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Assessing biophysical limits to the economic development of remote islands: the case of Isabela in the Galapagos Archipelago[1]

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Abstract: In assessing the sustainability of island tourism, the resident population size and yearly number of visitors are key factors. However, to assess the overall resource requirement and environmental impact on local ecosystems, we must also consider the metabolic rates and density of energy and material flows related to the activity of residents and tourists. We present here an innovative approach, the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), with the aim of providing an integrated characterization of the metabolic pattern of island tourism. We use the tourism model implemented in the island Isabela in the Galapagos Archipelago as a case study. We show how MuSIASEM allows us to assess the overall requirement of resources and environmental services and the environmental impact for a given model of tourism. MuSIASEM employs a multi-level matrix to represent these characteristics in an integrated way, thus emphasizing the nexus between different biophysical factors.

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Keywords: Isabela, Galapagos, Tourism Development, Societal Metabolism, MuSIASEM, Nexus.

JEL codes: Q20, Q51, Q57, R11, R12

1. Introduction

The natural World Heritage status granted to the Galapagos Islands (UNESCO, 1978) carries with it an important responsibility for Ecuadorian policy makers. Rather than relying on models of optimal development designed behind the desk, they have to team-up with scientists and the local population to achieve the goal of economic development alongside ecological sustainability. However, it is crucial to separate the idea of sustainable development forseen for the islands from perpetual economic growth while maintaining a harmonious relation with nature as several authors have catalogued as the model for the Archipelago (Gardener and Grenier, 2011; Taylor 2006, 2007).

The Galapagos Islands, beyond their exotic nature, have a resident population of over 25,000 inhabitants (INEC, 2010; Gardener and Grenier, 2011), its economy is primarily based on tourism and it receives over 180,000 tourists a year (GNPD, 2012). Given these terms of the problem, the metabolic pattern of food, energy, water, and materials associated with human activities taking place on the islands has to remain compatible with the preservation of the fragile ecosystems found in the archipelago. An analysis of such compatibility requires a comparison between the quantity and quality of the flows metabolized by humans and the availability of environmental services generated by local ecosystems (both on the supply and sink side). To this purpose, we must generate meaningful numbers capable of describing the interface between the metabolic pattern of human activity and the metabolic pattern of local ecosystems. This is important not only to understand the existing situation (determined by the actual resident population and load of tourists) but also to analyze the biophysical constraints associated with a larger resident population and a larger number of tourists.

The local population growth rate in 2010 was at 3.3 percent per year, down by more than 50% compared to the early 90's (INEC 2010). However, this growth rate still implies important increases in the resident population of the islands in the medium long range. Along with the resident population, the number of tourists is also growing. The pace of this growth is higher, at about 9 per cent per year, and has not changed within the last 20 years. This implies doubling the number of tourists every 8 years. Clearly, this steady growth of human activity on the islands has progressively increased the biophysical pressure of the community on local resources and put the health of protected ecosystems at risk.

Reacting to this challenge and in parallel to the National Plan for Good Living (“Plan Nacional para el Buen Vivir"; SENPLADES, 2013), the Ecuadorian government has embarked on discussions with the local communities in the Galapagos Islands to develop new agendas for sustainability (SENPLADES, 2009, 2013). These discussions are of great importance as it is clear that considerable changes in the status quo are already taking place and will continue to occur in the near future if actual trends are not reversed. Beyond the solemn purpose of preserving the biodiversity of the Galapagos National Park (Bensted-Smith et al 2002; Snell et al 2002), it is gradually becoming evident that new diagnostic tools should be developed to analyze the relation between environmental impact and socio-economic dynamics. We need these tools to help understand the interaction of the local communities with the environment of the islands in relation to the external limits on the expansion of human activities and the implications of the preservation and integrity of local ecosystems.

Methodologies such as the carring capacity of tourism (Amador, et al 1996), the ecological footprint (Wackernagel et al 2002, Córdova-Vallejo et al, 2012) or the geographic footprint (Grenier, 2008; 2010) have been proposed so far for the monitoring of environmental impact in the Galapagos Islands. They share a common logic in that they individuate a link between the biophysical flows used by society and the environmental impact on local ecosystems. The main asset of these approaches is that they convey the idea that human activity implies an impact on the integrity of ecosystems. The ecological footprint in particular has greatly increased public awareness of the biophysical constraints to economic and technological progress. On the other hand, the ecological footprint has been widely critized by the scientific community for the poor theoretical basis underlying the construct (Bastianoni et al. 2012; Blomqvist et al. 2013; CMSPSP, 2009; Fiala, 2008; Giampietro and Saltelli, 2014; Haberl et al. 2001; Lenzen et al., 2007; Ponthiere, 2009; Tabi and Csutora, 2012;

van den Bergh and Grazi, 2010; Van den Bergh and Verbruggen, 1999; Wiedmann and Barrett, 2010; Wiedmann and Lenzen, 2007). The potential problems with this indicator become especially relevant in unique cases like the Galapagos Islands, where the local socio-economic model and the local ecosystems differ markedly from expected global patterns.

