"Carbon emission offsets for aviation-generated emissions due to international travel to and from New Zealand" – revised personal version of paper to appear in Energy Policy (in press 20 December 2008) NOTE: Final official version can be found using Digital Object Identifier (DOI) listed here: doi:10.1016/j.enpol.2008.10.046

# CARBON EMISSION OFFSETS FOR AVIATION-GENERATED EMISSIONS DUE TO INTERNATIONAL TRAVEL TO AND FROM NEW ZEALAND

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**Abstract**

International air transport emissions are not subject to liability under the Kyoto Protocol. However, pressure is mounting globally for international aviation to be included in post-Kyoto arrangements. In the absence of international collective action, a number of so-called carbon offsetting schemes have emerged that allow individual travellers and companies to compensate for their international air travel emissions. These schemes offer technological solutions, such as planting sink forests to sequester emissions. To consider the implications of future collective action, this paper presents a case study assessment of the physical feasibility of five schemes for all short duration journeys to and from New Zealand. This is the first comprehensive national-level case study assessment of competing offsetting options for international aviation emissions in the peer-reviewed literature. The $CO_2$-e emissions produced by the air travel of international visitors to New Zealand, and for New Zealand residents travelling overseas, is calculated in this paper to be 7893 Gg and 3948 Gg, respectively in 2005. It is then shown that no single offsetting scheme targeted inside the country appears physically and/or politically realistic. This indicates the sheer size of these emissions, and the challenge that the international community faces for collective action on this matter.

**Keywords**

Carbon emissions offsetting; air travel; international tourism

**Aims, Background and Policy Context**

This paper aims to address the question of whether or not carbon emissions from international air transport can be offset at a national level through recognised and currently available technological solutions.

Observations of accelerating global climate change have increased the urgency with which the world considers the need to reduce and mitigate carbon emissions. An increase in demand for air travel internationally has lead to an increase in emissions attributable to the aviation industry. There is increasing media comment in regions such as Europe on the role that long-haul travel plays in global climate change (for example, Guardian Unlimited, 2007), and these regions are a source of a significant fraction of the international visitors to New Zealand. In the absence of firm international policy to allocate responsibility for the emissions from international air travel, countries such as New Zealand are addressing the question as to whether destination or source countries should be viewed as ethically responsible for the greenhouse gas emissions attributable to the visitors. Considering the significant export earnings that some nations, particularly some developing countries, obtain from international visitors, this is an important issue.

This paper presents a quantitative case study where the contribution that air travel makes to New Zealand's greenhouse gas emissions profile is calculated, both for international visitor arrivals to New Zealand, and for travel overseas by New Zealand residents. Using these calculations, analysis is then presented of the implications of attempting to offset these emissions through existing recognised methodologies, such as reforestation and energy efficiency measures. The policy implications of these results are discussed, along with suggestions for future strategies.

Although it is unlikely that New Zealand would be expected to accept liability for both emissions attributable to international visitor arrivals and also for emissions attributable to travel by New Zealand residents overseas, it is interesting from a policy perspective to compare the level of emissions, including historical trends, and to look at possible scenarios for reducing the level of emissions by either group. Such an analysis does not appear to have been attempted in a New Zealand context before, and this paper can also inform the wider international discussions on how to deal with these issues.

New Zealand is an Annex I Party to the Kyoto Protocol, and has undertaken to reduce greenhouse gas emissions for the country to 1990 levels in the first commitment period (2008-2012). However, New Zealand's Kyoto-liable emissions grew by approximately 25 % the period 1990 to 2005 (Ministry for the Environment, n. d.), making achieving the first commitment period target extremely challenging. The New Zealand Government, as with all Annex I countries, is preoccupied with dealing with emissions that are liable under the Kyoto Protocol. For example, the New Zealand Government has set, a policy objective of "resilient, low carbon transport" for the country, but international transport is only briefly mentioned in the relevant section of the energy policy document, The New Zealand Energy Strategy (New Zealand Government, 2007).

In 2005, transport, including domestic aviation, made up 18 % of the current Kyoto-liable emissions for New Zealand (Ministry for the Environment, n. d.). As required by the IPCC, New Zealand's Greenhouse Gas Inventory (Ministry for the Environment, n. d.) includes emissions attributable to domestic aviation (which is Kyoto-liable), and international aviation (which is not Kyoto-liable), calculated from bunker fuels.

New Zealand's economy is heavily dependent on international tourism, which accounted for 19.2% of New Zealand's exports in the year ending March 2006 (Statistics New Zealand, 2007a), making it a bigger export earner than the dairy trade, which accounted for 13.2% of export receipts in 2006 (Statistics New Zealand, 2007b). International tourism produced 9% of the country's GDP when direct and indirect (industries supporting tourism) contributions are included (Statistics New Zealand, 2007a). Overseas travel by New Zealand residents, on the other hand, has negative financial implications for the balance of trade for the country.

The overwhelming majority of the international visitors to New Zealand arrive by air. Few of the international visitors to New Zealand come for business or education (approximately 13% in 2005) (Ministry of Tourism, n. d.). Similarly, the overwhelming majority of New Zealand residents leave NZ by air. The percentage breakdown of destinations for New Zealand travellers, however, are somewhat different from the source countries of international visitors to NZ. For example, 18% of visitors to NZ in 2005 were from Europe, but only 8.2% of trips by NZ residents were to Europe.

Located in the South Pacific, New Zealand is an island nation, geographically isolated, and with a traditionally high level of international travel by its residents.

Travelling the world, and living and working in other countries for a year or more, is regarded as a rite of passage into adulthood for young people, and is commonly referred to as "the Big O.E." (Overseas Experience). Alongside this tradition, is what might be called "the little O.E.", comprised of shorter trips (less than one year) overseas, including work and holidays. Almost all of the current generation of New Zealand residents travel by air to their international destinations.

With increasing awareness of the impact of air travel on the Earth's climate system, New Zealanders are starting to question the environmental cost of these "O.E." traditions. In particular, the New Zealand Government has recently launched a Discussion Paper entitled "Sustainable Transport – Update of the New Zealand Transport Strategy", which notes a very high level of international travel by New Zealanders, at 1.9 million trips per annum (Ministry of Transport, 2007), or roughly one overseas trip per year for 50% of the resident population of 4 027 947 people (Statistics New Zealand, 2007d)). In contrast, the USA figures for the year 2000 are approximately one trip out of the USA for 20% of the resident population, with approximately half of these trips to Canada or Mexico (U.S. Department of Commerce, 2007; US Census Bureau, 2001). The discussion paper "Sustainable Transport – Update of the New Zealand Transport Strategy" contains a "Vision for the Future" which includes the phrase "Users face full costs including the costs of emissions" under the heading "Moving people into and out of New Zealand" (Ministry of Transport, 2007). This paper will help inform the implementation of such a policy by assessing the physical implications of international travel.

