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Environmental impact assessment including indirect effects—a case study using input–output analysis

Manfred Lenzen[a], Shauna A. Murray[b,*], Britta Korte[c], Christopher J. Dey[a]

[a] *School of Physics, A28, The University of Sydney, Sydney, NSW 2006, Australia*
[b] *School of Biological Sciences, A08, The University of Sydney, Sydney, NSW 2006, Australia*
[c] *Institut für Landschafts-und Umweltplanung, Technische Universität, Franklinstr. 28/29, 10587 Berlin, Germany*

Abstract

Environmental impact assessment (EIA) is a process covered by several international standards, dictating that as many environmental aspects as possible should be identified in a project appraisal. While the ISO 14011 standard stipulates a broad-ranging study, off-site, indirect impacts are not specifically required for an Environmental Impact Statement (EIS). The reasons for this may relate to the perceived difficulty of measuring off-site impacts, or the assumption that these are a relatively insignificant component of the total impact. In this work, we describe a method that uses input–output analysis to calculate the indirect effects of a development proposal in terms of several indicator variables. The results of our case study of a Second Sydney Airport show that the total impacts are considerably higher than the on-site impacts for the indicators land disturbance, greenhouse gas emissions, water use, emissions of NO_x and SO_2, and employment. We conclude that employing input–output analysis enhances conventional EIA, as it allows for national and international effects to be taken into account in the decision-making process.

Keywords: Environmental impact assessment; Indirect effects; Input–output analysis; Australia

* Corresponding author. Tel.: +61-2-93513536; fax: +61-2-93514119.
E-mail address: smurray@bio.usyd.edu.au (S.A. Murray).

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1. Introduction

1.1. The EIA standard and system boundaries

Environmental impact assessment (EIA) is a planning instrument for predicting the effects on the environment from altering or building a new establishment. For the purposes of EIA, the meaning of *environment* incorporates physical, biological, cultural, economic and social factors. The International Organisation for Standardisation (ISO) Standard 14011, which covers EIA, includes principal steps such as general requirements, environmental policy, planning, implementation and operation, checking and corrective action, and management review. In these steps, the definitions of processes such as *auditing* and *scope* are included. Auditing is a term used in EIA principally to describe the check for compliance with criteria of environmental approval, but also as an internal review of environmental management practices by proponents. Additionally, and more importantly in the context of our work, it is a form of site evaluation for environmental liability before purchase or development by proponents. The reporting of results applies to all of these uses of the audit (Australian and New Zealand Environment and Conservation Council, 1992). The scope describes the extent and boundaries of the audit in terms of factors such as physical location and organisational activities, as well as the manner of reporting (International Organisation for Standardisation, 1996b, 5.1.1).

According to the ISO, as many environmental aspects as possible should be identified in an EIA (International Organisation for Standardisation, 1996a, 4.2.2), but corresponding indicators are not specifically dictated. In addition, the procedure of setting a *system boundary* of the audit, that is, the spatial and temporal boundary of the proposal's effects to be estimated, is not specified. In EIA, this boundary is left to be determined by the client and the lead auditor (International Organisation for Standardisation, 1996b, 5.1.1). In practice, almost all EIAs study the direct, on-site effects alone, using process analysis and audit-type methods. As will be shown below, off-site effects can be up to several orders of magnitude greater than on-site effects, and are usually not extensively addressed in conventional EIAs.

In addition to direct effects, developments cause environmental pressure indirectly through the consumption of goods and services, and the activities of the numerous producing industries in the national as well as foreign economies. Indirect effects are of infinite order: in the case of building an airstrip, for example, they not only include environmental pressure exerted by the airstrip itself (impacts on vegetation, wildlife and the physical environment), but also the land occupied by producers of construction machinery, by steel plants producing the steel for the machinery, by mining operations providing the iron ore for the steel factory, by manufacturers of mining equipment, and so on. These impacts are generally off-site, and may even occur in foreign countries. This process of industrial interdependence proceeds infinitely in an upstream direction, through the whole life cycle of all products, like the branches of an infinite tree. A technique that enables the calculation of indirect effects is input–output analysis.

1.2. Input–output analysis

Input–output analysis is a top-down linear macroeconomic approach to describe industrial structure. Sectoral monetary transaction data are employed in an interindustry model to account for the complex interdependencies of industries in modern economies. Although input–output analysis was developed for economic analysis, generalised input–output frameworks have been applied in environmental analyses since the late 1960s (see, for example, Isard et al., 1967; Leontief and Ford, 1970). Applied to economic and environmental indicators such as employment, land disturbance, water and energy use, it yields *total indicator intensities*, that is the amount of an indicator required to produce and deliver a value unit of a particular commodity. Total indicator intensities include direct and indirect contributions. For example, the direct or zeroth-order land disturbance of the commodity 'tourist resort in North Queensland' is the land cleared at the site to create space for the resort. A first-order indirect contribution is the land used for growing food for tourists. A second-order indirect contribution along another path is the land used for mining the coal that is combusted in the power plant providing the resort with electricity. Total indicator intensities include requirements of infinite order. The mathematical framework of input–output analysis applied to EIA is outlined in Section 3.

