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Environmental footprint analysis of an urban community and its surrounding bioregion†

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ABSTRACT

Environmental or 'ecological' footprints have been widely used as partial indicators of sustainability; specifically of resource consumption and waste absorption transformed in terms of the biologically productive land area required by a population. The environmental footprint of the Unitary Authority of Bath & North East Somerset (*BANES*) in the South West of England (UK) has been estimated in terms of global hectares (gha) required *per capita*. *BANES* has a population of about 184,870 and covers an area of 35,200 hectares, of which two-thirds is on 'green belt' land. The *UNESCO World Heritage City of Bath* is the principal settlement, but there are also a number of smaller urban communities scattered amongst its surrounding area ('hinterland' or 'bioregion'). The overall footprint for *BANES* was estimated to be 3.77 gha *per capita* (gha/cap), which is well above its biocapacity of 0.67 gha/cap and 'Earthshare' of 1.80 gha *per capita*. *Direct Energy* use was found to exhibit the largest footprint component (a 31% share), followed by *Materials & Waste* (30%), *Food & Drink* (25%), *Transport* (10%) and *Built Land* (4%), whereas the *Water* footprint was negligibly small (~0%) by comparison. Such data provides a baseline for assessing their planning strategies for future development.

KEYWORDS: Local government; Sustainability; Town & city planning

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1. INTRODUCTION

1.1 Background

Environmental or 'ecological' footprints have been widely used in recent years. They provide indicators of resource consumption and waste absorption transformed based on biologically productive land area required *per capita* with prevailing technology. Such footprints represent a partial measure of the extent to which the planet (WWF, 2016; Grooten and Almond, 2018), its nations (Hammond, 2006; Borucke *et al.*, 2013; WWF, 2016; Grooten and Almond, 2018), or communities (Rees and Wackernagel, 1996; Wackernagel, 1998; Girardet, 1999; Doughty and Hammond, 2004; Eaton *et al.*, 2007; Beck *et al.*, 2010) are moving along a sustainable development pathway. Recently, Collins and Flynn (2015) reported the results from the *Google* search engine that displayed over 2 million (M) hits related to the concept, along with over 14,000 on *Google Scholar* (see also McManus, 2016). Such footprints vary between populations at different stages of economic development and varying geographic characteristics (Hammond, 2006). Cities have been shown to be unsustainable in the sense that their footprints greatly exceed, or overshoot, their biocapacities by typically 15 - 150 times (Doughty and Hammond, 2004). Sustainable development is desirable and, hopefully, attainable on a global scale. However, it is less obviously applicable on a city scale (Doughty and Hammond, 2004), where the term 'sustainable cities' (Haughton and Hunter, 1994; Girardet, 1999; Rotmans *et al.*, 2000; Jenks and Dempsey, 2005; Pickett *et al.*, 2013; Portney, 2013; Nijkamp and Perrels, 2014; Hassan and Lee, 2015) is sometimes used synonymously with concepts such as urban autonomy, self-reliance or self-sufficiency. Cities only survive because they are linked by human, material and communications networks to their hinterlands or bioregions (Rees and Wackernagel, 1996; Desai and Riddlestone, 2002; Doughty and Hammond, 2004; Eaton *et al.*, 2007). Thus, the notion of sustainability can only be realistically applied within a wide geophysical framework, where the urban-rural interface might play an important role in land use planning. External activities, including trade flows, will arise beyond the local authority (LA) boundary. The larger the system boundary used for the EFA, the smaller this effect will be. It cannot be eliminated, except at a global scale. Nevertheless, the approach has been seen to yield valuable insights albeit constrained by the information underpinned by 'material flow analysis' (MFA), in this case, across local authority (LA) boundaries. Doughty and Hammond (2004) recommended that sustainability assessment, planning and monitoring should therefore be undertaken at the bioregional scale or beyond. This would be aimed at reducing environmental footprints by encouraging greater self-reliance and low-impact development across regions, whilst protecting indigenous ecosystems.

1.2 The Issues Considered

'Ecological' or environmental footprints (and related parameters) represent, albeit partial, sustainability indicators (Hammond, 2006). Resources used and wastes produced by a defined population are converted to a common basis: the area of productive land and aquatic ecosystems sequestered [in global hectares (gha)] from whatever source in worldwide terms. This footprint is illustrated schematically in Fig. 1, where the various constituent elements are depicted (Chambers *et al.*, 2000; Eaton *et al.*, 2007). Early environmental footprint research conducted Wackernagel and Rees (1996) found that most western lifestyles, such as those in Europe and North America, have consumption patterns that result in footprints which are far greater than the amount of geographically available land. In the case of cities, this 'overshoot factor' (Eaton *et al.*, 2007) amounts to some 20 times the urban area for the heritage city of Bath (Doughty and Hammond, 2004) in the *United Kingdom of Great Britain and Northern Ireland* (UK), 16 times for Santiago de Chile (Wackernagel, 1996), 125 times for London (UK) (Girardet, 1999), and more than 200 for Vancouver (the major coastal seaport city in British Columbia, the westernmost province of Canada) (Wackernagel and Rees, 1996). These factors, which Rees and Wackernagel (1996) suggest are representative of a 'sustainability gap', do not correlate directly with urban population size or geographic land area, but depend largely on economic wealth *per capita* and building density (Doughty and Hammond, 2004; Eaton *et al.*, 2007). Much clearly needs to be done in terms of significantly reducing the environmental footprints of communities as part of the overall sustainability agenda.

