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Centre for Integrated Sustainability Analysis

Sustainable island businesses: a case study of Norfolk Island

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Sustainable island businesses: a case study of Norfolk Island

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Abstract – Conventional measures aimed at tackling the energy and waste issues of island communities focus on technological solutions, such as the introduction of renewable energy sources. There exists a history of technology implementations on small islands that have failed because of a lack of continuing skills and financial resources needed for ongoing operation and maintenance. Despite these experiences, what has received little attention so far are measures aimed at achieving island-friendly solutions by reducing their material metabolism, for example by recycling and re-use. The two case studies presented in this work show that conservation, efficiency and reductions of the overall material metabolism of economic activity can be as effective as purely technologically-driven changes. Both case studies demonstrate exceptional sustainability performance in terms of material flow, and greenhouse gas emissions. The income growth scenarios show that – from a sustainability point of view – increasing tourist yield rather than tourist numbers is preferable for coping with price hikes and a finite resource base, and is also more likely to keep within bounds the strain on the island's people and infrastructure.

Keywords: Island environments, Sustainability, Triple Bottom Line, Scenario analysis.

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1 Introduction

Regarding sustainability, most island communities face two major challenges: energy supply and waste disposal. First, most islands do not have indigenous energy resources, but instead have to ship in fuels over often considerable distances. Second, most islands do not have enough space for operating landfills, so that waste is often burnt under hazardous conditions, with resulting toxic emissions to air.

Especially the oil embargos forced many island governments to re-think their energy supply strategies, and to consider introducing renewable energy sources, and efficiency and conservation policies (Lather 1981; Richmond 1983). Similarly, landfill shortage and high energy prices have stimulated debates about waste-to-energy facilities (Miranda and Hale 2005). Renewable energy technologies vary considerably between island settings, depending on the availability of resources such as hydro-potential (Kai *et al.* 2004) or agricultural wastes (Singal *et al.*; Cloin 2005). On very remote, small islands, solar-photovoltaic is often the only feasible renewable energy source (Sheridan 1989; Anonymous 2002). Wind power is by far the most utilized renewable energy source on islands around the world (Chen *et al.*; Mitra 2006).

Amongst the many obstacles preventing new energy and waste technologies to be implemented on remote islands are

- regulatory, legal and institutional barriers (Yu and Gilmour 1996; Weisser 2004),
- high upfront capital cost (Yu and Gilmour 1996; Jafar 2000; Weisser 2004),
- lack of skills to maintain technically sophisticated facilities (see for example Lloyd and Tukana 1990; Lefale and Lloyd 1993; Yu and Gilmour 1996; Jafar 2000; Weisser 2004),
- lack of knowledge (Weisser 2004) and inappropriate design (Jafar 2000),
- small size of the island economies preventing economies of scale for some technologies (Mayer 2000; Weisser 2004), and
- visual obstruction, noise, odour, and other community objections.

1.1 Aim of this work

Given the abundance of studies focusing on technological solutions for islands such as renewable energy systems, this work is aimed at demonstrating alternative innovative strategies of reducing environmental impacts in a remote island community whilst respecting social and economic objectives. These strategies recognise that conservation, efficiency and reductions of the overall material metabolism of economic activity can be as effective as purely technologically-driven changes. In consultation with local stakeholders, I have analysed two case studies of island producers, aimed at reducing the material throughput of production systems, such as recycling and re-use, and at reducing the dependence on imported fuels. In order to quantify social, economic and environmental impacts in a holistic way, I have subjected on-site activity data to a life-cycle assessment across social, economic and environmental indicators (the so-called "Triple Bottom Line"), spanning the entire supply chain of business operations.[1] In addition, I have analysed the island's power station, because

[1] Compare with a similar, but theoretical scenario analysis for the Greek island of Corfu by Skordilis 2004.

of its obvious importance for energy and greenhouse gas emissions of island producers dependent on electricity. Finally, I have attempted an assessment of the island as a whole.

This paper is organised as follows: Section 1.2 introduces Norfolk Island. Section 2 explains the methodology and provides further references to not burden the reader with mathematical details. Following, Section 3 introduces all case studies and presents and discusses the results of the life-cycle assessment. Section 4 concludes.

1.2 Our case study: Norfolk Island

Norfolk Island is a self-governed Australian Territory in the South Pacific, situated at approximately 29° south latitude and 168° east longitude, about half way between Auckland in New Zealand, and New Caledonia. It is perhaps most famous for its history: Named by Captain James Cook in 1774, and home for a succession of British penal colonies between 1788 and 1855, it was settled in 1856 by the descendants of the Bounty mutineers and Tahitian women, who arrived from Pitcairn Island (located between Tahiti and Easter Island). A language mix of Tahitian and 18th-century seafaring English is still in use.

The island is highly dependent on imports shipped mainly from Australia and New Zealand. Comparatively high living cost are covered by income mainly from tourism (Australian Bureau of Statistics 2006). Regular air passenger connections exist to Brisbane and Sydney in Australia, and Auckland in New Zealand.

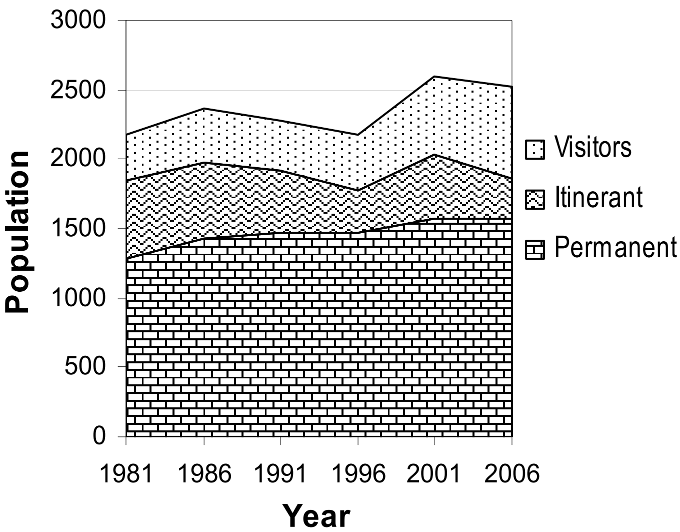

Fig. 1: Population trends on Norfolk Island (Mathews various years).

The currently 1,800 inhabitants and 35,000 annual visitors of Norfolk are supplied with electricity by diesel engines meeting an average 900 kW load. Considering that visitors stay on average just over one week, the number of people on the island at any one time is on average about 2,500 (Fig. 1). This translates into a power requirement of below 0.5 kW per capita, which is low in comparison with other islands. In colder climates such as Scotland, island inhabitants requiring electricity for space heat can easily use more than 2 kW (Twidell and Pinney 1985).

2 Life-cycle accounting for business

A fundamental principle of this work is the adoption of a life-cycle perspective. Rather than focusing on what goes on within the factory fences, farm gates or company premises, a life-cycle assessment (LCA) traces impacts through the entire upstream supply chain of a business. LCA has a tradition of many decades, resulting for example in a prolific academic literature[2] and international standards[3]. Today, practitioners mainly us two methods – process analysis and input-output analysis. These methods are distinct in that process analysis produces generally more accurate results for immediate, on-site impacts, but involves significant systematic errors caused by the truncation of the life-cycle system by a finite boundary (Lenzen 2001). Input-output analysis can handle infinite supply chain systems and hence does not suffer from truncation errors; it does however generally not adequately describe the production processes specific for most small- and medium-scale applications. For those reasons, the state-of-the-art in LCA is perhaps a combination of the best of both methods – *hybrid analysis* (Bullard *et al.* 1978; Heijungs and Suh 2002; Suh *et al.* 2004).

Applied to businesses, life-cycle accounting of environmental, economic and social impacts has many advantages, amongst which are:

1. It avoids loopholes: Assume an Australian dairy company “A” that owns the entire production chain, i.e. production of raw milk at the farm, transport logistics from farm to factory and the manufacturing site. This company has significant water usage (mainly at the farm). Assume that the same company “A” demerges into two companies “A1” and “A”, or outsources to a company “A1”, with “A1” consisting of the farm and transport logistics, while the "new A" is responsible only for dairy manufacturing. If only on-site, but not upstream impacts were reported, company “A” could improve its water use performance artificially but significantly, despite the fact that the supply chain and hence the impact of the product processed milk is exactly the same. Life-cycle accounting removes such incentives to “greenwash” by changing corporate ownership.
2. It enables meaningful benchmarking: Assume two water suppliers “B” and “B1”, where both B and B1 provide water supply and sewage services to urban households, but in addition “B1” owns and manages a catchment, and pumps bulk water into the urban area.[4] If only on-site impacts were taken into account, comparisons between these two water suppliers would not be valid because - even though they supply the same product - they would exhibit different degrees of vertical integration and a different business structure. In this case “B1”’s impact is likely to be higher than “B”’s only because of the additional catchment management activities. In order to provide a fair comparison, the upstream supply chain of “B” must be taken into account.
3. It provides incentives for change towards sustainability: An Australian manufacturing company “C” uses large quantities of packaging materials for their product. The packaging material consists of HDPE and aluminium. Both materials are energy-, greenhouse-gas- and water-intensive. The management of the company decides to

[2] The better known journals are perhaps the *Journal of Industrial Ecology*, the *International Journal of Life-Cycle Assessment*, *Environmental Science & Technology*, and the *Journal of Cleaner Production*.
[3] Klüppel 1998; Lecouls 1999; Ryding 1999; Marsmann 2000
[4] This is a real-world case, with “B1” being Sydney Water Corporation, and “B” being any of the final water distributers (City West Water, South East Water, and Yarra Valley Water), which are supplied with bulk water by Melbourne Water Corporation.

replace the packaging material with starch-strengthened biodegradable plastic that is less energy, greenhouse- and water-intensive. If only on-site impacts were reported, "C" would not be rewarded for this shift to a more sustainable packaging. However, by incorporating supply chain effects, "C"'s improved environment performance can be demonstrated. This will also be important for all of "C"'s customers that report on their supply-chain impacts: They are likely to switch to "C" as their supplier if "C" can demonstrate that its production is cleaner than that of competitors.

4. It gives decision-makers a wider range of options: Company "C" also uses gas in their manufacturing processes. Their kilns are already the top of the range, and marginally more efficient kilns would cost a lot of money. A company engineer finds that the embodied energy saved by switching from aluminium packaging to biodegradable plastic is larger than the direct energy saved by buying new kilns. It makes sense for "C" to target the "low-hanging fruit" first, and reduce supply-chain- rather than on-site energy.[5]
5. It informs about real risk and liability: A manager of an Australian ethical fund assesses the risk that is posed to a construction company "D" and a water supplier "E" when faced with a greenhouse tax. The manager decides to incorporate "E" into the ethical portfolio, because "D"'s emissions from on-site construction machinery are lower than "D"'s emissions from water treatment processes. However, "D" may face much higher additional, indirect risks than "E", which arise out of price increases of carbon-intensive inputs such as aluminium frames and cement. The fund manager can improve decision-making by taking into account direct and indirect risk.

