The University of Sydney
Integrated Sustainability Analysis ™

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Student topic

Analysing global biofuel expansion using a Dynamic Ecological Footprint method

1 Background

Since the Ecological Footprint was invented (Rees 1992; Wackernagel 1994) it has experienced tremendous success in communicating the concept of limited world resources to governments and the general public alike. The Ecological Footprint measures – in terms of *bioproductivity* – the amount of biotic resources needed to meet humanity's demand for food, timber etc, and to compensate for humanity's CO_2 emissions from energy use. This bioproductivity is expressed in "global hectares", representing an area of world-average biological productivity, including both land and water. Global hectares are calculated from actual hectares by weighting with yield factors and equivalence factors (Wackernagel *et al.* 2005). A variety of modifications have been suggested.[1] The Ecological Footprint method has been and is still subject to ongoing discussion, the details of which have been published previously.[2] A standardisation process is currently underway in order to unify diverging methodologies.

1.1 The need for a dynamic Ecological Footprint method

There is substantial evidence that in the long term, diminished ecosystem functioning will deteriorate the services humans are able to derive from natural and artificial landscapes, for example agricultural bioproductivity. According to the literature, ecosystem functioning, in turn, is influenced by a multitude of impact pathways, amongst which the perhaps more prominent involve land use and conversion, and climate change (see Pimentel *et al.* 1976; Naeem *et al.* 1999; Armsworth *et al.* 2004; Asner *et al.* 2004; Spangenberg 2007, Fig. 1).

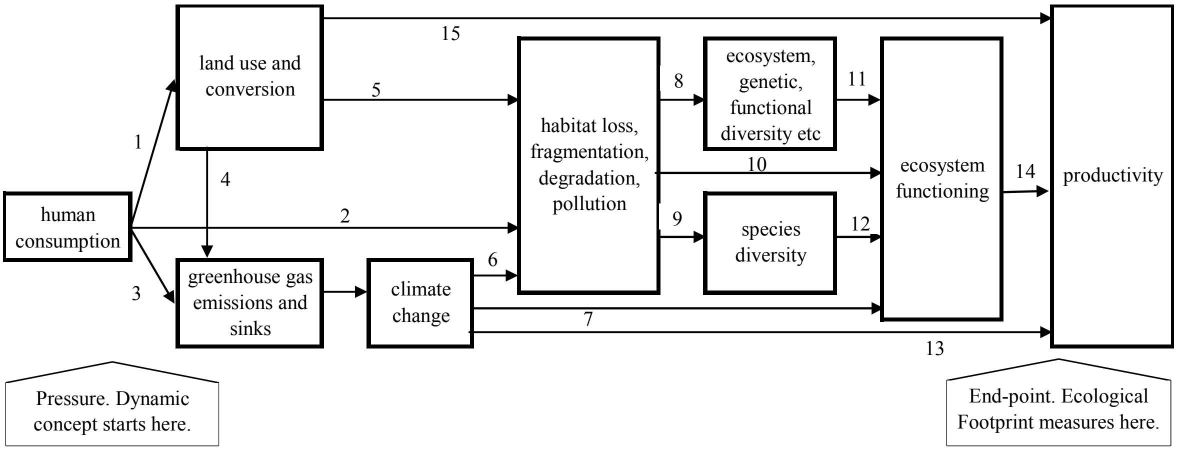

Fig. 1: Impact pathways linking human consumption and agricultural bioproductivity.

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[1] Bicknell *et al.* 1998; Simmons *et al.* 2000; Ferng 2001; Luck *et al.* 2001; Ferng 2002; Stöglehner 2003; Ferng 2005; Venetoulis and Talberth 2006; Venetoulis and Talberth 2007 and Lenzen and Murray 2001; 2003; McDonald and Patterson 2003; Chen and Chen 2006; Gao *et al.* 2006; Chen and Chen 2007; Peters *et al.* 2007.

[2] Levett 1998; van den Bergh and Verbruggen 1999; Ayres 2000; Costanza 2000; Opschoor 2000; Rapport 2000; van Kooten and Bulte 2000; Lenzen *et al.* 2007a; Wiedmann and Lenzen 2007.