1.3. EIA and indirect effects—a literature review

EIA has been frequently criticised for its relatively narrow spatial and temporal scope: as Lakshmanan and Johansson (1985, p. 1) point out, while "projects may be localised spatially, their consequences are incident on various activities at many spatial levels (local, regional, national, and international), and have diverse environmental, economic, social, and institutional effects". Similarly, Shepherd and Ortolano (1996) stress that "EIA at the project level is insufficient ... [because it] starts too late, ends too soon, and is too site-specific". They propose a Strategic Environmental Assessment (SEA) for urban development proposals, that takes into account a broader range of impacts such as cumulative, secondary and indirect impacts (Shepherd and Ortolano, 1996). Rose et al. (1978, p. 129) emphasise that "whether net benefits of a proposal are positive or negative in a regional or national context is of fundamental importance to national policy". Nevertheless, off-site effects are not addressed in traditional EIA. In this respect, the statement of Johnson and Bennett (1981) that "no consensus has been reached on a standard analytical approach which provides a comprehensive, quantitative assessment of economic and environmental impacts" still holds true.

Whitney (1985) concludes that the reason for the lack of more comprehensive and sophisticated approaches within EIA is the "EIA process itself, which gives no incentive for more rigorous forms of analysis to be employed". In this criticism, he was referring not only to the lack of attention to indirect effects, but to cumulative effects in general. The latter are addressed in methods such as Cumulative Effects Assessment (CEA; Canter, 1999). Methods such as CEA do not generally define procedures to be used for EIAs on individual projects, but are regional strategies aiming to assess information about the effect of a number of projects in a region over a longer term. These methods are therefore aimed at implementation on a local authority level, rather than individual project level (Thomas, 2001).

Several previous works incorporate indirect effects into EIA. An early attempt to link an economic and an ecological system in a single regional integrated input–output framework is documented in a study on the impact of a proposed marina in Kingston Bay, MA, USA (Isard et al., 1972). Similarly, waste flows were examined in a regional interindustry model of the state of Maryland, USA, and applied to the analysis of the impact of a Disneyland recreation complex (Cumberland and Korbach, 1973). Johnson and Bennett (1979) combine a 23-sector input–output table for Darlington County, USA, with a nonlinear environmental model for water pollution and quality, including environment–economy feedback through pollution control cost, and assessing the consequences for employment, income and water pollution of a nuclear power plant. The local and regional employment and income generated by a 4500-MW geothermal energy development in Imperial County, USA was calculated using an 84-sector regional input–output model (Rose et al., 1978). These authors emphasise that for typical energy developments, on-site operations are capital-intensive, but employ very few people. In these cases, the majority of employment is created through indirect effects, such as stimulated by secondary demand for goods and services. The study by Rose et al. (1982) is detailed: in addition to direct, indirect and induced employment and income effects, they examine income distribution among occupations, the share of wages and proprietary income, and changes in migration and age composition.

In Australia, a 25-sector input–output model for the Hunter Valley region has been used to assess the regional environmental impacts of coal-fired electricity development (James, 1983). James (1985) and Goldrick and James (1994) combine the same model with national input–output combustion emissions models, and regional water quality and air pollutant dispersion models, in order to determine the impacts of coal-based energy development and a large aluminium smelter in terms of emissions of sulfur oxides and fluorides, salinity levels in the Hunter River, and indirect and induced regional employment and income.

The approaches listed above represent static models. Using a 200-sector dynamic input–output model (INFORUM), Strategic Environmental Assessment (SEA) was developed in the 1970s as an integrated economy–environment–

energy model for analysing (mostly energy) policies (Lakshmanan and Ratick, 1980; Lakshmanan, 1985). In another dynamic application, Romanoff (1984) and Ramanoff and Levine (1993) examine time lags in regional employment creation due to project scheduling (Levine and Romanoff, 1989), using a Sequential Interindustry Model (SIM). Recognising the data intensity of regional dynamic input–output models, Solomon (1985) and Solomon and Rubin (1985) suggest resorting to econometric models using time-series data and recursive equations interlinking economy and environment. A review of economic methods for EIA can be found in a paper by Lea (1985).

In the present study, we will provide an example of current EIA practice in Australia, and then describe the methodology of input–output analysis. The main part of this study is a static calculation of the total effects in terms of land disturbance, greenhouse gas emissions, water use, emissions of NO_x and SO_2, and employment for our case study—the construction of a Second Sydney Airport. We will show how the data derived can enhance the conventional EIA, in order to provide a more complete picture for decision-makers.

