PV technologies. In particular, Cevallos-Sierra et al. (2018)[45] identified the archipelago as one of the provinces in Ecuador that could potentially benefit the most from solar resources. Global horizontal irradiance (GHI) values in Galapagos are in the range 1650–2250 kWh/m^2-year. The best areas for solar resources are the coasts of Santa Cruz, the coastal strip of Baltra, northern and southern Floreana, and a large area of San Cristobal[24].

The wind conditions in the islands are not optimal for electricity generation, mainly due to their low latitude, with winds in the range of 4.2–7.28 m/s[32]. However, two wind parks have been installed successfully in the archipelago, and have reached capacity factors around 13–15%[24].

According to Llerena-Pizarro et al. (2019)[24] there is a production of around 550–950 tons/year of organic matter from municipal waste in the archipelago that could be transformed into biogas in biodigestors. Romo-Rabago, in Tyler (2018)[42], assessed the impact of using biodigestors to treat solid residue in San Cristobal island and concluded that it would be possible to produce around 50,735 m^3/year of biogas. This biogas could be used to produce around 304 MWh/year of electricity[42], around 2% of the island's annual consumption. Other potential sources of energy identified by Llerena-Pizarro et al. (2019)[24] are bovine manure produced by the close to 10,000 heads of cattle present in the islands, which could also be processed in biodigestors.

The potential of geothermal energy has also been documented, with a possibility of generating close to 100 MW on Isabela, but without the existence of official information. Wave energy generation potential has also been identified[24]. However, no quantitative assessment of these resources has been published to date.

Cubi, in Tyler (2018)[42], performed a life cycle assessment (LCA) comparing the use of diesel and gasoline for transport and energy generation with a) the use of natural gas for electricity generation and gas to liquid technologies for transport; and b) the use of biodiesel produced on the mainland from jatropha for both services. The natural gas alternative only decreases by 10% the total LCA emissions compared with the current situation (diesel + gasoline) at three times the cost. Additionally, this scenario would require the development of natural gas production in Ecuador, or a 70% increase in the use of natural gas in mainland Ecuador to make it economically viable to import natural gas to the country, as the energy consumption of Galapagos is not sufficient to justify imports from abroad. The case considering jatropha oil, on the other hand, reduces the LCA emissions by 69% at a similar cost as the current situation. However, the land use requirement for this scenario is between 20 and 150 km^2, and this could potentially distort food production markets[42]. It is important to note that none of these alternatives reduces the dependency of Galapagos on mainland energy imports.

Morales et al. (2017, 2018)[46,47] performed a simulation analysis of the electric grid in Santa Cruz (not considering the Baltra interconnection) analysing how it would behave under scenarios of high penetration of induction cookers and electric vehicles (one per each connected client) and increased population growth, as well as how 15% of demand side load management would affect its operation. They also analysed the possibility of using battery energy storage to store morning PV generation surplus for use during the peak demand, as well as the adoption of time of use tariffs that "penalise" consumption during peak periods[46]. Several technical parameters were assessed and the general conclusions state that a demand side management system and the use of batteries would decrease the peak load and are techno-economically feasible.

Clairand et al. (2019)[48] assessed several scenarios with different levels of penetration of electric vehicles (EV) and induction stoves (IS) in Santa Cruz. For these scenarios, the authors analysed the possibility of supplying the extra demand through new solar PV generation and new batteries backed up by the existing diesel capacity. The authors concluded that the scenario with 100% penetration of EVs and ISs presents an energy consumption of 56 GWh/year (in contrast with the 32 GWh/year consumption for the scenario with 0% penetration) which could be supplied using the current system plus an additional 5.62 MW of solar PV.

Llerena-Pizarro et al. (2019)[24] proposed a hybrid power generation system for the archipelago to reach zero fossil fuel use by 2025. The proposed system consists mainly of solar PV generation supported by battery energy storage and biogas thermal electricity generation. The different interactions in the proposed system are shown in Fig. 23, and the specific capacities that would be required are given in Table 10. The technical feasibility of the system was simulated, however no economic feasibility analysis was presented.