Apart from the obvious links (1 and 3) these pathways represent[3]

2. the emission of pollutants into soil, water and air, including fertilisers,
4. the emission of greenhouse gases due to land use changes (for example clearing),
5. the fragmentation and degradation of habitat as a result of conversion of land for human purposes,
6. the disappearance of habitat because of changing climatic conditions,
7. the ceasing of certain ecosystem functions because of climatic changes,
8. the decrease and loss of ecosystem diversity because of habitat loss,
9. the decrease and loss of species diversity because of habitat loss,
10. the ceasing of certain ecosystem functions because of the disappearance of the very ecosystem,
11. and 12. diminished ecosystem functioning because of decreased ecosystem and species diversity,
13. changes in bioproductivity as a direct consequence of climate change,
14. changes in bioproductivity as a direct consequence of biodiversity changes, and
15. changes in bioproductivity as a direct consequence of agricultural practices, for example through salinisation, nutrification, eutrophication, or erosion.

In this view, human consumption exerts the *pressure*, acting via land use and greenhouse gas emissions to biodiversity and ecosystem functioning, with bioproductivity being the end-point of impacts, or *state*. To close the loop, available bioproductivity (biocapacity) will in turn limit what humans can consume.

It appears that land use and conversion, and biodiversity constitute drivers of delayed changes in ecosystem functioning, just as emissions constitute a driver for delayed global atmospheric temperature and sea levels. In other words, today's biodiversity and habitat loss will have a profound effect on future bioproductivity levels. In both cases, the relationships are likely to be highly non-linear and may involve threshold effects.

Research that explores and understands these causal links is needed in order to make informed decisions for a sustainable future.[4] Consider the analogy of climate change: If governments only

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[3] Note that Fig. 1 serves solely to explain the motivation of this work, and is in no way the only and the most general representation of these causal links. Moreover, there are certainly links which are not shown in Fig. 1 such as the loss of species as a direct consequence of changed climatic conditions, that is without involving habitat loss, and the decrease of bioproductivity as a direct consequence of land degradation, without involving ecosystem functioning.

[4] Arrow *et al.* 1995 (p. 93) makes this point for the example of ecosystem resilience: "A more useful index of environmental sustainability is ecosystem resilience. One way of thinking about resilience is to focus on ecosystem dynamics […]. Even though ecosystem resilience is difficult to measure and even though it varies from system to system and from one kind of disturbance to another, it may be possible to identify indicators and early-warning signals of environmental stress. For example, the diversity of organisms or the heterogeneity of ecological functions have been suggested as signals of ecosystem resilience. […] the signals that do exist are often not observed, or are wrongly interpreted, or are not part of the incentive structure of societies. This is due to ignorance about the dynamic effects of changes in ecosystem variables. […] The development of appropriate institutions depends, among other things, on understanding ecosystem dynamics and on relying on appropriate indicators of change. Above all, given the fundamental uncertainties about the nature of ecosystem dynamics and the dramatic consequences we would face if we were to guess wrong, it is necessary that we act in a precautionary way so as to maintain the diversity and resilience of ecosystems."

monitored, and acted on signs for climate change (for example temperature levels) in policy making, rather than on greenhouse gas emissions, decision-makers would just be starting to suspect potentially dangerous processes, since anthropogenic influences on global temperatures and sea levels have only been acknowledged relatively recently. We know today that it is already too late to avoid long-term climate change per se, however it is the knowledge that *emissions drive temperature levels* that alarmed people about potential climate change more than twenty years ago. Therefore, in terms of Fig. 1, policy needs to investigate "early-warning" drivers that affect bioproductivity.

1.2 The Dynamic Ecological Footprint (DEF)

A new Dynamic Ecological Footprint has been developed by a collaboration of the University of Sydney and Stockholm Environment Institute at the University of York (UK). This new method addresses the following issues:

- The static Ecological Footprint method measures the end-point of the causal chain in Fig. 1 (bioproductivity). It is backward-looking accounting of what occurred, not an extrapolation of how it could affect the future. It thus does not contain an “early-warning” signal: By the time bioproductivity has decreased because of biodiversity loss, habitat loss, and/or land and soil degradation due to unsustainable agricultural practices, it may be too late for abatement action. Therefore, policy needs models that deal with the pressure variables in Fig. 1, and link them to the bioproductivity end-point. [5]
- The static Ecological Footprint method examines a resource question (ie how much bioproductivity do we have and how much do we use?) without asking about ecological or other driving forces that ultimately support bioproductivity. Pursuing the resource question in isolation from ecological factors can lead to outcomes that actually *deteriorate* ecosystems (Lenzen *et al.* 2007a).[6] This is because taking our resource base as a yardstick provides incentives for expanding high-yield croplands and monocultures at the expense of natural ecosystems. Incorporating ecological variables into the Ecological Footprint method avoids these counter-productive incentives.
- The static Ecological Footprint method lumps together two components: land and greenhouse gas emissions. Both quantities are associated with impacts that have significantly different lifetimes: While land and ecosystems may recover or be restored over decades after an initial disturbance, greenhouse gas emissions will have an effect for centuries. As a result, entities abating the long-lived component earlier will cause less future impacts. This circumstance has significant implications for policy and negotiations about sharing the burden of climate change (Lenzen *et al.* 2004): Ignoring temporal issues can lead to serious distortions in allocations of Footprints to national or sub-national

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[5] The works of McDonald and Patterson 2003, Lenzen and Murray 2001; 2003 and Peters *et al.* 2007 are predecessors to the dynamic framework presented in this work as they cover pathways 1-6 in Fig. 1. The dynamic method connects these approaches to a common end-point (bioproductivity).