Although international air transport emissions are not subject to liability under the Kyoto Protocol, they are included separately in the national greenhouse gas inventories required by the IPCC (Eggleston et al., 2006). Pressure is mounting globally for international aviation to be included in post-Kyoto considerations of carbon emissions (Oberthür, 2003). Voluntary offsetting programmes are already in place with some airlines, allowing passengers to pay for the mitigation of the carbon emissions resulting from their travel. Anderson et al (2008) noted that national carbon-reduction policies and targets often exclude international aviation emissions. Brand and Boardman (2008) commented on the lack of personal level research data on international travel, and the difficulties that this presents for the development of policy. However, despite these limitations, the European Union plans to include air transport within the existing European emissions trading scheme (ETS) and reports such as Morrell (2007) have examined the implications of different allocation options.

There are several policy issues regarding the emissions from international aviation:

(1) Emissions from international air transport were left out of the national Kyoto obligations of Annex I countries, and responsibility for resolving the international air transport emissions problem was devolved to the International Civil Aviation Organisation (ICAO). However, limited progress has been made (Oberthür, 2003).

(2) An international aviation fuel tax is almost impossible to implement, due to the international bilateral aviation agreements following the ICAO post-1944 recommendation on reciprocal tax exemptions for foreign aircraft (Oberthür, 2003).

(3) Even if agreement can be reached on the calculation of emissions, it is not clear how responsibility would be allocated. SBSTA stands for "Subsidiary Body for Scientific and Technological Advice", and its role is to "[counsel] the Conference of the Parties on matters of climate, the environment, technology, and method." (UNFCCC, n. d.). The five preferred allocation alternatives out of the list commonly referred to as the "eight options", following the SBSTA 4 meeting of 1996, are, in no particular order: (i) no allocation (the current

situation), (ii) allocation by country where the fuel is sold, (iii) allocation by country of registration of airline company, (iv) allocation by country of destination/departure of plane, or (v) allocation by country of destination/departure of passengers and freight. The three "not preferred" options were (vi) allocation by country of origin of the passengers or freight owner, (vii) allocation in proportion to the national emissions of each country and (viii) allocation by the emissions generated within each country's national space. Allocation by country of origin of the passengers or freight owner was not a preferred option because data on this matter is not widely publicly available in many cases (Miljøstyrelsen Miljøministeriet, 2003). The other "not preferred" options (options vii and viii) were not preferred due to fairness and effectiveness reasons (Miljøstyrelsen Miljøministeriet, 2003).

(4) The main methods for dealing with the emissions could be an emissions charge/tax, offsetting, emissions trading, or rationing, but there are problems associated with each of these. An approach that covers the whole aviation sector has been discussed at international level negotiations, for example at the 2008 Bangkok Climate Talks (First Session of the Ad Hoc Working Group on Long-Term Cooperative Action (AWG-LCA1) and the Fifth Session of the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP5)), as described in ICAO (2008). Rather than attributing liability to individual countries, travellers, and/or companies, this so-called "sectoral approach" would mean that emissions targets would be set for the sector and operators would then be required to reduce emissions (EU, 2008).

**Methodology**

The calculations contained in this paper are performed in two stages. First, the carbon emissions from the air travel of international visitors to New Zealand and of

New Zealand residents travelling on short duration trips overseas are calculated. Then the physical requirements to offset these emissions are calculated. These calculations are based on existing offsetting technologies, and do not attempt to predict or model any future technological improvements.

In principle, there are multiple possible ways to calculate the carbon emissions associated with international air travel:

(1) Bunker fuels: recording how much fuel is used to refuel planes in each country.

(2) Passenger focus: calculating emissions based on passenger numbers and distance flown.

(3) Plane focussed: calculating emissions based on particular plane types and distances flown.

(4) Freight and passenger focus: calculating emissions based on both freight carried and passenger numbers.

There are several problems with each of the possible ways to calculate the emissions:

(1) Bunker fuels: bunker fuel-based calculations only cover plane journeys that refuel in New Zealand (analysts from the Energy Information and Modelling Group, Ministry of Economic Development, personal communications, December 2007 and February 2008). This implies, for example, that some journeys originating in Australia may not be counted, and neither will sectors such as London to Los Angeles on a flight from London to Auckland. In addition, separating the data for fuel used for refuelling domestic flights from that used for international flights can be problematic. An ongoing review by the Energy Information and Modelling Group, Ministry of Economic Development, has identified previous under-reporting in New Zealand of fuel used for International Transport and a consequential error in the fuel calculated as used for Domestic Transport. Corrected figures for years 2006 - 2007 will be published in the upcoming release of the New Zealand Energy Data File

(Analysts from the Energy Information and Modelling Group, Ministry of Economic Development, personal communications December 2007 and February 2008). Allocation of emissions to countries which are not final destinations is a policy issue, e. g., in the case of the USA for travellers on the continuous route Auckland to Los Angeles to London.

(2) Passenger focus: this is usually done using "global fleet values" for planes which are not necessarily representative of particular airline fleets.

(3) Plane focussed: this requires details of each plane type, and does not necessarily take into account loadings.

(4) Freight and passenger focus: Freight values are not as readily available as passenger data.

There are also a range of Radiative Forcing Index (RFI) values given in the international peer-reviewed literature for calculation of the net effect of carbon emissions from flights, whichever of the methods above are used. Although it has been acknowledged that the RFI is not a suitable metric, it has also been acknowledged that the impact of aviation is greater than the carbon emissions alone (DEFRA, 2008, quoting Professor David Lee). As outlined below, in this paper we apply the RFI of Sausen et al. (2005), and acknowledge the uncertainties associated with this approach. This approach is conservative, as it equates to applying what Brand and Boardman (2008) have classed as a low to moderate Aviation Impacts Multiplier.

The focus of this paper is on the policy implications of mitigating the carbon emissions associated with air travel by international tourists and New Zealand residents, and, therefore, a passenger focus-based calculation is the most appropriate and informative method to use. Unlike some other countries, New Zealand has very good publicly available data on these journeys so that these calculations can be performed. The steps that are followed are, firstly the total number of passenger flights to (or from) each country are obtained, then the total distance flown is calculated, and finally the carbon emissions associated with these flights are calculated. The quantitative implications of the limitations of this methodology are discussed further in the results section. A contrast with the other methodologies is also quantified, particularly the bunker fuels methodology, which is the method currently used in national greenhouse gas inventories.