As a result, life-cycle approaches to business accounting are advocated for example by the World Business Council on Sustainable Development and the World Resources Institute[6]. In contrast to LCA itself, however, there are yet no strict guidelines or standards with which businesses need to comply. The Global Reporting Initiative (GRI) has chosen the notion of the Triple Bottom Line (TBL) in laying the groundwork for such guidelines (Global Reporting Initiative 2002). TBL extends the single (financial) bottom line usually encountered in corporate annual reports, by adding a social and an environmental bottom line. At this time, the TBL accounting procedures envisaged by the GRI are still fraught with inconsistencies, amongst which is the so-called *boundary problem* (Global Reporting Initiative 2005), which is especially relevant to, and solved by LCA. Foran *et al.* 2005b show how LCA can be integrated into the TBL framework, and applied to supply chain management issues at a wide range of organisational scales.

Perhaps the first consistent life-cycle TBL study of the industrial sectors of an entire economy is the analysis of the Australian economy – *Balancing Act* (Foran *et al.* 2005a, www.isa.org.usyd.edu.au/balancingact). This analysis uses the National Accounts, physical satellite accounts, and input-output techniques in order to characterise 135 industry sectors in terms of four financial, three social and four environmental indicators.[7] For each of the 135 sectors, every indicator is enumerated in a supply-chain context, where all upstream impacts

[5] A similar situation is posed in the Clean Development Mechanism stipulated under the Kyoto Protocol: Highly efficient economies facing high cost for marginal emission reductions are better off reducing emissions elsewhere, and reporting reductions as their credit.

[6] World Business Council on Sustainable Development 2002; World Resources Institute and World Business Council for Sustainable Development 2004

[7] The eleven indicators comprise positive ones (+, more is better) and negative ones (–, less is better); they are: Primary energy consumption (MJ, –); Greenhouse gas emissions (kg CO_2-e, –); Water use (L, –); Land disturbance (ha, –); Gross operating surplus (A$, +); Exports (A$, +); Imports (A$, –); Employment (emp-y, +); Income (A$, +); Government revenue (A$, +); Upstream linkage (no unit, +).

are included.[8] Results are presented as tables, and visually as spider diagrams and bar graphs. In conjunction, the eleven indicators provide a macro-landscape of the Australian economy which allows the benchmarking of producers against many sectoral management issues, and the identification of trade-offs between conflicting performance objectives.

The results presented in this article were obtained using the Australian version of the TBL software BL^3 ("BL-cubed"; www.bottomline3.com).[9] The structure of this software is based on the *Balancing Act* study, however it was designed during a 2-year pilot study under the auspices of the New South Wales Government[10] to be applied to businesses rather than large economic sectors. User data inputs comprise expenditure and revenue accounts, as well as information about on-site impacts, such as the number of people directly employed, on-site energy and water use, emissions, and land occupation and disturbance. The software engine then embeds these user-specific data as an additional "sector" into an input-output database of the Australian economy, and performs a generalised input-output analysis in order to enumerate the life cycles of all operating inputs. Results are shown as tables, and as bar, area and spider diagrams.

2.1 Shared responsibility

The TBL accounts calculated for the business case studies assume that the responsibility for TBL impacts is shared amongst producers and consumers. This convention is based on the intuitive understanding that in any economic transaction, the demander and supplier play some role in causing the transaction. It is also necessary in order to avoid double counting of life-cycle impacts. This can be explained as follows (Lenzen 2007):

Assume a manufacturing company producing computers that are sold both to households and to other businesses. Assume that the manufacturer compiles a list of inputs to produce the total output of computers, to be used as data input into calculating a life-cycle TBL account. One part of the company's TBL impacts can be thought of being associated with producing computers sold to households, and the remainder being associated to produce computers for other businesses. The latter part, the TBL impacts caused by producing computers for other businesses, would also form part of those other businesses' life-cycle TBL accounts, were they to prepare one. If added up, these accounts would double-count, or multiple-count life-cycle impacts (compare with an alternative storyline by Hammerschlag and Barbour 2003).

Moreover, computers sold to other businesses could be used to produce items that, directly or indirectly, are purchased as inputs by the computer manufacturer. For example, a computer

[8] The methodological details underlying this work are published elsewhere, and since they are not needed for the understanding of this work, they will therefore not be re-iterated here. Readers interested in input-output economics and generalised input-output analysis as a basis for life-cycle assessment across the Triple Bottom Line can consult a detailed mathematical exposition in the *Balancing Act* study www.isa.org.usyd.edu.au/balancingact – Volume 1, and references therein.

[9] Since there are no input-output data available for Norfolk Island, and since a large proportion of operating inputs are produced in Australia, the Australian input-output tables were used to assess Norfolk Island businesses. Imports from New Zealand were assumed to be produced with TBL characteristics identical to those of Australian industries. Based on interviews with island business operators, nominal cost of imported commodities were assumed to consist of 50% commodity cost, 40% shipping, and 10% lighterage and stevedoring (Nobbs 2007). TBL impacts of all case study are compared with the average Australian producer of the same commodity, as identified in data by the Australian Bureau of Statistics 2004.

[10] See www.isa.org.usyd.edu.au/research/TBLEPA.shtml and www.environment.nsw.gov.au/resources/200794_sustreporting.pdf.

could be sold to a company manufacturing specialised steel making equipment, and installed in a computer-operated steel ladle, which in turn produces steel for steel sheets pressed into computer casings. In cases such as this, double-counting would even occur within the computer manufacturer's own TBL account.

This double-counting problem was solved by Gallego and Lenzen 2005, who split TBL impacts into two portions, with the respective responsibility allocated to the supplier and demander of any economic transaction. This responsibility sharing ensures that TBL impacts of all producers in an economy form a mutually exclusive and at the same time collectively exhaustive set, and that they add to the correct national total.

In this work I assume that suppliers and demanders of any commodity assume a 50%-50% share of the responsibility that the production of the commodity entailed. As a consequence, the TBL account of a producer who uses 100 GJ of fuels for on-site operations shows only 50 GJ, since the remaining 50 GJ would be passed on to the customers of the producer.

2.2 TBL indicators

In this work the following TBL indicators were used:

Economic indicators:

– *Gross operating surplus* (GOS) is defined as the residual of a producer's total inputs, after subtracting all intermediate inputs, compensation of employees, and net taxes and subsidies. It consists of operating profits, and consumption of fixed capital for capacity growth and replacement (depreciation). GOS indicates the capacity to innovate through turnover of the capital stock as well as the capacity for expansion and investment.
– *Total intermediate uses* are the sum of the supply of goods and services by all industries in the economy. It describes the indirect turnover generated by a particular producer, and thus indicates the general stimulus created in the whole economy by that producer.

Social indicators:

– *Employment* means full-time-equivalent employment measured as full-time employment plus 50% part-time employment of employees, including employers, own account workers, and contributing family workers.
– *Family income* reflects compensation of employees, including wages, salaries, superannuation and workers' compensation payments.
– *Government revenue* consists of taxes less subsidies on products for intermediate demand, other net taxes on production, and net taxes on products for final demand (incorporated within the sales price). Taxes contribute to support the national commons, such as health, education, defence, social benefit payments, public transport etc.

Environmental indicators:

– *Energy consumption*, in primary terms, is the combustion of fuels, such as coal, natural gas, fuel petrol, diesel and kerosene. Items such as crude oil for refinery feedstock and wood are not included, since they are either not combusted or renewable. As a measure of non-renewable fossil fuels this indicator is crucial to an understanding of resource depletion.

- *Material flow* describes the mass of resources and other biomass extracted from the natural environment in order to produce industrial output.
- *Water use* denotes the consumption of self-supplied and in-stream water (from rivers, lakes and aquifers, mainly extracted by farmers for irrigation) as well as mains water. Collected rainfall such as in livestock dams on grazing properties is not included. Water use is an issue not on Norfolk Island, but on the Australian mainland which, due to a highly variable climate, including periodic drought, faces unpredictable water supply. In regions under water pressure, significant environmental damage has occurred because of water diversion.
- *Land disturbance* factor considers effects of land use on biodiversity and ecosystem quality, expressed as the species diversity of vascular plants. It measures the condition of land, that is, the degree of alteration from its natural state.
- The combined climate change effect of all *greenhouse gas emissions* into the atmosphere is expressed in terms of the equivalent amount of carbon dioxide which would produce the same effect.[11] This indicator includes the *carbon footprint* (Wiedmann and Minx 2007).

Positive indicators are those where more is deemed good (gross operating surplus, intermediate uses, employment, family income, government revenue), whereas negative indicators are characterized by “less is better” (all five environmental indicators).

[11] In accordance with guidelines set out by the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions are expressed in tonnes of CO_2-equivalents (CO_2-e) and calculated as a weighted sum of nominal emissions of various gas species using gas-specific global warming potentials.

3 A case study of three Norfolk Island producers

3.1 Soft drink factory

The Cascade factory produces mainly carbonated soft drinks, but secondary products include bulk chilled water, ice for bars and pubs, juices, and liqueurs. In the future, Cascade plans to introduce diet soft drinks containing natural herbal instead of artificial sweeteners. One important aspect of the Cascade soft drink brand is that it sells in recyclable glass bottles. The main environmentally relevant operating inputs are a) water for washing and product, b) LPG for bottle sterilisation, and c) kerosene, diesel and caustic soda (½% solution in hot water) for bottle cleaning and the removal of the label glue (Fig. 2).

A prominent feature of the production line is the implementation of material recycling:

- Glass bottles are distributed in re-used plastic crates for recycling. This means that no waste in form of cardboard cases or plastic bottles occurs. In order to encourage the consumer to recycle, a deposit of 10 A¢ and 25 A¢ is levied on 750 ml and 300 ml bottles, respectively.
- Instead of disposing into the sewage system, the bottle washing stage empties into an aeration line, allowing the caustic soda to chemically break down, and to settle into the soil in a bunding area. Similarly, the detergent-sanitiser chemical used for bottle sterilisation is recycled.
- Instead of transferred to landfill, bottles unsuitable for re-use are crushed and used for road fill.
- The operator has put in place both in-house labour skills and external suppliers to ensure that the bottling line (which is no longer manufactured) can be repaired. This strategy has not only avoided the production of new machinery (with associated impacts), but also enabled crates and bottles from decommissioned drink factories across Australia to be re-used.

Fig. 2: Bottle cleaning line at the Cascade soft drink factory.

Fig. 3: Bottling line and CO_2 for carbonisation of soft drinks.

