Environmental footprint analysis as an integrating tool for evaluating the energy-land-water nexus

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Environmental or 'ecological' footprints (*ef*) have been widely used in recent years as indicators of resource consumption and waste absorption transformed on the basis of biologically productive land area [in global hectares (gha)] required *per capita* with prevailing technology. They represent a partial measure of the extent to which an activity [that might be associated with communities, technologies, or systems] is 'sustainable'. In contrast, 'carbon footprints' (*cf*) are the amount of carbon (CO_{2e}) emissions associated with such activities. But, unlike environmental footprints, they are generally presented in terms of units of mass or weight (kilograms per functional unit), rather than in spatial units (such as gha). These carbon footprints have become the 'currency' of debate in a climate-constrained world. They are increasingly popular ecological indicators, adopted by individuals, businesses, governments, and the media alike. Here *ef* is broken down into carbon emissions (effectively *cf*), embodied energy, transport, bioproductive and built land, water, and waste components respectively. This component based approach facilitates the examination of sustainability issues quite broadly, along with specific matters (such as the linkages associated with the so-called 'energy-land-water nexus'). It provides a means of comparing the various footprint components on a common basis. The approach is not without potential controversy, but yields a better way of comparing environmental sustainability topics than many of the alternatives. Such assessments provide a valuable evidence base for developers, policy makers, and other stakeholders.

The term 'natural capital' is typically used to denote the stock of natural assets and resources that yield ecosystem goods and services, such as those required for food (including those associated with the pollination in crops), timber, and the absorption or recycling of human waste arisings (including CO_2), as well as water catchment and erosion control. Maintenance of this natural capital is consequently central to securing environmental security and sustainability over the longer term. In turn, a key subset is the so-called 'nexus', or set of complex interactions, between energy requirements, land uses and water consumption levels worldwide. This energy-land-water (ELW) nexus gives rise to multiple positive and negative impacts that have become widely recognised in policy making circles. Energy generation is obviously the main driver for anthropogenic climate change, whilst there are competing demands on land use (both LUC and iLUC) for both food and biofuel production. Water is needed for drinking, irrigation, food and biofuel crop production, hydro-electric dams, and various leisure pursuits. They are all exacerbated by increasing ELW demands arising from the growth in world population that is moving towards 8 bn in 2025 and 9.5 bn by 2050, as well as human socio-economic developments generally. Such demands are often framed in terms of energy, food or water 'security'. It is argued that a strategy which focuses on just one element of the nexus, without considering the others, is likely to lead to major unintended consequences. Thus, many have advocated the need for an integrated approach to the management and governance of nexus issues across various sectors and at different scales in order to ensure sustainability. This would necessitate research and the modelling of ELW impacts within an informed, transparent and integrated framework for planning and decision support. Environmental footprint analysis (EFA) provides a means of evaluating natural capital or ecosystem services impacts that arise from the ELW demands of humanity.

Three transition pathways for the UK have been evaluated in terms of their environmental footprints. The *Market Rules* (MR) and *Central Co-ordination* (CC) pathways employ a high proportion of centralised generation capacity (i.e., fossil-fuelled and nuclear power stations), whereas the *Thousand Flowers* (TF) pathway is assumed to adopt a distributed generation approach based on small and community-scale technologies. Electricity demand was projected to decrease significantly under the TF pathway by 2050, but its total environmental footprint was greater than either that under the MR or CC pathways. This is mainly due to the increase in the contribution of the bioproductive land component associated with biofuel production and that of the carbon footprint (rising to 10.9 and 12.5 Mgha respectively by 2050), which are both seen to be lower than in either of the MR and CC cases. The increase in these TF pathway components was mainly due to increased usage of biofuels for power generation. In order to reduce the overall TF footprint in a low carbon future it would therefore be necessary to adopt other renewable power technologies, like offshore wind and solar photovoltaic arrays, in order to satisfy the increase demands due to the electrification of heat and transport. Water and waste footprint components made almost negligible contributions under all three transition pathways.