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Delving into the carbon footprints of Singapore—comparing direct and indirect greenhouse gas emissions of a small and open economic system

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ABSTRACT

Small and open economic systems like cities face specific challenges for greenhouse gas accounting. They typically import most of their energy requirements as secondary energy products based on conversion processes which caused emissions elsewhere. Emission estimates therefore already require attention not only to direct on-site activities. Moreover, for a comprehensive approach it is suggested to include upstream and downstream processes of connected socioeconomic systems and the indirect life-cycle related emissions of imported and exported goods.

Singapore is used in this longitudinal study as an example of an urban scale economy. Accounts for direct emissions are compared with trade corrected estimates of indirect emissions. Results indicate that direct emissions account for only about 20% of the overall upstream emissions necessary to sustain the input side of the economic production process (domestic emissions plus indirect emissions embodied in imported goods). If indirect emissions embodied in exports are considered and subtracted from the previous figure, the trade corrected accounts for direct and indirect emissions still exceed direct emission accounts, although by less than 40%. Given the increasing trends in world trade and urbanisation, indirect pressures of urban systems should be included in discussions of effective and fair adaptation and mitigation strategies.

1. Introduction

There is considerable debate about the contribution of urban areas to global anthropogenic greenhouse gas emissions. Recent estimates calculated that at least 67% of the global energy use and an even larger share of fossil fuel related greenhouse gas (GHG) emissions are emitted from urban activity (International Energy Agency, 2008; Satterthwaite, 2008). Questions therefore arise how to allocate responsibility for those emissions and how to identify effective strategies to abate this significant source of environmental impacts as continuing urbanisation is an overarching trend (United Nations, 2008). The complexities of cities include large numbers of agents, activities and processes. The functionally open character of urban settlements makes the discussion of system boundaries particularly relevant when accounting for their contribution to man made greenhouse gas emissions. Most attempts to allocate responsibility for GHG emissions at a national scale are based on administrative and therefore territorial system definitions. They are mainly focussing on the production side of the economic process. In that view it is aimed to account for emissions at the spatial point where they are released into the atmosphere. A strict focus towards "on-site emissions" nevertheless can leave out emission intensive upstream (or up-wire) processes. Already the production and transport of primary energy carriers required energy inputs, losses and emissions which are not reflected in a strict direct emissions account (Hall and Cleveland, 1981; Cleveland et al., 1984). In the case of secondary energy carriers like electric power, heat networks and petroleum based energy products, which all require conversion processes, those emissions can be considerable and often occur at locations far away from the urban centre where they are consumed. Moreover also the production of general, non fuel commodities abroad which are transported and traded internationally for consumption in other locations require energy and cause greenhouse gas emissions, referred to as indirect and embodied emissions. Especially in more regionalised accounts the contributions of such indirect emissions can be substantial and extend the volume of direct emissions.

An alternative rationale towards emissions accounting is therefore to apply a life-cycle perspective in the system definitions. In such a view the system is conceptually not defined

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spatially but as a socioeconomic unit and emission responsibility is defined by the sum of functional processes or consequential activities in the process chain of production and consumption no matter where they are conducted. Such an approach was also requested in the Johannesburg plan of implementation of the World Summit on Sustainable Development (Commission on Sustainable Development, 2002) and is currently debated in the Marrakech Process of UNEP and UNDESA (UNEP, 2005; Cosbey, 2009; Tamiotti et al., 2009).

Responsibility for embodied emissions should not be restricted to account for imported goods. In order to avoid double counting at the global level and arrive at a fair allocation of responsibility to the final consumer, it is important to also consider the indirect emissions embodied in exported goods and subtract them from the net responsibility for indirect emissions (Ahmad and Wyckoff, 2003; Peters and Hertwich, 2008a, b, c). This is particularly relevant to urban centres as they are typically also locations of manufacturing, industry and other production processes and provide products to other urban as well as non urban consumers. Finally also accounting for 'downstream' emissions arising after use, at the final stage in the life-cycle of a commodity during waste treatment or recycling is relevant when assessing the impacts of cities. If the focus is strictly towards "on-site emissions" such impacts would be effectively externalised when treatment occurs outside of the city limits.

The implications of trade with energy and GHG intensive products raised particular concerns, if trading partners have different obligations towards emission reduction targets. Authors identified the potential problems of "carbon leaking" into regulated markets (Peters and Hertwich, 2008a, b, c; Hertwich and Peters, 2009) as major obstacle towards international GHG reduction policies and pointed at the unfair market conditions if certain producers (e.g. non participants or non-Annex 1 countries) are able to avoid emission caps, trading schemes or carbon taxes but compete on a single integrated market. This paper uses the example of Singapore, a city-state and open economy to compare results based on different allocation concepts. It is restricted to greenhouse gasses. To our knowledge it is a first attempt to account for indirect greenhouse gas emissions in a time series approach for the city-state of Singapore.

