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Carbon Footprint of the Galapagos Islands – Quantifying the Environmental Impact of Tourist Activities

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Abstract

The main goal of this paper is to quantify the green house gas emissions (also referred to as carbon footprint) of the Galapagos Islands. The analysis includes emissions from energy generation and of related economic activities of the tourism industry, including international travel to the islands. We have also included the green house gas emission generated by the transportation of fuel, food, supplies and water from Ecuador mainland to Galapagos Islands across multiple modes. We estimated a total carbon footprint of 532,373 tonnes of CO_2-eq, of which 68.82% corresponds to international air travel, 17.86% corresponds to fuel consumption for energy generation and 6.01% due to transportation of food from mainland to the islands. These emissions were allocated between residents and tourists to outline strategies for a sustainable tourism management in the islands.

Keywords: GHG emissions, sustainability, Galapagos Islands, tourism, climate change

1 Introduction

Tourism development has become a major driver to economic growth in the Galapagos Islands since 1999 (Taylor et al., 2006). Galapagos receives more than 160,000 tourists per year (INGALA, 2010). The continuous growth in tourism and its associated economic opportunity has also caused a steady growth in immigration (INEC, 2010). This growth in tourism and population has negative impacted the islands, including the introduction of invasive species and increased pressure on the natural resource base from agriculture and fishing. There has also been an increase in the demand for infrastructure, goods and services. This has led to unsustainable levels of energy and water consumption; contamination of air, soil, and fresh and seawater resources among others (Torsten Hardter et al., 2010). Several policies to control the impact to the island ecosystems have been proposed in Cayot et al. (1996) and Reck et al. (2008). Most of

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the previous research about tourism impact in the archipelago is based on qualitative judgment since the data required to quantify environmental impact of tourists is not easy to obtain. The purpose of this paper is to quantify the green house gas emissions (GHG) of economic activities in the Galapagos Islands. We incorporate details of the flow of goods into and out of the islands given the increasing importance of supply chain perspectives in sustainability topics (Seuring and Müller, 2008).

Throughout this paper, we will use the term "carbon footprint" to refer to the green house gas (GHG) emissions measured in carbon dioxide equivalent (CO_2-eq). All CO_2-eq have been computed using 100-year IPCCC global warming potential factors (Forster et al, 2007).

1.1 The Galapagos Islands

Galapagos is an archipelago of 19 islands, 47 islets and 26 rocks that cover an area of 3,113 square miles. It is located in the Eastern Tropical Pacific, 600 miles west of the coast of Ecuador in South America (Ruales, 2004). While humans only inhabit four of the islands, the rest of the Galapagos Islands play host to an array of rare and endemic wildlife. Significant human settlements of the Galapagos did not occur until the 1900s, making it possible for 96.7% of the Islands' original biodiversity to remain today. Its unique ecosystem, has been widely documented (see Di Carlo et al., 2011) and continues to attract interest of the scientific community and the general population at large.

The four inhabited islands are San Cristobal, Santa Cruz, Isabela and Santa María, also known as Floreana. The un-inhabited area corresponds to what is now the Galapagos National Park (Aguirre, 2002). Figure 1 shows the population growth since 1950, according to the Ecuadorian Census Bureau (INEC, 2010). Of the 25,124 current inhabitants 91% of the population is concentrated on the two largest Islands of San Cristobal and Santa Cruz. The 9% remaining corresponds to the population of Isabela and Floreana Islands.

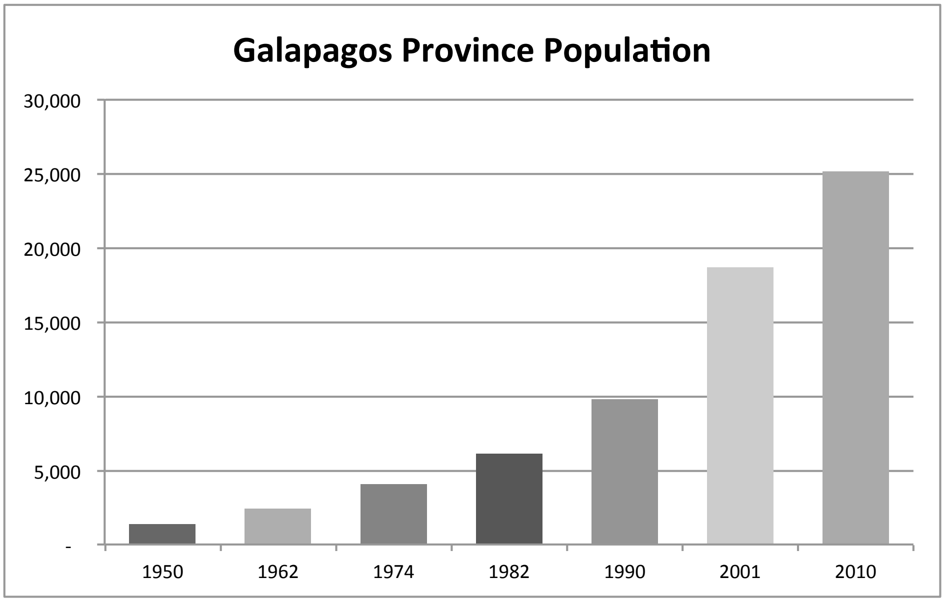

Figure 1 - Galapagos Population 1950 -2010   (INEC, 2010)

The residents of the Islands depend directly or indirectly on the ecosystem, which provides resources and supports the cultural services that increasingly form the basis of the local economy. By affecting key ecosystem processes and emblematic species, climate change could influence the wellbeing of all people who live in the islands (Quiroga et al., 2011; Pickering, 2011).

The economy of the archipelago is based on the use of their natural resources in favor of the development of tourist activities (see Table 1). For example, 9.5% of the population works in hotels and restaurants activities, while 5.1% of the working population is involved in manufacturing activities.