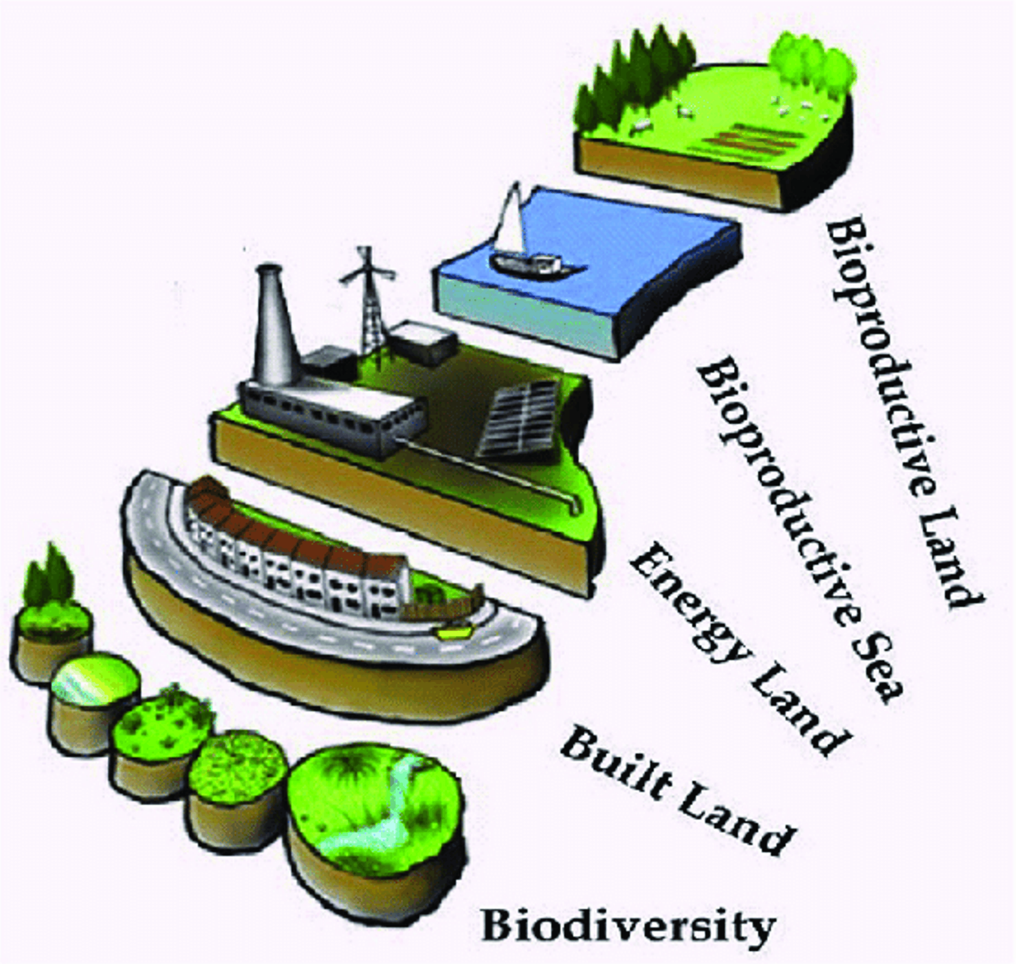


Fig. 1. Schematic representation of the environmental footprint, and its land types. *Source:* Eaton *et al.* (2007); adapted from Chambers *et al.* (2000).

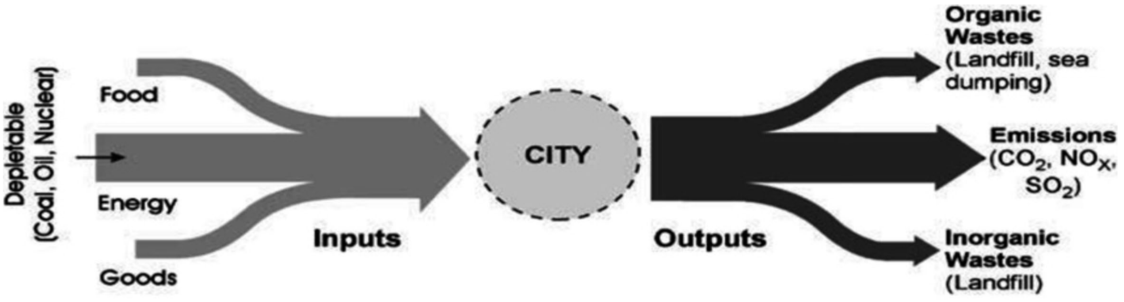
In the present study, the environmental footprint of the 'Unitary Authority' of Bath & North East Somerset (*BANES*) in the South West of England (UK) has been estimated [see the location of Bath illustrated in Fig. 2]. The area covers ~35,200 hectares (ha) and extends some 36 km east to west and 17 km north to south. Its geographical position lies between the Cotswold and Mendip Hills giving it a diverse and complex character; drained primarily by the River Avon. The current study therefore represents an example of sustainability assessment on an urban scale, together with the surrounding 'bioregion'. Liu *et al.* (2015) considered a related biofuels footprint study of Hammond and Seth (2013) using a similar *environmental footprint analysis* (EFA) technique to be an example of the employment a 'systems integration framework' for global sustainability assessment. A mixed 'compound'/'component' approach to footprint accounting has been adopted here, where the footprint components (such as energy, transport, food, materials and waste, and water) represented broad policy-making categories (Doughty and Hammond, 2004; Eaton *et al.*, 2007; Hammond and Seth, 2013; Hammond and Li, 2016; Hammond *et al.*, 2019). This approach has enabled the examination of the *Manufactured* and *Natural Capital* elements of the 'four-capitals' model of sustainability (Ekins, 1992) quite broadly, along with specific issues. The evidence utilised both proxy (or 'top-down') data extracted from national statistics, and local (or 'bottom-up') data provided by local organisations. Such assessments provide a valuable evidence base for developers, policy makers, and other stakeholders across the world. Finally, the uncertainties and deficiencies of using environmental footprints (and related parameters) as sustainability indicators are examined, including problems of urban and rural boundary definitions, data gathering, and the basis for weighing the various consumption and associated impacts.

2. CIRCULAR THINKING: 'REDUCE, REUSE, RECYCLE, RECOVER'

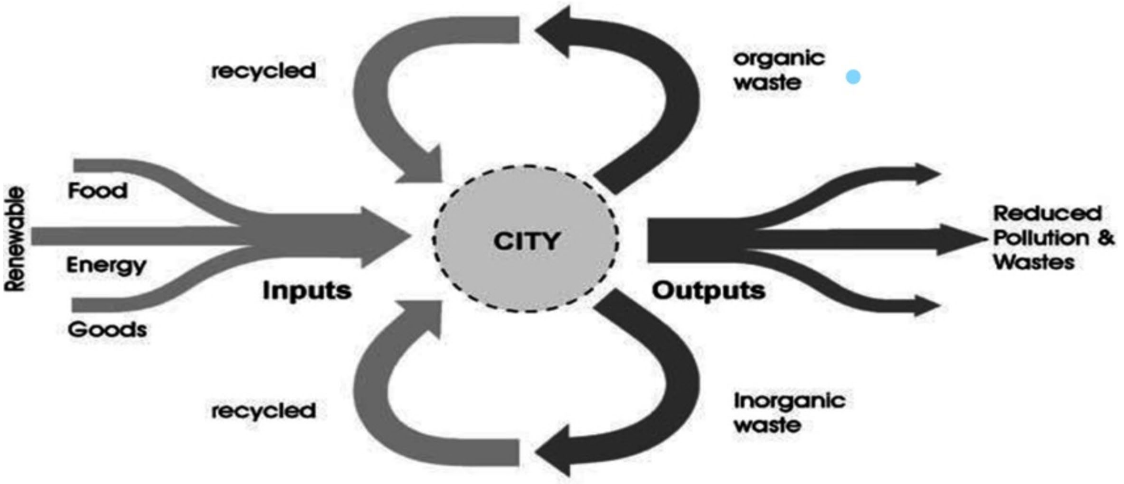
Discourses on 'sustainable cities' [see, for example, Giradet (1992; 1999), Haughton and Hunter (1994), Rogers (1997), the UK *Urban Task Force* (1999), Rotmans *et al.* (2000), Jenks and Dempsey (2005), Portney (2013), and Nijkamp and Perrels (2014)] hark back to the 1970s' idea of autonomy or self-sufficiency in the built environment. It then became popular to strive for "autarkic" buildings or settlements (Harper and Boyle, 1976; Littler, 1979; Doughty and Hammond, 2004; Pan, 2014; Lopez, 2018). Such utopian visions of urban habitats stretching from the level of individual buildings to that of whole settlements were precursors for the notion of sustainable cities as popularised in the modern architectural and urban studies literature (Pan, 2014; Lopez, 2018). Nevertheless, clusters of buildings and an integrated human-scale transport infrastructure can enhance energy conservation and reduce environmental impact. Even what have often been termed 'compact cities' are not in themselves sustainable (Doughty and Hammond, 2004): they survive only because they are inextricably linked by human, material and communications networks to their hinterlands or 'bioregions' (Doughty and Hammond, 2004; Eaton *et al.*, 2007). These include trade flows, access to health facilities by the rural communities, and public transport links. This outlying support structure extends from the regional to national and even global scale in the case of trade flows.