The operator of the factory has also implemented measures aimed at reducing energy and water use. While 20% of total electricity is used for machinery such as the bottling line (Fig. 3), 80% is needed to operate the cool room, which in turn stores mostly juice concentrates, and to a minor extent natural essences for soft drinks. In order to reduce electricity use, the cool room is lifted off the factory floor, and enclosed with sandwich foam thermal insulation. An audit of the factory yielded that further reductions in energy use would be possible by insulating the three water heaters. About 10% of the 800,000 litres of water used in the factory is sourced from rain water, instead of being extracted from a bore. While bore water is used for washing and sterilisation, rain water is filtered with a 1μm triple paper cartridge and purified using a UV flow-through filter, before used for the product itself.

3.1.1 Overall results

The TBL results for Cascade soft drinks provide an interesting picture. First, note that all figures represent life-cycle impacts, that is they comprise direct, on-site impacts plus indirect, supply-chain impacts. Second, note that even though Cascade employs 5 people, the employment impact is given as 2.59 employment-years (Tab. 1). This is because according to the shared-responsibility principle, 2.5 jobs are passed on to consumers of Cascade soft drinks, who then can claim that they indirectly created 2.5 jobs through purchasing from Cascade.[12]

For comparisons of Cascade with larger enterprises in the same (soft drink) sector to be meaningful, TBL impacts have to be normalised to the business size (Tab. 2). A number of observations can be made: First, Cascade's impact on material resources is significantly lower than that of the average Australian soft drink manufacturer, which is clearly a result of the considerable recycling efforts of the operator. Similarly, water use and land disturbance are significantly below-average. Energy consumption and greenhouse gas emissions are about average.

Note that the factory provides employment and family income far above the nation-wide average, which is probably due to its small size, and the decision of the operator to repair rather than replace machinery. Possibly because of the labour-intensive production, and despite the fact that the Norfolk Island government does not levy any taxes at the time of writing[13], gross operating surplus is below-average. Probably as a result of the relatively high degree of island autonomy and recycling, total intermediate uses, or in other words the stimulus to the wider economy through purchases, is below average.

[12] The remaining 0.09 employment-years are indirect effects of job creation in Cascade's supply chain.
[13] The tax impact is purely indirect.

Indicator	User Impact
Material flow	7.92 t
Energy consumption	121 GJ
Greenhouse gas emissions	8.76 t CO2-e
Water use	0.43 ML
Land disturbance	0.26 ha
Family income	24,925 $
Employment	2.59 emp-y
Government revenue	516 $
Gross operating surplus	2,827 $
Total Intermediate Uses	6,935 $

Tab. 1: Total TBL impact for Cascade soft drinks (BL^3 software output). For a definition of the indicators see Section 2.2.

Indicator	Cascade Soft Drinks	Total Sector Intensity
Material flow	178 g/$	1,126 g/$
Energy consumption	2.72 MJ/$	2.58 MJ/$
Greenhouse gas emissions	197 g CO2-e/$	209 g CO2-e/$
Water use	9.67 L/$	38.5 L/$
Land disturbance	0.06 m2/$	0.14 m2/$
Family income	56.1 ¢/$	21.7 ¢/$
Employment	6.70 emp-min/$	0.59 emp-min/$
Government revenue	1.16 ¢/$	2.62 ¢/$
Gross operating surplus	6.36 ¢/$	21.0 ¢/$
Total Intermediate Uses	15.6 ¢/$	89.9 ¢/$

Tab. 2: Comparison of TBL intensities for Cascade soft drinks and the average Australian soft drink producer (BL^3 software output). Results are normalised per $ of product sold.

The comparison of TBL intensities can be used for benchmarking purposes by calculating the ratio of intensities for the business and the sector-average. Depicted in a spider diagram (Fig. 4), these ratios then elegantly convey an overview of the business' TBL performance on 10 economic, social, and environmental indicators in one visual representation. The ratios divide business intensity by sector intensity for negative indicators listed in Section 2.2 ("less is good"), so that better performance leads to lower ratios. For positive indicators ("more is good"), these ratios have been inversed, so that once again better performance leads to lower ratios. The TBL spider is hence – within limits – interpretable as "dents are good, spikes are bad". Cascade demonstrates an overall positive TBL outcome, with all but three indicators within the central area, and the remaining spikes due to island-specific circumstances (see Section 4.2).

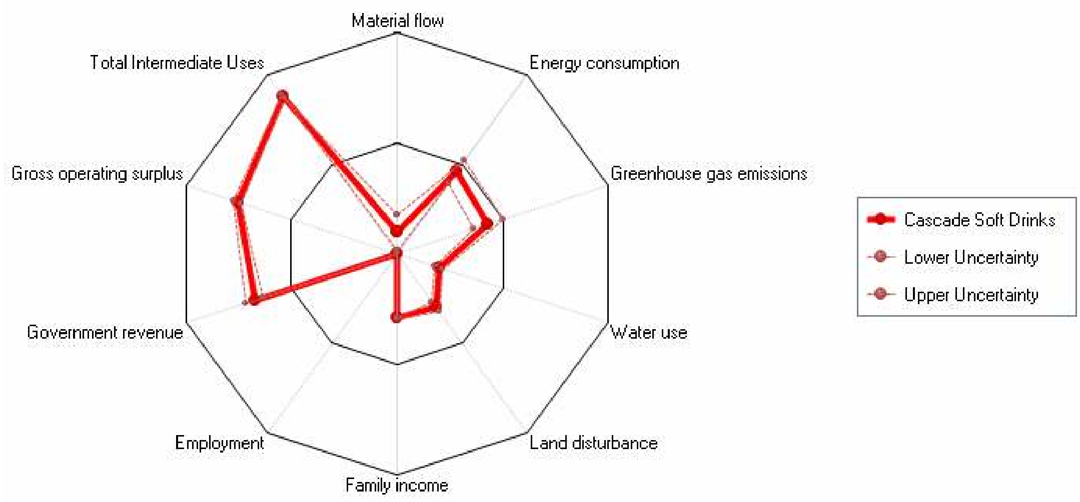

Fig. 4: Benchmark spider diagram for Cascade soft drinks (red bold polygon, BL^3 output). The central polygon represents the Australian economy-wide average performance. The centre locates ten-times-*better* performance (*not* ten-times-lower), the outer rim ten-times-*worse* performance (*not* ten-times-higher).

The comparison of Cascade with the average soft drink producer takes into account the fact that due to the average recycling rate 6-7 cycles per bottle, about 6,500 replacement bottles per year (435 g each) have to transported from the Australian mainland (1,500 km by sea, or 4,000 net-tonne kilometers, ntkm). Similarly, 20 bottles of LPG weighing 2 tonnes are shipped every six weeks (25,000 ntkm). On the other hand, the comparison must also take into account that local sales avoid the shipping of 90 tonnes of PET-bottled soft drinks annually, amounting to 127,000 ntkm/y. After subtracting the associated energy (50 GJ) and greenhouse gas emissions (4 tonnes CO_2-e) as a credit (calculated using data from Lenzen 1999), the adjusted net energy and emissions effect is clearly in favour of producing soft drinks locally (this is taken into account in Fig. 4).

3.1.2 Detailed results

The overall results in the previous Section provide an overview, but are not detailed enough for corporate planning and decision-making. The BL^3 software offers three levels of decomposition: 1) A *commodity breakdown* shows which of the operating inputs are associated with high TBL impacts; 2) a *Production Layer Decomposition* shows whether overall impacts are caused directly by suppliers to the business (proximate effects), or indirectly by suppliers of suppliers (remote, supply-chain effects); 3) a *Structural Path Analysis* combines commodity breakdown and Production Layer Decomposition, in that it unravels the entire TBL impact into single paths, that make up the supply-chain system like branches make up a tree.

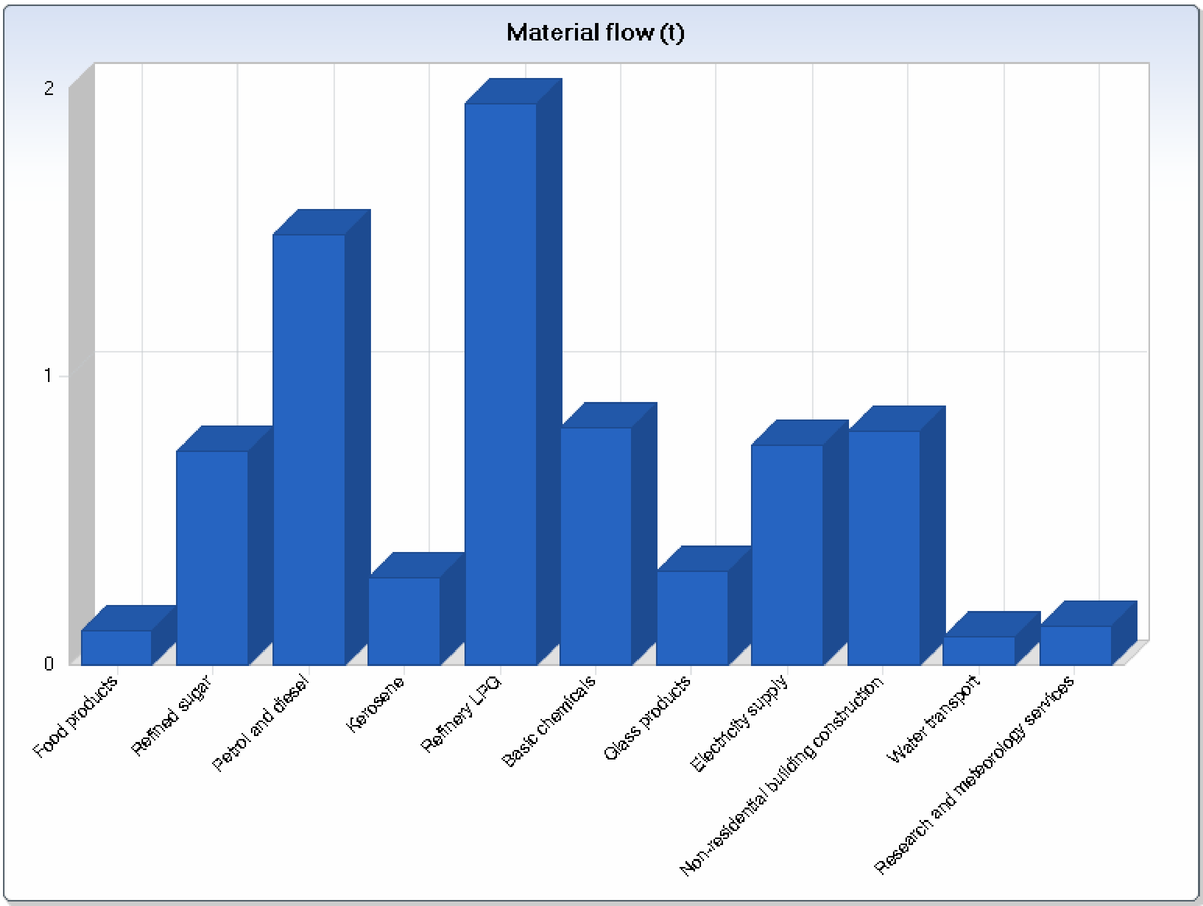

Fig. 5: Commodity breakdown of material flow for Cascade soft drinks (BL^3 output).