Table 1
Economic activity in the Galapagos Islands

Line of Activity	Employed Population age 10 and over	%
Wholesale and retail	1,600	12.8%
Public administration and defense	1,334	10.7%
Not declared	1,215	9.7%
Accommodation activities and meals	1,191	9.5%
Agriculture, hunting, forestry and fishing	1,127	9.0%
Construction	935	7.5%
Transport and storage	880	7.0%
Activities of administrative and support services	877	7.0%
Teaching	697	5.6%
Manufacturing industries	639	5.1%
Activities of households as employers	522	4.2%
Activities of human health care	308	2.5%
Arts, entertainment and recreation	292	2.3%
Other service activities	260	2.1%
Professional, scientific and technical	221	1.8%
Information and communication	163	1.3%

Financial and insurance	97	0.8%
Electricity, gas, steam and air conditioning	72	0.6%
Water distribution, sewerage and waste management	33	0.3%
Activities of extraterritorial organizations and bodies	19	0.2%
Mining and quarrying	13	0.1%
Real estate	6	0.0%
TOTAL	12,501	100.0%

Source: INEC 2009.

Approximately, 3.3% of the Galapagos Island land mass is used for agricultural and farming activities and are concentrated mainly on Santa Cruz Island (INGALA, 2003). During the last 10 to 15 years the agriculture and the feedstock industries have been declining steadily. The quality of the soil is not optimal and these activities are not as profitable compared to tourism. The main agricultural products harvested on the islands (oranges, manioc, coffee beans, potatoes and corn) and the local live feedstock does not satisfy local demand due to the increase in the resident population and the tourism activity.

1.2 The Tourism Industry

Starting in 1969, when charter flights began bringing small groups of adventure travelers to the Islands, tourism flourished. Figure 2 shows the trend of the number of tourists visiting the Galapagos Islands since 1979 until 2009. As mentioned earlier it has now become the main economic activity of the archipelago and has shown to be destructive of the ecosystems (Cayot, et al., 1996). According to Torsten Hardter et al., (2010), the growth in tourism and population has caused a big impact on all natural resources of the islands, including agriculture, fishing, fresh and sea water, soil, air and also potential public health problems. Several policies to control the impact to the island ecosystems have been put in place (Cayot et al., 1996; Reck et al., 2008). They focus on managing the activities and itineraries of the tourist ships to control the number of people visiting at the same time the same site on the same day. The government has also set limits to the number of visits to any site of interest on the islands, to allow tourism to grow in a controlled manner.

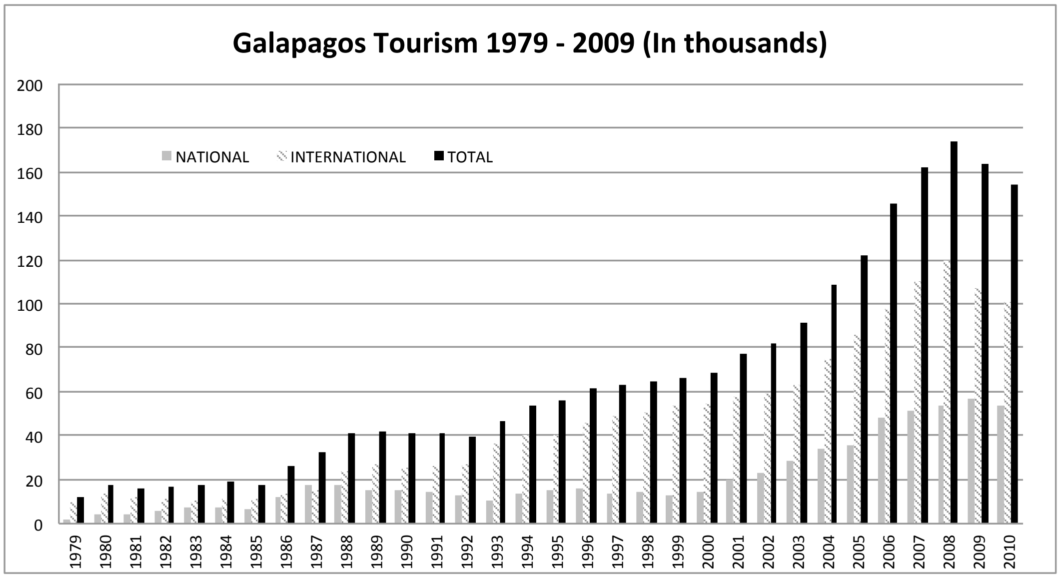

Figure 2 – Number of tourists (in thousands) visiting Galapagos per year (INGALA, 2010)

As show in Figure 2, the tourism visits to the Galapagos Islands had an average growth of 8% since 1979. The growth for the past three years has been between 4% and 5%, which is consistent with the global tourist growth given by the World Tourism Organization (UNWTO) in its 2011 Highlights Report (UNWTO, 2011). Note that 65% of the incoming tourists correspond to international visitors. On average, a tourist stayed 4.9 days in the archipelago in 2010 (see Table 2). 40% of the visitors will make lodging reservations in the islands and schedule daily tours coordinated by the hotel or local guides in Santa Cruz or San Cristobal. The remaining 60% of the tourists will lodge in one of the authorized ships which will go around the Islands on a predetermined routes. Regardless of how the tourists organize their visit, the vast majority of their food, water and other supplies are transported from Ecuador mainland into the islands. As a consequence, the supply chains that serve the Galapagos Islands to support the tourism industry have also expanded, diversified and grown.

Table 2
Average tourists stay in the Galapagos Islands

Days of stay	2009	Cum. %	2010	Cum. %	2011	Cum. %
0	1.97%	1.97%	2.28%	2.28%	2.27%	2.27%
1	1.13%	3.10%	1.27%	3.55%	1.04%	3.31%
2	3.03%	6.13%	3.45%	7.00%	3.68%	6.99%
3	20.25%	26.38%	18.48%	25.48%	18.02%	25.01%
4	25.90%	52.28%	29.15%	54.63%	27.33%	52.34%
5	5.64%	57.92%	6.33%	60.96%	7.07%	59.41%
6	6.12%	64.04%	4.93%	65.89%	5.67%	65.08%
7	31.41%	95.45%	29.19%	95.08%	28.85%	93.93%
8	2.76%	98.21%	2.89%	97.97%	3.42%	97.35%
9	1.79%	100.00%	2.03%	100.00%	2.65%	100.00%
Avg. Stay	4.95		4.87		4.94	

Source: INEC 2010

1.3 Quantifying environmental impacts from tourism

Scott et al. (2010) argue for the need of estimates of carbon dioxide emissions to manage and achieve the goals set for the tourism industry for 2035. Although most of the literature related about tourism impacts is based on qualitative description (Kuo and Chen, 2009), some researchers have tried to quantify the environmental impacts from island tourism. For instance, Gössling et al. (2002) propose a methodological framework for the calculation of ecological footprints related to leisure tourism, based on the example of the Seychelles. In addition, Patterson (2003) conducted and eco-efficiency analysis of New Zealand tourism. In the study of Gössling et al. (2005) authors analyzed several tourism destinations and found travel distance as the factor most likely to result in an unfavorable eco-efficiency, and that air travel was the most problematic global environmental impact of tourism.