For this reason, in this paper, we propose an alternative approach, the multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM) (Giampietro and Mayumi 2000a,b; Giampietro et al. 2009, 2011, 2013, 2014), to perform a coherent analysis of the biophysical conditions and constraints for the island Isabela in the Galapagos archipelago. The metabolic pattern is analyzed both on the supply and demand side by quantifying the pattern of human activities for both residents and tourists and the related throughputs of various biophysical flows (drinking water, general water use, energy, solid wastes).

The MuSIASEM approach bears a multi-scale feature, giving way to scaling up and down, to compare the local dynamics of Isabela within the larger context of the Galapagos and of Ecuador. A multi-scale approach is essential because it allows us to tailor and calibrate the quantitative analysis for both large and complex communities and small and simple communities addressing the unavoidable existence of peculiarities in specific situations.

Our analysis of the biophysical conditions and constraints in Isabela generates information regarding current patterns of human activity (for both residents and tourists), and land use patterns which in turn, determine the requirements of flows to sustain the overall socio-economic metabolism of the island. Understanding this link between patterns of human activity, land use and the associated pattern of biophysical flows is extremely important as it makes it possible to generate informed scenarios about the future provision of flows of materials and energy (both on the supply and the sink side) (Ramos-Martin and Giampietro, 2005). These flows of materials and energy are necessary for guaranteeing the expression of the expected patterns of activity of both residents and tourists. However, these flows of materials and energy also have consequences both for the environment, in terms of impacts, and the economy, when considering the monetary flows associated with the stabilization of these flows.

2. Methods

Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) (Giampietro and Mayumi 2000a; 2000b; Giampietro et al. 2011) is a methodological framework that combines biophyscial flows, such as that of energy and materials, with economic and demographic variables. It links these flows over different scales of analysis (e.g., national, regional or local scale) and studies their implications for the integrity of ecological systems. The approach has been applied in previous studies to rural and national systems (Serrano, 2014, Scheidel and Sorman, 2012), including Ecuador (Falconi 2001). More recently, the methodology has been applied to analyse the nexus between food productions, energy, water and land use (Giampietro et al. 2014).

The theoretical framework of MuSIASEM builds on the concept of bioeconomics developed by Georgescu-Roegen (Georgescu-Roegen, 1971; Mayumi, 2001). The representation of a given system is based on the definition of two types of analytical elements:

(1) Fund elements refer to those elements of the system that in the analytical representation are assumed to remain 'the same' – they have the same size and the same characteristics at the beginning and at the end of the duration of the analysis. In the present application, the concept of fund refers to human activity (measured in days/year), land use (measured in hectares/year) and accommodation capacity (measured in bed capacity). These elements are essential for the analysis since they provide important transformative services for a process to happen;

(2) Flow elements refer to those elements that are transformed by the funds and may either enter or leave the process under analysis, such as imported agricultural goods, energy and materials, or monetary flows. By definition, the flows entering a system are different from the flows exiting the system; their metabolism is required to maintain the overall existence and reproduction of the system (Ramos-Martin et al., 2005, 2009).

The integrated assessment feature of the societal metabolism approach focuses simultaneously on analysing the performance of various dimensions (e.g., economic,

ecological, social) across multiple-scales (e.g., household, village, province, national state). In the present analysis of the metabolic pattern of Isabela Island, we use:
As fund elements:

- Human activity – this fund is defined over different hierarchical levels: (i) level n – total human activity on the island of Isabela accounting for the days/year of both residents and tourists; (ii) level n-1 - divided in two categories: days/year of residents and days/year of tourists; (iii) level n-2 - the activity of residents is divided in two categories: working days/year (in the paid work sector) and the "overhead of human activity of resident" represented by the days/year of residents that are represned as outside the paid work sphere; (iv) level n-3 – at this level of analysis the working days/year of the resident population are divided into two subcategories: working days/year in the tourism sector and working days/year outside the tourism sector
- Accommodation capacity; this fund refers to the infrastructures used to accommodate tourists, is presented as a single category.
- Land use – this fund is divided in four subcategories: (i) infrastructure areas, beaches and mangrove areas (residential); (ii) forestry production units (rural pasture); (iii) agricultural production units (rural cropfields); (iv) the national park (protected areas).

As flow elements:

- Energy – divided in three subcategories: (i) diesel fuel; (ii) gasoline fuel; (iii) electricity;
- Water – divide in two subcategories: (i) drinking water, (ii) other water uses;
- Solid waste generation.

