There is a wealth of studies on the trends of environmental pressures that demonstrate that the main driver for the level and increase of resource uses and pollutant emissions is private consumption, and predominantly that in industrialized countries (Parikh and Painuly 1994). As a consequence, demand-side measures for achieving sustainability appear as promising complements to existing abatement strategies. The latter have been focusing on technological improvements, but have so far not lead to significant alleviations of many environmental problems. This is largely because population and affluence have outgrown technological progress (Mélanie et al. 1994, Hamilton and Turton 1999).

When considering the design of demand-side measures, it is important to view them in a holistic, that is economy-wide and life-cycle context. Probably the first emergence of a substantial body of literature on resource policy studies grounded in life-cycle thinking was triggered by the oil crises of the 1970s. A large number of energy analyses were carried out on energy technologies, consumer choices and government policies. During this period, important methodological issues became apparent. In particular, the problem of system boundaries and truncation errors became the nexus of a debate between proponents of traditional process- or audit-type approaches and input-output-assisted techniques. The latter methods have since been refined

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9 International Federation of Institutes for Advanced Studies 1978.
considerably for the purpose of life-cycle, policy and sustainability analyses\textsuperscript{11}, and they have been applied to a large number of indicators. Input-output analysis takes a top-down linear macro-economic approach to describe industrial structure. Sectoral monetary transaction data are employed in an inter-industry model to account for the complex interdependencies of industries in modern economies. Applied to economic and environmental indicators such as employment, land disturbance, water and energy use, it yields the amount of an indicator required to produce and deliver a value unit of a particular commodity. The main idea of the input-output approach is that in addition to direct effects, any economic activity causes environmental pressure indirectly through the input 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. Introductions into input-output theory can be found in articles by Leontief (1953), Duchin (1992) and Dixon (1996).

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. A detailed technical account of errors associated with input-output calculations can be found elsewhere\textsuperscript{12}. In the following I will concentrate on energy, both as a proxy and as


an example to illustrate some applications of the technique, and some differences between industrialized and developing countries.

1. Energy metabolism of cities – case study of Sydney

Supporting the lifestyles of the populations of modern cities requires both vast quantities of natural resources and leads to environmental stresses such as air and water pollution. Research into the metabolism of cities therefore aims to understand the physical flows into, within and out of cities with a view to reducing the use of resources and the environmental impacts. One important physical indicator is energy use. Most studies on cities only consider direct or end-user energy consumption. Since the function of cities is to serve the lives of their residents, indirect energy use in cities, or energy embodied in the consumption of goods and services by its residents, can be regarded as being as important as direct energy use. However, physical models of cities are extremely complex and have difficulty in dealing with boundary issues, and hence the indirect resource requirements. Input-output analysis and detailed household expenditure data can be used in order to obtain comprehensive energy use breakdowns, for example for the 14 Statistical Subdivisions (SSDs) of Sydney (Lenzen et al. 2002).

Fig. 1: Total energy requirement per-capita (GJ/cap) for the 14 Sydney SSDs.
The larger energy requirements associated with the SSDs nearer the centre of Sydney and the coast reflect an immediate correlation with wealth and the ability to afford expensive housing (Fig. 1). Further spatial differences can be understood in terms of train line access, geographical restrictions, and the road and bus transport network. Mathematical techniques such as multivariate regression and structural path analysis are used to interpret the results. Clear correlations have been drawn for example between energy use, income and household size.

Figure 2 (left) shows that direct energy requirements of households are inelastic with income - the main driver for the increase in total energy requirement with income results from indirect energy required by industries for producing consumer goods and services. Another important result is that the energy intensity diminishes towards higher incomes, reflecting the fact that wealthier households purchase proportionally more services, which are characterised by lower energy intensities. Figure 3 (right) shows the total per-capita energy requirement and the energy intensity as a function of the number of household members. Larger households appear to require less energy per capita, which is however not due to a decrease in the energy intensity of the consumer basket, but to increased sharing of resources.
Further correlations of energy requirements, such as with age, house type, tenure type, urbanity (high- or low-population-density suburbs), education and employment status can be enumerated. Further techniques such as structural path analysis (see Defourny and Thorbecke 1984, Treloar 1997, Lenzen 2002) can be used to demonstrate how significant differences in lifestyles between inner and outer areas of Sydney leads to different energy use characteristics. This final consumption-based approach to analysing the energy requirements for households has important implications for policy measures aimed at reducing energy use, which at present tend to only consider direct energy.

2. **Energy requirements in developing countries – case study of Brazil.**

Brazil is known for its uneven income distribution. The income gap between the rich and the poor is tremendous and, unfortunately, growing. However, Brazil features a unique renewable energy supply system, with a large proportion of hydro-electricity and sugar-cane-based alcohol used in private cars.