All of these studies focus on leisure-related activities. A more comprehensive study is conducted by Kuo and Chen (2009). They used the life cycle assessment (LCA) tool to inventory and calculate the environmental impacts of island tourism. More specifically, they calculated the environmental load in transportation, accommodation and recreation activity sector in Penghu Island. However, the food transportation sector is not included in this study. Based on the review of literature, no previous studies that attempt to quantify the environmental impact of the food and supplies supply chain in a tourism island.

It has been shown, for example, that the demand of energy at various functions of the product tourism is different (Becken et al., 2003) and a large portion of this energy is consumed during air travel, not only by tourists but also by the food that is transported by air. In particular, in the case of the Galapagos Island, it is also important to take into account the impact of the supply chain that supports the tour operating industry (which includes food, supplies, fuel, and water).

Therefore, the goal of this paper is to quantify the impact of tourism in Galapagos in terms of green house gas emissions generated by the consumption of fuel, food, supplies and water in the Islands.

The remainder of this paper is organized as follows. In Section 2 we present an overview of the methodology and scope of the study. We include a description of the main sources of emissions and the main data sources used for the analysis. In Section 3 we present in detail the various components of the green house gas emission estimation for the Galapagos Islands, including any assumptions and recommendations for emission mitigation. We conclude in Section 4 with recommendations on how to improve our estimates and suggestions for future studies.

2 Methods

2.1 Scope and General Framework

There are four main activities that generate GHG emissions in the Galapagos Islands. First, we have emissions from energy generation to support the various houses and buildings across the islands. Energy generation is currently fossil fuel based. Second, we have all the emissions from organic and inorganic waste generated by both residents and visitors after the consumption of water, food and other supplies. Third, we have the fuel burnt by the various boats and vehicles that are used for moving residents, visitors, food and supplies from, to and within the islands. Finally, we have the emissions generated by local agricultural and livestock management, including any impacts due to land-use change. Figure 3 summarizes the various activities as well as the relevant inputs needed to estimate the GHG emissions for each of them.

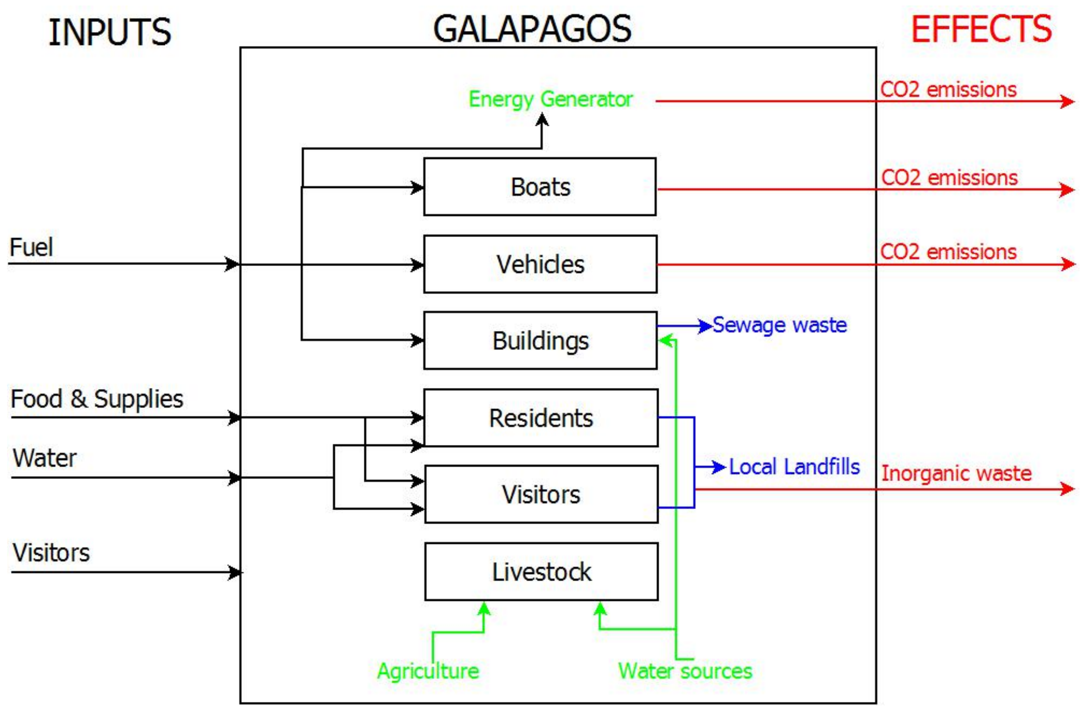

Figure 3. *Scope of Galapagos activities included in the analysis*

Of the entire Archipelago´s surface, 96.7% corresponds to the National Park and the remaining 3.3% is urban or rural area. Table 3 shows the main islands San Cristobal, Santa Cruz, Isabela, Santa Maria and Baltra with the percentage of colonized area and the number of farms. Agriculture used to be the main economic activity of the islands (Ruales, 2004), however, according to the Ministry of Agriculture, cited by Carpio (2001), the largest percentage of agricultural area (57.8%) is covered by pasture or silvopastoral systems that support only an estimated 1,500 head of cattle. The government of Ecuador has established strict rules in biodiversity management in the islands, so we expect minimal increase of these emissions overtime and negligible effects from land-use change over time. Thus, GHG emissions due to local farming activities have not been included on this study, since they have effectively been replaced by tourism activities and food imports.