Fig. 2. The geographic location of the *UNESCO World Heritage City of Bath* within the United Kingdom. *Source:* Doughty and Hammond (2004).

Wolman (1965) noted that the inputs and outputs of urban living are unsustainable; finite energy resources and other material inputs with waste outputs, i.e., a 'linear' process. This was subsequently termed 'linear metabolism' by Girardet (1992; 1999), and is depicted schematically in Fig. 3 (a). A more desirable system would be one that he called 'circular metabolism' (Girardet, 1992; Girardet, 1999) in which the inputs are efficiently harnessed and the waste products are reduced, reused, recycled, or recovered. The latter is in line with the 'waste hierarchy' and the contemporary notion of the '*circular economy*' (see, for example, Cooper *et al.*, 2017; Cooper and Hammond, 2018). A schematic representation of cities as part of 'circular metabolism' is depicted in Fig. 3 (b). Communities – local and unitary authority areas (including cities) - can therefore play a useful role as potential exemplars of



(a) **' Linear metabolism' cities (consume and pollute at a high rate)**



(b) **'Circular metabolism' cities (minimise new inputs and maximise recycling)**

Fig. 3. The 'metabolism' of cities: towards sustainability. *Source:* Doughty and Hammond (2004); adapted from Girardet (1992; 1999) and Rogers (1997).

the type of holistic (or systems) thinking that is a prerequisite for sustainability assessment and planning. Local authority planners, and related professionals, are ideally placed to account for the impacts of resource and waste flows across the urban/rural boundary. However, their actions are constrained by factors under the purview of regional and national governments.

Resource efficiency or *circular economy* (CE) approaches (*Ellen MacArthur Foundation*, 2013; Cooper *et al.*, 2017; Cooper and Hammond, 2018; EC, 2020) can be viewed as an alternative to the conventional *linear 'take-make-consume-dispose'* economic model, which attempts to minimise waste and material inputs to the economy through eco-design, recycling and reusing products (EC, 2020). However, the *Ellen MacArthur Foundation* (2013) present it more broadly in terms of expanding the 'waste hierarchy', 'circling longer', or enabling cascaded use. The *Foundation* claims that these approaches increase employment, more effectively capture value, mitigate exposure to supply chain and market risks, and better develop customer relationships. Consumers are encouraged to separate and recycle products, including used batteries and light bulbs. If producers make it easy to recycle such items, then consumers are much more likely to do so. A high level of embodied energy and carbon in goods and services (Hammond and Jones, 2008; Hammond and Jones, 2011a) – fuel use and GHG emissions that arise upstream of the point of production or use - are traded internationally. This consequently means that much of the reduction in energy use and GHG emissions that results from applying CE interventions ('reduce, reuse, recycle, recover') will occur outside of the country in which they are utilized (Cooper and Hammond, 2018). Similarly, energy demand due to exports from a region is likely to decrease due to CE approaches applied elsewhere.

3. BIOREGIONAL THINKING

The term of 'bioregionalism' was originally coined in the early 1970s by a Canadian poet, Allen Van Newkirk (see, for example, Taylor, 2000**)**. It evolved into an environmental movement and 'green' political philosophy aimed at fostering an 'ethics' or local sense of place. It takes a holistic, rather than reductive approach to geographic developments. This was reflected, for example, in the 'Cascadian Corridor' – a major bioregion of the American Pacific Northwest stretching from British Columbia in Canada to Washington and Oregon in the USA. Subsequently, the concept has taken many twists and turns overlapping with ecological, environmental, economic, geographic and social discourses. Taylor (2000) noted in this context that Wackernagel and Rees (1996) employed 'ecological' or environmental footprinting as a tool to show that human activities typically overshoot the carrying capacity of the Earth. In contrast, bioregional thinking (Taylor, 2000**)** provides a vision whereby ecologically sustainable communities might be created within the limits and regenerative powers of the natural world. Here a more practical approach is taken: in line with that adopted by the environmental consultancy and entrepreneurial charity *Bioregional* (instigated in the UK, but now with offices around the world), who have promoted '*closed loop recycling*', as well as the use of environmental footprints as headline indicators of '*One Planet Living*' (Desai and Riddlestone, 2002). They have explored ways of meeting human needs for food, housing, paper, textiles, and wood products from local renewable and waste resources in the spirit of what is now termed the '*circular economy*' (Cooper *et al.*, 2017).

Doughty and Hammond (2004) recommended on a heuristic basis that sustainability assessment, land use planning and monitoring should be undertaken at the regional scale across the urban-rural interface. This would be aimed at reducing environmental footprints by encouraging greater self-reliance and low-impact development across regions, whilst protecting indigenous ecosystems. This case has also been argued from a Canadian perspective by Rees and Wackernagel (1996) and from a European one by Renn *et al.* (1998). The latter suggest, taking the German industrialised region or 'Lander' of Baden-Württemberg as their example, that cities have too many input resources (products and services) crossing their boundaries to be considered sustainable. Subsequently Eaton *et al.* (2007) observed, based on their study of Swindon and Wiltshire, that the environmental burdens caused by urban and rural living in developed countries feedback onto each other. Cities and towns require resources from beyond their geographic boundaries, but rural communities also take advantage of the modern infrastructure and services typically provided in an urban setting. Thus, the notion of sustainability can only realistically be applied in a broad geophysical context, and consequently the land use planning effort might more appropriately be focussed on a bioregional scale. External activities, including trade flows, will arise beyond the LA boundary. The larger the system boundary used for the EFA, the smaller this effect will be. It cannot be eliminated, or full sustainability ensured, except at a global scale.

4. THE BIOREGIONAL CASE STUDY: BATH & NORTH EAST SOMERSET (UK)

4.1 Historical Development

Doughty and Hammond (2004) described the historical development of the city of Bath from pre-Roman times to the present day. They observed that its origins lay in its development as a Roman spa (Davies and Bonsall, 1996; Elliott and Menneer, 2004; Southern, 2012). Around 1.15 M litres of hot spring water erupt from the ground each year in Bath, and was utilised by the Romans both for bathing and for the central heating of their dwellings (Kellaway, 1991). Davies and Bonsall (1996) noted that "the economy of Bath was closely associated with the rural hinterland". In the aftermath of this Romano-British era, Bath became successively a Saxon monastic town and then a Norman cathedral city. Its economy was stimulated by the abundance of three natural resources: the hot springs, the Oolitic limestone from which much of settlement was constructed, and the associated mineral deposit of Fuller's Earth clay (Kellaway, 1991; Davies and Bonsall, 1996). But the local economy depended mainly on the wool trade until the end of the 15th Century (Davies and Bonsall, 1996; Doughty and Hammond, 2004). Its hot baths were largely disused after the withdrawal of the Romans in the 5th Century, until their supposed medicinal properties became more widely recognised in the 16th Century as a cure for illnesses, such as leprosy, smallpox and infertility. Inevitably, this led to the growth of the city in medieval times [*circa* 1100-1500 CE (in the *Common Era*)]; with a mixture of baths, churches and houses, many constructed by local entrepreneur s to meet the needs of visitors. By the late 1300s (in the *Common Era*) the population of the city was estimated to be about 1000-1100 (Davies and Bonsall, 1996).