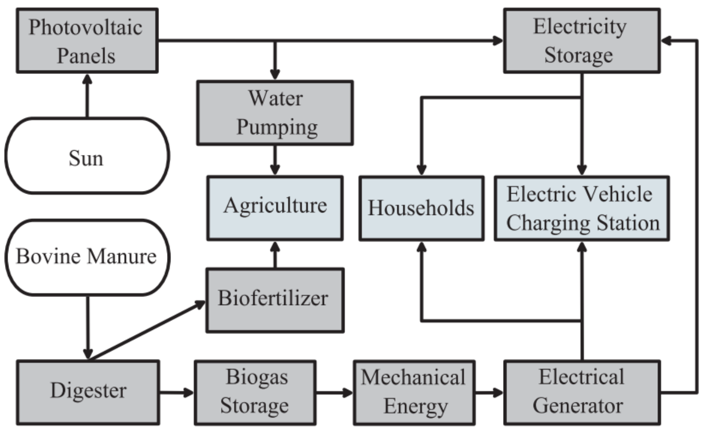

Fig. 23: Logic of the system proposed by Llerena-Pizarro et al.[24]

	New annual demand to supply by 2025 [MWh]	New PV [kW]	New Biogas [kW]	New Batteries [kWh]
Floreana	19.4	2.4	1.9	20
Isabela	3,960	405	475	2988
San Cristobal	1,969	97	300	1586
Santa Cruz	15,256	2,858	4,500	21,469

Table 10: Proposed additional installed capacity of each technology by island by 2025 [24]

It is important to mention that Llerena-Pizarro et al. (2019) assumed that the current demand will be supplied by the existing generation mix (highly dominated by diesel).

Eras-Almeida et al. (2020)[32] proposed a similar approach to reach zero fossil fuel use by 2030 using imported biodiesel instead of biogas, for the islands of Santa Cruz and Baltra. Several options where analysed and the results presented in Table 11 summarise the alternatives that optimise the penetration of renewable generation and the levelised cost of the energy produced (LCOE). Two energy consumption growth scenarios were considered, 50 GWh/year and 74 GWh/year, with the first considering energy efficiency policies applied in the islands.

A scenario to achieve 70% renewable energy penetration without using biodiesel was also assessed, but this yielded very high LCOE in the range 85–100 US$/kWh, and required the use of 180–280 ha of land for energy generation. This is considered infeasible from both economic and environmental (land use) perspectives.

	PV [kW]	Wind [kW]	Diesel [kW]	Biodiesel [kW]	Battery [kWh]	Renewable energy [%]	LCOE [US$/kWh]
Santa Cruz (74 GWh/year)	19,820	2,250	13,900	-	24,980	39	18.95
Santa Cruz (74 GWh/year)	20,030	5,450	-	13,900	25,620	100	25.19
Santa Cruz (50 GWh/year)	10,970	2,250	13,900	-	4,300	37.5	17.10
Santa Cruz (50 GWh/year)	12,250	5,450	-	13,900	4,300	100	23.22

Table 11: Proposed installed capacity of each technology by island by 2030[32]

The study also analysed the possible impact of distributed rooftop PV generation. The authors concluded that there is the potential to generate 18 MW using rooftop PV systems, and noted that due to the lack of available land, this could be the most attractive alternative to increase the penetration of renewable generation.

It is worth noting that this analysis presents significant discrepancies in the installed capacity required to meet the demand on Santa Cruz Island by 2030 compared to that in the study by Llerena-Pizarro et al. (2019), to meet demand by 2025.

Adrichem et al. (2019)[49] proposed a 2.25 MW floating PV system in Academy Bay, Santa Cruz. The system would consist of a 79 x 205.5 m floating platform located atop waters with 25 m depth to decrease the shadow's impact on benthic species. The system was estimated to cost around 6.83 million USD, leading to around 0.105 USD/kWh LCOE, if a 1.59% discount rate is used. However, a PV panel cost of around 1.5 USD/W was considered, which could be an understatement of the actual costs.

CLEAN ENERGY OPTIONS

This section explores the different technologies that are currently available and could be well-adapted for a future clean energy scenario, considering the current social, geographical and energy context presented in the previous sections.

ELECTRICITY GENERATION

SOLAR PV

Solar energy is one of the most abundant resources in the archipelago due to its location on the equator. Galapagos has an average of close to 6 kWh/m^2-day, with low variability throughout the year. The lowest levels are related to the cloudier rainy season.