An example for one of ten commodity breakdowns is shown in Fig. 5 for the factory's showcase indicator material flow. The largest contributors are the LPG and the diesel shipped in from the Australian mainland. Material flow for glass bottles is unusually low, thanks to the high degree of recycling. The category 'Basic chemicals' includes the caustic soda, and upstream chemical uses. Material use associated with the input 'Electricity' is only indirect, and consists mainly of the diesel combusted in the island's power station.

The commodity breakdowns for most other indicators rank Cascade above its input commodities, for example Cascade uses more energy, water and employment on-site than is embodied in any of its inputs. Commodity breakdowns are useful mainly for deciding which operating inputs need to be addressed in order to improve on overall TBL performance.

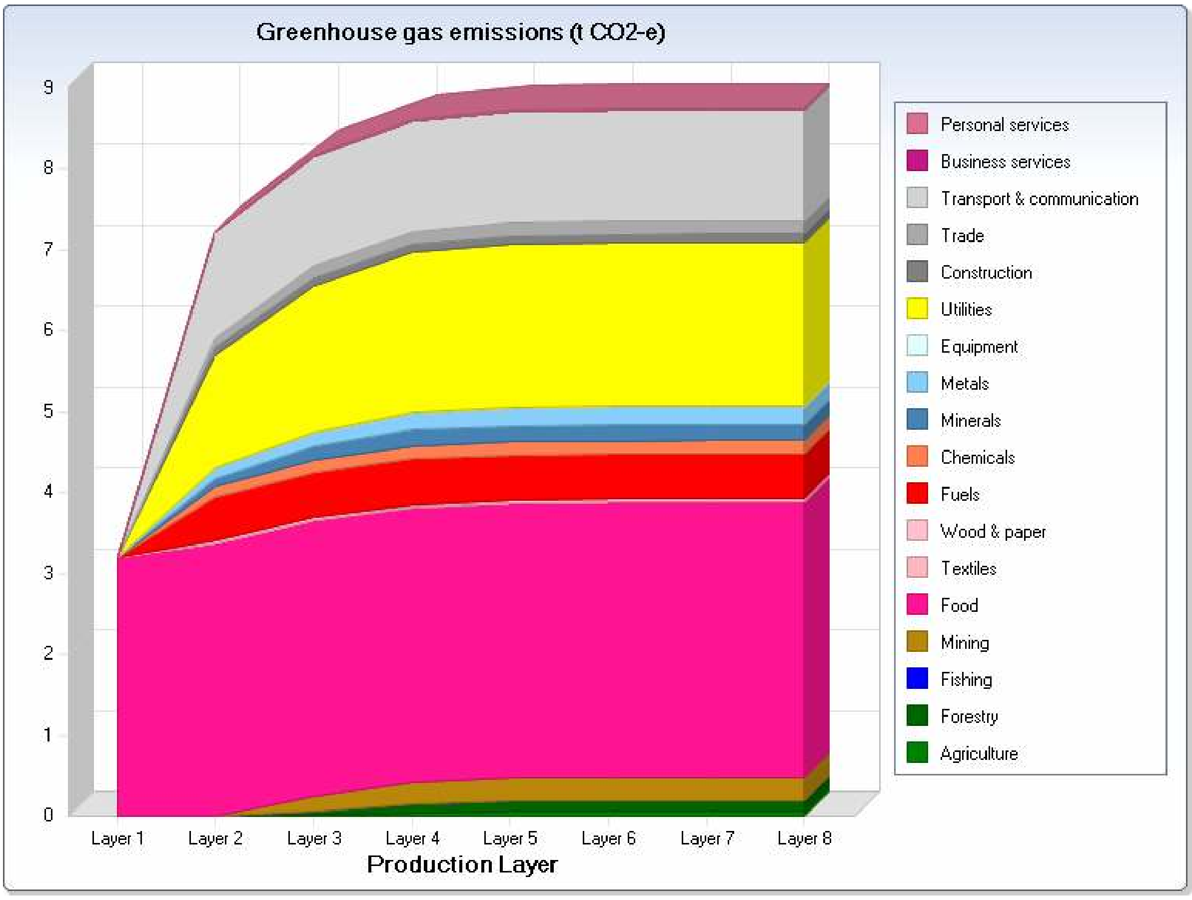

Fig. 6: Production Layer Decomposition of greenhouse gas emissions for Cascade soft drinks (BL^3 output). Layer 1 represent Cascade, layer 2 Cascade's suppliers, layer 3 the suppliers of Cascade's suppliers, and so on. The colours reflect a rough grouping of industry sectors in the Australian economy.

One of ten Production Layer Decompositions is shown in Fig. 6 for the example of greenhouse gas emissions. On-site impacts (layer 1) amount to just above 3 t CO_2-e, and are allocated to the 'Food' category, because Cascade is part of this category. Amongst Cascade's direct suppliers (layer 2), major emitters are within 'Transport' (ships) and within 'Utilities' (the power plant), followed by 'Fuels' (the refineries on the mainland that produce the LPG, diesel and kerosene that Cascade uses). At layer 3, suppliers of suppliers to Cascade enter the picture: Amongst them are metal and minerals manufacturers that make components for ships, or bottles, and mining establishments that extract the raw ores that are transformed into machinery and other equipment. Another example for a contribution from layer 3 would be a sand mine supplying sand to a glass company making bottles for Cascade. Towards higher-order layers, contributions to total greenhouse gas emissions become smaller and smaller, and eventually saturate. At this stage, the producers contributing to Cascade's supply chain would be located all over Australia, and probably well across neighbouring countries.

Production Layer decompositions are useful for deciding which type of action to take: While mitigating proximate (1st- or 2nd-order) impacts can be achieved by establishing direct contact with the respective suppliers, more distant supply-chain impacts are best addressed by re-engineering and procurement decisions, that is for example substituting wood for concrete.

Rank	Path Description	Path Value	Path Order	Percentage in total impact
1	Cascade Soft Drinks	45.7 GJ	1	37.8 %
2	Electricity supply > Cascade Soft Drinks	15.8 GJ	2	13.1 %
3	Water transport > Cascade Soft Drinks	14.1 GJ	2	11.6 %
4	Refined sugar > Cascade Soft Drinks	9.90 GJ	2	8.18 %
5	Refinery LPG > Cascade Soft Drinks	5.07 GJ	2	4.19 %
6	Basic chemicals > Cascade Soft Drinks	3.82 GJ	2	3.15 %
7	Petrol and diesel > Cascade Soft Drinks	3.13 GJ	2	2.59 %
8	Glass products > Cascade Soft Drinks	2.12 GJ	2	1.75 %
9	Non-residential building construction > Cascade Soft Drinks	1.45 GJ	2	1.19 %
10	Raw sugar > Refined sugar > Cascade Soft Drinks	1.28 GJ	3	1.06 %
11	Wholesale trade > Cascade Soft Drinks	1.17 GJ	2	0.97 %
12	Electricity supply > Research and meteorology services > Cascade Soft Drinks	0.88 GJ	3	0.72 %
13	Food products > Cascade Soft Drinks	0.87 GJ	2	0.72 %
14	Electricity supply > Services to water transport > Cascade Soft Drinks	0.74 GJ	3	0.62 %
15	Electricity supply > Electricity supply > Cascade Soft Drinks	0.70 GJ	3	0.58 %
16	Kerosene > Cascade Soft Drinks	0.66 GJ	2	0.54 %
17	Paper products > Cascade Soft Drinks	0.64 GJ	2	0.53 %
18	Ready-mixed concrete > Non-residential building construction > Cascade Soft Drinks	0.41 GJ	3	0.34 %
19	Electricity supply > Domestic telecommunication services > Cascade Soft Drinks	0.39 GJ	3	0.33 %
20	Electricity supply > Glass products > Cascade Soft Drinks	0.37 GJ	3	0.31 %

Tab. 3: Structural Path Analysis of energy use for Cascade soft drinks (BL^3 output). The path order represents the index of the production layer from which the path originates.

A Structural Path Analysis (Tab. 3) provides the most detailed representation of a business' supply chain impacts. In terms of energy, on-site fuel combustion is the most important component (38% of total energy impact), followed by diesel combusted in the island's power house (13%). Characteristic for a remote island location is the high contribution of shipping fuel (12%), which surpasses the energy embodied in material inputs such as sugar (8%), chemicals (3%) and glass (2%). The paths ranked 3rd and 7th represent the energy expended in refineries to produce fuels combusted in the soft drink factory. An audit of the factory site showed that in the short term, on-site energy use could be reduced by thermally insulating the water heaters used for bottle washing and sterilisation. In the long term, it may be benefitial to re-locate the bottle washing facilities into the vicinity of the island's power station in order to utilize the abundant waste heat. This would also positively affect the material flow indicator: Diesel and kerosene represent the top two material flow structural paths, and together make up 35% of the total. Substituting these inputs by waste heat from the power house would lead to an even better material flow performance.

3.2 Pig farm

In addition to bacon, ham, and other pork products, the pig farm near Point Howe at the northern tip of Norfolk Island produces vegetables and fruit. The main business objectives expressed by its operator are providing jobs for local people, producing all year round, and minimising the dependence on imported inputs.

The farm features an anaerobic digester that captures methane emanating from the effluent of the pig pen. The pit of the pig pen is regularly flushed with water, which transports the animal waste from the pit to the digester (sized approximately 60 m^3). During this transfer the effluent passes through channels fitted with protrusions (Fig. 7). These protrusions cause turbulences in the effluent flow, thus avoiding the accumulation of sediment in the pit. The captured methane is piped into a processing area for use as biogas in providing heat for cooking and drying (Fig. 8). The digester effluent flows into three settling ponds, where biotic material is allowed to break down under ultraviolet light.

Fig. 7: One of many protrusions in channels connecting the pen pits with the digester.

Fig. 8: Biogas used for cooking of meat products.

The digester is designed to process effluent from up to 300 pigs. At the time of writing, there were 70 pigs in the pen. Assuming a methane yield of 0.1 m^3/head/day[14], this amounts to an annual methane production of about 2,500 m^3 or 1.7 tonnes, yielding a calorific energy value of more than 85,000 MJ. After subtracting the CO_2 emitted from burning the biogas, the avoided greenhouse gas emissions are 34.8 t CO_2-e per year. Finally note that there are

[14] Task Force on National Greenhouse Gas Inventories 1996; Hydro Tasmania 2003.

additional methane emissions stemming from enteric fermentation within the animals' digestive system. At about 2.4 t CO_2-e per year, these are however smaller than those from effluent.