The architecture of Bath city centre is predominantly of the Palladian style (named after the Italian architect, Andria Palladio), built mainly in the period 1714-1830 when a succession of Hanoverian King Georges (I to IV) reigned over the United Kingdom, and the era is consequently known as 'Georgian' (Davies and Bonsall, 1996; Doughty and Hammond, 2004; Woodward, 1992). Building in Bath really took off from 1726 when the river between Bath and Bristol was made navigable, and building materials could be imported into the city by water from Bristol. The characteristic soft, yellow (Oolitic) limestone was extracted from quarries on nearby Combe Down (Lord, 2010; Hawkins, 2011; Adamson and Francis, 2012). The city expanded dramatically from the original medieval core to meet the needs of visitors, with new public spaces linked by terraced houses in the Palladian style. Much of Bath's present architectural elegance is associated with John Wood the Elder (1704-1754) and his son, John Wood the Younger (1728-1782); both architects and developers (Woodward, 1992; Davies and Bonsall, 1996). However, one of the main reasons for the city developing rapidly in the 18th Century was a visit to the city by Queen Anne in 1702, followed by the aristocracy of the country. This early development of the city, just after this period of expansion, is illustrated in the contemporary map (c. 1787) shown in Fig. 4. The medieval core is clearly evident towards the bend in the river. However, it is 'Georgian Bath' that remains the focus of

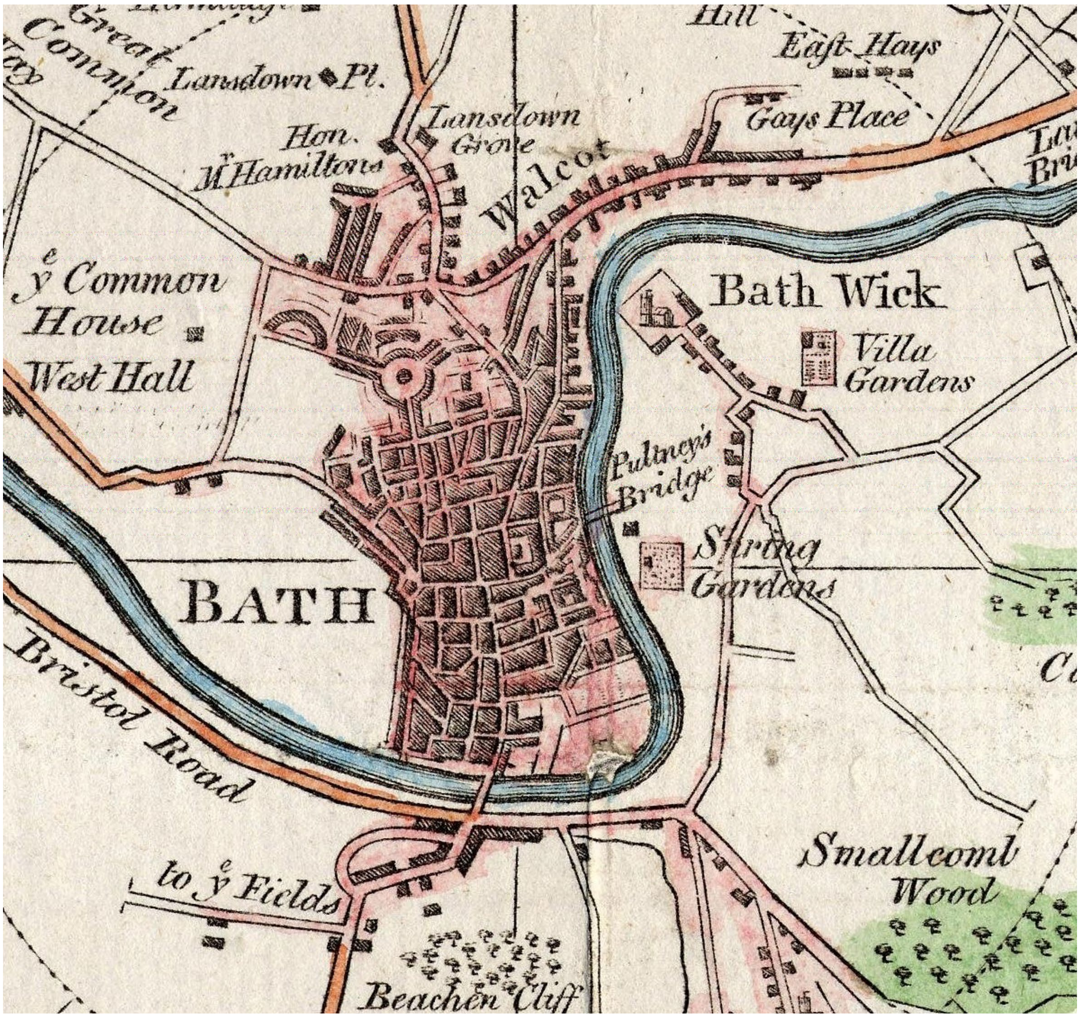


Fig. 4. The 18th Century ('Georgian') City of Bath c. 1787. *Source:* Bath Record Office, Map No. 37 [courtesy of Bath & North East Somerset (*BANES*) Council, UK].

the city's heritage and its world renown. Its fundamental layout is still much as that indicated by this map (see again Fig. 4).

During the reign of Queen Victoria (1837-1901) industrial and commercial activities in Bath expanded significantly, resulting in a reputation for cabinet-making, printing and engineering (Davies and Bonsall, 1996; Doughty and Hammond, 2004). Much of this took place to the South West of the Georgian city and of the River Avon; in an area that stretched out to the industrial village of Twerton. The construction of a canal network [including the Kennett and Avon (1810) that traversed the city], and then the *Great Western Railway* (1840) linking the city directly with Bristol and London, facilitated trade with the Capital and other parts of the UK. Local government reorganisation in 1994 meant that the city became part of the unitary local authority of Bath & North East Somerset: the *BANES* Council. This brought together the City of Bath and the former rural district of Wansdyke (Doughty and Hammond, 2004). The architectural heritage of the city was officially recognised by UNESCO in 1987, when it became one of some ten 'World Heritage Sites' in Britain at that time. Bath itself now has a population of about 100,230 (in 2015), and the residents have an income that is generally higher than the UK average.

4.2 Human and Physical Geography

BANES covers an area of 34,708 ha, of which two-thirds is so-called ‘green belt’ land: an area of open land with fields or parks around a town or city, on which building is restricted. The community represents an example of development on an urban scale, coupled with its surrounding ‘bioregion’. It has a varied geography including a number of river valleys and rolling hills. The population of the area has been slowly, but steadily, growing during recent decades, and stood at about 184,870 in 2015. Just over half the population live in the historic *UNESCO World Heritage City of Bath*; the principal settlement in the district. There are also a number of smaller urban communities scattered amongst its surrounding area (‘hinterland’ or bioregion). The other main centres of population include the towns of Keynsham, Midsomer Norton, and Radstock. Picturesque historical villages such as Claverton, Freshford, and Monkton Combe are located towards the east of Bath. They have numerous buildings that are again constructed of locally quarried Oolitic limestone. The town of Keynsham, situated to the west of the city on the River Avon between Bath and Bristol, had links to the brass industry in the past. In addition, it had a long chocolate-making tradition that stretched from the mid-18th century until 2010, when *Cadbury* chocolate factory (known as *Somerdale*) ceased production there. Today Keynsham is focused on its role as a historic market town. Similarly located in the west of the *BANES* area is the Chew Valley; originally created by the River Chew, and giving rise to generally low-lying and undulating land. The River Chew was dammed in the 1950s in order to create the Chew Valley Lake, which provides drinking water for the nearby city of Bristol to the west and other surrounding areas. The lake is a prominent landscape feature of the valley, a focus for recreation, and is internationally recognised for its nature conservation or biodiversity interest (because of its bird species, plants and insects). Dairy and some beef cattle farming takes place on the fertile valley pasturelands; alongside extensively grown cereals and fodder crops. The industrial towns of Midsomer Norton and Radstock to the south of Bath were at the centre of the former Somerset coalfield, but are now centres for manufacturing and engineering.