Considering these levels of irradiation and 18% efficiency for PV panels, 100,000 m^2 would be sufficient to generate the annual electricity demand of Santa Cruz in 2018 (35 GWh) if enough energy storage was in place. However, land availability is a potential issue in the islands, as 97% of the surface is within the national park boundaries. An alternative based on floating PV panels was proposed by a team from the University of Delft[49] with an estimated cost of 3.1 USD/Wp. Another option would be to use rooftop-mounted solar PV distributed on the different buildings in the islands. These systems could in theory produce close to 80% of the annual electricity demand of Santa Cruz, assuming that there are around 7000 houses on the island[44] and the installation of a 3.8 kWp PV system on each house, with a 13% capacity factor, as estimated by Pesantez (2015) for the city of Guayaquil[50].

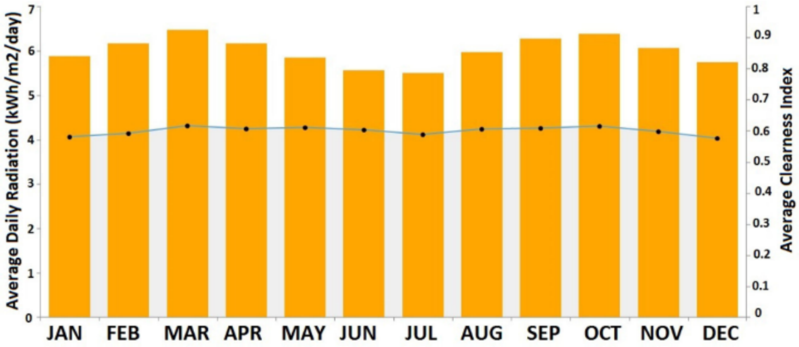

Fig. 24: Average daily horizontal irradiance during each month[48]

WIND TURBINES

Due to its location close to the equator, the wind speed in the islands are not especially good, with a 5–6 m/s yearly average at 50 m. There are currently two wind parks in operation and there is potential for further development. However, the impact on birds and the visual impact have to be taken into consideration.

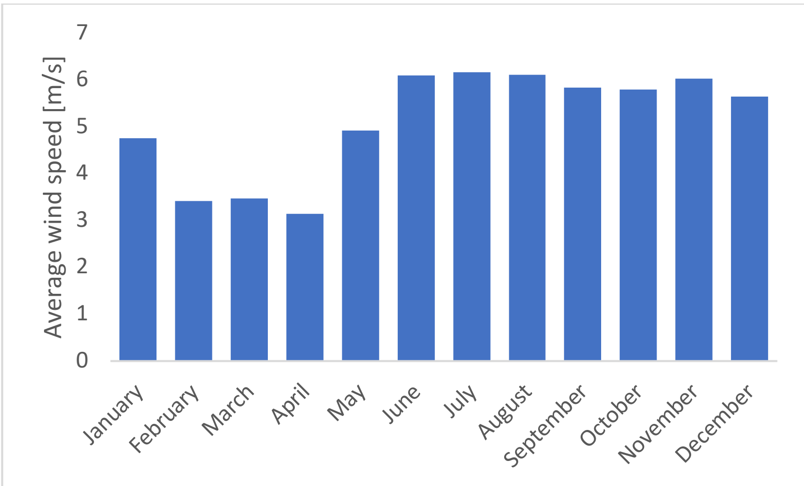

Fig. 25: Average wind speed in Baltra at 60m height[33]

BIOGAS

According to Llerena-Pizarro et al. (2019)[24] there is a production of around 550–950 tons/year of organic matter from municipal waste in the archipelago that could be transformed into biogas via biodigestors. Romo-Rabago, in Tyler (2018)[42], assessed the impact of using biodigestors to treat solid residue in San Cristobal and concluded that it would be possible to produce around 50,735 m^3/year of biogas in the island. If expanded according to population, it could be assumed that a production of 150,000–200,000 m^3/year could be reached in the archipelago from waste. This biogas could be used to produce around 900 MWh/year of electricity if burned in a generator[42], around 2% of the annual electricity consumption, or replace around 0.5% of the diesel used for electricity generation. Other potential sources of energy identified by Llerena-Pizarro et al. (2019)[24] are bovine manure produced by the close to 10,000 heads of cattle present in the islands that could also be processed in biodigestors, but this is yet to be quantified.