Because of legal restrictions to businesses to partially generate their electricity from alternative sources (see Section 3.3), the farm does currently not generate electricity, but draws approximately 48,000 kWh/year from the island grid, mostly for freezing and cooling, but also for various mechanical tasks such as curing, mincing, filling, slicing, and vacuum packing.

3.2.1 Overall results

The general shape of the pig farm's spider diagram (Fig. 9) is similar to the one of the soft drink factory (Fig. 4): Environmental performance is exceptionally good, while intermediate uses, surplus, and government revenue are below-average due to island-specific circumstances (see Section 4.2). Employment and family income are comparable with average pig farms.

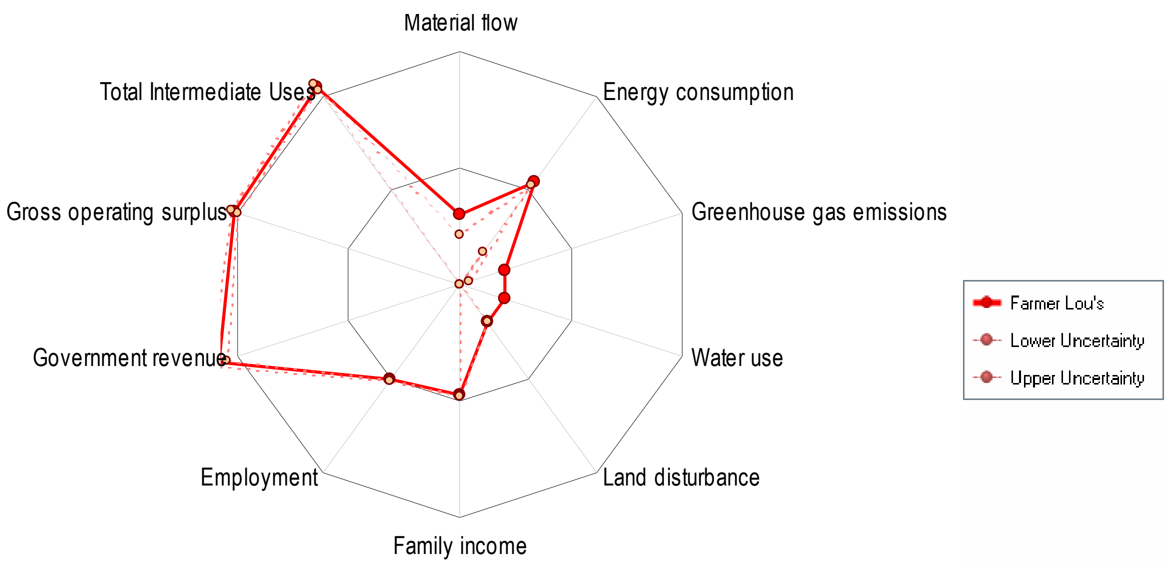

Fig. 9: Benchmark spider diagram for the pig farm (red bold polygon, BL[3] output). The central polygon represents the Australian economy-wide average performance. The centre locates ten-times-*better* performance (*not* ten-times-lower), the outer rim ten-times-*worse* performance (*not* ten-times-higher).

Once again, the comparison must also take into account that local sales avoid the shipping of about 10 tonnes of meat products annually, amounting to 15,000 ntkm/y. After subtracting the associated energy (6 GJ) and greenhouse gas emissions (½ tonne CO_2-e) as a credit (calculated using data from Lenzen 1999), once again, the adjusted net emissions effect is clearly in favour of producing meat products locally (this is taken into account in Fig. 9).

The showcase indicator of the pig farm is greenhouse gas emissions: While the average pig farm emits in excess of 3.5 kilograms of greenhouse gases per $ of output produced, the Norfolk pig farm emits less than ¼ kilogram. This is partly thanks to the methane digester, without which the farm's greenhouse gas indicator would have been three times higher.

3.2.2 Detailed results

Rank	Path Description	Path Value	Path Order	Percentage in total impact
1	Electricity supply > Farmer Lou's	14.2 t CO2-e	2	64.2 %
2	Farmer Lou's	3.23 t CO2-e	1	14.6 %
3	Water transport > Farmer Lou's	1.70 t CO2-e	2	7.70 %
4	Electricity supply > Electricity supply > Farmer Lou's	0.62 t CO2-e	3	2.83 %
5	Diesel > Electricity supply > Farmer Lou's	0.35 t CO2-e	3	1.58%
6	Wheat > Fodder and feed > Farmer Lou's	0.19 t CO2-e	3	0.88 %
7	Electricity supply > Fodder and feed > Farmer Lou's	0.08 t CO2-e	3	0.36 %
8	Oats, sorghum and other cereal grains > Fodder and feed > Farmer Lou's	0.08 t CO2-e	3	0.34 %
9	Fodder and feed > Farmer Lou's	0.07 t CO2-e	2	0.33 %
10	Animal food > Fodder and feed > Farmer Lou's	0.07 t CO2-e	3	0.30 %
11	Electricity supply > Services to water transport > Farmer Lou's	0.07 t CO2-e	3	0.30 %
12	Hay > Animal food > Fodder and feed > Farmer Lou's	0.05 t CO2-e	4	0.23 %
13	Wholesale trade > Farmer Lou's	0.05 t CO2-e	2	0.21 %
14	Beef cattle > Offal, hides, skins, blood meal > Animal food > Fodder and feed > Farmer Lou's	0.04 t CO2-e	5	0.20 %
15	Electricity supply > Local government > Farmer Lou's	0.04 t CO2-e	3	0.19 %

Tab. 4: Structural Path Analysis of greenhouse gas emissions for the pig farm (BL^3 output). The path order represents the index of the production layer from which the path originates.

The Structural Path Analysis (Tab. 4) demonstrates that the greenhouse gas emissions from electricity use (14.2 t CO_2-e, 50% of total emissions shared with downstream customers) are the single most important contribution to the pig farm's greenhouse impact, followed by on-farm CO_2 emissions from burning CH_4, and CH_4 emissions from the animals' enteric fermentation (together 3.23 t CO_2-e, 50% of total). Without the methane digester, pig effluent emissions would have been the highest factor at almost 40 t CO_2-e. Emissions from shipping rank third, contributing 7.7% to the farm's overall greenhouse impact.

An obvious measure for further reduction would be to negotiate with the island's power producers about a way in which the farm can generate electricity from methane, either without unduly imposing a variable and unpredictable load on the power house, or by contributing adequately to the power house's fixed maintenance cost (see next Section).

3.3 Power plant

Not only for the two case studies above, but for any Norfolk Island resident and business operator, electricity is a crucial cost and a strong incentive for reductions alike. Therefore, an analysis of the power generation system of the island is appropriate. The government-run power house (Fig. 10) accommodates six 1-MW 16-cylinder diesel engines (Fig. 11), of which only two at any time are required to meet the system peak demand of 1.4 – 1.6 MW (Hydro Tasmania 2003). Waste lubrication oil is recycled by blending it with the diesel fuel to be combusted. At the time of writing, the power house operators were experimenting with LPG gas injection into the air intake of the diesel engines, in order to elevate the temperature in the engines' expansion chambers, leading to a more efficient combustion of the diesel fuel, and hence reduced emissions.

Fig. 10: Norfolk Island power house.

Fig. 11: 1 MW diesel engine.

Diurnal demand variations are in the order of 100%, but seasonal variations are smaller and mainly due to varying tourist numbers. The system runs at an average load of about 900 kW which, at a capacity factor of just under 90%, generates currently about 7 million kWh annually. About 2 million litres of diesel fuel are shipped annually from Singaporean refineries[15] via New Caledonia and Fiji at a cost of around 1.1 A$/L[16], approximately one third of which represents shipping, handling and insurance cost. With a conversion efficiency of 3.6 kWh/L (34%, Fig. 12), this translates into a fuel component of electricity cost of about 20 A¢/kWh, which in turn constitutes roughly 40% of the cost of electricity to the consumer. Thus, the cost of electricity on Norfolk Island is about 4-5 times higher than those in Australian mainland cities. By far the main electricity consumers on the island are large retail outlets with high needs for refrigeration.

The main challenge for the power house operators in accepting small- or large-scale alternative energy sources is to upkeep the reliable functioning of the diesel engines for backup purposes. This is especially problematic if alternative sources are intermittent, or affected by sporadic failure. The main reason is that the maintenance of the power system represents a considerable fixed cost that does not decrease even if power demand decreases.

[15] Like in most Pacific Island nations, see Weisser 2004.

[16] This is the cost of fuel to the Government Administration, who runs the power house. At the time of writing the diesel price at the bowser was close to $2/L. The difference consists of 20 A¢/L road tax, 10% duty, and retail margins.

This poses a barrier to introducing any intermittent alternative energy source, since the electricity price is likely to increase because of the need for diesel backup with associated fixed maintenance cost. Similarly, from the point of view of the power house operators, small-scale private generating facilities represent a potentially unpredictable, intermittent demand for back-up in cases of their failure or lack of maintenance. Allowing such small-scale generators sporadic access to the centralised power system would imply an unacceptably unequal contribution of electricity consumers to fixed maintenance cost.

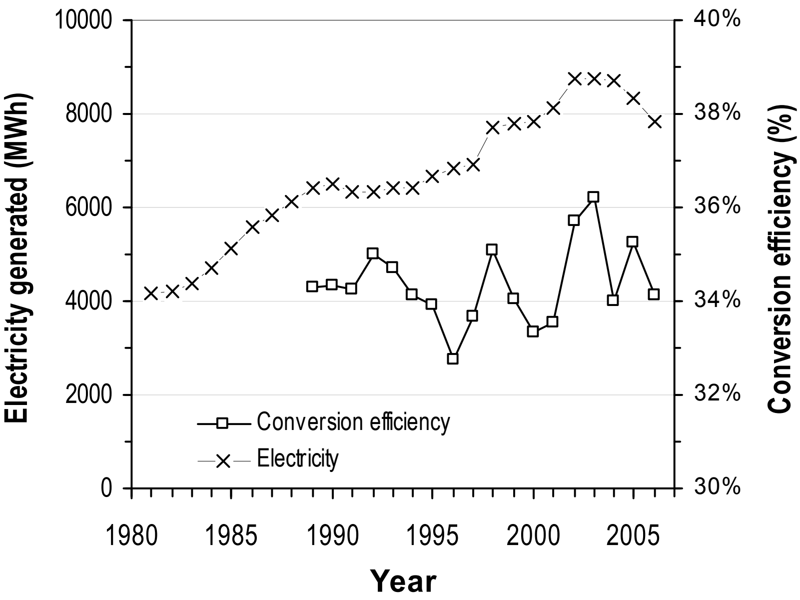

Fig. 12: Electricity generated and conversion efficiency at the Norfolk Island power house over time (generation data from Administration of Norfolk Island various years, and courtesy of John Christian).