The Oolitic limestone from which much Georgian Bath was constructed was mined from below the village of Combe Down within, and towards the southern edge of, the city boundary. This village sits on a ridge: ‘combe’ meaning a steep-sided valley derived from Old English ‘cumb’. Ralph Allen (1693-1764), the principal developer of the stone mines, arrived in Bath in 1710 (Woodward, 1992; Davies and Bonsall, 1996; Elliott and Menneer, 2004), and generated a fortune as a Postmaster; administering and reforming the postal system. By the mid-1720s he had financed the River Avon Navigation scheme, which made the river navigable between Bristol and Bath. He identified the potential for the greater use of ‘Bath stone’ as a building material, and purchased almost all of Combe Down with its quarries between 1726 and 1731. The village grew to consist of over 700 houses, four schools, a Ministry of Defence site at Foxhill, and other amenities (including a private hospital, three churches and three ‘pubs’), having a population of about 5500 by the 1990s (Lord, 2010; Adamson and Francis, 2012). By that time it was clear that Combe Down was dangerously undermined, having an estimated void of 366,000 m^3 beneath the village, which was in need of urgent remediation due to the risk of major collapse. Stone had been extracted using the ‘room and pillar’ method (Hawkins, 2011), so that chambers were mined out, leaving just

15% of the original stone made up of 3735 roof-supporting pillars over an area of 25 ha (Adamson and Francis, 2012). Cover between the roof of the mine and the dwellings above was as little as 1.6 m in places (Adamson and Francis, 2012). A project to backfill the stone mines was completed in 2009 using over 590,000 m^3 of foamed concrete - the largest mine remediation project of its kind in the world (Lord, 2010) - that minimised environmental and social impact, along with protecting endangered species (greater and lesser horseshoe bats). This development was funded by a large grant of over £150 M from *English Partnerships* (now the *Homes and Communities Agency*) under the newly established UK Government's *Land Stabilisation Programme*. Community stakeholder engagement was ensured via active collaboration between the *Combe Down Stone Mines Community Association* (CDSMCA) (1999-2010) and *BANES* Council (Lord, 2010; Adamson and Francis, 2012).

Protecting the historic character and environmental quality of the *UNESCO World Heritage City of Bath*, whilst providing modern road transport connections, has not been without difficulty. Successful park and ride schemes, originally at Newbridge to the east, Landsdown to the south, and at the University of Bath (at their Claverton Down campus over the week end), were introduced in the 1980s (Macpherson, 1992) with the aim of restraining the growth of car parks in the city centre and removing on-street parking from the central retail area. Subsequently, the University site was abandoned, but a new park and rode was established at Odd Down in the south. In order to avoid traffic congestion caused by vehicles passing through the city, an A4/A46 Batheaston/Swainswick Bypass (Gosney *et al.*, 1997) was built as part of a *Highways Agency* improvement scheme for the busy Bristol-Southampton corridor. This £70 M project was finally opened in 1996 after 50 years of planning, a hard-fought public enquiry, and road protests over the environmental sensitivity. Visual intrusion was partially mitigated by inserting 1.7 km of the road through a diaphragm-wall cutting (Gosney *et al.*, 1997). Much still needs to be done to improve traffic flow and tackle the Bath's poor urban air quality. There are business and community groups, for example, advocating for new bus and tram schemes within the city (perhaps even extending out to neighbouring communities). Others favour a city centre 'clean air zone' (CAZ), along with the encouragement of more cycling and walking. Such a CAZ was introduced in mid-March 2021 with commercial (but not private) vehicles being charged for entering or passing through the city.

The community of *BANES* has a good track record in terms of innovations in waste collection and recycling. Indeed *BANES* Council has a vision of 'Zero Waste' community to steer the development of its waste services, and carried out a novel trial to evaluate biogenic municipal waste collection. This examined the kerbside garden and food waste collections from some 3000 households over a full year. Their intention was to determine the best method for collecting waste, and the type of response from differing household types and areas. 'Bin lorries' – special-purpose vehicles for the collection of domestic (and commercial) waste – were weighed in the trials to determine the amount of waste that was collected. It provided a useful breakdown of the potential for biogenic waste retrieved from the community (Hammond *et al.*, 2020). Bulky household waste – items such as furniture (like chairs, tables or sofas), mattresses, textiles, and WEEE (including desktop computers, fridge freezers, micro-wave ovens, or television sets) – have the potential to be recycled or reused. Although they account for only some 5% of municipal waste in England (Alexander *et al.*, 2009), they may be handled by either *local waste collection authorities* (LWCAs) or local commercial and ‘third sector’ facilities [such as *household waste recycling centres* (HWRCs) or *furniture reuse organisations* (FROs)]. Collection and reuse of bulky items was surveyed by Curran *et al.* (2007), where 1450 householders completed hand-delivered questionnaires in the city of Bath, the nearby urban borough of Swindon (see also Eaton *et al.*, 2007), and the southern coastal city of Portsmouth. 60% of respondents were found to take items to HWRCs principally because they are free, relatively convenient, and are without delay. LWCAs took between a couple of days to several weeks to collect bulky waste items (Curran *et al.*, 2007; Alexander *et al.*, 2009). *BANES* Council will currently undertake kerbside collection of a maximum of 10 items after online booking, but discriminates between those that it will handle; primarily on the basis of their size and toxicity.

4.3 The Influence of Strategic Policy and Planning on *Bath & North East Somerset*

The *BANES* Council seeks to develop a *systems approach* to achieving a ‘virtuous circle’ in terms of sustainability: balancing economic and social development with environmental protection (see also Doughty and Hammond, 2004). Its latest corporate strategy aims to address the challenge of the “climate and nature emergency”, whilst “improving people’s lives” in the community. The Council therefore intends to improve public infrastructure, including the environmental performance of its buildings, transport and local renewable energy generation over the coming decades. It produced forward-looking documents that laid the foundations for both a *Sustainable Community Strategy* over the period 2009-2026 (*BANES* Local Strategic Partnership, 2009) and an *Environmental Sustainability & Climate Change Strategy* for the shorter time-horizon of 2012-2015 (*BANES* Local Environmental Partnership, 2012). The former was prepared with the aid of the *BANES Local Strategic Partnership* of stakeholders, whilst the latter was developed with the assistance of the parallel *BANES Environmental Sustainability Partnership* (ESP). Sustainability is defined by the Council in terms of delivering improvements to the quality of life without compromising that of future generations. Thus, its *Sustainable Community Strategy* seeks to meet six key challenges out to 2026 (*BANES* Local Strategic Partnership, 2009): (i) creating a productive and relatively strong local economy, (ii) climate change mitigation and adaptation, (iii) ensuring the availability of affordable housing, (iv) promoting healthy lifestyles (with residents’ life expectancy that is longer than regional and national comparators), (v) limiting crime and involving people in local community safety work, and (vi) reducing the inequalities that exist in many local communities (thereby ensuring that “everyone, regardless of their background or circumstances, is given the same opportunities to achieve and do well in life”).