[6] Also at www.isa.org.usyd.edu.au/publications/documents/ISA&WWF_Bioproductivity&LandDisturbance.pdf.

entities (such as companies).[7] A dynamic, temporally explicit method can overcome such distortions.

The report by Lenzen *et al.* 2007b outlines how the new Dynamic Ecological Footprint method is applied to forecasting and policy analysis, and thus has become a complementary tool to the existing method. Specifically, it

a) incorporates biodiversity variables as driving factors of future Ecological Footprints,
b) shifts the point of data input towards the pressure variables in Fig. 1, and link a quantitative analysis through to the end-point bioproductivity.

Thus, the bioproductivity end-point (referred to as the "Ecological Footprint") coincides with the metric of the static method, but it is influenced by driver variables in a dynamic way. Lenzen *et al.* 2007b apply these in a temporal analysis of country-level consumption, production, land use, greenhouse gas emissions, species diversity, and bioproductivity up to 2050. These authors quantitatively decompose the global trend of narrowing the biocapacity-Ecological-Footprint gap into accelerating and retarding driving forces, qualify these results by a comprehensive appraisal of uncertainties, and provide a practical example for how the dynamic method may be applied to sub-national entities such as corporations.

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[7] This has been amply demonstrated for the case of climate change: CH_4 and CO_2 have different atmospheric lifetimes, and the effect that abating entities have on the future climate does not only depend on the amounts of emissions reduced, but on the temporal profile of reductions (Rosa and Schaeffer 1995; Rosa and Ribeiro 2001; Rosa *et al.* 2004).

2 Aim of the project

This aim of this project is to undertake a scenario analysis of global biofuels expansion, using the Dynamic Ecological Footprint tool developed at the Centre for Integrated Sustainability Analysis. This biofuels expansion scenario should then be compared with the business-as-usual case (Lenzen *et al.* 2007b).

The project will highlight potential trade-offs between emissions reductions through the use of a renewable fuel on one hand, and large-scale deforestation and biodiversity loss on the other.

This project distinguishes itself in being very topical which is attested by a recently released UN report (UN-Energy 2007), and its coverage in the media (see for example Bittal 2007).

3 Tasks

1. Literature review and summary (for example Lipinsky 1978; Pimentel *et al.* 1981; Giampietro and Pimentel 1990; Giampietro *et al.* 1997), with emphasis on the quantification of biofuels life cycles in terms of energy use and greenhouse gas emissions (compare with Chambers *et al.* 1979; Herendeen and Brown 1987; Strauss and Grado 1992; Börjesson 1996a; b).

2. Specification of a global biofuels scenario up to 2050, with emphasis on Brazil (Goldemberg 1996; Ribeiro and Rosa 1998).

3. Calculation of the future trajectories of global greenhouse gas emissions, biodiversity and productivity under the biofuels scenario.

4. Comparison with the business-as-usual scenario in Lenzen *et al.* 2007b.

The student is encouraged to document the research findings in a form suitable for submission to an international peer-reviewed journal.

4 Knowledge and skills required

- Handling simple iterative equations
- Basic knowledge about energy use and greenhouse gas emissions
- Basic knowledge about land use patterns

Programming skills are helpful.

5 Supervisor

Prof Manfred Lenzen (m.lenzen@physics.usyd.edu.au)

6 Background reading

Armsworth, P.R., Kendall B.E. and Davis F.W. (2004). An introduction to biodiversity concepts for environmental economists. *Resource and Energy Economics* 26, 115-136.

Arrow, K., Bolin B., Costanza R., Dasgupta P., Folke C., Holling C.S., Jansson B.-O., Levin S., Mäler K.-G., Perrings C. and Pimentel D. (1995). Economic growth, carrying capacity and the environment. *Science* 268(5210), 520-521.

Asner, G.P., Elmore A.J., Olander L.P., Martin R.E. and Harris A.T. (2004). Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources* 29, 261-299.