2. Case study of current EIA practice—Second Sydney Airport

The Second Sydney Airport Proposal was chosen as a representative example of the procedures and results of a typical EIA carried out according to current Australian guidelines. For further information on the institutional and policy setting of EIA in Australia, see Boer and Martyn (1994), Thomas (2001) and Australian EIA Network (2001). The proposal was to build a new domestic and international airport in Western Sydney. A potential location was selected for assessment: Badgerys Creek. The environmental assessment process was designed to help answer questions such as where a second airport should be built, how many aircraft the airport should handle, what the environmental impacts of the proposal would be, and how they should be managed.

The completion of the Environmental Impact Statement (EIS) took more than 3 years, at a cost of more than A$13.5 million. The public review of the Draft EIS (PPK Environment and Infrastructure, 1997a,b) from 23 December 1997 to 30 March 1998 attracted more than 15,600 written public comments from more than 11,200 authors. All public comments received were taken into account in the preparation of a supplement to the Draft EIS by the proponent (Environment Australia, 1999b). The completed EIS was then reviewed by the Federal Environment Minister, who concluded that there was no insurmountable environmental issue that would prevent the project proceeding (Environment Australia, 1999a).

In the EIS, a number of alternative options were considered for providing increased airport capacity to meet the forecast growth in passengers and aircraft movements in Sydney. The alternatives considered included different sites, or increasing the capacity of the existing Sydney Airport, other Sydney airports and other major airports in Australia. The probable design, staging, construction and operation of each option were considered in the EIS. The potential impacts of the airport options on metropolitan, regional and local planning, and on existing and future land uses were examined, and cost estimates were provided for airport construction, infrastructure, airport operation, planning and land use impacts, noise impacts, physical and biological impacts, social impacts and economic impacts of the proposal. However, not all costs could be quantified during the preparation of this EIS. Further studies were undertaken about potential effects of aircraft noise, meteorological conditions, air quality, geology and soils, flora and fauna, hazards and risks, Aboriginal and non-Aboriginal culture heritage, socio-economic, visual and landscape impacts. The cumulative impacts of the proposal and the likely environmental implications of the potential future expansion of the airport were also examined.

Based on the procedures described above, among other findings, the EIS arrived at the impacts of the master plan for the categories of energy consumption, employment, land and water use associated with the construction of three alternative airport design options. As these options are reasonably similar, we focus only on Option B as the one requiring the largest land area (2900 ha). This

Table 1
Results from the Second Sydney Airport EIS, Badgerys Creek Option B, for selected indicators

Factor	Component	Amount
Land use (in ha)	airstrip, buildings	964
	open	2089
	access, sealed	38
	access, cleared	118
	rail route, sealed	102
	rail route, cleared	118
	water supply	5
	waste water option 1	7
	waste water option 2	4
	power and transmission line	1
	overhead power	2
	aviation fuel	15
	natural gas	4
	total	3467
Water (in Ml)	total	39,000
Fuel (automotive diesel oil in ml)	earthwork	50
	pavement	30
	buildings	5
	sundry	5
	total	90
Employment (in emp-y)	direct	8860
	indirect	17,326
	total	26,186

emp-y = employment years, ha = hectares, Ml = megalitres.

option would be located largely on land owned by the Federal Government, but would require the acquisition of an additional 1200 ha of land to the south, southwest and southeast. The master plan would provide all the facilities required for an airport accommodating 30 million passengers a year. Two 4000-m long, parallel runways, separated by 2300 m, northeast- to southwest-orientated, would be provided for the airport. The separation distance leaves space for development of a linear terminal configuration with car parking and a commercial area.

A summary of results from the Second Sydney Airport EIS for selected indicators concerning airport Option B is given in Table 1. The airstrips, buildings, reservoirs and particularly open space adjacent to the airstrip account for the majority of the land use. The area of open space is twice as high as the sealed area, and land use for road and rail access is comparatively small. Direct fuel use according to the EIS is dominated by fuel required for earthworks and pavements. Indirect employment is estimated to be about twice that of direct employment. Since the projected impacts of the airport's operation were equal for all options, they are not reported here. The figures include impacts of on-site activities and regional infrastructural measures. The EIS explicitly addresses indirect effects, however, these were quantified only for employment.

3. Methodology

3.1. Input–output analysis

In this study, we employ a hybrid EIA approach combining static input–output analysis with a conventional EIS. In this approach, the direct (on-site) environmental impacts are assessed in a detailed audit, while all remaining higher order requirements (for materials extraction, manufacturing, and services) are covered by input–output analysis. Such hybrid techniques have been suggested for regional analysis (Ashcroft and Swales, 1982) and have also been applied in life-cycle assessments (LCA; Bullard et al., 1978; Moskowitz and Rowe, 1985; Lave et al., 1995; Wagner and Wenzel, 1997; Treloar, 1997; Hondo and Sakai, 2000; Joshi, 2001; Lenzen, 2001a).