Visitor arrival numbers to New Zealand from 1983 to 2005 and forecasts of future arrivals through to 2012 were taken from publicly available information, provided through the Tourism Research website of the New Zealand Ministry of Tourism (Ministry of Tourism, n.d.(a)). These data are broken down into the top 21 visitor origin countries. Following the approach outlined in the New Zealand Tourism Strategy to 2015 (Ministry of Tourism, Tourism New Zealand, and Tourism Industry Association, 2007), we assume visitor numbers will grow at 4% from the 2012 forecast. Note that these assumptions do not allow for differing future environmental and financial scenarios that may affect visitor numbers. Such considerations are beyond the scope of this paper. All visitors are included in our calculations, no matter what their specified purpose for visiting New Zealand. "Holiday" or "visiting friends and relatives" are the main stated purposes for visitors travelling to New Zealand, with "business" or "education" given as the reason for visiting New Zealand by only approximately 13% of 2005 visitors (Ministry of Tourism, n. d.). A single origin international airport was assigned as the point of departure for each of the 21 source countries. Domestic transport within origin and destination countries is omitted, since it is already included in national greenhouse gas emission liabilities, whereas international air travel is not. The origin airports are shown as diamonds in Figure 1.

Numbers of New Zealand residents departing New Zealand on return trips of less than one year's duration in the period 1982 to 2006 were taken from a publicly available statistical database (Ministry of Tourism, n.d.(b)). No future projections are included for travel by New Zealand residents. Using a similar approach to that taken above, visitor numbers to each destination country for the top 30 destinations were used. Thirty destinations were included because New Zealand residents travel to a wider range of countries than the twenty-one major source countries of international visitors to New Zealand. As before, each of the destination countries were assigned a nearest international airport as a point of arrival (Figure 1), and the distance from New Zealand was then calculated for each of these airports.

To calculate carbon emissions attributable to New Zealanders travelling internationally, we focus on New Zealand residents returning to the country after a period of less than one year. This cut-off is used because residents departing for periods of more than one year are grouped with permanent emigrants as "permanent and long-term departures" in international travel and migration data compiled by Statistics New Zealand. The numbers used in this study, therefore, exclude those travellers leaving on the traditional "Big O.E." journey: for example, those taking up the two-year working holiday visa arrangement in the United Kingdom, as well as those permanently leaving New Zealand. Eighty percent of the 15400 permanent and long-term departures to the UK in 2005 were New Zealand residents, which would account for an additional approximately 20% to the $CO_2$-e emissions attributable to departures for the UK. However, as this is the main destination for the "Big O.E.", the relatively small contribution of this cohort highlights that the "little O.E." can be assumed to be a much larger contributor to international aviation $CO_2$-e by New Zealand residents than the "Big O.E."

The distance from the origin (or destination) airport to (or from) New Zealand was then calculated for each airport using the WGS-84 Ellipsoid (NIMA, 2000) assuming a great circle path to Auckland (star in Figure 1). Following the recommendations of the IPCC Special Report Aviation and the Global Atmosphere (Penner et al., 1999), the distances were increased by 9% to account for non-direct (i.e., not along the straight line between destinations) routes and delays/circling. Circling is less of an issue for flights originating and terminating in New Zealand, but is likely to be more important for the common route from Europe to New Zealand through Los Angeles International (LAX). We use the 9% loading factor in the absence of any New Zealand specific data. Suggested variations to this figure, for example using 6% instead of 9%, are small compared to the uncertainty associated with the RFI used. The climate impact for each visitor to (or resident of) New Zealand is determined through the $CO_2$ emissions from the return flight, weighted to include the radiative forcing changes beyond $CO_2$ itself, as detailed below. We express the result through $CO_2$-equivalent ($CO_2$-e), in the conventional manner.

The $CO_2$ emissions are calculated following the methodology provided by the United Kingdom Department of Environment, Food and Rural Affairs (DEFRA, 2007). For travel over distances greater than 3700 km, $CO_2$ emissions are calculated from 105 g/km, multiplied by the flight distance, to give the $CO_2$ emissions in g. For the case of international visitor travel to New Zealand, all the origin airports meet the distance requirements for long-haul, with the exception of the Australian (Sydney) and Pacific Islands (Nadi, Fiji) origin airports, which are medium-haul under the DEFRA approach, with travel distances between 425-3700 km. In this case, the $CO_2$ emissions are calculated at 130 g per km rather than 105 g/km. Similarly, New Zealand residents travel is separated into long-haul and medium-haul destinations, some of which (for example, the Cook Islands) are not significant source countries for international visitors to New Zealand.

In order to transform our $CO_2$ emissions into $CO_2$-e, and, thus, include the effects on tropospheric ozone and methane from $NO_X$ emissions, water vapour, particle emissions and the formation of high-altitude contrails, we apply a RFI, following the standard approach (Penner et al., 1999). We take the RFI to have a value of 1.9, based on the radiative forcing calculated for the year 2000 international air travel fleet (Sausen et al., 2005). This calculation includes the impact of contrail radiative forcing, but excludes the increased RFI effects of enhanced cirrus cloudiness for which there are still large degrees of uncertainty, approximately half as large as the suggested RFI of 1.9 (e.g. Sausen et al., Fig. 1, 2005). Thus the $CO_2$-e for each overseas visitor (or New Zealand resident) travelling to and from New Zealand for each origin airport has been determined, as shown in Figure 1. The $CO_2$-e values are given for each origin airport in metric tonnes (i.e., 1000 kg). For long-haul travel the simple formula is:

$$CO_2\text{-e (g)} = 105 \text{ (g/km)} \times \text{great circle path flight distance (km)} \times 1.09 \times 2 \times 1.9$$

Results are then given in Gg, the standard unit for carbon emissions inventories. A gigagram (Gg) is identical to a kilotonne. Note that this calculation is conservative, since the RFI used is 1.9 (Sausen et al., 2005), but as acknowledged in that study, the RFI value could be as high as 4, while the Penner et al. (1999) figure was 2.7. Brand and Boardman (2008), for example, use Aviation Impacts Multipliers of between 1.5 and 4 in their calculations. The total impact of the flights of international visitors to New Zealand is determined by combining the $CO_2$-e values from Figure 1 with the 1983-2015 visitor numbers shown in Figure 2. This combination is presented in Figure 3, with the total $CO_2$-e over this time period shown by the black line. In order to quantify the effect of differing regional sources, we have grouped countries into continental aggregates. The aggregates sum to slightly less than the total, due to countries located outside of these regions (e.g., South Africa).

Data on international travel by New Zealand residents shown in Figure 4 and the values given in Figure 1 are combined to give the values shown in Figure 5, the variation with time of the greenhouse gas emissions attributable to New Zealand residents travelling out of New Zealand from 1982 to 2006.