After having defined these categories we can characterize the metabolic pattern of Isabela using a set of specific flow/fund ratios associated with the metabolic characteristics of the different fund elements. Indeed, mapping the above flows against the fund of human activity, we obtain useful information on the socio-economic performance of the system (e.g., consumption of drinking water per day of tourist activity, solid waste generation per working day in the non-tourism sector; MJ of gasoline consumed per day of resident activity). Mapping the flows against the fund land use we obtain useful information on the environmental impact (or limits) associated with the metabolic pattern. The metabolic characteristics calculated from flow/fund ratios are intensive variables (rates, densities, intensities) and are observed at the level of individual fund elements (How much does a tourist drink in a day; How much is the yield of a given fieldcrop?).

In the present study, we use the MUSIASEM approach purely as a diagnostic tool with the aim to provide a coherent framework to measure the impacts of and the biophysical constraints to the current metabolic pattern of Isabela as an example case study within the Galapagos Islands.

3. Results

3.1 Overview of demographic and socioeconomic data in the Galapagos and Isabela Island

3.1.1 Residents and Human Activity

Official registries from the National Institute of Statistics and Census of Ecuador (INEC 2010) indicate that in 2010 there were 2,256 inhabitants in Isabela, 1,054 of whom were women and 1,202 men. Isabela accounts for around 9% of the archipelago's population, which in 2010 was estimated at slightly over 25,000 people. Population growth in the islands is explained by three variables: birth rates, mortality and immigration. In the early 2000s, population growth in the islands reached an annual maximum rate of 5.9% which, afterwards started to decline due to the immigration policies introduced via the Special Law for Galapagos, in 1998 stabling off the incoming flux from the mainland of working adults to fulfill the labour demand (INEC, 2001; Kerr et al. 2004). In 2010, the rate decreased to 3.3% (INEC, 2010). Projections by INEC highlight three possible pathways for future population growth: high, medium and low. Leaving aside the effect of immigration and taking 2010 as a baseline year with a natural population growth rate of 2.2% (without immigration), possible projections for the three scenarios indicate 1.7% growth rate based on a hypothesis of high growth, 1.4% for the middle scenario and 1.1% for a low growth scenario. Although data from INEC (2010) suggest that the effect of immigration has paced off and is currently not as relevant (representing around 1% of population growth), immigration should represent a key issue in scenarios of economic development for the Archipelago in relation to a probable shortage of labour supply especially related to the turism industry.

3.1.2 Employment Conditions in the Galapagos

According to INEC and the Council of Government of Galapagos (2009), 66.5% of the overall population of the Galapagos is employed. This represents approximately 16,700 people earning wages. Santa Cruz island concentrates most of the paid work, especially commercial activities, transport and repairs, hotel services and manufacturing, in contrast to San Cristobal and Isabela. Almost 50% of all productive activities take place in Santa Cruz whilst only 35% are based in San Cristóbal and the remaining 15% in Isabela (INEC-CGG, 2009).

Isabela, as the rest of the islands, has a predominantly young adult population. The workforce can be calculated from the population structure, denominated economically active population (15-65 years of age) being around 70% of total population. Therefore, starting from the population of 2,256 people in 2010 for Isabela, the potential workforce corresponded to 1,557 people (2,256 × 0.7). Out of the potential workforce in Isabela, only 71% of the population is currently economically active while 27% is inactive and 2% unemployed (INEC 2010). Consequently, the number of employed people is 1,121 people (1,557 × 0.71). A study from 2009 (INEC-CGG, 2009) states that the unemployment rate in Isabela, even when accounting for both hidden and official unemployment, was lower than for the overall archipelago, at 2.6% instead of 4.9%.

The sectoral division of the economically active population in Isabela shows that the majority of the jobs are in tourism and service sector followed by agriculture, husbandry forestry and fishery, retailers, construction and public administration (including police) (INEC-CGG, 2009).

3.1.3 Tourism Dynamics in the Galápagos and in Isabela

The number of tourists in the Galapagos, both domestic and foreign has increased steadily since the 60s. In the 70s, the total incoming tourists did not exceed 20,000 visitors, however in 2013 more than 185,000 (DPGG, 2012) tourists were recorded with an approximate share of 30% being nationals and 70% being foreign tourists. According to estimates, Isabela receives between 28,000 and 37,000 visitors per year

(MINTUR, 2012) representing approximately 20% of all of the visitors entering the Archipelago. The length of stay of tourists on Isabela determines the impact that their activity has on the island.

3.2 Characterization of Human Activity

As an essential fund element, the Human Activity is different between permanent residents of the island and tourists influxes staying a certain number of days. This helps understanding the levels of impact that the tourism sector creates compared to other activities of the society. For doing so, we define a certain number of "days-year" factor (the number of people multiplied by the length of their stay) in order to account for their overall impact and requirement in terms of materials over the averge span of a year.