The ESP strategy for 2012-2015 clearly overlaps with the *Sustainable Community Strategy* in the environmental and climate change domains. Its vision sets out to establish Bath & North East Somerset as “an area with lively, active communities that are low carbon and resource efficient, and unique places and beautiful surroundings that are building for a greener and low carbon future” (*BANES* Local Environmental Partnership, 2012). Emphasis is placed on the reduction in the use of fossil fuels, although a residents’ survey indicated that over 80% had already taken some action to reduce energy use. The *BANES* Council wants to encourage the take-up by residents, commerce, industry and the public sector of energy efficiency measures (particularly loft thermal insulation in homes), the adoption of ‘clean’ or renewable energy devices, and stimulate behavioural change in order to support energy demand reduction. It also seeks to persuade people to adopt low carbon transport (public transport, bicycling, and walking), reduce municipal waste (via the ‘waste hierarchy’, i.e., “reduce, reuse, recycle and recover value from waste”), and enhance the natural environment and wildlife. Finally, the Council wishes to secure and promote a local, healthy, sustainable and ethical food supply in the area.

5. METHODS AND MATERIALS

5.1 The Environmental Footprint Methodology

The use of ‘ecological’ or environmental footprint analysis has grown in popularity over the last few decades, both in Europe and North America. They provide a simple, but often graphic, measure of the environmental impact of human activity: whether or not in the foreseeable future humanity will be able to “tread softly on the Earth” (Hammond, 2000). The terms ‘environmental’ and ‘ecological’ footprints are used interchangeably here [as they were previously by Doughty and Hammond (2004), Hammond (2006), Eaton *et al.* (2007), Cranston and Hammond (2010), Alderson *et al.* (2012), Hammond and Seth (2013), Hammond and Li (2016), and Hammond *et al.* (2019)], although the former expression is preferred. Ecology is that branch of biology dealing with the interaction of organisms and their surroundings. ‘Human ecology’, sometimes used for the study of humans and their environment, is closer to the usage implied by footprint analysis (Doughty and Hammond, 2004).

Footprint calculations involve several steps. Initially the *per capita* land area appropriated for each major category of consumption (aa_i) is determined (Wackernagel and Rees, 1996; Doughty and Hammond, 2004; Hammond and Li, 2016; Hammond *et al.*, 2019):

$$aa_i = \frac{c_i}{p_i} \sim \frac{\text{annual consumption of an item}}{\text{average annual yield}}, \frac{\text{kg / capita}}{\text{kg / ha}}$$

In order to calculate the *per capita* footprint (ef) in global hectares (gha), the appropriated land area for each consumption category is then summed to yield:

$$\text{ef} = \sum_{i=l}^{i=n} aa_i$$

One global hectare represents a hectare (ha) of biologically productive land at the average global productivity. Footprints of different communities or areas need to be standardised in this way, so that global hectares account for disparities in land productivities. Computation then leads to a matrix of consumption categories and land use requirements, which is ideally suited to a spreadsheet implementation. In order to determine the total footprint for a given country, region or community (EF), the *per capita* figure is simply multiplied by the relevant population size (N), viz.

$$EF = ef\ (N)$$

However, this is generally a less useful parameter for comparative purposes between countries or communities with different sized populations (Wackernagel and Rees, 1996; Doughty and Hammond, 2004; Hammond, 2006). The footprint analysis method adopted here is broadly consistent with that developed by the *Global Footprint Network* (GFN) [http://www.footprintnetwork.org/] and related bodies.

EFA, sometimes termed 'eco-footprint analysis' (Rees, 2000), is one of a number of alternative approaches available for local authority policy makers and planners in order to enable them to evaluate aspects of community sustainability (Hammond and Jones, 2011b). Others include simple sustainability checklists, multi-criteria decision analysis (MCDA), sustainability maps or 'tortilla' diagrams, and a sustainability appraisal framework (as advocated by the UK sustainability NGO *Forum for the Future*; founded by Sara Parkin and Jonathan Porritt). A participatory MCDA approach to sustainability assessment is perhaps the most comprehensive thus far devised. Allen *et al.* (2008) argued that there are a number of reasons for discouraging such aggregate methods [including, amongst them, environmental *Cost-Benefit Analysis* (CBA) (see also Hammond and Winnett, 2006; Alexander *et al.*, 2009)]. Decision-makers are typically presented with a single, aggregate decision criterion or metric, which actually hides many disparate environmental impacts. Therefore, Allen *et al.* (2008) suggested that it is important that the implications of these impacts are faced, particularly by policy makers, rather than obscured by the methodology. By disaggregating the different footprint components, as in the present study, the various impacts are made explicit for planners and other stakeholders.

5.2 A Component-based Footprinting Approach

The EFA resource components had to be identified and categorised to reflect broad and identifiable policy making categories, which match the consumption of 'natural capital' (Eaton *et al.*, 2007; Hammond and Seth, 2013). In the present study, these components were (Simmons *et al.*, 2000; Doughty and Hammond, 2004; Eaton *et al.*, 2007; Hammond and Li, 2016; Hammond *et al.*, 2019): *Built Land*; *Direct Energy*; *Food & Drink*; *Materials & Waste*; *Transport*; and *Water*: see Fig. 5. The initial phase of footprint analysis involves the collection of consumption data covering the various components (Chambers *et al.*, 2000; Simmons *et al.*, 2000; Eaton *et al.*, 2007). This yields the flow of resources into and out of the geographical bioregion. Proxy (or secondary) data adapted from national statistics were employed in the absence of sector-specific (or primary) data (Hammond, 2006; Eaton *et al.*, 2007; Hammond and Seth, 2013; Alderson *et al.*, 2012; Hammond and Seth, 2013; Hammond and Li, 2016; Hammond *et al.*, 2019). This collation and analysis of data is highly disaggregated with many individual items of information. The different footprint components (such as those depicted in Fig. 5) need to be normalised, so that global hectares account for disparities in land productivities. In addition to the consumption data needed for footprint analysis, yield and conversion (or 'equivalence') factors were required. Equivalence factors are a productivity-based scaling parameters (Wackernagel and Rees, 1996; Chambers *et al.*, 2000) that convert a specific land type (e.g., cropland, pasture, forest pasture, forest, or fishing ground) into a universal unit of bioproductive land area (in gha). In the case of land