## Results and Discussion

### Emissions attributable to travel by international visitors to NZ

The 2005 $CO_2$-e emissions attributable to air travel to and from New Zealand from the 2.4 million visitors is calculated by the above method to be 7893 Gg. Note that this excludes international air travel by New Zealand residents, which is analysed below. For comparison, New Zealand's official greenhouse gas emissions, which exclude international aviation emissions, for that period were 77,159 Gg $CO_2$-e (Ministry for the Environment, n.d.; note that this figure also excludes sinks such as the category land use, land-use change and forestry). Visitor numbers are projected to grow at 4% a year, reaching 3.5 million in 2015 (Ministry of Tourism, Tourism New Zealand, and Tourism Industry Association, 2007).

As has been pointed out earlier in this paper, New Zealand's Kyoto-liable emissions grew by approximately 25 % the period 1990 to 2005, yet the country's commitment is to reduce emissions to 1990 levels by the end of the first commitment period in 2012. Carbon emissions attributable to international visitors travelling to New Zealand are not liable under the Kyoto Protocol. These emissions in 1990 are calculated in this paper to be 2901 Gg, and in 2005 to be 7893 Gg. This is an increase of 172 %.

The $CO_2$-e values are very strongly driven by visitor origin rather than visitor numbers. Figure 3 shows the breakdown of $CO_2$-e emissions by visitor origin for 2005, in contrast to Figure 2, which shows the breakdown of visitor numbers by destination. Note that while the visitors from Australia make up approximately 37% of the total number, these represent only 13% of the $CO_2$-e. In contrast, visitors from Europe make up approximately 18% of total visitor numbers, but account for 43% of the $CO_2$-e attributable to international visitor air travel. The impact of the Asian economic crisis of 1997 on international visitor arrivals from the Asian region is reflected in the sharp decline in $CO_2$-e values shown in Figure 3, from 1997 to 1998. The sharp decline is particularly driven by a collapse in the number of international visitor arrivals from South Korea over that period.

Figure 6 (solid line) presents the $CO_2$-e emissions for international visitors' air travel to New Zealand as an additional percentage compared to New Zealand's total Kyoto-liable emissions, taken from the 1990-2005 inventory (Ministry for the Environment. n.d.). It can be seen that the significance of the emissions has risen significantly over that short time period, with the emissions increasing from an additional approximately 5% of the total in 1990 to an additional approximately 10% of the total in 2005. The calculated emissions total for 1997 of 4855 Gg is consistent with the value for the emissions from international aviation by visitors to New Zealand of 4106 Gg that can be derived from Table 30 of Patterson and McDonald (2004) for the same period. The official New Zealand value for international aviation-related carbon emissions for 1997 was 1725 Gg (Ministry of Economic Development, 2007), however, this is based on a bunker fuels calculation, therefore, only accounts for planes refuelling in New Zealand. Also, as noted previously, the 2008 version of the NZ Energy Data File will include corrected figures for years 2006-2007 (Analysts from the Energy Information and Modelling Group, Ministry of Economic Development. personal communications, December 2007 and February 2008).

The significance of these emissions, currently not included in the calculation of a nation's Kyoto liabilities, is clear when contrasted with New Zealand's known 2005 emissions profile, as shown in Figure 7. In 2005, the $CO_2$-e emissions from the travel of international visitors to New Zealand was calculated to be an additional approximately 10% of the country's official Kyoto-liable emissions, or roughly equal to that produced by thermal electricity generation (8192.5 Gg in 2005). (Ministry for the Environment, n.d.) New Zealand's electricity generation in 2005 was 23.238 TWh from large hydroelectric plants, and 14.286 TWh from thermal generation plants (Ministry for the Environment, n.d.). The contribution of aviation to the anthropogenic greenhouse effect globally is widely taken to be around 3.5%, which is the figure given in Penner et al. (1999), although Gössling and Peeters (2007) calculate that it could be as high as 6.8% for 2005. The contribution of international air travel to New Zealand's greenhouse gas emissions is, therefore, considerably larger than the world average, and hence is a concern to policy makers in New Zealand. Pricing of these emissions, which would ultimately fall back onto individual travellers, is likely to influence decisions on destination and length of stay.

The primary issues are both environmental and also the perception of international visitors who choose to come to New Zealand. Meaningful offsetting strategies are required for the industry to maintain its present mode of operation, in the absence of a more decisive international regime, for dealing with international aviation-related emissions.

**Emissions attributable to international travel by New Zealand residents**

The 2005 $CO_2$-e emissions attributable to air travel originating in New Zealand by New Zealand residents, including the return leg of trips, was calculated by the methodology described above to be 3863 Gg.

New Zealand’s official Kyoto-liable greenhouse gas emissions for 2005, which exclude international aviation emissions, were 77,159 Gg CO2-e. The emissions generated by New Zealand residents flying internationally, therefore, comprise an additional 5% compared with the current Kyoto-liable emissions (Figure 7). The contribution of New Zealand residents to carbon emissions from international aviation is, therefore, approximately 50% of those emissions due to international visitor air travel to New Zealand.

As stated earlier, short duration, “little O.E.” trips are assumed in this paper to be a much larger contributor to international aviation $CO_2$-e by New Zealand residents than the “Big O.E.”. While we are not able to track the aviation-related emissions attributable to New Zealand residents living and working in other countries whilst on their “Big O.E.”, these emissions would be likely to be attributed to either their country of residence or destination country under a regime that attributed liability to particular countries. Comparing the contribution to climate change from international air travel by New Zealanders with the New Zealand greenhouse gas profile, it can be seen that New Zealanders make a higher contribution from international air travel than the world average.

**Policy implications of these results**

**Possible offsetting solutions**

There are some physical problems associated with these aviation-related emissions, which can be summarised as follows:

(1) The emissions have an adverse impact on the climate.

(2) The emissions are growing fast.

(3) There are no technological solutions on the horizon that will drastically reduce the emissions at source.

The contribution of air travel by international visitors to New Zealand's greenhouse gas emissions represents a growing risk to New Zealand's international image. Becken (2007), in a focus group based study, found that tourists in New Zealand have expressed a desire for more information about how air travel impacts on climate, and stated that this would "increase their awareness when making travel-related decisions". We suggest that any mitigation strategy will be more positively viewed by international tourists if the strategies are applied inside New Zealand. We, therefore, consider five possible methods to offset these greenhouse gas emissions; the installation of energy-efficient lightbulbs, replacing thermal electricity generation with windfarms, reducing road transport, regenerating native forests, and improving the efficiency of thermal electricity generation. These five methods were chosen because of they are commonly suggested and commercially available carbon offsetting or emission reduction methods in a New Zealand context. To quantify the practicality of the offsetting strategies, we evaluate the technical and physical feasibilities of each method separately. Note that these calculations assume that there are no future financial or environmental scenario changes that would restrict these technologies being implemented.