3.2.1 The division between residents and tourists

With the information listed above, it is possible to define a typical profile of Human Activity for both the residents and tourists present in Isabela. Residents – according to aforementioned demographic data - comprise 2,256 people residing on the island for 365 days/year. Tourists –according to the estimates– are around 37,000 visitors per year (taking the higher estimate of number of visitors) staying on average 2 days in Isabela (MINTUR, 2012).

As regards the relative amount of human activity that can be associated with these two groups, residents are assumed to stay on the island throughout the whole year, whereas tourists stay only for a limited number of days. When we multiply the number of people with the corresponding average number of days on the island per year, we obtain an indicator expressed in "days-year".

- Total Human Activity (THA) residents: 2,256 residents × 365 days of residence per year = 823,440 days/year
- Total Human Activity (THA) tourists: 37,000 tourists × 2 days of residence per year = 74,000 days/year

When getting into an analysis of the metabolic flows associated to human activity it is essential to calculate the amount of human activity in number of “days-year” in order to account for the relative impact that the activity generates. With this type of calculation, the number of “days/year” of tourists corresponds to 1/11th of that of the residents in Isabela.

3.2.2 Structure of Labour Supply

Another key characteristic determining the viability of economic scenarios is the availability of labour. The MuSIASEM approach, starting from the information given by demographic variables, analyzes both the potential and actual labour supply in relation to the labour demand determined by the mix of economic activities. Looking at the existing distribution of labour across the relevant economic sectors, we can define a profile of allocation of hours of labour in the economy. By doing so, it becomes possible to contextualize the role of tourism within the whole supply available to the paid work sector.

According to official statistics, around 200 people are employed in sectors related to tourism in Isabela (MINTUR, 2012). We then make the assumption of 250 working days per worker per year (5 days for 50 weeks in a year) for full-time jobs[2]. In this way, we can generate an accounting of work supply and demand expressed in “working days” per year. With this assumption, the 200 workers in the tourism sector supply around 50,000 working days per year. This work supply covers the demand of touristic goods and services generated by 74,000 “days/year” of tourist activity. Hence, 1 day/year of tourist activity in the island requires (guarantees) 0.68 working days per year in the tourism industry. This observation points at the key importance of the tourist’s length of stay on the island.

Indicated labour statistics officially included in the tourism sector account for less than 18% of the total supply of working days (around 50,000 working days). In fact, the remaining 82% (232,500 working days) of labour supplied by the residents to the economy of Isabela (930 workers × 250 working days per year) is allocated to other sectors, such as public administration and fisheries. However, we should note that

[2] This is a rather high assumption that tries to cover for unreported, but related to tourism, work from other sectors such as commerce or services.

there might be indirect connections of other sectors in providing support to tourism activities.

3.3 Characterizing the land use and land cover of the Island

Isabela, the largest island of the Archipelago, currently has 98.9 % of its total land area (465,338 ha) as a part of the Galapagos National Park (Plan de Manejo del Parque Nacional Galápagos, 2005). Therefore, only 1.1 % of the total land remains outside the park–about 5,300 ha. Only 1% of this area outside the park is actually urban area and the remaining 99% accounts as rural (Fig 1). This implies that the urban area, Puerto Villamil, is very small compared with the whole Island. It has an area of about 152 ha and hosts a majority (2,092 people or 93%) of the population of the island (INEC, 2010). Following a pattern observed worldwide, the concentration in urban areas is due to the greater economic diversity and productivity in comparison to rural areas with agricultural production providing a lower economic productivity to labour (Giampietro et al., 2014).

Figure 1. Rural and Urban Land Use in Isabela, Galapagos Islands.

3.3.1 The Rural Area of Isabela

The distribution of land in rural zones is basically represented by the presence of farms, with an approximate coverage of 3,350 ha. The most common farm typology (28 of the 94 farms registered) has an average size of 30 ha (MAG- DPA y Fundación Semillero de Proyectos, Isabela, 2001.) Currently there are 167 Agricultural and Forestry Production Units (139 Agriculture and 28 Forestry) covering approximately 2,000-3,000 ha. This rural economy is structured around four rural organizations with about 25 members working full-time (~6.250 working days) and 75 part-time staff (~500 hours/year ~ 4,700 working days) (Simbaña, 2012 Personal Communication).

Due to the low economic productivity of the agricultural sector, an important share of agricultural activities is carried out as part-time jobs, implying that only a small percentage of land in production is handled by full time dedicated producers. For the same reason, some of the main crops like bananas, papaya, yucca, sweet corn, and green banana are only partially commercialized to local markets (MAGAP, 2012 Personal Communication).

3.3.2 The Urban Area of Isabela

The vast majority of resident population and tourists staying on land are located in Puerto Villamil, the capital of Isabela. Following the classification of the urban area of the Department of Planning of the Council of Goverment of Galapagos (2012), we can distinguish three typologies of land use within the urban area: infrastructure areas, beaches and mangrove areas. The urban infrastructures represent the larger part of residential area with the commercial zone concentrated around the central nucleus. Hotels and other touristic enterprises stretch across a coastal strip.