An ideal energy transition would see a reliable, base-load-type reduction of power demand. In 2003 a pre-feasibility study was finalised on options for renewable energy for Norfolk Island (Hydro Tasmania 2003). Amongst the scenarios appraised, wind/solar-cum-storage, biomass, hydro-power, wave power and energy efficiency measures can provide base-load outputs. Of these, biomass comes in limited and possibly declining amounts. The potential for hydropower is negligible. Solar systems were deemed too expensive, and wave power technology not yet sufficiently mature. Widespread energy efficiency measures were found to be fraught with barriers to investment, largely caused by the high sensitivity of residents to upfront capital cost. The most promising amongst alternative energy sources was found to be a wind-diesel system with either hydrogen cell or pumped-storage (as operated on many islands around the world[17]).

Considering that at present about 66% of the energy contained in the diesel fuel escape unused as waste heat, utilising the waste heat from the power house, for example for centralised cool stores, appears to be an extremely attractive option which was put forward by

[17] Chen *et al.*; Duic *et al.*; Kai *et al.*; Kaldellis *et al.* 2001; Carta *et al.* 2003; Duic and da Graça Carvalho 2004; Manwell and McGowan 2004; Ntziachristos *et al.* 2005; Bueno and Carta 2006; Gazey *et al.* 2006; Kaldellis and Kavadias 2007.

the power house operators. Refrigeration is by far the main end-use of electricity (10-20% of total uses), plus there are other needs for heat, for example for sterilisation, cleaning, drying, laundry, etc. If in the long term, commercial consumers of heat were able to re-locate into the vicinity of the power house, significant reductions of imported diesel could be achieved with simple and proven small-scale co-generation technologies (compare Prasad 1990).

3.3.1 Overall results

The TBL benchmark spider diagram (Fig. 13, calculated from data in Administration of Norfolk Island 2007) shows an overall balanced performance, with most environmental indicators close to the average Australian electricity supplier, except for water use which is significantly lower than average. These scores reflect the fact that – in terms of an energy use and greenhouse gas emissions – fossil-fuel-based electricity generation technologies perform similar, and that the additional transport requirements are small compared to the effects occurring during fuel combustion. Water use is smaller because the power house does not use cooling water such as a large power plant, but instead a chemical coolant called Tech50.

Since the power plant is run by the government administration, the gross operating surplus and government revenue indicators are not really applicable. This is because first, the objective of the government is to supply the community with power and not to make a profit, and second because the power house is part of the government. Hence, in this analysis they contain only indirect surplus and taxes of suppliers. Once again the stimulus to other island and overseas sectors (‘intermediate use’) is below-average, which is probably a cause of the need for the island to operate as autonomously as possible.

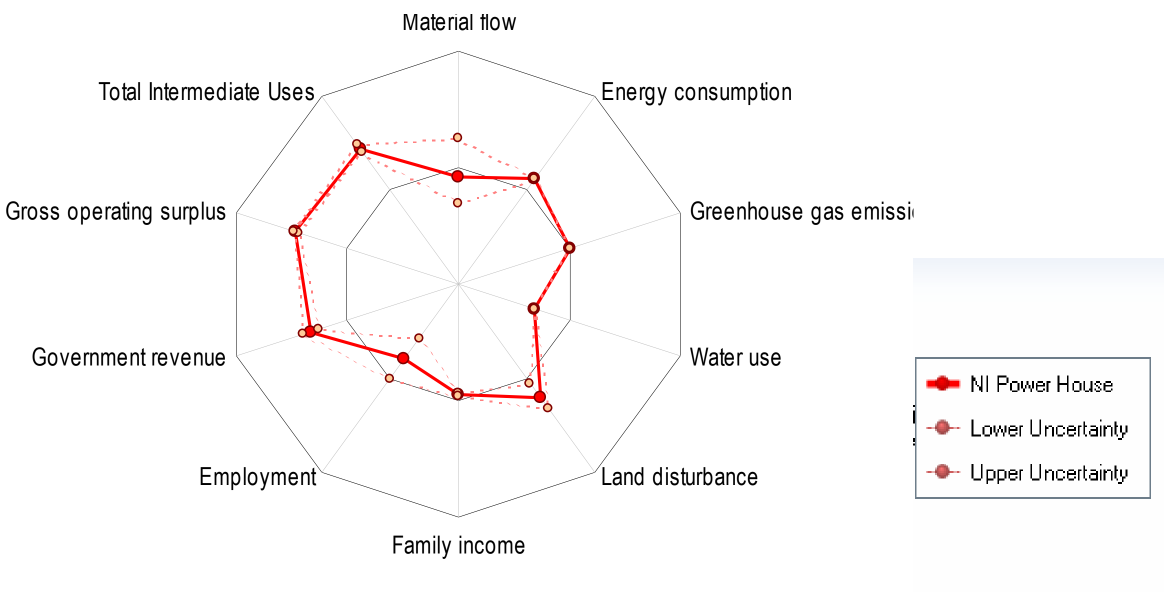

Fig. 13: Benchmark spider diagram for the power house (red bold polygon, BL^3 output). The central polygon represents the Australian economy-wide average performance. The centre locates ten-times-*better* performance (*not* ten-times-lower), the outer rim ten-times-*worse* performance (*not* ten-times-higher). Environmental indicators are compared per-kWh$_{el}$ generated, with the remaining social and economic indicators per $ of output as usual.

3.3.2 Detailed results

For the sake of brevity, only a commodity breakdown for the indicator 'employment' is presented here (Fig. 14). Similar breakdowns, as well as Production Layer Decompositions and Structural Path Analyses, exist for all indicators.

Under responsibility sharing, the power house retains 5.5 units of its 11 units of direct full-time employment, with the other half being credited to downstream demanders. Significant employment is created through the generator and general plant maintenance contracts (2.5 jobs), plus within shipping and port handling (1.5 jobs combined). The remainder is made up of small contributions in refining, building maintenance, road transport and business management industries.

In total, the power house can claim to have created about 5 jobs within its supply chain.

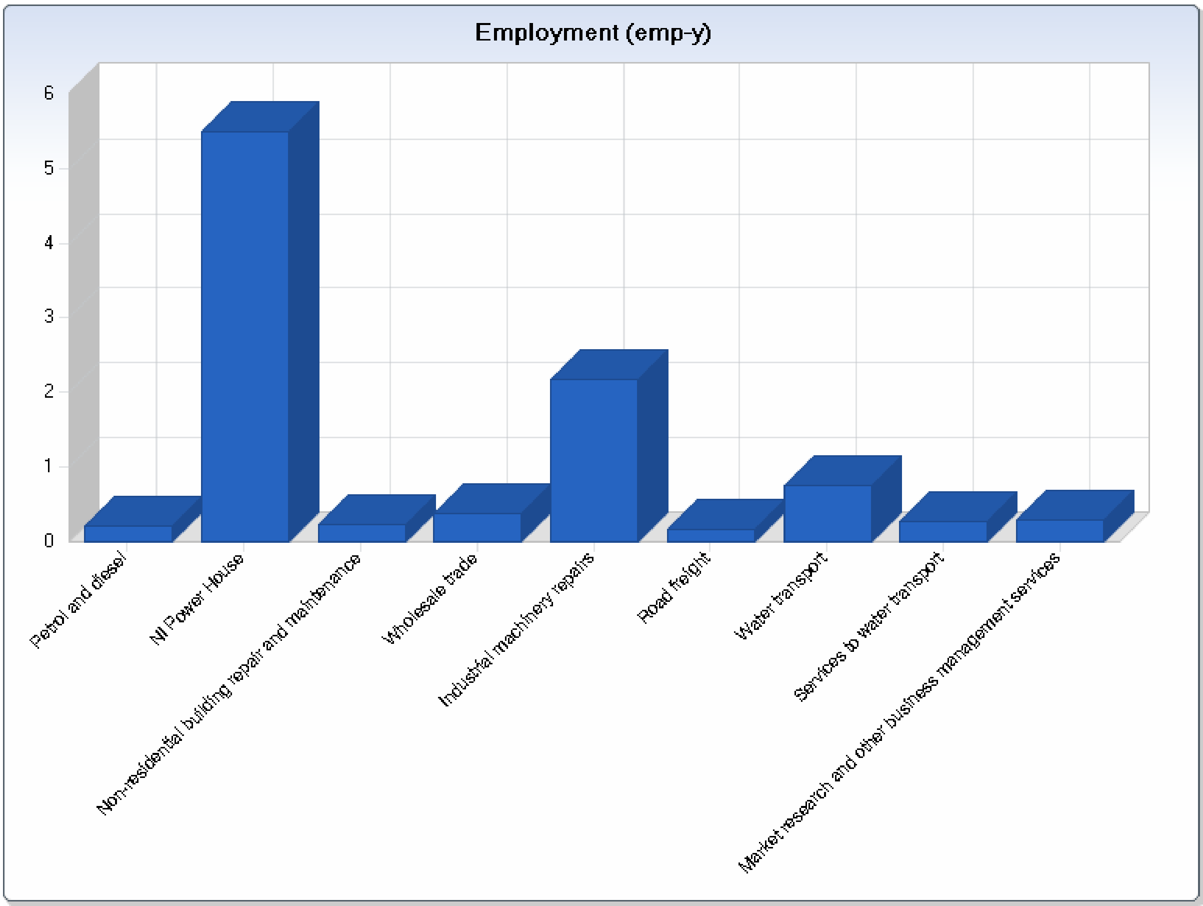

Fig. 14: Commodity breakdown of material flow for the power house (BL^3 output).

3.4 Whole-island analyses

As energy use and tourist incomes are prominent issues for Norfolk Islanders, it is worth examining the cross-relationships between the two. Norfolk Island imports petroleum-based fuels which arrive by tanker ship from New Caledonia or Fiji. About one third of total fuels is diesel used in the power house (Fig. 15). The remainder is aviation fuel (approximately 40%) and petrol (approximately one quarter). In addition, minor quantities of LPG (about 400-500 tonnes annually) arrive by gas tanker. In monetary terms, fuel imports typically constitute 10-15% of total imports (Buffett 2007), which is about average in comparison to other islands, which range between 6% (Federated States of Micronesia) via 17% (Fiji) to up to 30% (Palau) (Richmond 1983; Jafar 2000).