**Energy-efficient lightbulbs** – In 2005, 14.286 TWh of electricity was generated by thermal power plants in New Zealand (Ministry for the Environment, n.d.). The installation of a 20 W energy-efficient lightbulb in a New Zealand household (assuming 5 hours of operation each day) would annually offset 31.9 kg of $CO_2$-e. Thus the installation of 248 million lightbulbs would be required to offset the 2005 visitor emissions, requiring 105 lightbulbs per international visitor to be replaced. This is unrealistic in the New Zealand context, as New Zealand is a small country with only 1.48 million dwellings in 2006 (Statistics New Zealand, 2007c).

**Windfarms replacing thermal generation** – A 1000 MW windfarm can produce 3.24 TWh in New Zealand (New Zealand Wind Energy Association, n. d.), partially offsetting thermal generation (gas, coal). In 2005, thermal generation emitted 0.573 g $CO_2$-e/Wh in New Zealand (Ministry of Economic Development, 2007; and Ministry for the Environment, n.d.). The installation of 4250 MW of wind generation would offset the 2005 visitor emissions. This is 4250 1 MW wind turbines, and equivalent to 96% of New Zealand’s 2005 total thermal generation, or 13.715 TWh. New Zealand’s total wind resource available to contribute to consumer energy has been forecast for 2015 as being only 6.740 TWh/yr (high confidence (80-90% confidence), at less than 16 cents per kWh)(Minister for the Environment, 2006) which is significantly less than the amount indicated above. The “Low confidence” forecast for 2015, 16.840 TWh at 16 cents per kWh, includes resources that would have permitting and access difficulties if they were to be developed (Minister for the Environment, 2006). In addition, wind cannot easily provide baseload for an electrical supply system. It would, therefore, be technically highly challenging to meet this offsetting goal through the use of wind.

**Reducing road transport** – In 2005, the $CO_2$-e emissions from all road transport in New Zealand was 12 600 Gg (Ministry of Economic Development, 2007). The carbon emissions attributable to international visitors flying to and from New Zealand in 2005 are, therefore, 63% of the total road transport value. It is clearly unrealistic to hope that reduced car use and road freight haulage in New Zealand could offset the visitor emissions in the short to medium term.

**Regenerating bush** – Regenerating New Zealand forests absorb 3 tonnes of $CO_2$ each year per hectare of forest (Landcare Research, n. d.). By setting aside land for forest to regenerate, some of the emissions produced by visitors to New Zealand could be offset. In order to offset the 2005 visitor emissions, 26 300 km$^2$ of regenerating forest would be required. This is the size of 15 Stewart Islands, or 10% of the country's total land area. It would require increasing New Zealand's total forested area by one third, probably by decreasing the 50% of New Zealand land area used for pasture (Ministry for the Environment, 1997). This approach appears somewhat unrealistic, and would be likely to have significant additional economic impacts, making it politically difficult to implement.

**Improved thermal generation efficiency** – According to Genesis Energy Ltd., the installation of the E3P-combined cycle gas turbine at Huntly replaced 385 MW of thermal generation, reducing $CO_2$ emissions by 1000 Gg/yr (Genesis Energy, n. d.). In order to offset the 2005 visitor emissions, 8.2 E3P units would need to be installed. Since this is approximately all of New Zealand's 2005 total thermal generation (97%), this approach would be technically challenging.

**Summary** – This research has focussed on offsetting schemes that are currently available technological solutions for carbon emissions attributable to international air transport. We have been unable to identify an offsetting option that is physically realistic, or politically realistic, within New Zealand's geographic boundaries. It would appear that any offsetting solutions that attempt to offset the entire carbon emissions load attributable to flights by international visitors to New Zealand would need to be at least partially based in other countries. It would seem logical to explore both offsetting in the country that the visitors originate in, and also in developing countries with schemes eligible for Clean Development Mechanism recognition. This is an area that our group is currently researching, along with the implications of economic instruments such as ETSs. Since the level of emissions for New Zealand residents is of the same order as that for international visitors, such offsetting schemes for New Zealand residents are also physically and/or politically unrealistic. The only options possible would appear to be at least partial off-shore offsetting for those emissions, or a reduction in air travel by New Zealand residents. The latter is a behaviour change scenario and we discuss possible options for this below.

**Possible non-technical solutions**

There are a number of policy tools that could be considered by the New Zealand Government to reduce emissions through a reduction in the level of international travel by New Zealanders. At the most draconian level, the Government could legislate to restrict the freedom of movement for New Zealanders to leave New Zealand. This would be unacceptable in a liberal western democracy like New Zealand. At a slightly less draconian level, the Government could, as it has done in the past, restrict the amount of currency that New Zealanders are able to take overseas, which indirectly impacts on their ability to travel. This is unlikely to be politically acceptable in current New Zealand society.

Another indirect policy tool, and one that might be more politically acceptable would be the use of a price on carbon emissions to act as a disincentive for New Zealanders to travel internationally, combined with the promotion of domestic tourism. However, promotion of domestic tourism would inevitably result in an increase in Kyoto-liable emissions, which highlights one of the perverse policy incentives that exist with the current international liability arrangements. International aviation emissions are not currently included in the proposed New Zealand ETS, and the current New Zealand Government is averse to a direct carbon charge. There are also issues with implementation of a direct carbon charge, since international aviation fuels are not taxed.

Carbon emissions from aviation are an international issue requiring an international solution. It is likely that a sectoral approach will be taken to aviation-generated emissions in the future, as there are numerous difficulties in the allocation of responsibility for emissions at national levels. This paper can help to inform such international level approaches, since it highlights the difficulties of dealing with such issues at a national level.

**Conclusions**

This paper has presented a comprehensive national-level case study assessment of the physical and political feasibility of competing carbon emission offsetting options for international aviation. This is the first time that such an assessment of these technological solutions has been presented in the peer-reviewed literature. Since international air transport emissions are not subject to liability under the Kyoto Protocol, critical evaluation of such schemes at a national level has been lacking. With pressure mounting for international aviation to be included in post-Kyoto arrangements, this research assists by filling the knowledge gaps with regard to the physical and political barriers that collective policy action will need to address in the future. By utilising the comprehensive travel data set available for New Zealand, this paper presents a case study assessment of the physical feasibility of five schemes for all short duration journeys to and from New Zealand. The $CO_2$-e emissions produced by the air travel of international visitors to New Zealand, and for New Zealand residents travelling overseas, is calculated in this paper to be 7893 Gg and 3948 Gg, respectively, in 2005. New Zealand is geographically isolated, and, therefore, travel to or from the country will result in proportionally larger carbon emissions. On the other hand, New Zealand is also theoretically, physically able to implement such offsetting schemes as reforestation. However, this paper indicates that no single offsetting scheme targeted inside the country appears physically and/or politically realistic. This indicates the sheer size of these emissions, and the challenge that the international community faces for collective action on this matter.