Even though the urban area is outside the Natural Park, it comprises areas that the Governing Council has declared of high biodiversity importance. These include mangrove zones, residential areas that have been constructed over mangrove zones and nesting sites of marine iguanas. Moreover, it has been identified that residential areas are heading toward an expansion on soils or land that is not suitable for construction as predefined by the Governing Council. Thus, in case of extension of housing, land use is limited by the national park limits on the west, the mangrove sites towards the east, the ocean on the south and inadequate soils for further expansion toward the north. These classifications are important to understand the current urbanization structure, to detect bad practices and good policies, and to identify possible future delimitations for residential site expansions and/or tourism infrastructure development.

3.4 Characterizing the infrastructure on Isabela (fund element): accomodation capacity for tourism

Current trends indicate a rise in touristic visits and different types of activities conducted in the inhabited islands of the archipelago. The strict control on cruise tourism within the last 10 years has kept the boat capacity constant, whereas land based tourism facilities have shown an extraordinary increase of around 187% in this same time period (GNPD, 2012), caused by an increase in overall pressure for tourism demand and for tourist services in populated areas.

The demand on local tourism facilities has not only increased accommodation means but has also affected other tourism services and establishments such as restaurants, bars, travel agencies or specialized transportation. According to data from the Ministry of Tourism referring to the year 2011, there are 27 officially registered hotels in Isabela, which provide 257 rooms with a capacity of 599 beds (MINTUR, 2012). Based on previous calculations of 37,000 yearly visitors staying an average of 2 days, Isabela receives 74,000 days/year of tourist per year. Thus at any given day, we may expect to find on average around 203 tourists (74,000 days/year divided by 365 days) on the Island. Clearly, this is a fluctuating average yielding an average occupancy rate of beds of around 34% assuming there are not big differences between numbers of visitors during the year.

This observation suggests that when considering the effect of a larger number of tourists and/or a change in the lengt of the visit, the number of beds and the occupancy rate become two critical factors that have to be monitored and adjusted.

3.5 Characterizing Biophysical Flows associated with human activity

3.5.1 Water Use

Water use has been divided in three distinct categories for the case of Isabela:

(i) Drinking water. In this analysis, based on consultation with local actors and direct observation, we have assumed that all drinking water by both residents and tourists is bottled. Based on an assessment of water consumption of 1.5 l/day for the residents and 2 l/day for the tourists we can now calculate the (low range estimate) total requirement of drinking water – about 1,400,000 liters/year - as follows:

* Drinking bottled water for residents – 1,250,000 l/year (823,440 days/year ×1.5 l/day);
* Drinking bottled water for tourists – 150,000 l/year (74,000 days/year × 2 l/day).

(ii) Water for public use. Consumption accounted for Puerto Villamil was measured as 130,200 m^3 (Municipio de Isabela, 2011-2012). To these values we have added (to calculate the gross requirement) a fraction due to losses, which has been assumed at 20%. Due to the lack of data on water loss in Isabela a national average reference value has been taken (Malo, 2014 unpublished data). In order to make a distinction between the water consumption of residents, tourists and other sectors we organize the data of the contracts in the following three categories: (1) final hotel owner registries (relevant for the accounting of tourist consumption); (2) service and government users, such as the National Park, the hospital, the police, the Navy, the Church and the Municipalities (relevant for the accounting of water consumption associated with working activities outside the tourism sector); and (iii) residents (relevant for the accounting of resident consumption). In this way, we can calculate the "amount of water consumed per day of human activity" in three distinct categories dividing the total consumption of water by the days of human activity in each one of these categories: (1) the daily consumption of water of tourists can be estimated at 390 l/day; which is consistent with other results found worldwide (Gössling et al., 2012); (2) the daily consumption of water of residents can be estimated at 140 l/day; (3) the daily consumption of water per jobs in the service and government sector can be estimated at 40 l/work day. It should be noted that human activity of tourists consumes almost three times more water per day than human activity of residents.

(iii) Agricultural water (water used for agricultural production). This water is obtained from various forms of rainwater catchment in the upper parts of the Island and by pumping ground water. We have not accounted for rain water catchment in the upper parts in this particular case.

3.5.2 Energy Use

In this accounting, energy use is characterized in relation to the same three categories of human activity: resident days/year, tourist days/year and working days/year in economic sectors outside the tourism industry.

The breakdown of energy use is given in **Table 1**. The table makes a distinction between fuels (used on land and sea) and electricity that is consumed by: residents, the tourism industry (accounted in relation to days/year of tourists), and other economic activities.