The result of generalised input–output analyses is a $f \times n$ matrix of *factor multipliers*, that is embodiments of f production factors (here: land types and greenhouse gas emissions) per unit of final consumption of commodities produced by n industry sectors. A multiplier matrix $\mathbf{M}$ can be calculated from a $f \times n$ matrix $\mathbf{F}$ containing sectoral production factor usage, and from a $n \times n$ *direct requirements* matrix $\mathbf{A}$ according to

$$\mathbf{M} = \mathbf{F}(\mathbf{I} - \mathbf{A})^{-1}, \qquad (1)$$

where $\mathbf{I}$ is the $n \times n$ unity matrix. The $f \times 1$ *environmental impact* $\mathbf{\Phi}$ of the proposal is then determined by multiplying the proposal cost (represented by a

$n \times 1$ commodity inputs vector $\mathbf{y}$) with the multiplier matrix $\mathbf{M}$, and adding a $f \times 1$ vector $\mathbf{\Phi}_d$ of direct (on-site) impacts:

$$\mathbf{\Phi} = \mathbf{M} \times \mathbf{y} + \mathbf{\Phi}_d. \tag{2}$$

$\mathbf{M} \times \boldsymbol{y}$ represents indirect requirements, that is environmental indicator quantities embodied in all inputs into the institution's operation. The total factor multipliers as in Eq. (1) can be decomposed into contributions from structural paths by "unravelling" the Leontief inverse using its series expansion

$$\mathbf{F}(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{F} + \mathbf{FA} + \mathbf{FA}^2 + \mathbf{FA}^3 + \ldots \quad . \tag{3}$$

The mathematical formalism used to derive Eqs. (1) and (2), and some of the results presented in this article is described in detail in a previous article (Lenzen, 2001b).

3.2. Data sources

The results presented in Section 4 were calculated for the indicators energy consumption, water use, employment, land disturbance, and emissions of greenhouse gases, NO_x and SO_2. The term 'energy' shall here be understood as combusted primary energy from nonrenewable sources such as fossil fuels. This definition includes solid, liquid and gaseous fuels such as coal, petrol and natural gas. Secondary energy carriers such as electricity are covered indirectly by their primary energy inputs, so that no double counting occurs. 'Water use' comprises both mains water and surface water extracted from rivers or lakes. It reflects net water use, and as such excludes in-stream users such as aquaculture and hydroelectric power plants (see Lenzen and Foran, 2001). 'Employment' is understood as full-time-equivalent employment, measured as full-time employment plus 50% of part-time employment of employees, including employers, own account workers and contributing family workers (Australian Bureau of Statistics, 1999). The term 'land disturbance' summarises recent efforts to incorporate land use into life-cycle assessment practice, not only in area terms, but also in terms of its environmental impact. Few authors have yet quantified impacts of different types of land use, but most recent approaches consider effects on 'ecosystem quality' or 'condition', expressed in terms of bioproductivity or biodiversity, for example as the species diversity of vascular plants (Lindeijer, 2000a,b; Swan and Pettersson, 1998; Köllner, 2000; van Dobben et al., 1998). Accordingly, the measure of land disturbance $D = \sum_i D_i = \sum_i A_i \times C_i$ used in this work is expressed as a weighted sum of land use areas A_i, with weights C_i (see Lenzen, 2001b). The weights reflect the degree of alteration of land from its natural state, or the land condition. They are listed in Table 2 for different land types. In accordance to guidelines set out by the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions are expressed in $CO_2 -$ equivalents ($CO_2 - e$), which are calculated as a weighted sum of nominal emissions of various gas species

Table 2
Weights C for land types (derived from Graetz et al., 1995; Hobbs and Hopkins, 1990; Swan and Pettersson, 1998; van Dobben et al., 1998; Köllner, 2000, Table 3; and also see Lindeijer 2000b), with area A affected in Australia