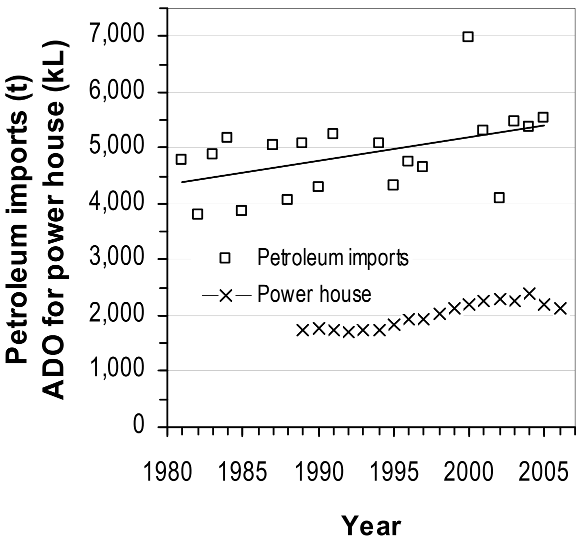

Fig. 15: Petroleum imports and diesel (ADO) used by the Norfolk Island power house over time (data from Administration of Norfolk Island various years).

Nominally, Norfolk Island residents are wealthy by Australian standards (Fig. 16): The average per-capita income of just over A$30,000 per annum appears to compare favourably with A$18,500 for the Australian mainland (Australian Bureau of Statistics 2007). However, anecdotal evidence about the comparative cost of typical consumer baskets[18] suggests that in terms of purchasing power, Norfolk Islanders are considerably worse off than the average Australian, which is mainly due to substantial shipping cost. In addition, since the consumer basket of Norfolk Islanders is heavily skewed towards fuels, the Norfolk Island Retail Price Index undergoes largely unrelated, and often higher increases than the Consumer Price Index on the Australian mainland (Stephens 2006).[19] Like in other small island states, fluctuations in international commodity prices combined with the island's small resource and exports base can lead to serious trade deficits and losses of earnings (Weisser 2004).

[18] A comparative Consumer Price Index between Norfolk Island and Australia has never been estimated, and the compositions of the commodity baskets of the Australian CPI and the Norfolk RPI have diverged since the inception of the RPI in 1983 (Government of Norfolk Island 1983).

[19] Between 1990 and 2004 alone, the Norfolk Island RPI would have increased by 20% above the Australian CPI.

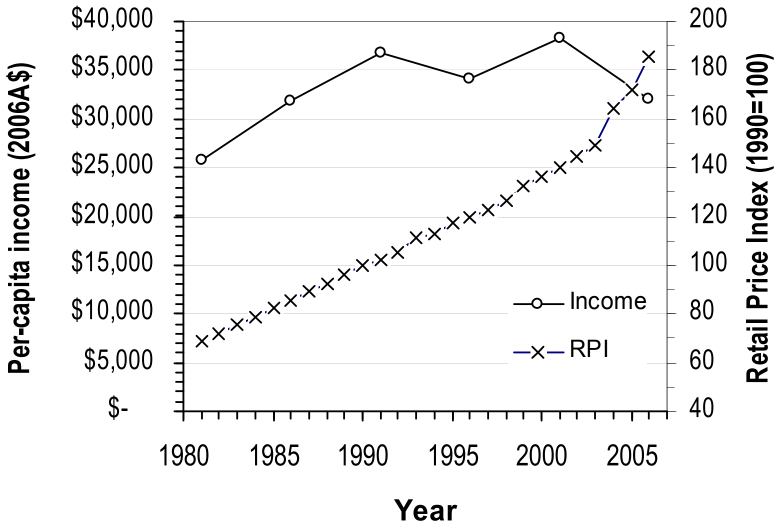

Fig. 16: Per-capita annual income in constant 2006 prices (derived from data in Mathews various years, and RPI-adjusted[20]) and Retail Price Index on Norfolk Island. Pre-1990 RPIs were extrapolated, since only post-1990 RPIs were available from the Norfolk Island Administration.

3.4.1 Static analysis of direct and indirect greenhouse gas emissions

Assuming for the sake of simplicity that all imports are sourced from Australia, and that all imports are used only by residents, a TBL analysis of $27 million of imports onto Norfolk Island (data from Buffett 2007) shows that greenhouse gas emissions caused on the island plus greenhouse gas emissions embodied in imports amount to about 25,000 tonnes CO_2-e, or about 14 tonnes CO_2-e per resident (Tab. 5). This compares favourably with the Australian average of about 25 tonnes CO_2-e per capita (Turton 2004). The per-resident figure is probably even too high, because tourists do consume a part of the goods shipped onto the island (for example petrol when renting a car).

In comparison, the 28,724 arrivals in 2006 required an air transport task of about 115 million passenger-kilometres[21], which caused about 30,000 tonnes of greenhouse gas emissions, or about 1 tonne per average return trip (Lenzen 1999).

[20] This work does not follow note 20 in Stephens 2006, which asserts that the part of the population that did not state any income can be estimated from aggregate figures on GDP and capital depreciation, and that this part (10-15%) "may account for up to 75% of total income". This is because the figure of $113 million given by Stephens 2006 is not GDP, but GNT (Gross National Turnover). GDP is the sum of wages, salaries, profits, and taxes and levies. In 2004-05, wages, salaries, and profits were approximately $31 million (Australian Bureau of Statistics 2006), whilst in 2005-06 the Island Administration recorded about $25 million (Administration of Norfolk Island 2007), which together explains the order of magnitude of income recorded in the 2006 census ($40 million, stated by 81% of the population).

[21] Assuming an average one-way trip length across all journey origins of 2,000 km.

Rank	Commodity	Greenhouse gas emissions
1	Norfolk Island (direct component)	18,820 t CO2-e
2	Shipping	2,250 t CO2-e
3	Meat products	440 t CO2-e
4	Food products	290 t CO2-e
5	Wholesale trade	262 t CO2-e
6	Fabricated metal products	234 t CO2-e
7	Kerosene	208 t CO2-e
8	Petrol and diesel	170 t CO2-e
9	Clothing	99.4 t CO2-e
10	Wool fabrics	87 t CO2-e
11	Household electrical applicances repair and service	85.4 t CO2-e
12	Printing and stationery	82.6 t CO2-e
13	Plastic products	76.8 t CO2-e
14	Tobacco	63.2 t CO2-e
15	Spirits	63 t CO2-e
	Total (direct and embodied in imports)	25,464 t CO2-e
	Per-resident	14.1 t CO2-e

Tab. 5: Direct (on-island) and indirect (embodied) greenhouse gas emissions for Norfolk Island (BL^3 output).

3.4.2 Trend and scenario analyses of energy and greenhouse gas emissions

A purely visual examination of the trends of total population (Fig. 1), per-capita income (Fig. 16), and electricity generated (Fig. 15) shows some similarities in that these curves increase between 1980 and 1990, decrease or stagnate up to 1996, then increase up to 2001, and decrease again up to 2006. In the following I attempt to explain total fuel use (in tonnes, Fig. 15) as a result of population growth, affluence growth (income/capita) and fuel efficiency. The latter is approximated by the ratio of fuel imports and economic income. I carry out a Structural Decomposition Analysis (SDA) of the trends[22], using the well known IPAT decomposition, meaning Impact = Population × Affluence × Technology.

Between 1981 and 2006, annual fuel imports (Impact) increased by 1244 tonnes per year (Fig 15). Population trends alone would have caused an increase of 710 tonnes over the same period, while Affluence alone would have been responsible for 840 tonnes. Technological improvements alone would have led to a reduction of 300 tonnes.

It is interesting to examine two scenarios that would increase Norfolk resident's annual income by A$1,000 per capita. The first scenario (I) is an increase in tourist numbers by 1,900 arrivals or 13,200 tourist-days, which at the current and constant spending of A$135 per tourist-day, would yield about A$1.8 million annually, or $1,000 per resident. The second (II) is an increase in tourist yield to achieve A$145 per tourist day. At currently about 200,000 tourist-days per year, this measure would also yield an additional income of $1,000 per resident.

[22] For further details on this technique see Lenzen 2006 and references therein. In this work I have applied the Marshall-Edgeworth decomposition formula.

Using SDA, and assuming that the island's energy-using technology (power supply, vehicles etc) will not change, an analysis of these scenarios shows that

- an increase in tourist numbers of 13,200 bed-nights (about 1,900 arrivals assuming an average stay of 7.7 days) would require the importation of an additional 75 tonnes of petroleum products, costing in excess of A$75,000, and leading to about 170 tonnes of additional greenhouse gas emissions caused by the combustion of fuels on the island, and an additional 22 tonnes emitted because of additional shipping (Lenzen 1999);
- an increase of A$1,000 in residents' annual per-capita income through higher tourist yields, would necessitate an additional 135 tonnes of petroleum products, costing in excess of A$130,000, and causing an additional 300 tonnes of greenhouse gas emissions.

These results hold independently of which sub-period within the entire period between 1981 and 2006 is appraised.

The above results refer to fuels brought onto the island. Indirect effects of the two scenarios, that is energy required and emissions caused elsewhere, are markedly different. For example, the majority of jet fuel for passenger air transport to Norfolk Island is taken up at the various journey origins. 1,900 additional arrivals yielding 13,200 additional bed-nights would require an additional air passenger transport task of 7.6 million passenger-kilometers, requiring about 24,000 GJ of jet fuel, causing about 1,900 tonnes of greenhouse gases. This indirect effect is 10 times higher than the direct effect occurring on the island.

In addition, an increase in income through increased tourist yield would lead to Norfolk Islanders buying more (the so-called rebound effect). Assuming that islanders would spend the entire additional A$1,000 of purchasing power on imports from Australia or New Zealand, this would lead to more energy use and greenhouse gas emissions in these countries. Assuming once again that all imports are sourced from Australia, a TBL analysis of $27 million of imports onto Norfolk shows that a homogeneous increase of the imported commodity basket by A$1,000 would cause an additional 300 tonnes of greenhouse gases to be emitted. This increase affects both scenarios I and II.

Scenarios	Direct (island effect)	Indirect effects (air travel and imports)	Total effect
I: Increase in tourist numbers	190	1900 + 300	2390
II: Increase in tourist yield	300	300	600

Tab. 6: Effect on greenhouse gas emissions of two alternative scenarios leading to an increase in income of A$1,000 per resident. Figures in tonnes CO_2-e.

Summarising, increasing tourist numbers instead of yield causes four times higher greenhouse gas emissions, for the same effect on resident income (Tab. 6). In short, this is essentially because *flying tourists emits more than shipping goods*.

4 Discussion

4.1 Comparison with other island destinations

In order to put the findings from the previous section into perspective, it is necessary to compare Norfolk Island with other small-island tourist destinations around the world. McElroy 2006 provides a sample of 36 destinations, amongst which Norfolk Island is neither the smallest nor the most proximate to major population centres. It is interesting to see that (Tab. 7)

- Norfolk Island has a comparatively low population density;
- in terms of the numbers of tourist on the island at any on time per resident[23], Norfolk Island ranks 2nd amongst 37 island destinations;
- in terms of the numbers of annual tourist arrivals per resident, Norfolk Island (16 per resident) ranks 1st amongst 37 island destinations;
- in terms of overall tourist income per resident, Norfolk Island (US$12,500 per resident) ranks 7th amongst 37 island destinations; but
- in terms of tourist spending per day, Norfolk Island (US$102) ranks only 23rd amongst 37 island destinations.