To promote the use of this technology is also one of the goals of the Galapagos sustainability plan (Plan Galapagos)[10], in which policy 1.1–goal 1.1.c aims to achieve a goal of 2% of houses with "sustainability parameters", such as biodigestors. As no details of the logistics of collection or use of the produced biogas are given in this document, it is possible to assume that the intention is to use that biogas directly in households for thermal purposes such as cooking or domestic hot water. However, it is worth analysing whether it would make more sense to operate a more centralised system. This would require a more complex waste collection system, but would achieve better control of the operation of the biodigestor and present the possibility to upgrade the biogas (CO_2 removal) and to use it in electricity generation.

BIODIESEL

Currently biodiesel from jatropha oil is used in the islands to generate electricity in diesel generators. This diesel is produced on the continent and shipped to the archipelago, which increases its cost and reduces the environmental gains. It is unlikely that the scarce cultivable land could be used to produce biofuels. Other sources for biofuels, such as second-generation biodiesel from algae could be used. In any case, the land and environmental footprint has to be carefully assessed. There would also probably be a better case for biodiesel used for marine transport rather than for electricity generation, as there are limited alternatives to replace the use of fossil fuels in speed boats.

Another option that is worth considering is the possibility of producing biodiesel from recycled cooking oil. Although this option would generate a limited amount of biodiesel, previous studies show that the cost of producing biodiesel from cooking oils in Brazil can be up to 45% lower compared to using virgin oils, and this also decreases the amount of oil that end up in landfills[51].

OCEAN THERMAL ENERGY CONVERSION (OTEC)

This technology generates power from the difference in temperature between the surface and the deep sea. The temperature difference increases with depth and tends to be more constant through the year in tropical locations.

Given the location of Galapagos on the equator, which results in availability of warm surface waters, and the presence of a 3000 to 3500 m deep trench (Fig. 26), OTEC could be a viable option for generating electricity. However, the distance to the main demand points and the small scale of the demand are parameters that could hinder the development of this option.

An alternative to power generation is the use of OTEC to desalinate sea water. One example of this is the Kavaratti plant in the Andaman Islands, India. This plant, currently in development, will have the capacity to produce around 100 m^3 of fresh water per day.

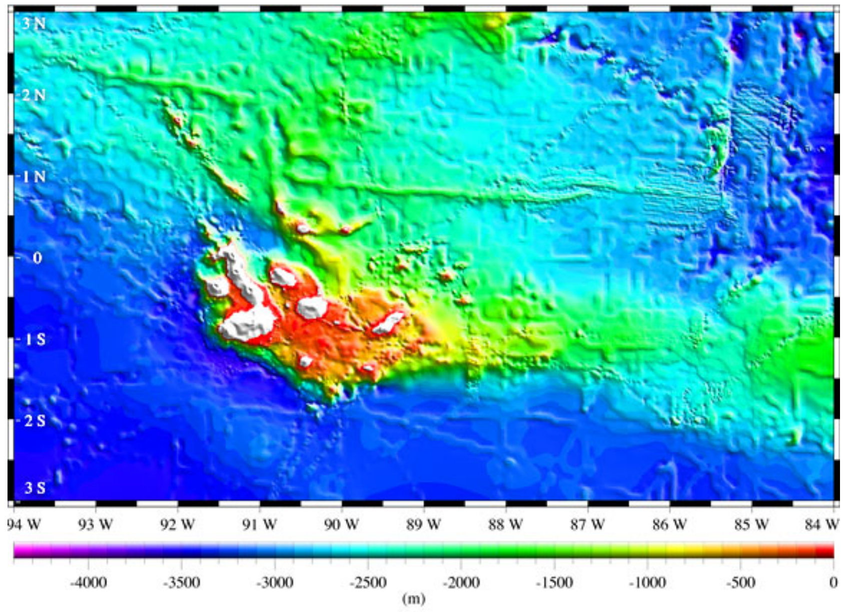

Fig. 26: Bathymetry of the Galapagos Islands and surrounding ocean floor[52]

TIDAL AND WAVE ENERGY

Tidal energy uses the energy from the movement of ocean water due to the change in tides. This could be harnessed by a dam that could retain the high tide water then use the potential energy of the height difference between the dammed water and the low tide, or by turbines that could harvest the energy of the current generated by the tidal movement. This type of energy is highly predictable, as it depends on the movements of the moon, earth and sun. However, this system only produces energy during a few hours per day, which would require an important amount of energy storage or other grid balancing technologies.