Table 3
Colonized area per island and number of farms

Island	Total (ha)	Colonized area: rural and urban (ha)	Percentage of colonized area	Number of Farms	Surface (ha)	% of Farms in Galapagos	% of the province of Galapagos
San Cristóbal	*55.8*	*8.398*	*15*	*231*	*8.016*	*36.4*	*32.7*
Santa Cruz	98.6	11.385	11.5	*200*	*11.441*	*31.6*	*46.6*
Isabela	458.8	3.568	0.8	*190*	*4.794*	*30*	*19.5*
Santa María	17.3	310	1.8	*13*	*0.285*	*2.1*	*1.2*
Baltra	2.7	2.7	100	*0*	*0*	*0*	*0*
Other Islands	155	0	0	*0*	*0*	*0*	*0*
TOTAL	788.2	26.356	3.3	*634*	*24.536*	*100*	*100*

Source: Plan de Manejo del Parque Nacional Galápagos 1996, cited by Aguirre (2002).

3 Analysis and Calculation

In this section we present the various calculations and assumptions used to estimate the GHG emissions within the scope of analysis of this study. We use 2010 data in all the calculations, adjusting whenever appropriate.

3.1 Transportation

Equation (1) is used to calculate the carbon emissions from transporting across different modes, consistent with The Greenhouse Gas Protocol guidelines (GHG Protocol, 2011):

$$Q=\sum EF_i \times W_i \times D_i \quad (1),$$

where Q is the total quantity of carbon equivalent emissions (tonne) one year; EF_i is the emission factor of transporting item i (via its associated transportation mode) (tonne/tonne-mile); W_i represents the total weight of item i to be shipped to the Galapagos Islands per year (tonne) and D_i is the distance associated with the transportation mode to ship item i.

The following sections describe the transportation emission calculations. All final transportation emissions are presented in Table 12.

3.1.1 Food, Water and Supplies

Due to the limited agriculture and industry in the Galapagos Islands, most of the food, supplies and water (bottled, drinkable) are shipped from the Ecuador mainland. In their recent analysis of food supply chains into Galapagos, Serrano and Celleri (2011) concluded that most of the perishable food is shipped via air while non-perishable products including food and non-food items are shipped via sea.

Based on the data from a major private tourism company that operates in the Galapagos Islands, we compiled a list of 162 items commonly ordered for tourist visits (Serrano and Celleri, 2011). We categorized all the items into perishable food, non-perishable food as well as supplies and water (Table 4) and allocated the quantities of annual menus to estimate the consumption per day for a typical visitor to the Galapagos Islands (Table 5).

Table 4
A breakdown analysis of items commonly ordered by tourists.

Type	Number of Items	Weight (tonnes)	Percentage by Weight
Perishable Food	77	49,586	67%
Non-Perishable Food	64	7,335	10%
Supplies and Water	21	17,605	24%
Total	162	74,526	100%

Table 5
Food, supplies and water consumption per tourist per day.

Type	Consumption per Tourist per Day (kgs)
Perishable Food	5.07
Non-Perishable Food	0.75
Supplies	0.3
Water	1.5
Total	7.62

For island residents, there is limited data available regarding their food, water and supplies consumption in this study. We used the published data of food consumption in Latin America and the Caribbean by World Health Organization (WHO, 2003) and adjusted it to 2010. We also adjusted the number taking into account the water content in food (USDA, 2011). Based on this number, we estimated the food consumption per capita per day of all residents. Using the same ratio of perishable and non-perishable food as in tourist food consumption, we estimated resident per capita consumption to be 0.83 kg perishable food and 0.12 kg non-perishable food. Regarding daily supplies and bottled drinkable water consumption, we assume both tourists and residents to require the same amount. Table 6 is a summary of food, supplies and water consumption per resident per day.

Table 6
Food, supplies and water consumption per resident per day.

Type	Consumption per Resident per Day (kgs)

Perishable Food	0.83
Non-Perishable Food	0.12
Supplies	0.3
Water	1.5
Total	2.75

For each type of item we assigned the appropriate mode of transportation, distance and the corresponding emission factor (Table 7). To estimate the total transported volumes of food, water and supplies, we used the average stay in the Galapagos Islands of 4.9 days (see Table 2) and 360 days for residents. Based on population figures, there are 25,124 residents in the Galapagos Islands in 2010. We assumed tourist population in 2010 to stay the same as 2009, at 163,480. Using this figure, we calculated the total weight of food, water and supplies in 2010 and then applied Equation (1) to all the weights by mode. Table 8 shows the final results.

Table 7
Transported item, transportation mode, travelled distance and emission factor (EPA, 2008) in the calculation.

Item Transported	Mode	Distance (miles)	Emission Factor (kg CO_2-eq/tonne-mile)
Fuel	Sea	771	0.018
Perishable Food	Air	823	3.333
Non-Perishable Food	Sea	771	0.018
Supplies	Sea	771	0.018
Water	Sea	771	0.018
Tourists	Air	823	3.333
Residents	Air	823	3.333

Table 8
Final weight and CO_2-eq calculations for transporting food, water, and supplies.

Type		Weight (tonnes)	CO_2-eq Emissions (tonnes)
Perishable Food	Tourists	4,144	11,361
	Residents	7,523	20,623
Non-Perishable Food	Tourists	613	9
	Residents	1,113	15
Supplies	Tourists	246	3
	Residents	2,713	37
Water	Tourists	1,226	17
	Residents	13,567	185
Total	***Tourists***	***6,229***	***11,390***
	Residents	***24,916***	***20,860***
Grand Total		**31,145**	**32,250**

3.1.2 Fuel

Using the detailed monthly fuel consumption records provided by Petrocomercial we calculated the total fuel consumption by fuel type and type of use for 2010 (Table 9). Since all fuel is transported into the Galapagos Islands via ocean, we transformed the volume information into weight to apply Equation (1) and estimate the total CO_2-eq emissions of transporting fuel to the island. Table 10 shows the final calculations.

Table 9
Consumption by fuel type and use in the Galapagos Islands in 2010.

Fuel Type	Used For	Consumption (gallons)
Diesel	Generators	2,323,400
	Vehicles	644,229
	Boats	5,594,600
Gasoline	Vehicles	919,931
	Boats	74,795
	Total	9,556,955

Table 10
Volume-weight conversion and CO_2-eq emissions for transportation of fuel.