Land type	Affected area (A)	C	Disturbance (D)
Consumed	2.3	1.0	2.3
Built	2.3	1.0	2.3
Degraded	16.4	0.8	13.2
Degraded pasture	15.5	0.8	12.4
Degraded crop land	0.8	0.8	0.6
Mined land	0.2	0.8	0.1
Replaced	101.1	0.6	60.7
Crop land	15.5	0.6	9.3
Cleared, ILZ	84.7	0.6	50.8
Non-native coniferous plantations	0.9	0.6	0.5
Disturbed	162.8	0.4	65.2
Thinned, ILZ	47.1	0.4	18.8
Significantly disturbed, ELZ	115.2	0.4	46.1
Reversibly built	0.3	0.4	0.2
Native eucalypt plantations	0.2	0.4	0.1
Partially disturbed	102.1	0.2	20.4
Indeterminately disturbed, ILZ[a]	36.5	0.2	7.3
Substantially disturbed, ELZ[b]	65.6	0.2	13.1
Slightly disturbed	378.1	0.0	0.0
Uncleared, ILZ	85.9	0.0	0.0
Slightly disturbed, ELZ	8.3	0.0	0.0
Reserves and unused Crown Land	284.0	0.0	0.0
Total	768.2		161.8

Resulting land disturbance is $D = A \times C$.
C = Land condition.
[a] Areas for which disturbance could not be assessed.
[b] Disturbance below-critical for biotic erosion.

using gas-specific global warming potentials of 1 (CO_2), 21 (CH_4), 310 (N_2O), 6500 (CF_4), 9200 (C_2F_6), 1300 (HFC-134a) and 23900 (SF_6) (Nakicenovic and Swart, 2000).

A matrix **F** containing sectoral energy consumption, water use, employment and emissions was obtained partly from well-documented sources such as the National Greenhouse Gas Inventory Committee (1998a), energy (Australian Bureau of Agricultural and Resource Economics, 1997a), water (Australian Bureau of Statistics, 2000b) and employment (Australian Bureau of Statistics, 1999) statistics. Further sectoral disaggregation was achieved by using supplementary reports (Wilkenfeld and Associates, 1998; Apelbaum Consulting Group, 1997) and unpublished estimates on the above factors (Australian Bureau of Agricultural and Resource Economics, 1997b,1999; Australian Bureau of Statistics, 2000a). Information on land disturbance was obtained from various disparate data sources, which are documented in an article by Lenzen and Murray (2001).

Finally, the direct requirements matrix **A** was derived from the Australian input–output tables (Australian Bureau of Statistics, 1999), while the vectors $\boldsymbol{y}$ and Φ_d were extracted from the Second Sydney Airport EIS (Airport Planning, 1997a,b; PPK Environment and Infrastructure, 1997a,b, see information used for compiling Φ_d in Table 1). Additional conversion factors (see Table 3) for energy and greenhouse gas emissions were obtained from energy statistics (Australian Bureau of Agricultural and Resource Economics, 1997a) and the National Greenhouse Gas Inventory Committee, 1996,1998b).

3.3. Uncertainties

While being able to cover an infinite number of production stages in an elegant way, input–output analysis suffers from uncertainties arising from a number of areas. These include the assumption of fixed coefficients representing linear production functions, source data sampling and reporting errors, lags between the reference years of the input–output database and the development proposal, assumptions about factor use and homogeneity in foreign industries, the assumption of proportionality between monetary and physical flow, the aggregation of input–output data over different producers, and the aggregation of input–output data over different products supplied by one industry. Due to limitations in space, we provide only an indication of the errors associated with the results presented in Section 4. A detailed technical account of errors associated with input–output calculations can be found in a previous article (Lenzen, 2001a).

Taking a conservative estimate of relative standard errors of multipliers (elements of **M** in Eqs. (1) and (2)) of 50%, and considering that the cost

Table 3
Comparative summary of results for the Second Sydney Airport EIS and the input–output analysis carried out in this work

Factor unit	Energy consumption (PJ)	Land disturbance (kha)	Water use (Gl)	Greenhouse gas emissions (Mt)	NO_x emissions (kt)	SO_2 emissions (kt)	Employment ′000 (emp-y)
On-site, EIS	3.5[a]	2.5[b]	39.0	0.24[c]	3.5[d]	0.30[e]	8.4
Indirect, EIS							17.3
Indirect, IO	49.3	73.6	76.9	5.3	20.8	28.2	66.6
Total, EIS + IO	52.8	76.2	115.9	5.5	24.3	28.5	75.0

[a] Energy content ADO: 0.0386 PJ/Ml (ABARE 1997a,b, p. 57).
[b] Derived from Table 1 by multiplying sealed land with $C = 1.0$ and cleared land with $C = 0.6$, and adding up.
[c] Emission factor ADO: 0.0704 Mt CO_2-e/PJ (derived from ABARE 1997a,b, p. 77 and NGGIC 1996, Workbook 3.1, p. 50).
[d] Emission factor ADO: 1.006 kt NO_x/PJ (NGGIC 1996, Workbook 3.1, p. 50).
[e] Emission factor ADO: 0.085 kt SO_2/PJ (NGGIC 1998a,b, Workbook 1.1, p. 87).

breakdown for the airport proposal comprises 20 items (in vector $\boldsymbol{y}$), propagation of stochastic errors yields relative standard errors of

$$\frac{\Delta\boldsymbol{\Phi}_f}{\boldsymbol{\Phi}_f} = \frac{\sqrt{\sum_{i=1}^{20}(y_i \Delta \mathrm{M}_{fi})^2}}{\sum_{i=1}^{20} y_i \Delta \mathrm{M}_{fi} + \boldsymbol{\Phi}_{\mathrm{d},f}} \approx 30\% \tag{4}$$

for all f factors in $\boldsymbol{\Phi}$. This result holds under the assumption of accurate financial data and on-site impacts $\boldsymbol{\Phi}_\mathrm{d}$.