Wave energy converters harvest the energy of the waves driven by the wind on the surface of the seas. It is less predictable than tidal energy, as it depends mostly on the wind. It also tends to be more modular, as wave energy conversion devices tend to be smaller in power and many of them can be placed together. In order to quantify the potential of this technology, an assessment of the resource characteristics has be performed based on models and local measurements. The interaction between the energy converters and the marine species must also be assessed.

GEOTHERMAL

The Galapagos archipelago is located atop a hot spot in the Pacific Ocean. Alcedo volcano, located on Isabela, has been specifically identified as a high-temperature geothermal source with a potential capacity of up to 150 MW of electric production[53]. However, no further information on the temperatures or other characteristics of the resource have been published.

Although a conventional geothermal power plant would require a high and relatively steady electricity demand, which is not the case on Isabela, as shown in Fig. 19, slim-hole power plants in the range of 100 to 1000 kWe are possible. This is well in the range of the average demand of 500 kW on Isabela.

A potential drawback of this reliable technology for generating electricity is its possible visual impact on the environment and the drilling and other interventions that would be required in the National Park area.

FUEL CELLS

Fuel cells allow the transformation of chemical potential energy stored in the molecular bonds of fuel to electricity. There are different types of fuel cells that use different fuels. However, the most common is the polymer electrolyte membrane (PEM) cell, which uses hydrogen that reacts with oxygen from the air, producing electricity and water.

This technology is modular and does not require special conditions for its location, apart from proximity to the fuel. Its scalability allows for its use to power small land vehicles, ships, and electricity generation plants without any environmental impact.

ENERGY STORAGE

The intermittent and seasonal nature of the most affordable and readily available technologies for electricity generation requires the use of supplementary technologies that provide flexibility to the energy system, allowing a better match between generation and demand. This flexibility can be provided by different technologies that can shift the energy generation in time (energy storage) paying an energy cost due to the storage efficiency, or by shifting the energy demand.

PUMPED HYDRO

Pumped hydro is by far the most used and mature energy storage technology in the world. However, it is highly constrained by geographical characteristics, as it requires two close reservoirs at different elevations to generate a difference in potential energy. More recent projects have proposed the use of the sea as a lower reservoir, which increases the range of locations, as it requires only an upper reservoir close to the sea. However, the use of sea water increases the costs, due to the requirement of more expensive materials.

All the major islands in the archipelago feature points with elevations above 400 m, however without natural reservoirs. Major interventions would therefore be required to build these potential reservoirs.

BATTERY STORAGE

There exist different technologies that allow electricity to be stored as chemical potential energy. Among these, lithium-ion batteries are the most used and more than 500 kWh of capacity are already in use in the electricity system of the archipelago. It is a modular and non-invasive technology that does not have major environmental impacts during its construction or operating phase, although an end of life recycling process needs to be considered.

The modularity of such a system allows for its colocation with distributed intermittent energy technologies, such as rooftop PV panels. However, its relative high cost of around 300 US$/kWh[54] limits grid-scale deployment for larger applications and long-term storage.

HYDROGEN

Hydrogen can be produced with an electrolyser that uses cheap surplus electricity produced through one of the above-mentioned renewable energy generation technologies. The hydrogen can be stored in high-pressure tanks for later use at relatively low costs (under 20 US$/kWh[55]), which allows its storage over long periods. It can be also transported through pipes or smaller containers in a similar manner to natural gas, and can be used to produce electricity in the grid or to move a vehicle by means of a fuel cell.

Storing and using hydrogen produced from solar or wind energy to generate electricity provides the required flexibility in the electric grid. It also allows for its use as a fuel for any vehicle, from cars to inter-island ships. The main drawback of this technology is that it requires new infrastructure to be built for producing, storing and transporting the hydrogen, as well as investing in the fuel cells to convert it into electricity. This means that an entire system built around this energy vector should be developed.