2. Material and methods

International standards exist to account for direct greenhouse gas emissions at the national level (Eggelston et al., 2006). Given the city-state character of Singapore, such figures are reported by a number of agencies.

The concept of indirect emissions (also referred to as 'life-cycle emissions', 'cumulative emissions' 'embodied emissions' or 'grey emissions') in contrast is less well established at the city scale. Although similar methods are discussed at the scale of individual products and projects (World Business Council for Sustainable Development and World Resource Institute, 2004, 2005) and are defined in the ISO 14046 series standards. Unlike the spatial system definition followed in direct emissions accounting, this approach applies a functional view to define the socioeconomic system. Additional to the direct emissions this approach aims to also consider the cumulative emissions over the whole life-cycle of a commodity at various stages of the supply chain: from the extraction of resources to manufacture, distribution, consumption to the disposal of waste after the phase of use ('cradle to grave'). This approach aims to allocate the aggregated responsibility for greenhouse gas emissions to the final consumer as his activity is considered central in driving the economic process.

The need for accounts which distinguish direct and indirect emissions and their implications for climate policy had been emphasised at the international level (Wyckoff and Roop, 1994; Ahmad and Wyckoff, 2003). Such accounts have been compiled for consumption at the household level for a couple of countries, e.g. Australia (Lenzen, 1998), the Netherlands (Vringer and Blok, 1995), Sweden (Carlsson et al., 2006), Spain (Sánchez-Chóliz and Duarte, 2004), Switzerland (Jungbluth et al., 2007), the UK (Wiedmann et al., 2008), and the EU as a whole (Reinders, Vringer et al., 2003). Typically such accounts have been conducted for high income countries, with a few exceptions (Pachauri and Spreng, 2002; Pachauri, 2007). Also balances of the emissions embodied in trade (BEET) between trading partners (e.g. China–US or China–UK (Li and Hewitt, 2008)) had been the focus of research (Peters and Hertwich, 2008a, b, c).

For calculations of embodied emissions so fare there are no universally agreed standards and procedures. Different methodologies are used by various authors in the field. Previous studies can be roughly grouped in two categories: (i) starting from economic information (input–output tables) on the structural interconnection of various sectors within one national economy and how private or public expenditure triggers economic activity, energy use and consequential emissions in various sectors. In some studies interregional input–output tables are applied, such as those provided by the GTAP database. While they provide coherent allocation of embodied emissions among sectors and regions, they often require mayor manipulation of input data which introduces uncertainties (Ahmad and Wyckoff, 2003; Hubacek and Giljum, 2003; Lenzen, Murray et al., 2007; Peters and Hertwich, 2008a, b, c).

The second group of studies (ii) is typically starting from physical material flow accounts and trade data and uses LCA data on the energy use, emissions or pollution embodied in those flows. The study on Singapore presented here belongs to the second group (Schulz, 2007). Problems associated to this method include the coherent use of cut-off criteria in each material flow category and possibilities of double counting.

Comparing results generated with both methods would improve this area of study.

Fig. 1 is illustrating the conceptual approach applied in this paper.

The dotted rectangle indicates the location of consumption, either within Singapore or abroad.

(a) Direct emissions approach: only white emissions are allocated to responsibility of Singapore. Indirect emissions approach: cumulative white and grey emissions are ***added*** to responsibility of Singapore.

(b) Direct emissions approach: only white emissions are allocated to responsibility of Singapore. Indirect emissions approach: cumulative grey and white emissions are ***subtracted*** from responsibility of Singapore.

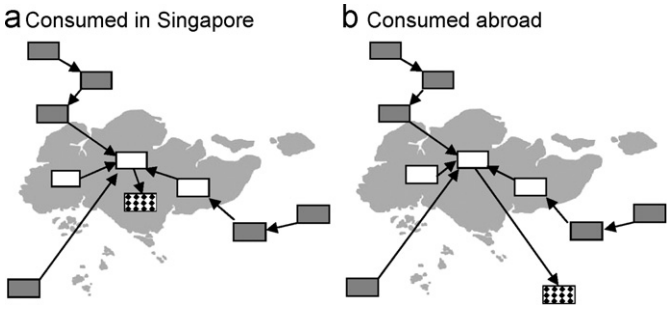

Fig. 1. Accounting concept: direct and indirect emissions of a product. (a) Consumed in Singapore. (b) consumed abroad.