Another estimate of errors associated with energy embodied in road construction can be obtained by comparing the cost-based figures used in this work with a detailed hybrid embodied energy analysis of secondary roads undertaken by Treloar et al. (1999). According to these approaches, constructing and upgrading 38 km of access road for the Second Sydney Airport requires A\$m 150 × 9.72 TJ/A\$m = 1.45 PJ (cost-based) and 39 TJ/km × 38 km = 1.48 PJ (hybrid analysis; full-depth asphalt) of primary energy. Similarly, from Inamura et al.'s (2000) case study of the Tohoku Expressway in Japan, a value of 55 TJ/km × 38 km = 2.1 PJ can be derived. The validity of these comparisons is certainly reduced by the assumption that the airport access roads are comparable to those examined by Treloar (1997) and Inamura et al. (2000). However, the general agreement of all figures demonstrates that—at least for this important item of road (and probably also airstrip) construction—the results obtained from this work are certainly within acceptable accuracy limits.

4. Results

Indirect effects were found to be significant for all factors (Table 3). The indirect energy requirements of the airport construction (energy embodiments in material and services) are an order of magnitude higher than the on-site energy use. Similarly, the ratio of total to on-site impacts for land disturbance is ≈ 30, for water use ≈ 3, for greenhouse gas emission ≈ 23, for NO_x emissions ≈ 7, for SO_2 emissions ≈ 95, and for employment ≈ 9. Note also that the more comprehensive input–output technique yields a much higher indirect employment than the EIS. The reasons for these differences are discussed further below.

Evaluating the series expansion of the Leontief inverse (see Eq. (3)), The structure of the indirect effects can be further examined by decomposing requirements into *production layers*. Energy consumption, land disturbance, water use and employment requirements increase with the number of production layers, converging to a constant value (Fig. 1). The same is true

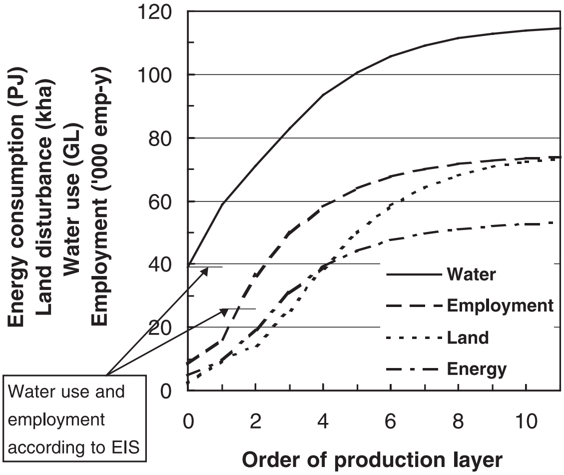

Fig. 1. Energy consumption, land disturbance, water use and employment as a function of production layer order.

for greenhouse gases, NO_x and SO_2 emissions (Fig. 2). The curves in both figures show similar behaviour, differing only in their rate of convergence to their respective total values. For all but total greenhouse gas emissions,

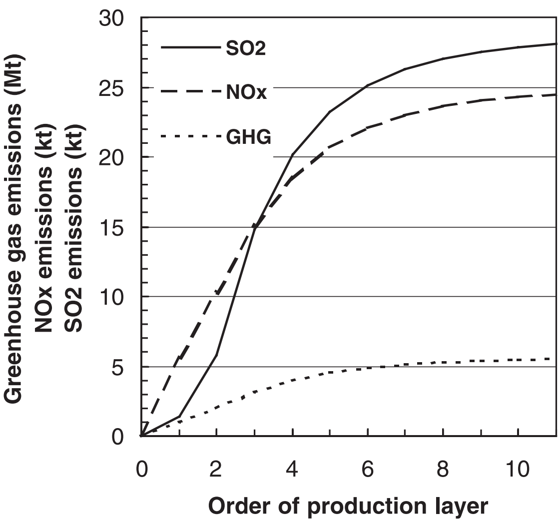

Fig. 2. Emissions of greenhouse gases, NO_x and SO_2 as a function of production layer order.

contributions from at least six production layers must be considered in order to achieve 90% *system completeness*. Given that the input–output model applied to this case study distinguishes $m=20$ inputs and $n=135$ industrial sectors, covering six production layers requires the assessment of $20 \times 135^5 \approx 9 \times 10^{11}$ input paths. Clearly, such a large number of individual contributions cannot be assessed in an EIA that does not incorporate input–output analysis.