The average period of stay (7.7 days on Norfolk) is higher than the average across the 37 destinations (5.9 days). Thus, in comparison, Norfolk Island achieves its high tourist income per resident through sheer arrival and bed-night numbers, which are almost unprecedented amongst island destinations. However those tourists spend below-average amounts of money on the island. This result is due to the age distribution of tourists to Norfolk which is heavily skewed towards the 60+ groups (Mathews various years). One can hence conclude that in terms of tourist load, Norfolk's people and infrastructure are relatively strained.

Considering the quite unfavourable development of the Retail Price Index and per-capita income in recent years (Fig. 16), an obvious strategy for boasting overall tourist income is to increase arrivals and/or tourist-day numbers. As indicated in the previous Section, from a sustainability perspective, this strategy could have adverse impacts on the local social, ecological, and resource environment. Take for example the precedent of Australian grazing industries: Faced with slumping world market prices for primary agricultural commodities and eroding earnings, producers simply increased production volumes, which only led to excessive land clearing and loss of biodiversity. Without any long-term structural adjustment such as re-directing production towards more value-adding, such reactions create an environmental–economic dilemma through increasing dependency on degrading production and further erosion of environmental quality (Daniels 1992). Daly 1993 has termed this strategic trap the "ecological race to the bottom": Short-term solutions lead to long-term damage and cost.

Given that Norfolk Islanders – in comparison – are already one of the most strained island communities, plans for further increases in tourist numbers should be accompanied by thorough social, environmental and resource assessments. Many Caribbean destinations in proximity to the United States earn in excess of US$150 per tourist-day at considerably lower

[23] Norfolk's ratio of tourists-to-residents is 34%, which is 0.34 tourists per resident are on the island at any on time, that is residents outnumber tourists only 3:1.

tourist and arrival numbers. These islands may serve as useful case studies for strategies showing how to increase the quality rather than the quantity of tourism.

	Population density (km^{-2})	Tourist/resident population	Income /resident (US$)	Income /tourist-day (US$)	Annual arrivals /resident
Norfolk Island	51.4	34%	12,500	102	16.0
Anguilla	131.9	9%	5,083	150	4.0
Antigua	152.3	7%	4,060	164	3.5
Aruba	362.7	22%	12,714	161	9.9
Bahrain	1040.3	2%	977	115	4.3
Barbados	639.5	5%	2,498	133	1.8
Bermuda	1280.0	8%	5,484	197	4.3
Bonaire	38.6	11%	6,250	156	4.2
UK Virgins Islands	140.0	38%	16,048	115	14.1
Cape Verde	100.5	1%	96	48	0.3
Cayman Islands	138.5	17%	16,250	269	9.3
Comoros	274.7	0.1%	25	112	0.0
Cook Islands	87.5	11%	1,810	46	3.6
Curacao	270.2	3%	1,721	145	1.4
Dominica	94.7	3%	662	60	1.0
Grenada	261.8	3%	708	71	1.4
Guadeloupe	252.6	2%	858	132	1.2
Guam	292.1	6%	12,918	586	7.3
Kiribati	131.1	0.1%	34	91	0.1
Maldives	1036.7	3%	1,064	84	1.5
Malta	1234.4	8%	1,466	52	3.0
Marshall Islands	392.3	0.1%	59	139	0.1
Martinique	391.5	4%	590	40	1.1
Montserrat	80.0	3%	1,125	90	1.3
Mariana Islands	157.2	6%	7,507	357	5.8
Polynésie Française	69.4	3%	1,551	158	0.8
Réunion	293.2	3%	333	36	0.6
St.Kitts	145.0	5%	1,590	95	1.9
St.Lucia	259.0	4%	1,753	107	1.7
St.Maarten	878.0	15%	13,694	245	11.2
St.Vincent	341.2	2%	690	106	0.6
Samoa	62.8	1%	218	58	0.5
Seychelles	175.8	5%	1,413	84	1.6
Tonga	144.8	1%	67	15	0.3
Turks&Caicos Is.	41.9	19%	17,278	245	9.2
Tuvalu	423.1	0.2%	118	143	0.1
US Virgin Islands	349.6	6%	9,803	449	4.9

Tab. 7: Comparison of key indicators for island destinations (derived from data in McElroy 2006, except for Norfolk Island).

4.2 TBL-labeling of products

One strategy of branding a destination as "high-quality" is through sustainability certification. The methodology and findings reported here may serve as a basis for creating a rating or labeling system across the Triple Bottom Line, which would prominently feature locally relevant indicators.

In order to be effective, labels must not include too much information, since consumers usually do not spend much time on reading labels while shopping. Even the benchmark spider diagram is too complex to be understood by a lay consumer in a few seconds. Hence, the scores on different indicators have to be aggregated somehow. This poses a problem since the quantities relating to different aspects of the Triple Bottom Line are completely uncommensurable, or in simple terms, "one cannot easily add apples and pears".

Rating is a traditional application in the discipline of Multi-Criteria Decision Analysis (MCDA), and much research has been dedicated to the aggregation problem. Decision outcomes using MCDA are strongly influenced by, amongst other factors

– the functional form of the aggregate (for example arithmetic or geometric means),
– the normalisation of the raw data (for example via ratios or via scaling into a [0,1] interval),
– the weighting of the different indicators in the average, and
– the choice of indicators to be considered.

Apply for example a geometric mean formula[24] to the ratios used in the spider diagrams (Figs. 4 and 9), and weight every indicator equally. One could the argue for excluding intermediate uses from the indicator list because – whilst meaningful on the Australian mainland as an indicator for economic stimulus – it is not meaningful for an island setting because less intermediate uses mean greater autonomy, which for an island mean less dependence on expensive imports. In the case of Norfolk Island one could further argue for the exclusion of government revenue as a business indicator, because of the substantial differences between the Australian and Norfolk taxation systems, over which a Norfolk business has no influence. Finally, many businesses are run mainly by self-employed people with few staff on wages and salaries, so that the family income indicator could be excluded unless self-employed income is imputed. Thus successively excluding certain indicators changes the star rating of both the soft drink factory and the pig farm (Tab. 8).

	All indicators	Excluding Intermediate uses	Excluding Government revenue	Excluding Family income
Soft drink factory	3.34	3.70	3.91	3.90
Pig farm	2.93	3.47	3.98	4.08

Tab. 8: Aggregated scores of soft drink factory and pig farm under various indicator suites.

[24] The geometric mean of n numbers $x_1, x_2, \ldots, x_n$ is calculated as $\sqrt[n]{x_1 x_2 \ldots x_n}$. A rating between 0 and 5 (a "star rating") can be generated by calculating $\mathrm{Max}\{0 , 5 - 2.5 \times \sqrt[n]{x_1 x_2 \ldots x_n}\}$.

Considering all indicators, the soft drink factory and pig farm would be 3½✰ and 3✰ businesses, respectively. Excluding the indicator 'intermediate use' from the analysis (on which both businesses score below average) would increase the pig farm's score to 3½✰. Excluding the indicator 'government revenue' from the analysis (once again, on which both businesses score below average) would increase both scores to 4✰. Finally excluding 'family income' would not change any score.

Thus, in principle, any business could find reasons to argue for certain indicators to be excluded from the analysis, and increase their score. In order to prevent such strategic behaviour (a term used in MCDA), a superior decision-making body could fix a set of indicator weights which ideally would reflect the priorities of the community. Say, for example, that Norfolk Island considered energy use, material flow and employment to be the most important indicators, and intermediate use, family income and government revenue (for the above reasons) the least important. Under indicator weights as in Tab. 9, the soft drink factory would score 3.77 (4✰) and the pig farm 3.6 (3.5✰).

Indicator	Weight
Material flow	15%
Energy consumption	15%
Greenhouse gas emissions	10%
Water use	10%
Land disturbance	10%
Family income	5%
Employment	15%
Government revenue	5%
Gross operating surplus	10%
Total intermediate uses	5%

Tab. 9: Example indicator weights. Note that all weights add up to 100%.

In principle, as long as the community arrives at an agreed priority setting in a participatory way, and the rationale behind the weighting is made transparent, the resulting TBL star-rating scheme is meaningful for its purposes.

5 Conclusions

Conventional measures aimed at tackling the energy and waste issues of island communities focus on technological solutions, such as the introduction of renewable energy sources. There exists a history of technology implementations on small islands that have failed because of a lack of continuing skills and financial resources needed for ongoing operation and maintenance. Despite these experiences, what has received little attention so far are measures aimed at achieving island-friendly solutions by reducing their material metabolism, for example by recycling and re-use. The two case studies presented in this work have shown that vision and creativity can work wonders in achieving "more with less". Both case studies demonstrate exceptional sustainability performance in terms of material flow, and greenhouse gas emissions. Furthermore, the whole-of-island analysis demonstrates that – from a sustainability point of view – increasing tourist yield rather than tourist numbers is a preferred strategy for coping with price hikes and limited resource base.

In many ways, an island is a micro-cosmos resembling the entire planet: It drastically conveys the inescapable reality of a limited world. Technology can distract from this reality by creating the illusion of boundless capacity for energy use and waste disposal. Similarly, growth optimism can distract by creating the illusion of boundless potential for income and affluence. These illusions will always be temporary: The literature abounds with examples of communities where

- new cost- and energy-saving devices have led to money soon spent elsewhere, often more unsustainably;
- improvements in the fuel economy of cars and expansions of road networks have virtually always been overridden by rapidly increasing mobility;
- new waste disposal facilities have only led to higher waste volumes;
- growing income streams (for example from more tourists) have not created happy people.

What these measures have in common is that they have provided temporary relief (from financial strain, traffic congestion, waste issues, unhappiness), leading first to a feeling of renewed freedom (to spend, drive and waste), only to be soon outpaced by

- higher lifestyle expectations leading to the old financial strain,
- higher mobility leading to the old traffic jams, and
- quickly overwhelmed waste facilities leading to the old waste issues.

The "solutions" were short-term, whereas the long-term, real issues and challenges were ignored, and as a consequence the old problems rebounded. On islands, these rebounds are likely to be more severe, because in contrast to continental communities, islands can neither draw on the space nor on the natural resources needed to sustain unrelenting growth.

Attempting to reduce the material metabolism of an island community has at least one critical advantage over such short-term solutions: It reveals to the decision-maker the real magnitude of resource needs and constraints of an island setting, instead of giving the impression that – with the "right" technology and "healthy" growth – consumption and affluence can be limitless. Attempting to reverse the escalator of aspirations that is forever outrunning unhappiness holds the promise of lives that allow fulfillment. In a future of depleted resources, climate change and sea level rise, island communities will sooner or later focus their attention on these real issues: to understand, and live within the limits posed by their finite paradises.

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