Consumption of fuels on land: Vehicle fuel can be split between residents (80%) and touristic activities (20%) based on the ownership of private cars and taxis registries (allocated for tourism use) (Oviedo et al, 2010). Note that **Table 1** implies a double counting as the electricity accounted on the right column (that is an energy carrier) is produced by consuming diesel already accounted for in the category fuels on land. The local electricity company estimates that 42% of electricity is used by residents, 33% by the tourism sector, and the remaining 25% by other economic sectors (ELECGALAPAGOS, 2012). The consumption of diesel for electricity generation has been divided across these three categories using the same proportions. The diesel and gasoline category of “Other” sectors also includes diesel used for industry and military uses. All butane gas consumption has been allocated to the residential sector.

Consumption of fuels at sea: The consumption of diesel and gasoline has been separated, allocating the diesel used by touristic boats to the tourism sector and the remaining fuels to residential needs and travel at sea. According to Duvrar and Grenier (2010) around 70 boat trips per month are made between Isabela and Santa Cruz island use by tourists and residents.

Consumption of electricity: Table 1 indicates the corresponding use of electricity per each category (residents, tourism industry and other sectors) in kWh/year.

Table 1. Energy use by energy carrier and end use

Isabela Island	Fuel (land)			Fuel (sea)		Electricity
	Gasoline (Gal)	Diesel (Gal)	GLP (Gal)	Gasoline (Gal)	Diesel (Gal)	KWh
Residents	157,400[a]	146,600[b]	57,600	17,600	35,600	1,310,000[c]
Touristic sector	39,300[d]	93,500[e]			149,600	1,030,000[f]
Others	7,500[g]	99,800[g]				780,000[h]

Data source: Capitanía de Puerto Villamil, 2012; Cordova-Vallejo et al, 2012; ELECGALAPAGOS, 2012, Jácome Montenegro, M.A., 2010; Petrocomercial 2012a, 2012b.

Where (a) 80% vehicles; (b) covering 42% of electricity, 80% of vehicles; (c) 42% electricity; (d) 20% vehicles; (e) Covering 33% of electricity and 20% of vehicles; (e) boats for touristic activities, (f) 33% of electricity; (g) Navy plus industry; (h) 25% electricity.

Based on the heat content values of each fuel type it is possible to calculate the total amount of gross energy consumption/requirement (GER) for each category (residents, tourism sector and other sectors) expressed in gigajoules (GJ). When adopting a days-year of human activity basis calculation we can say that the tourism sector's energy use per day/year of tourist activity is more than 8 times higher than the energy consumption per day/year of resident, as illustrated by Table 2.

Table 2. Total Energy Uses per Category of Human Activity in Isabela Island

	Human Activity (days/year)	**Labour Supply (days/year)**	**Total Energy (GJ-GER)**	**Energy/"day/year" (MJ/day)**
Residents	823,440		57,100	70
Tourism sector	74,000		42,870	580
Other		232,500 [3]	16,460	70[4]
Total	897,440		116,430	

This analysis can be further detailed across energy use on land, sea and air travel for residents, tourists and other sectors (**Table 3**). This indicates that the tourism sector

[3] working days
[4] per working day

has a much larger consumption of energy carriers at sea than on land, whilst the contrary is true for residents.

Table 3. Distinction between Gross Energy Requirement necessary on Land, and at Sea and energy consumption per days/year.

Isabela	Human Activity (days/year)	Energy Land (GJ-GER)	Energy Sea (GJ-GER)	Energy Land (MJ/day)	Energy Sea (MJ /day)
Residents	823,440	49,300	7,800	60	9.5
Tourism sector	74,000	19,700	23,200	270	313
Other		16,500			
Total (n)	897,440	85,500	31,000		

3.5.3 Solid Waste Generation

The residents of Isabela generate around 1.1kg of solid waste per person per day, whereas tourists generate around 2.1kg per person per day (Gobierno Autónomo de Isabela, 2011-2012). When these values are multiplied by the days of human activity per year for each category we find that residents generate approximately 900 tonnes of solid waste per year, whereas tourists generate around 155 tonnes of solid waste per year.

According to the estimates of the Municipality of Isabela (2011) around 3.3 tonnes of solid waste are generated per day for a total of 1,200 tonnes per year. Thus, the difference between the overall generation of solid waste (1,200 tonnes/year) and the sum of the waste generated by residents and the tourists (1,050 tonnes) indicate that the remaining sectors generate approximately 150 tonnes of solid waste. Thus we have allocated this amount in relation to the number of labour days dedicated to other sectors. From this data we can construct indicators of intensity of solid waste generation across sectors as illustrated in **Table 4**.

Table 4. Total Solid Waste Generation per Category of Human Activity

Isabela I.	Human Activity (days/year)	**Labour Supply (days/year)**	Total solid waste (ton/yr)	Waste/day eq. of human activity (Kg/day)
Residents	823,440		900	1.1
Tourism sector	74,000	50,000	150	2.1

Other economic sectors		232,500[a]	150	0.6[b]
Total	897,440	283,500	1,200	

a: working day; b: per working day.