Structural path analysis (SPA), another input–output-based decomposition technique (see Treloar, 1997; Lenzen, 2002), can be employed to identify the most important contributions to the production layers, and hence explain the shape of the curves in Figs. 1 and 2. SPA involves extracting individual contributing paths by decomposing all production layers implicit in Eq. (3). In the present paper, SPA is used below to explain important features in the results, but for the sake of brevity, the detailed path rankings are not included.

The water, employment and energy curves against production layer appear to converge at the same rate (Fig. 1), and the first 10 important paths are dominated by 0th- (direct) to 2nd-order contributions. For the energy requirement, these stem mostly from fuels and electricity used by construction firms, and energy embodied in construction materials such as basic iron and steel, concrete, structural metal products, and electronic equipment. On-site water requirements are surprisingly high, representing about one-third of total water requirements. Remaining indirect requirements, such as cooling water used in power plants providing electricity, and water used upstream in construction and steel making industries, play a relatively minor role. Indirect employment is dominated by contributions from service industries such as technical, property and business management services, and by employment in structural metal and electrical equipment sectors. The curve for land disturbance converges considerably slower. In addition to 0th- and 1st-order land requirements from nonresidential building, this can be explained by the remainder of important paths being of 3rd and 4th order, many of them associated with the agricultural, forestry, food and textile industries. An example of a third-order path is the land disturbed by planting conifers to produce timber for wooden structural elements used in the construction of the airport. This complexity of land disturbance embodiment is not intuitive when one thinks of the construction of an airport.

The major components of indirect SO_2 emissions are associated with the production of nonferrous metals, iron and steel products, and coal-based electricity. Nonferrous metals are required for electrical equipment, and for roads and pavements, etc. Basic iron and steel products (pipes, tubes, sheets, etc.) are used extensively in the airport construction, causing indirect SO_2 emissions during their production. NO_x and greenhouse gas emissions show components that are similar to those of the energy requirement, but with additional contributions from cement and concrete making.

5. Discussion

5.1. Issues in the use of input–output-enhanced EIA in practice

The strength of typical EIAs, such as the case study examined here, lies in their detailed description of local impacts from specific projects, including many indicators which may not be directly quantifiable, or for which limited data are available. However, this process- or audit-type approach to EIA is limited to on-site effects, and ignores the fact that a development may indirectly have consequences over a wider region. 'Regional' as defined in the Sydney EIS, refers to the suburbs surrounding the airport, but the proposal impinges on a much wider area. Large proposals in particular, such as an airport, have national and international consequences that are important to take into account in the decision-making process.

In general then, the results from a hybrid EIA will be larger than those from a conventional EIA. In the case study presented here, the additional impacts would possibly not have changed the decisions made on the basis of the existing EIS because the ratio of environmental impacts (water use, greenhouse gas emissions, land disturbance, air pollutant emissions) to employment created did not change significantly after including indirect effects. However, it is possible that proposals exist for which this would not be the case, and for which the inclusion of indirect effects would change the result so significantly that decision-makers would rank available options differently. Such effects have been demonstrated to occur for example in renewable energy development, where so-called "crossovers" in the ranking of options can result from the addition of higher production orders (Lenzen and Treloar, in press).

We have shown how indirect effects of an individual proposal can be calculated. However, if a number of proposals fall in the same area, it may not be necessary to conduct case-by-case hybrid EIAs including indirect effects calculated using input–output analysis because the regional impacts might be very similar. In this situation, an integrated regional systems model has been suggested as being the most appropriate assessment tool (Goldrick and James, 1994).

The calculation and understanding of the indicator intensities for an input–output-assisted EIA requires a fair degree of mathematical ability, so that for EIA practitioners this method could remain a "black box" (see DeSouza, 1979). This may prove satisfactory if practitioners were able to access standard databases complied by a central body, in much the same way as public databases for life-cycle assessment (LCA), so that the inclusion of upstream impacts is not an onerous task. LCA practitioners use their databases as part of standard software that deals with the boundary between on-site and upstream suppliers, and between the conventional audit part and the input–output part (see, for example, Suh, 2001). For more in-depth analysis, an automated structural path extraction program would enable EIA practitioners to streamline their project audit (see Treloar, 1997; Hondo and Sakai, 2000). For project proponents, the result from using such a tool may provide greater scope for environmental impact reductions, such as reallocating procurement from upstream suppliers with significant impacts. Mandating the inclusion of input–output analysis does therefore not have to be a major imposition on EIA practitioners, and as stated, there is a successful precedent in the case of LCA.