One example of this strategy is in place on the island of Eday, in Orkney, where an electrolyser produces hydrogen with electricity from a wind turbine that otherwise would have been curtailed. The hydrogen is stored and later shipped to a nearby island, where a fuel cell uses it to generate electricity[56].

DEMAND SHIFTING

An alternative to shifting the energy generation in time by means of energy storage is to shift the energy demand in time (also known as demand side response). This is related to the possibility of deferring some energy uses in time, as some services are not required in a specific moment but rather during a time window. Examples of these uses include running washing machines, charging electric vehicles and pumping operations to fill tanks. Other energy uses that allow some flexibility in their operation are those with high thermal inertia, such as refrigeration services (fridges).

The operation of this schemes requires a high degree of coordination between the energy supplier and the end users, which usually involves “smart grid” elements such as local switches that would communicate with the network and manage the operation of the flexible load, as well as regulatory modifications that would enable the technical operation and would modify the market to provide revenue streams to the different participants.

An interesting case study that could be applied in the archipelago would be to implement electricity-driven water desalination and pumping systems. Although water demand is not necessarily flexible, it can be decoupled from water desalination and pumping by use of a water storage system that works as a buffer. This would allow the freshwater production to stop at times of low energy supply availability, providing demand side flexibility to the electric network.

LAND TRANSPORT

ELECTRIC VEHICLES

Electric vehicles (EV) represent examples of a mature technology, and are currently in use in the island. However, constraints in the electric grid hinder the expansion of EVs, and a moratorium on new EV imports is in place[39]. Further development of the electric grid and charging infrastructure would allow the number of EVs operating in the islands to increase.

It is important to stress that EVs are only clean if the electric grid they are charging from is green. It will therefore only make sense to increase the number of EVs if the grid expansion plans move towards a cleaner electricity supply.

One added advantage of using this technology is that it could provide an extra source of flexibility to the grid through the implementation of a smart charging timing scheme, and the possibility of using the energy stored in the car’s batteries for grid support if required. On the other hand, the long charging periods (between 40 min for a super-fast charger to 8 hours) mean that the users would need to adapt their behaviour for driving and charging their cars.

HYDROGEN VEHICLES

Hydrogen vehicles use a fuel cell to transform hydrogen stored at a high pressure in an on-board tank into electricity that drives an electric motor. They therefore function like an EV, from the point of view of a drive train. However, instead of the energy being stored in batteries, it is stored in a tank filled with hydrogen. Although hydrogen vehicles represent a less mature technology than EVs, they do not require a change in the behaviour of users, as hydrogen can be recharged in a similar way to fossil fuels, and hydrogen cars display a similar autonomy to the internal combustion of fossil fuel vehicles.

It is important to note that the use of hydrogen vehicles would require the deployment of new infrastructure for hydrogen production, storage and transport. This means that, as previously mentioned, using hydrogen for land vehicles would make more sense if other energy uses such as sea transport and electricity generation were also converted to this fuel type.

BIOGAS AND BIODIESEL

Conventional fossil fuel internal combustion engines can operate with biogas almost without any modifications (if using a natural gas engine) or with minor modifications (if using a petrol engine). However, the use of biogas for vehicles would require creating the storage and distribution infrastructure in order to make the gas available at the recharging points.

As previously mentioned, biogas can be produced from anaerobic digesters using organic domestic waste. However, as the volume that could be produced is limited, it is important to analyse if a partial conversion of vehicles to biogas would make sense or if there are other uses that could benefit more from this fuel.

Biodiesel is a well-established technology that operates in the same manner as conventional fossil fuel (diesel engines), and its use does not require major changes to a conventional diesel engine. From all the presented technologies, biogas and biodiesel are the least disruptive, as they does not require any change in the users' behaviour, and do not require any change in the current fuel recharge infrastructure in the case of biodiesel. However, biodiesel does produce local pollution, which should be considered.