Some combination of offsetting approaches may work in the future, but this will require significant research efforts combined with societal changes. Future research will need to identify what level of changes, such as land use change from pastoral to forests, are acceptable in a policy context, as well as quantifying the impact of such changes. In the short term, it is more likely that offsetting schemes operating outside of New Zealand's geographic boundaries would be required. This has important policy implications for collective action, and for other individual nations such as the UK and Thailand that also have large numbers of international tourist arrivals. Given the difficulties with offsetting within geographic boundaries, along with wider issues to do with the allocation of responsibility for emissions, it is likely that a sectoral approach will be taken to aviation-generated emissions internationally. This work can help to inform such international level approaches, since it adds to the debate over the implications of technological solutions.

**Acknowledgements**

Thank you to the anonymous reviewers for their detailed comments, and also to Nick Dirr, who provided helpful comments at the early draft stage of this paper. Thanks to our colleagues and others who provided comments and suggestions on this research. Special thanks to the analysts from the Energy Information and Modelling Group, Ministry of Economic Development who assisted us. We also would like to acknowledge staff from the Ministry of Transport, Ministry of Tourism, Ministry for the Environment, and Ministry of Foreign Affairs and Trade for helpful discussions on our work. The authors also wish to acknowledge the role of the National Energy Research Institute in initiating this Special Issue of Energy Policy. This work was supported by the University of Otago through the Department of Physics departmental Performance-Based Research Fund (PBRF) allocation of research time and resources to Dr Smith and Dr Rodger.

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## Figures

**Figure 1 – Greenhouse gas emissions for a return flight between Auckland and international airports. The airports selected are assumed to be the primary airports which the visitors have travelled from or to, ignoring any "domestic" travel. Values are shown in tonnes of carbon dioxide equivalent ($CO_2$-e).**

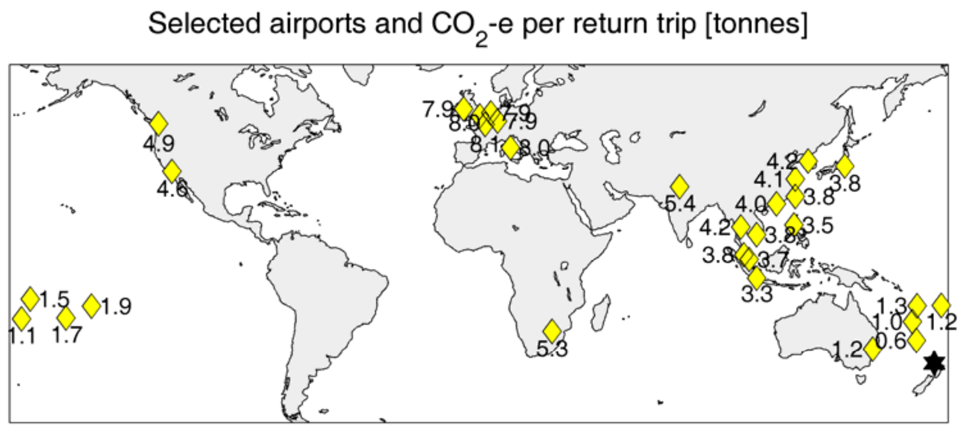

**Figure 2 – International visitor arrivals in New Zealand for the period 1983 to 2005, with forecasts from 2012-2015 based on a 4% growth rate.**

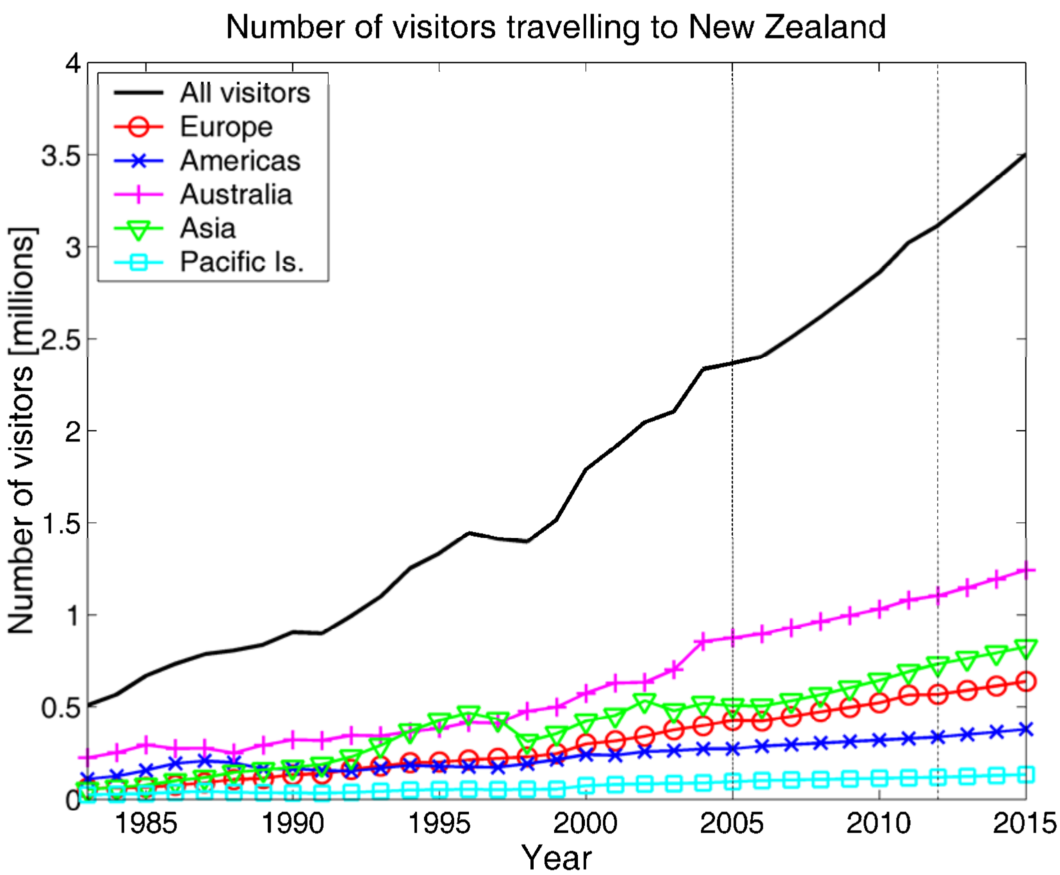

**Figure 3 – Variation with time in greenhouse gas emissions attributable to visitors travelling to New Zealand, based on the visitor numbers shown in Figure 2.**