Ayres, R.U. (2000). Commentary on the utility of the ecological footprint concept. *Ecological Economics* 32, 347-349.

Bicknell, K.B., Ball R.J., Cullen R. and Bigsby H.R. (1998). New methodology for the ecological footprint with an application to the New Zealand economy. *Ecological Economics* 27(2), 149-160.

Bittal, J. (2007). UN warns against rush to biofuel crops. *Guardian Weekly*, 176(22), 18-24 May, 10.

Börjesson, P.I.I. (1996a). Energy analysis of biomass production and transportation. *Biomass and Energy* 18.

Börjesson, P.I.I. (1996b). Emissions of CO_2 from biomass production and transportation in agriculture. *Energy Conversion and Management* 37(6-8), 1235-1240.

Chambers, R.S., Herendeen R.A., Joyce J.J. and Penner P.S. (1979). Gasohol: Does it or doesn't it produce positive net energy? *Science* 206(4420), 789-795.

Chen, B. and Chen G.Q. (2006). Ecological footprint accounting based on emergy - A case study of the Chinese society. *Ecological Modelling* 198, 101-111.

Chen, B. and Chen G.Q. (2007). Modified ecological footprint accounting and analysis based on embodied exergy - a case study of the Chinese society 1981-2001. *Ecological Economics* 61, 355-376.

Costanza, R. (2000). The dynamics of the ecological footprint concept. *Ecological Economics* 32, 341-345.

Ferng, J.-J. (2001). Using composition of land multiplier to estimate ecological footprints associated with production activity. *Ecological Economics* 37, 159-172.

Ferng, J.-J. (2002). Toward a scenario analysis framework for energy footprints. *Ecological Economics* 40, 53-69.

Ferng, J.-J. (2005). Local sustainable yield and embodied resources in ecological footprint analysis - a case study on the required paddy field in Taiwan. *Ecological Economics* 53, 415-430.

Gao, C., Jiang D., Wang D. and Yan J. (2006). Calculation of ecological footprint based on modified method and quantitative analysis of its impact factors - A case study of Shanghai. *Chinese Geographical Science* 16, 306-313.

Giampietro, M. and Pimentel D. (1990). Alcohol and biogas production from biomass. *Plant Sciences* 9(3), 213-233.

Giampietro, M., Ulgiati S. and Pimentel D. (1997). Feasibility of large-scale biofuel production. *BioScience* 47(9), 587-600.

Goldemberg, J. (1996). The evolution of ethanol costs in Brazil. *Energy Policy* 24(12), 1127-1128.

Herendeen, R. and Brown S. (1987). A comparative analysis of net energy from woody biomass. *Energy* 12(1), 75-84.

Lenzen, M., Borgström Hansson C. and Bond S. (2007a). On the bioproductivity and land disturbance metrics of the Ecological Footprint. *Ecological Economics* 61(1), 6-10.

Lenzen, M., Dey C.J. and Murray S.A. (2004). Historical accountability and cumulative impacts: the treatment of time in corporate sustainability reporting. *Ecological Economics* 51, 237-250.

Lenzen, M. and Murray S.A. (2001). A modified ecological footprint method and its application to Australia. *Ecological Economics* 37(2), 229-255.

Lenzen, M. and Murray S.A. (2003). *The ecological footprint - issues and trends*. ISA Research Paper 01-03, Internet site http://www.isa.org.usyd.edu.au/publications/documents/Ecological_Footprint_Issues_and_Trends.pdf, ISA The University of Sydney, Sydney, Australia.

Lenzen, M., Wiedmann T., Foran B., Dey C., Widmer-Cooper A., Williams M. and Ohlemüller R. (2007b). *Forecasting the Ecological Footprint of Nations: a blueprint for a dynamic approach*. ISA Research Paper 07-01, Internet site http://www.isa.org.usyd.edu.au/publications/DEF.pdf, ISA, The University of Sydney, Sydney, Australia.

Levett, R. (1998). Footprinting: a great step forward, but tread carefully. *Local Environment* 3(1), 67-74.

Lipinsky, E.S. (1978). Fuels from biomass: integration with food and materials systems. *Science* 199(4329), 644-651.

Luck, M.A., Jenerette G.D., Wu J. and Grimm N.B. (2001). The urban funnel model and the spatially heterogeneous ecological footprint. *Ecosystems* 4, 782-796.

McDonald, G. and Patterson M. (2003). *Ecological Footprints of New Zealand and its Regions*. Internet site http://www.mfe.govt.nz/publications/ser/eco-footprint-sep03/index.html, Ministry for Environment New Zealand, Wellington, New Zealand.