3.6 Studying the nexus between Land, Water, Energy and Population: the analysis of the metabolic pattern of the socio-economic system of Isabela

3.6.1 The multi-level table characterizing the metabolic pattern

The MuSIASEM approach establishes a nexus between different biophysical flows, such as water, energy, waste generation, and different fund elements that are to be sustained within a society, such as human activity associated with a given population (including residents and tourists) and the given pattern of land uses.

The matrix illustrated in Table 5 simultaneously characterizes in the columns:

*** Flow elements (quantities per year)**: four categories of flows

    * input side (consumption): energy, drinking water, other water consumption
    * output side (emission): solid waste

* **Fund elements (quantities per year)**: three categories of funds

    (i) human activity (days/year); (ii) labour supply (working days/year); and (iii) land uses (hectares of managed land in a given year).

This matrix makes it possible to establish a bridge between the quantitative representation of flows and funds in the metabolic pattern (**Table 5**) and an analysis of environmental impacts of human activity on Isabela.

Table 5. The metabolic pattern establishing a nexus across flows, benchmarks and fund elements for the residential area of Isabela[5].

Urban Zone of Isabela island							
	Fund Variables			Flow Variables			
					Input		Output
	Human Activity	Labor Supply	Land Use	Energy	Water for public use	Drinking water	Solid Waste
	w.equivalent days/year	working days	hectares	(GJ-GER)	(m3-NWU)	(m3/year)	t/year
Residents	823,440		74	57,100	115,200	1,250	900
Touristic sector	74,000	50,000	7	42,900	28,900	150	150
Others		232,500	35	16,500	7,900		150
Total	897,440	282,500	116	116,500	152,000	1,400	1,200

This integrated analysis makes it possible to have an overall assessment of the flows of energy and materials that are required by the metabolic pattern associated with human activity in the island of Isabela. The aggregated values of the flows indicated in the row labelled "Total" make it possible to assess the level of openness of the system. That is, looking at the various "totals" one can calculate how much of the supply capacity and sink capacity entailed by these quantities is available on the island (e.g. flows that can be produced and dumped in situ) and how much is externalized outside the island. On the other hand, the detailed analysis of these flows – provided in the analysis of these flows given in the previous tables – makes it possible to define their usefulness for the various human activities in the society. More specifically it makes it possible to define the nature of the flows (e.g. the difference between different types of fuels and electricity) in relation to the characteristics of the final users determining the overall consumption of the given flow.

[5] Note that days/year of tourists are different from working days/year in the tourism sector. As indicated in Section 3.2.2; 1 day/year of tourist activity in the island requires 0.68 working days/year in the tourism industry. Required flows/days.year have been calculated based on the relevant flow(s) divided by days/year of toruists.

Table 6. The integrated characterization of the metabolic pattern of Isabela combining the size of the fund elements (in the different categries) and their metabolic characteristics.

Input flows requiring supply capacity or import	
Requirement of energy for human activity on the island (for land and sea). Overall amount of energy expressed in Gross Energy Requirement thermal (Tons of Oil Equivalent à 1 TOE = 42 GJ thermal)	=
(# residents * 365 * Gross Energy Consumption per day Resident)	+
(# days/year of tourists * Gross Energy Consumption of the tourism sector per day/year of tourist)	+
(# working days in the rest of the economy * Gross Energy Consumption per working day in the rest of the economy)	
Requirement of drinking water	=
(# residents * 365 * Drinking water per day Resident)	+
(# days/year of tourists * Drinking Water per day Tourist)	
Requirement of water for other uses	=
(# residents * 365 * Gross Water Use per day Resident)	+
(# days/year of tourists * Gross Water Use per day Tourist)	+
(# working days in the rest of the economy * Gross Water use per working day in the rest of the economy)	
Requirement of food	=
(# residents * 365 * Food Energy per day Resident)	+
(#days/year of tourists * Food Energy per day Tourist)	

Output flows requiring sink capacity or export	
Solid Waste	=
(# residents * 365 * Solid Waste generated per day Resident)	+
(# days/year of tourists * Solid Waste generated per day Tourist)	+
(# working days in the rest of the economy * Solid Waste generated per working day in the rest of the economy)	

The definition of the metabolic characteristics of fund elements is illustrated in **Table 6**. This characterization obtained in the diagnostic step is extremely important for defining benchmark values that describe the qualitative aspects of the fund categories. An example of this process of benchmarking is illustrated in Table 7.

Table 7. Characterization of the metabolic characteristics of intensive fund/flow variables in Isabela island that can be used to generate scenarios of alternative models of tourism development.