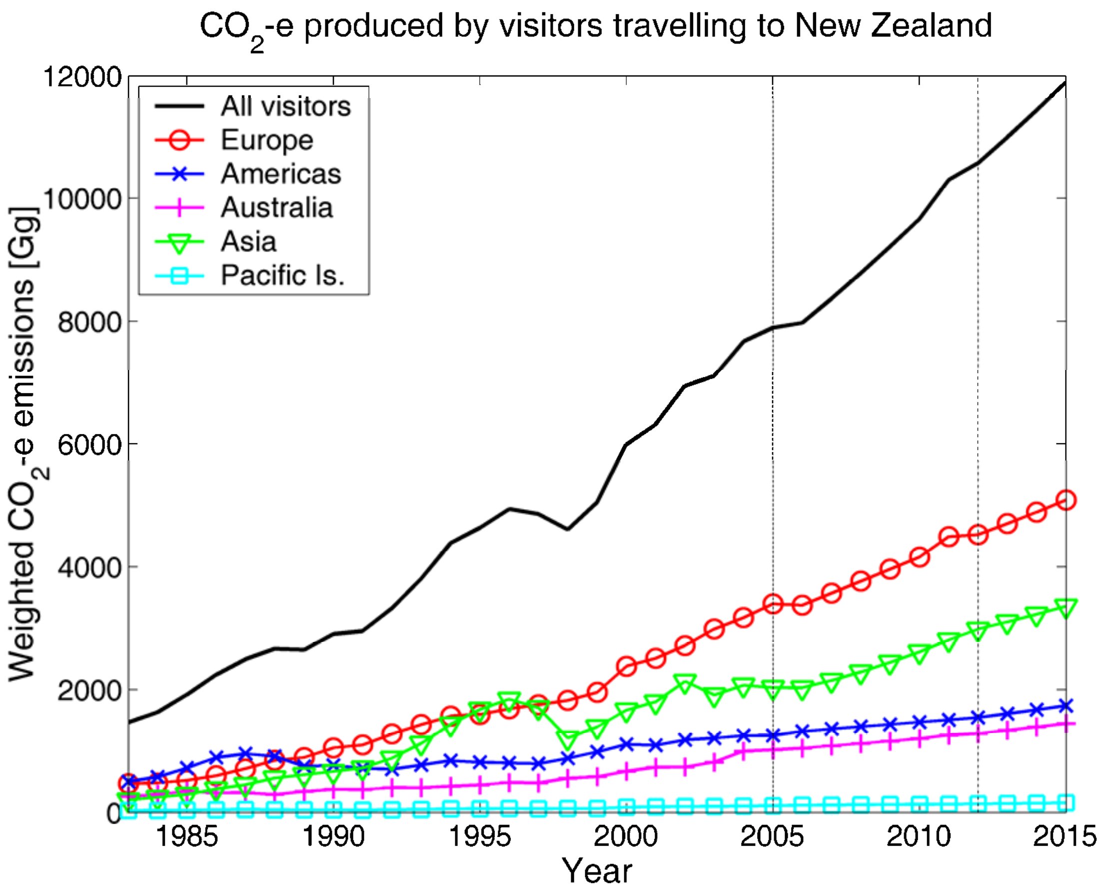

**Figure 4 – Departures from New Zealand by residents on short duration (less than one year) return trips for the period 1982 to 2006.**

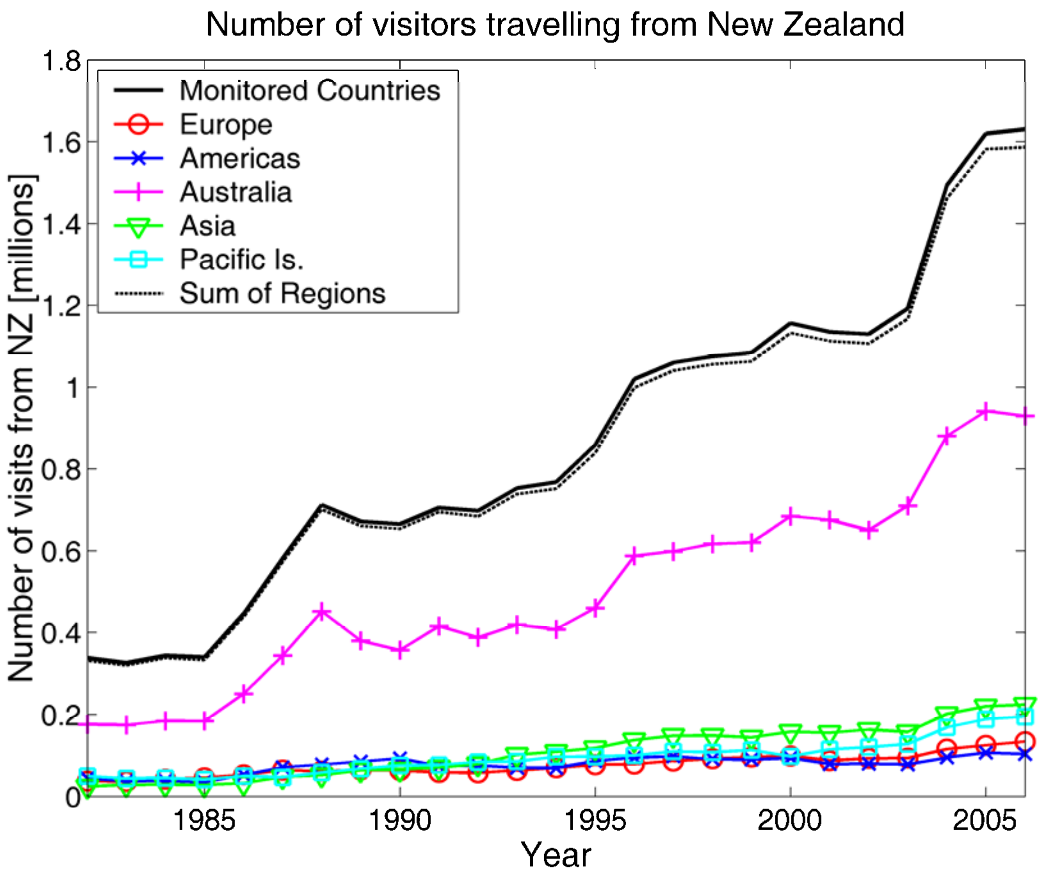

**Figure 5 – Variation with time in greenhouse gas emissions attributable to NZ residents travelling from New Zealand to international destinations from 1982 to 2006.**