MARINE TRANSPORT

The main fuel consumption in Galapagos is in boats for inter-island transportation. The main mode of inter-island tourist and inhabitant transport is via 12–16-passenger speed boats with average engine power of 450 hp (in some cases up to 900 hp), capable of making the 80 km trip in 2 hours in favourable conditions. This mode of transport presents comfort and safety issues, but offers a fast and relatively cheap way to travel. Any alternative has to be able to compete with the current service if no change in the transport logic is achieved. Energy efficiency analyses are currently being performed by the Escuela Superior Politécnica del Litoral, to improve hull efficiencies under the "ZEGAL" project. However, the aim is to obtain between 10–15% improvements in fuel efficiency, and any attempt to reach zero fossil fuel use in marine transport would require a change in the fuel or technology being used.

ELECTRIC VESSELS

Electric vessels are not very common, as their autonomy is hindered by the cost and weight of the batteries. This is especially true when high speeds are required, as this further increases the battery requirement to provide the increase in power. Currently, most electric boats in Galapagos are short ferry-type boats with solar PV panels, such as the Genesis Solar catamaran in operation in the Itabaca channel. These kinds of vessels are usually suitable for short trips where speed is not an issue, as they usually have maximum speeds bellow 7–10 knots (13–18 km/h). Taking this into consideration, solar-electric boats would be an option for short touristic trips (with an added benefit being the low noise level of the electric motors) or for small water taxis.

BIOGAS AND BIODIESEL

Similarly to land vehicles, it is possible to run combustion engines on boats designed for fossil fuels using different biofuels with minor modifications. Considering the relatively fewer options for decarbonising inter-island maritime travel compared to land transport or electricity generation, it seems appropriate that the limited amount of biofuels that could be produced in the archipelago should be focused on this use.

HYDROGEN VESSELS

Hydrogen can be used as a fuel for ferries and other ships. It can be burned directly in a specially designed internal combustion engine, as proposed in the HyDIME project in the Orkney Islands[57], or converted to electricity in a fuel cell to move an electric motor, as in the Nemo H_2 ferry[58]. Although there are few examples of hydrogen being used in marine applications, its versatility could make it a long term solution, as it can be produced in the archipelago using renewable energy technologies. However, as previously mentioned, the use of hydrogen in any specific application would require that most of the energy uses in the islands should be switched to this technology to maximise the utilisation of all the infrastructure that must be deployed.

FINAL REMARKS

This section presents some final comments aiming to summarise the outcome of the energy system analysis and present some general recommendations for possible paths to decarbonise the energy system in the Galapagos archipelago.

Marine transport is the largest fuel consumer in the archipelago. Unfortunately, it is the sector with the comparatively fewest options for replacing the use of fossil fuels. Solar-electric vessels could represent an option for some of the services, such as for short ferry crossings, short tours, and water taxis. However, their use to replace the rapid inter-island speedboats connecting the islands is not currently feasible. An alternative for the fossil fuel used by these rapid boats could be the use of biofuels, or potentially hydrogen.

Intermittent renewable generation, such as solar PV or wind, are the cheapest clean options to generate electricity, but create a need for additional flexibility in the electric system. Demand shifting could represent a cost-effective contributor for meeting this flexibility requirement. However, additional flexibility options will most likely to be required. Biofuel-run thermal generation could provide this service, although it seems preferable to use the limited amount of biofuels that could be produced in the islands to replace the fossil fuels in sectors that are more difficult to decarbonise, such as marine transport. An alternative for this flexible back-up is the use of energy storage, such as batteries or the generation of an intermediate energy vector such as hydrogen, which is relatively cheap to store.

For land transport, biofuels represent a cheap and simple option, however these should be spared for marine transport as mentioned above. Electric vehicles are already a reality in the islands and could represent a solution for most of the land transport, but their limited range and high charging times (compared with fossil fuels) require behavioural changes in users. Hydrogen could also represent a viable alternative for land transport decarbonisation, but its use would require a shift to this energy vector in other energy-consuming sectors in order to maximise the use of the new infrastructure required for its implementation.

It is important to take into consideration that achieving zero fossil fuel use will require major technological changes. However, prior to addressing these investment-intensive changes, it is worth assessing whether less technology-intensive approaches, such as energy efficiency measures, could reduce the energy intensity in the islands.