![Fig. 4: Expenditure elasticity of the energy requirement as a function of annual per-capita expenditure.](image)

![Tab. 1: Expenditure elasticities of the energy requirement for various countries.](table)

<table>
<thead>
<tr>
<th>Country</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>0.40</td>
</tr>
<tr>
<td>Norway</td>
<td>0.72</td>
</tr>
<tr>
<td>Australia</td>
<td>0.74</td>
</tr>
<tr>
<td>USA</td>
<td>0.78-0.85</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.83</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.90</td>
</tr>
<tr>
<td>Brazil</td>
<td>1.01</td>
</tr>
</tbody>
</table>

Since Brazil is a country in development, consumers in the lower- and middle-income ranges are still catching up on unfulfilled demand. This fact leads the total energy intensity of household expenditure to stay almost constant with expenditure level, or in other words, the expenditure elasticity of the energy requirement is close to 1 (Fig. 4). A detailed look at components reveals that for household energy and car fuel (“direct”), the
energy intensity is even increasing with expenditure, since the elasticity is greater than 1. Only for the energy embodied in goods and services (“indirect”), we find a small degree of saturation (elasticity just under 1).

There is a broad range in energy intensities within consumption categories as well as between geographical regions of the country (Tab. 2). The energy requirements of the three main consumption categories, food, shelter and mobility, show very different and varying elasticities. Food, as a basic necessity, is relatively inelastic, while mobility (cars, fuel, public transport) and shelter (domestic energy, building materials) develop rapidly and more than proportionally with income. The latter two categories exhibit elasticities of less than 1 in the case of Australia, showing that demand for these items has become saturated in the higher income classes. Note that for Brazil, the total elasticity is close to 1 for all cities.

<table>
<thead>
<tr>
<th>City</th>
<th>Food</th>
<th>Mobility</th>
<th>Shelter</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVERAGE</td>
<td>0.48 ±0.03</td>
<td>1.19 ±0.02</td>
<td>1.12 ±0.03</td>
<td>1.01 ±0.00</td>
</tr>
<tr>
<td>Belém</td>
<td>0.46 ±0.04</td>
<td>1.17 ±0.04</td>
<td>1.17 ±0.04</td>
<td>1.00 ±0.01</td>
</tr>
<tr>
<td>Belo Horizonte</td>
<td>0.54 ±0.05</td>
<td>1.18 ±0.05</td>
<td>1.03 ±0.02</td>
<td>0.99 ±0.01</td>
</tr>
<tr>
<td>Curitiba</td>
<td>0.48 ±0.02</td>
<td>1.20 ±0.03</td>
<td>1.11 ±0.06</td>
<td>1.03 ±0.01</td>
</tr>
<tr>
<td>Distrito Federal</td>
<td>0.49 ±0.05</td>
<td>1.18 ±0.05</td>
<td>1.16 ±0.05</td>
<td>1.01 ±0.03</td>
</tr>
<tr>
<td>Fortaleza</td>
<td>0.40 ±0.04</td>
<td>1.21 ±0.03</td>
<td>1.07 ±0.05</td>
<td>0.99 ±0.01</td>
</tr>
<tr>
<td>Goiânia</td>
<td>0.49 ±0.05</td>
<td>1.30 ±0.04</td>
<td>1.07 ±0.03</td>
<td>1.04 ±0.01</td>
</tr>
<tr>
<td>Porto Alegre</td>
<td>0.47 ±0.03</td>
<td>1.19 ±0.03</td>
<td>1.06 ±0.04</td>
<td>0.99 ±0.01</td>
</tr>
<tr>
<td>Recife</td>
<td>0.52 ±0.05</td>
<td>1.09 ±0.05</td>
<td>1.11 ±0.04</td>
<td>0.99 ±0.03</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>0.51 ±0.05</td>
<td>1.20 ±0.03</td>
<td>1.21 ±0.04</td>
<td>1.05 ±0.01</td>
</tr>
<tr>
<td>Salvador</td>
<td>0.58 ±0.03</td>
<td>1.13 ±0.05</td>
<td>1.01 ±0.03</td>
<td>1.00 ±0.02</td>
</tr>
<tr>
<td>São Paulo</td>
<td>0.46 ±0.04</td>
<td>1.19 ±0.04</td>
<td>1.19 ±0.04</td>
<td>1.01 ±0.02</td>
</tr>
</tbody>
</table>

Tab. 2: Expenditure elasticities of the energy requirement for Brazilian capital cities (Cohen et al. 2003) and main consumption categories.

These results demonstrate that demand-side measures and policies aimed at fostering sustainability will require different designs for industrialized and developing countries. Given that population and living standards in developing countries are growing rapidly, further research into these issues is needed, that a) considers more socio-economic-demographic driving factors, and b) encompasses a larger number of countries.
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