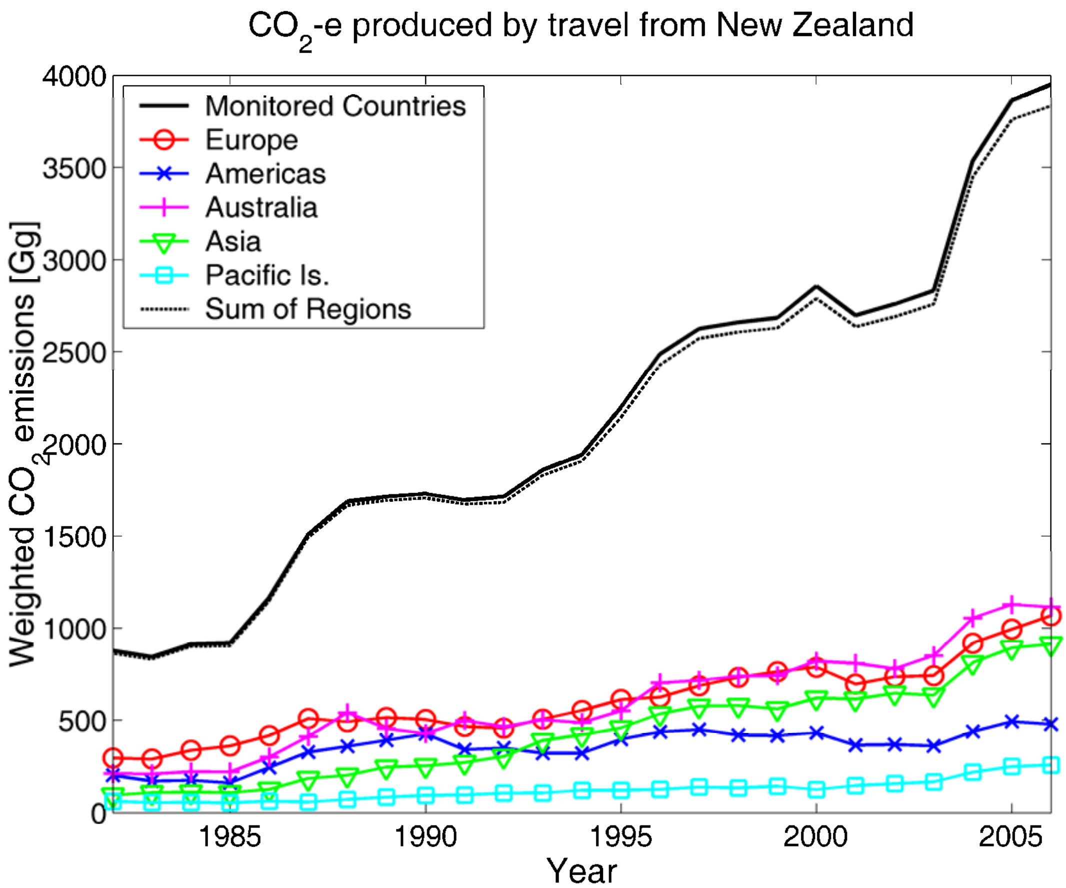

**Figure 6 – $CO_2$-e emissions from international visitors to New Zealand as a fraction of New Zealand's total emissions (solid line), and $CO_2$-e emissions from international travel by New Zealand residents as a fraction of New Zealand's total emissions (dashed line). New Zealand's total emissions are taken from the 1990-2005 inventory.**

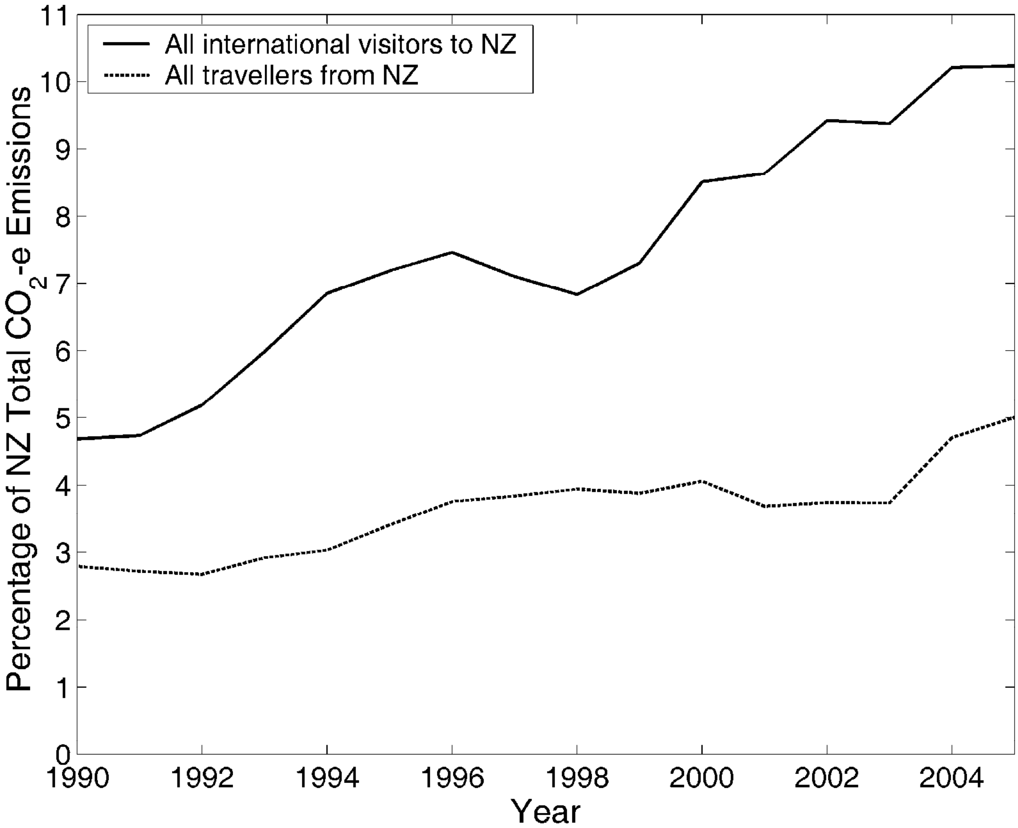

**Figure 7 – New Zealand's 2005 $CO_2$-e emissions profile for emissions that the country is liable for under the Kyoto Protocol (solid colours), and the additional $CO_2$-e emissions that are generated by international visitors to New Zealand (square-hatched section), and by New Zealand residents travelling internationally (diagonally hatched section).**