Intensive Variables	Intensive Values
Gross energy Consumption per day residents	70 MJ/day
Gross energy Consumption per day/year of Tourist	580 MJ/ day.year
Gross energy Consumption per working day in the rest of the economy	70 MJ/day
Gross Water Use per day Resident	140 liters /day
Gross Water Use per day/year of Tourist	390 liters/day.year
Gross Water Use per day Resident	40 liters day
Drinking Water per day Resident	1.5 liters day
Drinking Water per day/year of Tourist	2.0 liters/day.year
Solid Waste load per day Resident	1.1 kg day
Solid Waste load per day/year of Tourist	2.1 kg/day.year
Solid Waste load per working day in the rest of the economy	0.6 kg day

4. Conclusions

In this paper, we have highlighted the importance of generating a “diagnosis” of the current situation of how these required biophysical flows (energy, water and generated wastes) are acting upon and are a consequence of the fund elements (Human Activity and Land Use patterns) of the system. Moving beyond mono-dimensional indicators and rather constructing an integrated assessment, bridging crucial nexus elements strengthens resource management needs and possible option spaces to elaborate upon. The societal metabolism approach, specifically implemented through the MuSIASEM methodology helps unravel such dynamics.

The Galapagos Islands, being a unique case with the status of Natural World Heritage, face even further biophysical constraints in the provision of their required flows as most of the land is part of the National Park. Additionally, the entire island-system is dependent on the influx of tourist flows, forming the main branch of economic activity, hence adding on to the burden of requirement of materials.

Conducting an analysis encompassing different levels and dimensions is vital for obtaining significant results from an integrated assessment point of view. Carring out a local level analysis takes into account factors that not only change from one local system to another, but also varies acros different scales. The search for a definitive number (such as an absolute number of carrying capacity or footprint), average values of the performance and assuming the same equivalency criteria for all categories will give a distorted view of the operating system, hiding the local dynamics and metabolic patterns of each specific study of analysis.

The spheres of water, energy, land and human activity (demographics) are closely interwoven and it is of utmost importance to identify and study these interrelationships, trade offs and synergies from an integrated assessment point of view. Especially when considering remote yet open systems, as in the case of the island Isabela, the flow of essential materials and energy to maintain the essence of the socio-economic structure plays a very critical role.

The diagnosis conducted within the scope of this analysis reveals that, regarding biophysical requirements, tourists consume approximately 40% of the total energy of Isabela, and need three times as much water and produce double the amount of solid wastes in comparison to the local residents of the island. Quoting from Allen et al (1999), it is highlighted that *"… [W]hen we manage ecologically, it is not the biophysical system in itself we manage but the people who impact the system."* (Allen et al., 1999). Therefore, it is imperative to move beyond the generic conservation narrative on the islands and provide understanding by measuring human impacts as illustrated through the diagnostic presented in this paper.

In terms of economic variables it is obvious that tourism represents an incredible powerful attractor for the development of the economy of Isabela. With an increased presence of tourists in the Archipelago it will be difficult, in the future, to develop economic activities in direct competition for capital, labour and land, with those associated with tourism. So we can expect that in the future the economy of Isabela will increase its dependence on tourism, reducing its diversity of sources of added value and increasing its dependency on imports. This trajectory is indeed risky, but probably an obliged one. In relation to this point is necessary to link the MuSIASEM approach to map monetary flows together with biophysical flows. In this way, it becomes possible to complement the biophysical analysis with an economic analysis establishing a bridge between two key dimensions of sustainability.

Although Isabela features as one of the Islands within the Archipelago of the Galapagos, it is an exceptional example of a remote island system, illustrating a complete open and dependent on external sources, based primarily on tourism activities. The preservation and the reproduction of desirable living conditions for the local residents requires a very delicate balance between the concern for the fragile local ecosystems (avoiding the damage to their distinct habitats) and the concern over the equally fragile social texture, that can be easily overwhelmed by the economic interaction with much stronger socio-economic systems (avoiding the take over of investors coming from outside the islands).

Joppe (1996) and Richnis and Pearce (2000) indicate the importance of involving local communities in decision making regarding their interests on tourism development. Precisely, not considering biophysical constrains as key elements both environmental as well socioeconomic, may be a cause of conflicts about the model of tourism. A societal metabolism approach not only can depict a deeper understanding of interactions of the nexus elements, but can also contribute to a better understanding of socio-economic and ecological functions, ultimately leading to effective planning for future options, by using the coefficients of resource use and impact found in such kind of studies.

Finally, if we aim for a sustainable society, we must come to the realization that resources are exhaustible and cannot be replaced indefinitely. This integrated analysis allows us to observe a "sudoku" effect between the components of the metabolic systems, where if we prioritize the ecological, an economic and social cost will occur; or if the priority is the economy, the cost is transferred to the ecological and social systems. Looking into the biophysical components of a metabolic system in detail helps us to have sufficient quality information so that policy and/or social decisions are fully understood in terms of their consequences on the environmental, economic or social spheres.

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