Naeem, S., Chapin F.S., Costanza R., Ehrlich P.R., Golley F.B., Hooper D.U., Lawton J.H., O'Neill R.V., Mooney H.A., Sala O.E., Symstad A.J. and Tilman D. (1999). Biodiversity and ecosystem functioning: Maintaining natural life support processes. *Issues in Ecology* 4, 1-11.

Opschoor, H. (2000). The ecological footprint: measuring rod or metaphor? *Ecological Economics* 32, 363-365.

Peters, G., Sack F., Lenzen M., Lundie S. and Gallego B. (2007). A novel Ecological Footprint calculation for the Australian water industry: Regionalisation and inclusion of downstream impacts. *Journal of Applied Input-Output Analysis*, in press.

Pimentel, D., Moran M.A., Fast S., Weber G., Bukantis R., Balliett L., Boveng P., Cleveland C., Hindman S. and Young M. (1981). Biomass energy from crop and forest residues. *Science* 212(4499), 1110-1115.

Pimentel, D., Terhune E.C., Dyson-Hudson R., Rochereau S., Samis R., Smith E.A., Denman D., Reifschneider D. and Shepard M. (1976). Land degradation: effects on food and energy resources. *Science* 194(261), 149-155.

Rapport, D.J. (2000). Ecological footprints and ecosystem health: complementary approaches to a sustainable future. *Ecological Economics* 32, 381-383.

Rees, W.E. (1992). Ecological footprints and appropriated carrying capacity: what urban economics leaves out. *Environment and Urbanization* 4(2), 121-130.

Ribeiro, S.K. and Rosa L.P. (1998). Activities implemented jointly and the use of fuel alcohol in Brazil for abating CO_2 emissions. *Energy Policy* 26(2), 102-111.

Rosa, L.P. and Ribeiro S.K. (2001). The present, past, and future contributions to global warming of CO_2 emissions from fuels. *Climatic Change* 48(2), 289-307.

Rosa, L.P., Ribeiro S.K., Muylaert M.S. and de Campos C.P. (2004). Comments on the Brazilian Proposal and contributions to global temperature increase with different climate responses - CO_2 emissions due to fossil fuels, CO_2 emissions due to land use changes. *Energy Policy* 32(13), 1499-1510.

Rosa, L.P. and Schaeffer R. (1995). Global warming potentials - the case of emissions from dams. *Energy Policy* 23(2), 149-158.

Simmons, C., Lewis K. and Barrett J. (2000). Two feet - two approaches: a component-based model of ecological footprinting. *Ecological Economics* 32, 375-380.

Spangenberg, J.H. (2007). Biodiversity pressure and the driving forces behind. *Ecological Economics* 61, 146-158.

Stöglehner, G. (2003). Ecological footprint - a tool for assessing sustainable energy supplies. *Journal of Cleaner Production* 11, 267-277.

Strauss, C.H. and Grado S.C. (1992). Input-output analysis of energy requirements for short rotation, intensive culture, woody biomass. *Solar Energy* 48(1), 45-51.

UN-Energy (2007). *Sustainable Bioenergy: A Framework for Decision-Makers*. Internet site http://esa.un.org/un-energy/pdf/susdev.Biofuels.FAO.pdf, United Nations, New York, USA.

van den Bergh, J.C.J.M. and Verbruggen H. (1999). Spatial sustainability, trade and indicators: an evaluation of the 'ecological footprint'. *Ecological Economics* 29(1), 61-72.

van Kooten, G.C. and Bulte E.H. (2000). The ecological footprint: useful science or politics? *Ecological Economics* 32, 385-389.

Venetoulis, J. and Talberth J. (2006). *Net Primary Productivity as a basis for Ecological Footprint analysis*. Redefining Progress, Oakland, USA.

Venetoulis, J. and Talberth J. (2007). Refining the Ecological Footprint. *Environment, Development and Sustainability*, in press.

Wackernagel, M. (1994). *Ecological Footprint and Appropriated Carrying Capacity: A Tool for Planning Toward Sustainability*. PhD Thesis, The University of British Columbia, Vancouver, Canada.

Wackernagel, M., Monfreda C., Moran D., Wermer P., Goldfinger S., Deumling D. and Murray M. (2005). *National Footprint and Biocapacity Accounts 2005: The underlying calculation method*. Global Footprint Network, Oakland, USA.

Wiedmann, T. and Lenzen M. (2007). On the conversion from local hectares to global hectares in Ecological Footprint analysis. *Ecological Economics* 60(4), 673-677.