5.2. Remaining problems and future directions

Finally, some notes of caution: we have calculated the indirect effects for several indicator variables, but not for all variables included in the EIS. This is because the relevant data are not available on a sectoral basis, or because the effects may not be additive but synergistic, or because the effects are not easily quantifiable. Examples of indicators included in the EIS, but for which indirect effects could not be calculated are abundance and diversity of flora and fauna, hazards and risks, and Aboriginal and non-Aboriginal cultural heritage. The addition of depth to the indicators chosen in this study has therefore only partly enhanced the completeness of the EIS, since additional indicators are still missing. Expanding on other indicators such as biodiversity might prove difficult because our understanding of the environment is limited, particularly concerning the timing or duration of effects (see Goldrick and James, 1994). Biological effects in particular are variable and difficult to predict. Moreover, impacts may be synergistic rather than additive, meaning that a combination of development projects can lead to overlapping impacts, or that indicators can be correlated. In these cases, the combined overall impact is smaller than the sum of all components. For this reason, some authors have concluded that input–output frameworks are not suitable for modelling biological interactions, because many ecological processes cannot be accommodated by simple linear relationships.

Similarly, time lags of economic and employment effects are often unknown, despite their importance for intertemporal weighting and discounting of impacts (compare Romanoff, 1984), and the presently static EIA approach has to be developed into a sound dynamic method in order to deal with marginal changes and forecasting.

Further problems exist in specifying the location of indirect impacts, which can occur close to the development, but also nationally and internationally. In some cases, it is important to include international impacts such as from the emission of greenhouse gases that cause global climate change. However, if decision-makers wanted to limit the analysis, for example, to national or regional employment, the input–output model could be further spatially disaggregated. Country-specific regional models could be constructed on a regular basis by statistical bureaus and incorporated into national EIA guidelines, thus providing a standardised way for project assessment. At a finer level of detail, using multi-regional frameworks, it is possible to examine more accurately where jobs are likely to be created, and whether there could be supply constraints due to regional full employment. Similarly, lost jobs could concentrate regionally, affecting regional communities more adversely than predicted by a national model. A further issue is that employment effects should ideally distinguish between the various occupational and income groups, since for example, more administrative jobs may be a burden for a regional community rather than a benefit. A constraint to conducting this research is the expense and time necessary to obtain such disaggregated data (Solomon, 1985). Some of these issues have been discussed in studies using Social Accounting Matrices or demographic-economic models (see Stone, 1966,1970; Stone et al., 1968; Schinnar, 1976,1977; Batey, 1985; Batey et al., 1988).

At levels higher than the assessment of projects as undertaken with EIA, the indirect impacts quantified by input–output analyses present a valuable tool for long-term strategic planning of governments. Rather than determining the impact of a particular project that in most cases a decision has already been made to proceed, the elucidation of macroeconomic impacts would facilitate a much broader assessment of the merits of different development strategies. For example, in the case study presented here, a considerable expansion of Australian rail infrastructure and a greater priority for international air movements at the existing Sydney airport may be viable alternatives with improved outcomes.

6. Conclusions

An enhancement of EIA allowed all upstream effects to be calculated for the indicator variables chosen. In the case of the Second Sydney Airport, the input–output-based results are generally an order of magnitude higher than those obtained during the on-site-only assessment, as documented in the EIS. We conclude that it is feasible and straightforward to add an input–output assessment to an existing EIS, as a detailed monetary cost breakdown of the project is usually available. Notwithstanding a number of shortcomings, employing input–output analysis can (1) significantly improve the completeness of any conventional EIS for a range of quantifiable indicators, (2) improve the ability to rank alternative options, and (3) provide a valuable overview of indirect impacts to be used for streamlining the EIA audit. For these reasons, input–output techniques could be incorporated as mandatory elements into EIA standards.

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Manfred Lenzen is a Senior Research Fellow at the School of Physics, University of Sydney, Australia. He has worked on energy conservation technologies such as highly insulating windows. His more recent interests include generalised input–output analysis, national accounting, ecological footprints, and life-cycle assessment.

Shauna Murray is a researcher in Biological Sciences at the University of Sydney, Australia. She has previously worked on the ecological footprint and its application to Australia, and also conducts research on microalgal biodiversity and toxicity.

Britta Korte is a student of landscape planning at the Institute for Landscape and Environmental Planning, the Technical University of Berlin, Germany. Her research was part of a 5-month internship she conducted at the University of Sydney.

Christopher Dey is a Postdoctoral Fellow at the School of Physics, University of Sydney, Australia. At present, he is carrying out research on renewable energy technologies such as solar–thermal electricity generation, and also environmental impact and life-cycle assessment.