Fuel	Volume (gallons)	Weight (tonnes)	CO_2-eq Emissions (tonnes)
Diesel for Generator	2,323,400	7,377	100.64
Diesel for Vehicles	644,229	2,046	27.91
Diesel for Boats	5,594,600	17,764	242.34
Gasoline for Vehicles	919,931	2,595	35.41
Gasoline for Boats	74,795	211	2.88
Total	9,556,955	29,993	409.17

3.1.3 Tourists Travel

Data regarding the country of origin for all tourists traveling into the Galapagos Islands in 2009 was received from Galapagos National Park (Galapagos National Park, 2009). Using the same assumption that the tourist population in 2010 stays the same as 2009, we determined to use the received data for the year of 2010 (Table 11).

Table 11
Number of tourists by origin in 2010.

Origin	Tourists	Percentage
Ecuador	56,766	34.7%
United States	44,461	27.2%
United Kingdom	10,953	6.7%
Germany	7,129	4.4%
Canada	6,946	4.2%
Australia	3,549	2.2%
France	3,162	1.9%
Italy	2,869	1.8%
Switzerland	2,621	1.6%
Netherlands	2,593	1.6%
Others	22,431	13.7%
Total	163,480	100%

We assumed that international tourists depart from the main airport in their home countries. They arrive in Quito, Ecuador. From Quito, all tourists take Ecuadorian airlines to go to the Galapagos Islands. A similar itinerary is used for the return trip. We assumed an average weight of 98 kg for each tourist, which includes 87 kg for the individual and 11 kg for the luggage (NTM, 2008). Therefore, the total emissions from traveling between Ecuador and their home countries are estimated as 309,036 tonnes. In addition, the emissions from traveling between Ecuador mainland and the Galapagos Islands add an additional 87,839 tonnes. Thus, the total emissions are 396,875 tonnes of CO_2-eq for tourist travel.

3.1.4 Residents Air Travel

Due to the lack of data, we estimated the average number of times residents travel to the Ecuador mainland per year in order to calculate the emissions caused by residents air travel. In 2010, the gross national income per capita in Ecuador is $9,270 and in the United States is $47,020 (World Bank, 2011). Based on a statistical report published by U.S. Bureau Labor Statistics (BLS, 2010), Americans spend 3% of their income on traveling; and among all travel related expenses transportation is 44%. We applied the same percentage on Ecuadorian population and calculated the transportation expense in their travel, which is approximately $122 per year. The round-trip air ticket from Galapagos Islands to the Ecuador mainland is at least $100, therefore we used 1.2 times as the average air travel times per year for residents. Using the same weight as the tourists, we calculated the emissions from traveling to the mainland per year that are 16,199 tonnes.

Table 12 is a summary of emissions from transporting goods and people to the Galapagos Islands.

Table 12
Transportation emissions of fuel, food, supplies and water, including tourists and residents air travel.

Transportation		Emissions (tonnes)	Percentage
Fuel		409	0.09%
Food		32,008	7.18%
Supplies		40	0.01%
Water		202	0.05%
Tourists	International	366,374	82.20%
	National	30,501	6.84%
Residents		16,199	3.63%
Total		444.593	100%

3.2 Usage and Consumption

In this section we calculate the GHG emissions generated in the island as part of their economic activities. Since Galapagos is a protected area, there are no industrial sources of emissions and minimal land-use or burning of organic materials.

3.2.1 *Fuel*

Fuel is used for electricity generation and for general transportation in the Galapagos Islands (see Table 13 for a breakdown). There are two types of fuels used in Galapagos: diesel and gasoline. We applied a carbon content of 22.23 pounds/gallon for diesel and 19.37 pounds/gallon for gasoline (EPA, 2004).

Table 13
Summary of carbon emission calculation from fuel consumption

Fuel Type	CO_2-eq Emissions (tonnes)	%
Diesel for generator	23,428	24.6%
Diesel for vehicles	6,496	6.8%
Diesel for boats	56,412	59.3%
Gasoline for vehicles	8,083	8.5%
Gasoline for boats	657	0.7%
Total	95,076	100%

3.2.2 *Food, Supplies and Water*

Greenhouse gas emissions are generated from the landfilling, incineration, and composing of post-consumer waste (Bogner et al., 2008). When the waste is recycled, emissions can be reduced because of the reduction of raw material use. Besides the emissions occurring from the process of waste management, emissions also occur when transporting waste to adequate waste management locations. The study of waste management on Santa Cruz Island from 2000 to 2010 suggests that recyclable waste is 63% of the total weight of the waste, and organic waste is 37% (Galapagos Ecuador Foundation, 2010). This study also shows that in all recyclable waste plastics is 8.6%, glass 23.9%, cardboard 59.5%, paper 6%, batteries 0.1%, and other materials 1.9%.

Through field interviews with waste management officials of Santa Cruz Island conducted in August 2011 it was estimated that the 2011 average weight of waste per person per day is 0.7 kg. We assume the waste generation pattern in 2010 to be the same as 2011. By multiplying the total population and the total days staying in Galapagos, the total weight of waste in 2010 is 6,419 tonnes. Based on the percentage of the recyclable and organic waste in the total waste (Galapagos Ecuador Foundation, 2010), we estimated the total recyclable waste in the Galapagos Islands in 2010 to be 4,044 tonnes and the organic waste to be 2,375 tonnes. We also applied the percentage of different types of recyclable waste (Galapagos Ecuador Foundation, 2010) and calculated the weight for each type (Table 14).

The study conducted by Galapagos Ecuador Foundation (2010) shows that most of the glass waste stays in Galapagos to be recycled. And all other recyclable wastes will be packed and shipped back to Ecuador mainland to be recycled. Organic waste is landfilled in Galapagos Islands. We calculated the emissions from transporting the waste to Ecuador mainland using

Equation (1). Regarding the emissions from the waste management process, we applied the greenhouse gas emission factor (EPA, 2010) in the calculation. Table 14 is a summary of the calculations.

Table 14
Waste type, weight, and GHG calculations.