When analysing any alternative to the current energy scenario, it is relevant to consider the different contexts on the inhabited islands of the archipelago. However, it is also necessary to consider that some technologies could only make technical or economic sense if implemented across the archipelago and across different energy uses.

Although the analysis performed in the last part of this document focused mostly on energy uses and technologies, it is important to keep a systems perspective when analysing the different alternatives, identifying their interactions with other systems, such as the food and water production and supply, community behaviour, and ecosystem conservation. In this sense, Fig. 27 presents a diagram summarising the relations between the main energy uses, their drivers and the technologies that can be used to supply those uses. This diagram could be expanded in the future by adding more interactions between energy and the other resource systems that are part of life in the archipelago.

As any important change in the energy system of the islands would probably have different impacts on its inhabitants, their priorities and expectations of future alternatives to the current energy scenario should be considered as one of the first inputs to the decision making process. This is essential to make the community feel that a clean alternative solution for the energy system is also part of the answer to their other various needs, and not just an imposed change to which they are forced to adapt.

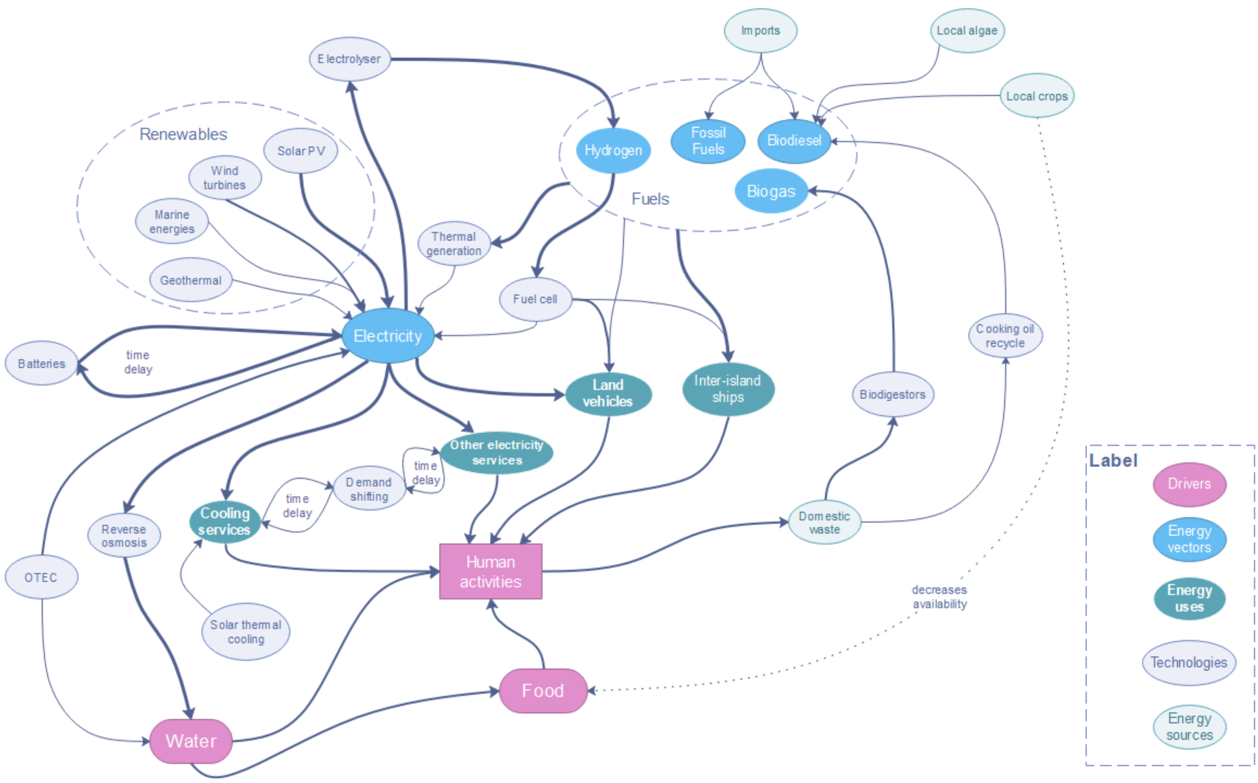

Fig. 27: Diagram of available options for energy supply in the Galapagos Islands and their relative relations

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