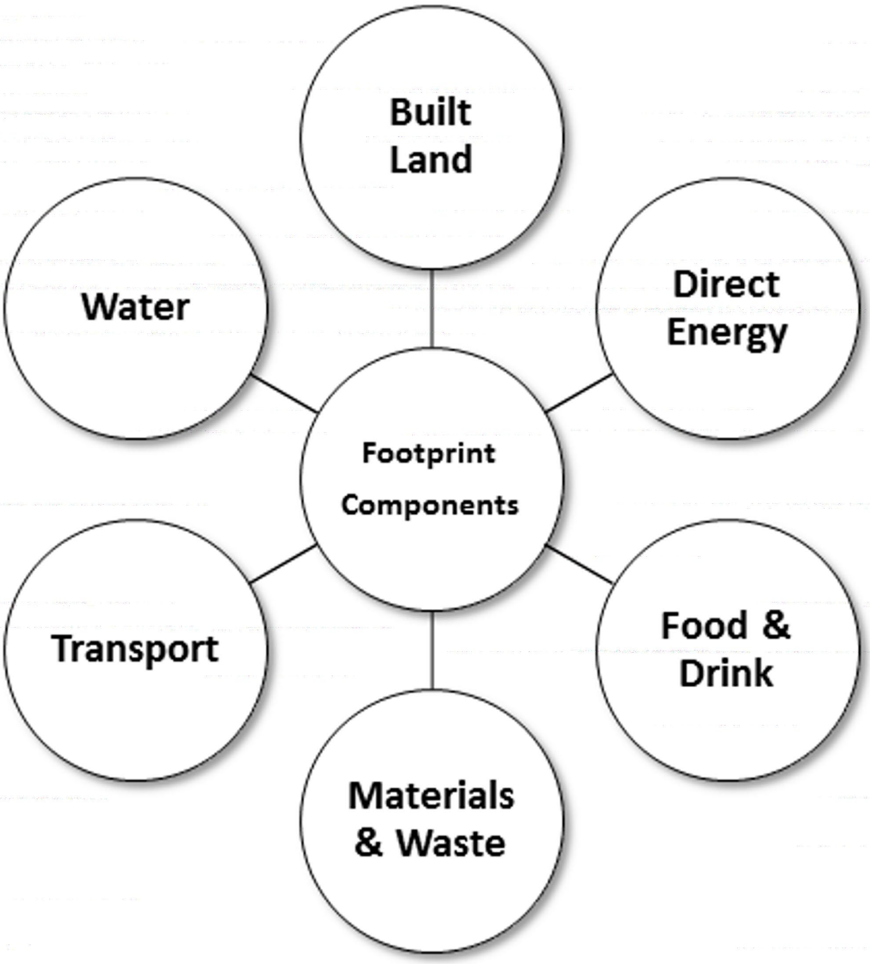


Fig. 5. Schematic representation of the component-based approach to environmental footprint analysis. *Source:* adapted from Eaton *et al.* (2007); based of the methodology of Simmons *et al.* (2000).

types with productivity higher than the average productivity of all bioproductive land and water on the planet (e.g., arable or cropland), the equivalence factor is greater than 1. According to Alderson *et al.* (2012) primary cropland has an equivalence factor of 2.10 (see also Hammond and Seth, 2013; Hammond and Li, 2016; Hammond *et al.*, 2019). Thus, to convert an average ha of cropland to the equivalent gha, it is multiplied by this cropland equivalence factor. In contrast, grazing land, has a lower productivity than cropland (~0.47). Equivalence factors are tabulated online by the *Global Footprint Network* (GFN).

Footprint analysis implies judgements about the relative weighting of the various consumption categories, and their environmental impact. It reduces all such impacts to a common basis in terms of global hectares *per capita*, which may not prove to be a unit that can be readily assimilated by ordinary people. EFA is also a 'static' process that provides a measure of aggregate environmental burdens at some specified date (or year). Nevertheless, it provides a useful basis for contrasting the footprint of human activity with the available productive area, biocapacity, or 'carrying capacity': the amount of biologically productive land and water areas available within the study area boundary and its productivity (Eaton *et al.*, 2007; Hammond and Li, 2016; Hammond *et al.*, 2019). The consequences of human consumption can then be graphically viewed against the ‘natural capital’ of a community, nation, region, or the planet as a whole. Indeed, footprinting can be used as an effective pedagogic device (or awareness-raising tool) for illustrating human resource use and waste generation, employing a simple measure (land area) that advocates view as readily understandable.

5.3 Environmental Footprint Components

The EFA resource components had to be identified and categorised to reflect broad and identifiable policy making categories (see again Fig. 5), which match the consumption of ‘natural capital’ (Eaton *et al.*, 2007; Cranston and Hammond, 2010). In the present study, these components were (Simmons *et al.*, 2000; Eaton *et al.*, 2007; Hammond and Li, 2016; Hammond *et al.*, 2019):

- Bioproductive and Built Land: Land appropriated for the built environment and biological purposes within the studied community.
- Direct energy: electricity, natural gas, solid fuel, and petroleum consumption.
- Materials and Waste: Consumption of products and materials, as well as the associated waste arisings, within the studied community. [The ‘embodied energy’ in materials, products and infrastructure was accounted for using the *Inventory of Carbon and Energy* – ICE database - developed by Hammond and Jones (2008; 2011).]
- Transport: Resource use associated with transportation requirements in the studied community.
- Water: The consumption of water by the studied community.

Details of the way in which the individual components were calculated in the present study can be found in two recent, *open access* publications: Hammond and Li (2016) and Hammond *et al.* (2019). In quantifying the input information associated with resource use and waste arisings, it is necessary to allow for factors such as data scarcity. Estimates of the effect of uncertainties in the constituent data for the related biofuel footprint study of Hammond and Seth (2013) were made using an established procedure for uncertainty analysis; as previously adopted by Eaton *et al.* (2007) and Alderson *et al.* (2012). The total environmental footprint in the latter studies was found to have an uncertainty that varied from about ±3% to ±11%. The footprint component uncertainties in the present case were estimated to be around ±13%.

5.4 Limitations of the Environmental Footprinting Approach

EFA can mislead policy makers, if poorly interpreted, according to McManus and Haughton (2006). Planners and others thinking of adopting the approach should therefore be aware of its strengths and weaknesses (McManus and Haughton, 2006). McManus (2016) returned to the topic in a book review of an EFA study by Collins and Flynn (2015) in the context of policy and practice. The latter authors had significant experience in using the approach in the Welsh capital city of Cardiff (population ~300,000) as part of the policy development process. There the emphasis was on the importance of securing confidence in the ‘experts’ and their methodology amongst community stakeholders. They also noted the significant role of a small number of consultancies (like *Best Foot Forward*) in conducting footprint studies (Collins and Flynn, 2015; McManus, 2016): some 234 inquiries over the 15 years around the Millennium. In addition, EFA can be employed to communicate the fact that environmental impacts extend beyond the urban domain into its bioregion or rural hinterland (Doughty and Hammond, 2004; McManus and Haughton, 2006; Eaton *et al.*, 2007). Cities and towns require resources from beyond their geographic boundaries (Doughty and Hammond, 2004), but rural communities also take advantage of the economic, educational, employment, health care, and leisure facilities typically provided in an urban setting (Eaton *et al.*, 2007). The *BANES* case study analysed here may be viewed as one applied over a sub-regional geographic and local authority area.