Waste Type		Weight (tonnes)	CO_2-eq from Transportation (tonnes)	CO_2-eq from Waste Management (tonnes)	Total CO_2-eq (tonne)
Recyclable	Plastics	349	4.76	-523.19	-518.43
	Glass	965	0	-270.20	-270.2
	Cardboard	2,408	32.85	-8,452.42	-8,419.56
	Paper	241	3.29	-846.78	-843.48
	Batteries	5	0.06	3.51	3.57
	Other material	76	1.04	-218.29	-217.25
Organic	Mixed organics	2,375	0	1,828.93	1,828.93
Total		6,419	42	-8,478	-8,436

As a result, the waste management activities on Galapagos Islands reduce 8,436 tonnes of CO_2-eq in 2010. This number does not include emissions due to electricity generation at the sorting facility or waste collection due to lack of detailed records. However, Galapagos electricity generation and fuel consumption estimations do include these emissions. It is important to highlight that we have not included the full life-cycle emissions of all the waste (e.g. plastic manufacturing) since they are not within the scope of the analysis.

3.3 Total Carbon Footprint

Figure 4 shows the total GHG emissions across all activities in the Galapagos Islands. Table 15 provides breakdown by emission source. We can see that international travel is the largest source of emissions (68.82% of the total emissions). This is mainly generated by the long-haul air travel from the United States and Europe. The second contributor is the use of fuel (17.86% of the total emissions) to support the tourism industry and other activities on the islands.

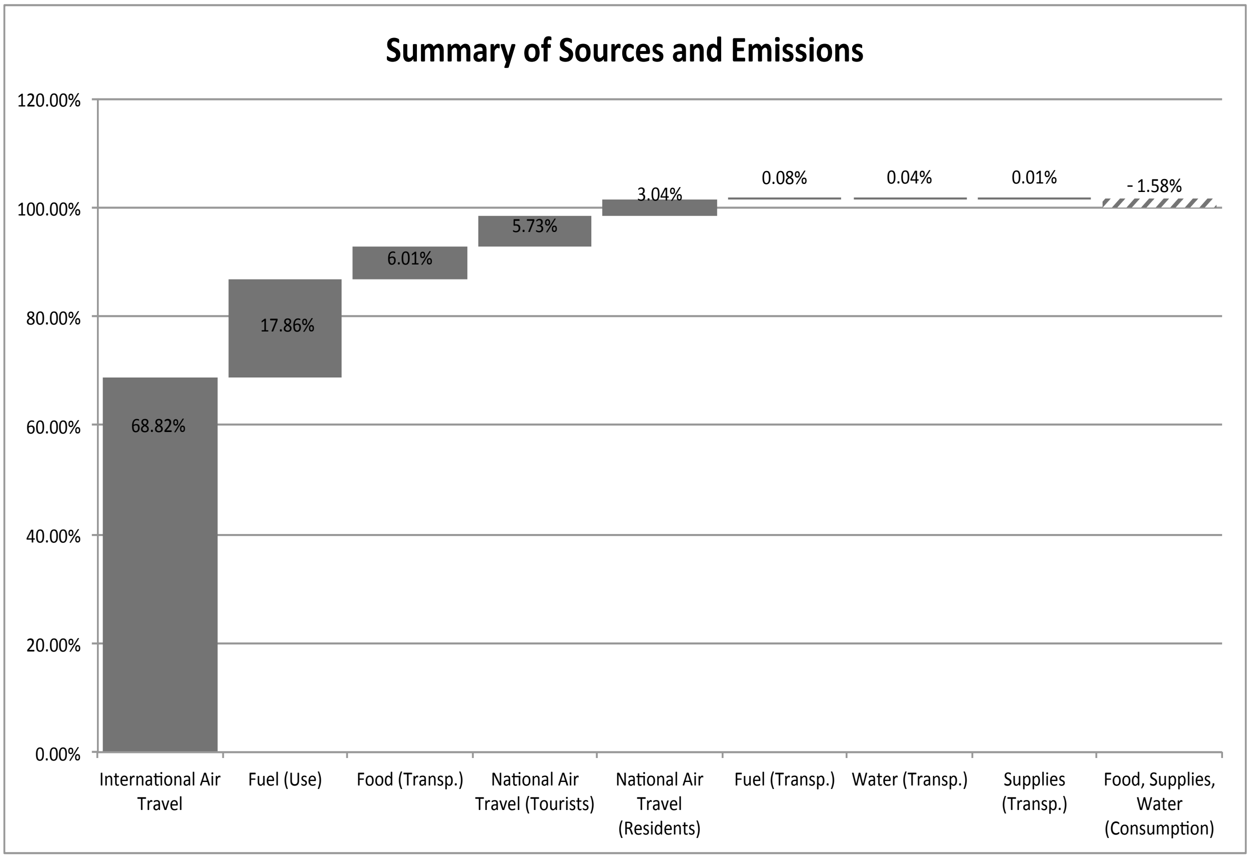

Figure 4 – Summary of Sources of Emissions and Their Contribution

Table 15
Total GHG Emissions by Source

Emissions Source			**Emissions in CO2-eq (tonnes)**	**Grand Percentage**
Transportation	Fuel		409	0,08%
	Food		32,008	6.01%
	Supplies		40	0.01%
	Water		202	0.04%
	Tourists	International	366,374	68.82%
		National	30,501	5.73%
	Residents		16,199	3.04%
	Sub Total		445,733	
Energy	Fuel		95,076	17.86%
Waste Management	Food, Supplies and Water		-8,436	-1.58%
	Sub Total		86,640	
Grand Total			**532,373**	**100%**

In order to better understand the source of environmental impacts, we allocated the emissions between tourists and residents (see Table 16). We use the concept of "equivalent days" as follows: the 163,480 tourists spend on average 4.9 days in the islands, while the 25,124 residents spent 360 days; thus, the 163,480 tourists are equivalent to 2,225 residents (163,480*4.9/360). We use "equivalent days" for fuel, food, supplies and water emissions, and fuel transportation. The remaining categories were directly assigned to tourists or residents by the emission.

Table 16
Allocation of Emissions between Tourists and Residents.

	Total	Tourists		Residents	
Individuals	188,604	163,480	86.7%	25,124	13.3%
Avg. Days of Stay		4.9		360	
Equivalent Days	27,349	2,225	8.1%	25,124	91.9%

Source	Total (tonnes of CO_2-eq)	Tourists (tonnes of CO_2-eq)		Residents (tonnes of CO_2-eq)		Per Tourist (kg of CO_2-eq)	Per Resident (kg of CO_2-eq)	Per Tourist Day (kg of CO_2-eq)	Per Resident Day (kg of CO_2-eq)
Fuel (Transp.)	409	33	8.1%	376	91.9%	0.2	14.9	14.9	14.9
Food (Transp.)	32,008	11,369	35.5%	20,638	64.5%	69.5	821.4	5,109.4	821.4
Supplies (Transp.)	40	3	7.5%	37	91.8%	0.02	1.5	1.3	1.5
Water (Transp.)	202	17	8.3%	185	91.8%	0.1	7.4	7.5	7.4
International Air Travel	366,374	366,374	100.0%	-	0.0%	2,241.1	-	164,651.8	-
National Air Travel (Tourists)	30,501	30,501	100.0%	-	0.0%	186.6	-	13,707.4	-
National Air Travel (Residents)	16,199	-	0.0%	16,199	100.0%	-	644.8	-	644.8
Fuel Use	95,076	7,735	8.1%	87,341	91.9%	47.3	3,476.4	3,476.4	3,476.4
Waste Food, Supplies, Water Consumption	(8,436)	(1,662)	19.7%	(6,774)	80.3%	(10.2)	(269.6)	(747.1)	(269.6)
Total	**532,373**	**414,370**	**77.8%**	**118,002**	**22.2%**	**2,534.7**	**4,696.8**	**186,221.7**	**4,696.8**

3.4 Analysis and Mitigation Strategies

As mentioned earlier, international air travel is the largest share of emissions. This explains why, on an equivalent day basis, a Galapagos tourist footprint is 39 times larger than a Galapagos resident footprint. Since tourism is a major source of economic growth, there is limited ability to mitigate air travel emissions besides supporting global initiatives that foster innovation in aircraft engine design. Carbon offsets may also be an option, as long as they are tied to local initiatives of carbon reduction.

After air travel, fuel use is the second largest share of emissions. Boats transporting tourists and residents within the archipelago generate the majority of these emissions (60%). Controlling the growth of these emissions should be a priority within the scope of the Galapagos region. Improved boat travel routes, better boat engines, higher utilization of vessel capacity and reduced idling are examples of initiatives that, based on experience in other internal combustion engines, could reduce emissions from 1% to up to 36% (NTM, 2008). Additional data collection is needed to narrow down the strategies that should be deployed among residents and tourist operators.

The third largest source of emission is the import of food from the mainland. There are two drivers for these emissions: the air transport due to item perishability and the food consumption of tourists (70% larger than the Galapagos resident). Tourist operators could balance the menus to include less perishable food and to plan shipments using regular shipping boats into the Islands. However, these two strategies need to be implemented cautiously since this may increase the amount of waste of products (e.g. in-transit spoilage) and emissions due to improper refrigeration equipment (e.g. chemical leakage). A third option is to work with tourists to reduce their food consumption while in the islands or plan custom-meals prior to arrival to the Islands to rationalize food purchases.

The fourth largest source of emissions is fuel consumption for energy generation (23,428 tonnes of CO_2-eq or 4.4% of total emissions). Traditional abatement strategies include energy use reduction, cleaner fuels and deployment of renewable energy alternatives.

Table 17 summarizes the four main emissions sources as well and selected mitigation strategies. The table also includes abatement potentials. We believe that boat fuel consumption is the most viable medium term strategy for reducing Galapagos Island GHG emissions.

Table 17
Main emission sources and abatement sources. Preliminary abatement potentials estimated by authors.

Source	Total Emissions (tonnes of CO2-eq)	% of Total Emissions	Abatement Strategies	Barriers	Abatement Potential	Abatement Potential (tonnes of CO2-eq)
Air Travel	366,374	68.8%	None. Engage with airline industry.	No direct influence	0%	-
Fuel Consumption - Boats	57,069	10.7%	Engine replacement; Idling; Higher utilization.	Fragmented boat owners	15%	8,560
Food Transport	32,008	6.0%	Tourist menu adjustment. Shift to ocean.	Customer service expectations; Multiple travel operators	10%	3,201
Fuel Consumption - Energy	23,428	4.4%	Energy conservation. Renewable.	High cost of technology; Fragmented deployment	5%	1,171

4 Conclusions

The Galapagos Islands are very fragile systems. Governments have actively managed human and industrial activities to preserve and maintain local bio-diversity. Due to the increase awareness of the risks of climate change, there is an interest to include other dimensions of environmental sustainability such as green house gas (GHG) emissions.

This paper is the first attempt to estimate the GHG emissions for the Galapagos Islands, commonly referred to as carbon footprint. The carbon footprint included primary data from fuel consumption used for energy and transportation; transport of food, water and supplies from the main island to support resident and visitors; waste management activities, including transport of recycled waste to Ecuador mainland; and air travel of both residents and tourists into the Galapagos Islands.

The top three sources of carbon emissions are the transportation of international tourists (68.82%), combustion of fuel (17.86%), and transportation of food (6.01%). It is important to highlight the relative importance of food transportation to the islands, an area usually not included in similar GHG studies.

This quantification allows a better problem identification and to propose more effective strategies. Given the limited direct influence Galapagos residents and authorities have on air travel emissions, we propose residents and authorities to focus on energy conservation/mitigation as well as strategies to reduce fuel consumption of the various boats used for local transport and tourist activities.

The study has some limitations; we did not have access to detailed resident food consumption or air travel patterns and used regional estimates instead. We also had limited access to tourist food waste information and we were unable to analyze boat fuel consumption at more granular levels. Besides these gaps, future extensions of the study could include more detailed information about the upstream food supply chain (e.g. local vs. imported) as well as surveys with tourist to explore their willingness to change food consumption patterns. A detailed study of boat engines and their maintenance will allow for more specific recommendations for GHG emission reductions.

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6 References

Aguirre, O., 2002. Plan Regional para la Conservación y el Desarrollo Sustentable de Galápagos. Instituto Nacional Galápagos. In Texto Unificado de la Legislación Ambiental Secundaria. Libro VII. Corporación de Estudios y Publicaciones y Ministerio del Ambiente, Quito, Ecuador.

BLS. Spotlight on statistics travel: U.S. Bureau of Labor Statistics; 2010.

Bogner J., Pipatti R., Hashimoto S., Diaz C., Mareckova K., Diaz L., Kjeldsen P., Monni S., Faaij A., Gao Q., Zhang T., Ahmed MA., Sutamihardja RTM., Gregory R., 2008. Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Waste Management and Research. 26, 11-32.

Carpio, H., 2001. Análisis del Mercado agropecuario en San Cristóbal. In: Informe Galápagos 2000-2001. Fundación Natura and WWF. Quito, Ecuador.

Cayot, L., Cifuentes, M., Amador, E., Cruz, E., & Cruz, F., 1996. Determinación de la Capacidad de Carga Turística en los sitios de visita del Parque Nacional Galápagos. Parque Nacional Galápagos, Puerto Ayoura, Galápagos, Ecuador.

Di Carlo, G., D'Ozouville, N., Henderson, S., De Koing, F., Larrea, I., Ortiz, F., Suarez, L., 2011. Introduction. In I. D. Larrea (Ed.), Climate Change Vulnerability Assessment of the Galapagos Islands. USA: WWF and Conservation Internacional.

EPA. Climate leaders greenhouse gas inventory protocol core module guidance, optimal emissions from commuting, business travel and product transport: U.S. Environmental Protection Agency; 2008.

EPA. Unit conversions, emissions factors, and other reference data: U.S. Environmental Protection Agency; 2004.

EPA. Waste Reduction Model: U.S. Environmental Protection Agency; 2010.

Filimonau, V., Dickinson, J. E., Robiins, D., & Reddy, M. V., 2011. A critical review of methods for tourism climate change apparisal: life cycle assessment as a new approach. Journal of Sustainable Tourism. 19(3), 301-324.

Font, X., Tapper, R., & Cochrane, J., 2006. Competitive strategy in a global industry: tourism. Handbook of Business Strategy. 7(1), 51-55.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland., 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (Eds.), Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Galapagos Ecuador Foundation. Metropolitan Touring Recycling Results; 2010.

GHG Protocol. GHG emissions from transport or mobile sources: Greenhouse Gas Protocol; 2011.

Gössling, S., Borgström –Hansson, C., Hörstmeier, O., Saggel, S., 2002. Ecological footprint analysis as a tool to assess tourism sustainability. Ecological Economics. 43, 199-211.

Gössling, S., Peeters, P., Ceron, J.P., Dubois, G., Patterson, T., Richardson, R.B., 2005. The eco-efficiency of tourism. Ecological Economics. 54, 417-434.

INGALA. (2003). Plan Regional para la Conservación y el Desarrollo Sustentable de Galápagos. Fundación Charles Darwin. Parque Nacional Galapagos INGALA.

INEC - Instituto Nacional de Estadística y Censos. Encuesta Condiciones de Vida Galapagos; 2009.

INEC - Instituto Nacional de Estadística y Censos. Encuesta de Condiciones de Vida en Galápagos; 2010.

INEC - Instituto Nacional de Estadística y Censos. (n.d.). Retrieved October 2010, from INEC: www.inec.gob.ec

Kuo, N.W., Chen, P.H., 2009. Quantifying energy use, carbon dioxide emission, and other environmental loads from island tourism based on a life cycle assessment approach. Journal of Cleaner Production. 17, 1324-1330.

Ministerio de Ambiente del Ecuador. Parque Nacional Galapagos. Plan para Manejo Sustentable de Galapagos. Galapagos, Ecuador; 2007-2009.

Novy, J. W., 2000. Incentive Measures for Conservation of Biodiversity and Sustainability: A Case Study of the Galapagos Islands. World Wildlife Fund - USA, Washington, DC.

NTM. Environmental data for international cargo and passenger air transport: The Network for Transports and the Environment; 2008.

Patterson, M.G., 2003. Environmental Performance and Ecoefficiency of the New Zealand Tourism Sector. Ecological Economics at the Cutting Edge: Meetnig of the Australia and New Zeland society for Ecological Economics. Auckland: University of Auckland. November 16, 2003.

Pickering, C., 2011. Changes in demand for toursim with climate change: A case study of visitation patterns to six ski resorts. Journal of Sustainable Tourism. 19(6), 767-781.

Quiroga, D., Mena, C., Karrer, L., Suzuki, H., Guevara, A., & Murillo, J. C., 2011. Dealing with Climate Change in the Galapagos: Adaptability of the Tourism and Fishing Sectors. In I. Larrea,

& G. Di Carlo (Eds.), In Climate Change Vulnerability Assessment of the Galapagos Islands. USA: WWF and Conservation International.

Ruales, C., 2004. Análisis socio económico de la Isla San Cristóbal-Galápagos con énfasis en aspectos de la actividad agrícola. Universidad San Francisco de Quito, Master of Science.

Scott, D., Peeters, P., & Goessling, S., 2010. Can tourism deliver its "aspirational" greenhouse gas emission reduction targets? Journal of Sustainable Tourism. 18(3), 393-408.

Serrano, A., Celleri, A., 2011. Optimización de la logística de envío de alimentos y suministros para los Yates A y B en Galápagos. Unpublised Industrial Engineering B.Sc. Thesis, Universidad San Francisco de Quito, Quito, Ecuador.

Seuring, S. Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production. 16, 1699-1710.

Tapper, R., & Font, X., 2004. Toursim Supply Chains - A report from Leeds Met fot the Travel Foundation.

Taylor, J.E., Hardner, J., Stewart, M., 2006. Ecotourism and Economic Growth in the Galapagos: An Island Economy-wide Analysis. Working Paper Nº 06-001. Agricultural and Resource Economics, University of California, Davis.

Torsten Hardter U, Larrea Oña I, Butt KM, Chitwood J., 2010. Waste management blueprint for the Galapagos Islands; WWF Galapagos program.

UNWTO. Tourism Highlights: The World Tourism Organization; 2011.

USDA. Water in meat and poultry: United States department of Agriculture Food Safety and Inspection Service; 2011.

WHO. Diet, nutrition and the prevention of chronic diseases: WHO Technical Report Series; 2003.

World Bank. World development indicators database; 2011. Available at: http://data.worldbank.org/data-catalog.

World Economic Forum. Supply Chain Decarbonization: The role of logistics and transport in reducing supply chain carbon emissions; 2009.