6. RESULTS AND DISCUSSION

6.1 Environmental Footprint Components

The footprints were derived from the resource flow data by assigning each consumption component to one or more of the environmental footprint land types (see Fig. 1). Each land type is associated with a specific productivity, so that the footprint can be calculated from the resources required/consumed and the area of land needed to produce the resources. *Energy land* was calculated differently by considering the absorption of fossil fuel emissions by the environment. Thus, a factor was applied to account for the carbon emissions (CO_2) [where carbon = $12 \times CO_2/(12 + 32) \sim 0.273\ CO_2$, on the basis of molecular weights] that can be absorbed by forests. Table 1 below provides a summary of the *per capita* environmental footprint (*ef*) results displayed in terms of both component and land type. Overall, it can be seen that each *BANES* resident has an *ef* of 3.77 gha (i.e., gha/cap). This corresponds to a total environmental footprint (EF) for the *BANES* bioregion of ~659,400 gha. It is apparent from both Fig. 6 and Table 1 that *Materials & Waste*, and *Direct Energy* are the two biggest contributors in terms of EF components with 30% of the total each. Rather surprisingly, transport only contributes 10%. This approach emphasises the significance of particular components, such as the *Material and Waste* and *Food*, which have a relatively large impacts on the overall footprint. A breakdown in terms of EF land types is shown in Fig. 7, which was obtained from related resource flows: energy land (52%), crop and forests (each 15%), pasture (12%), built land (4%), and 'bioproductive sea' (actually freshwater, 2%). Thus, *Energy land* contributes over half of the footprint, largely because it is associated with all but one of the components. *Bioproductive land*, which has been broken into its individual categories of crop, pasture and forest, contributes 42%. The contribution made to the footprint by each component is roughly comparable between *BANES* in the present study and the earlier one by Eaton *et al.* (2007) for the bioregion associated with nearby Swindon and Wiltshire.

The corresponding biocapacity of the *BANES* bioregion was determined by multiplying the land area by the corresponding equivalence and yield factors. Equivalence factors are used to normalise the land area by converting from hectares to global hectares, and have been taken from those tabulated by the *Global Footprint Network* (GFN). Eaton *et al.* (2007) provided the values for the yield factors for different land types. The biocapacity of the *BANES*

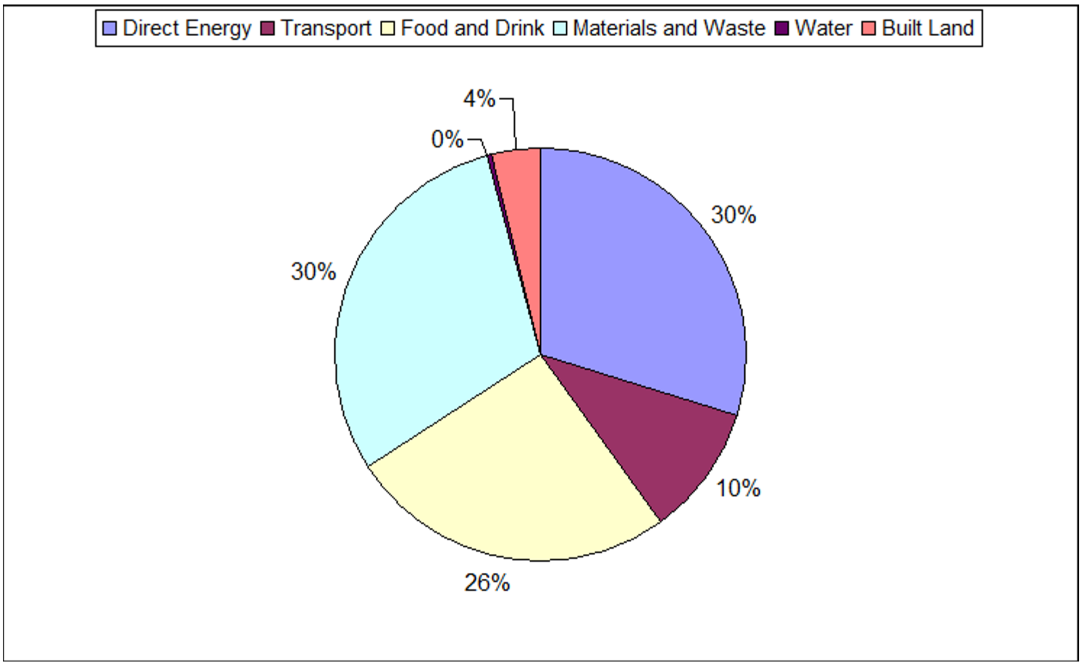


Fig. 6. Environmental footprint balances for *BANES*: Breakdown by component.

bioregion was found in this way to be 0.67 gha/cap. An 'ecological deficit' (Eaton *et al.*, 2007) is then evident because the environmental footprint exceeds the available biocapacity. Given that the *BANES* bioregion has an environmental footprint of 3.77 gha/cap and a biocapacity of only 0.67 gha/cap, the overall ecological deficit for *BANES* is 3.10 gha/cap. The corresponding deficits associated with individual land types is presented in Fig. 8. This is normally compensated in either of two ways: the deficit might be balanced by imports into the bioregion; called an 'ecological trade deficit', or it could be met through the overuse of domestic resources. That would lead to *natural capital* depletion; an 'ecological overshoot'. Clearly, the *BANES* bioregion is living beyond its environmental and resource 'means' with an overshoot ratio of 5.64:1.

The biocapacity *per capita* of *BANES* is lower than both the UK and world average; primarily because almost 50% of the bioproductive land area is made up of the least productive land type - pasture. However, the *BANES* bioregion consumes approximately a 20% less per person than the UK average resident [*ef* = 4.71 gha/cap (Borucke *et al.*, 2013)], and thus has a lower *ecological deficit* than the UK average: see Table 2. Environmental footprints are intended to highlight how local activities of can contribute towards solving a global problem. The world, with a population of ~7.3 bn [all global data reported here is for the year 2014 (Grooten and Almond, 2018)], is currently consuming more resources than it can sustainably produce and emissions it can assimilate with a related environmental footprint (*ef*) of ~2.64 gha/cap according to the 'World Wide Fund for Nature' (WWF) *Living Planet Report* (e.g., WWF, 2016; Grooten and Almond, 2018) [see again Table 2]. So-called '*One Planet Living*' (Desai and Riddlestone, 2002; Eaton *et al.*, 2007) would necessitate a global average *per capita* footprint equal to the world average biocapacity of ~1.71 gha/cap (Grooten and Almond, 2018). [This is slightly lower than the value of 1.8 gha/cap suggested by Eaton *et al.* (2007), because the world human population has increased in the interim, whilst the total

Table 1. Environmental footprint and components: *Bath & North East Somerset* (gha/cap).

Footprint Component	**Bioproductive Land**			**Bioproductive Sea**	**Energy Land**	**Built Land**	**Total**
	Crops	**Pasture**	**Forest**				
Direct Energy	0	0	0	0	1.140	0	1.140
Transport	0	0	0	0	0.393	0	0.393
Food & Drink	0.532	0.272	0	0.076	0.077	0	0.957
Materials & Waste	0.017	0.176	0.551	0	0.381	0	1.120
Water	0	0	0	0	0.010	0	0.010
Built Land	0	0	0	0	0	0.141	0.141
Total	**0.549**	**0.448**	**0.551**	**0.076**	**2.000**	**0.141**	**3.770**

global land area has remained essentially unchanged.] The only way in which such demand is sustained is via the consumption of resources laid down over geological timescales; principally fossil fuels. But they are not renewable, except over an extremely long-term timescale, and are the predominant source of atmospheric 'greenhouse gas' (GHG) emissions.

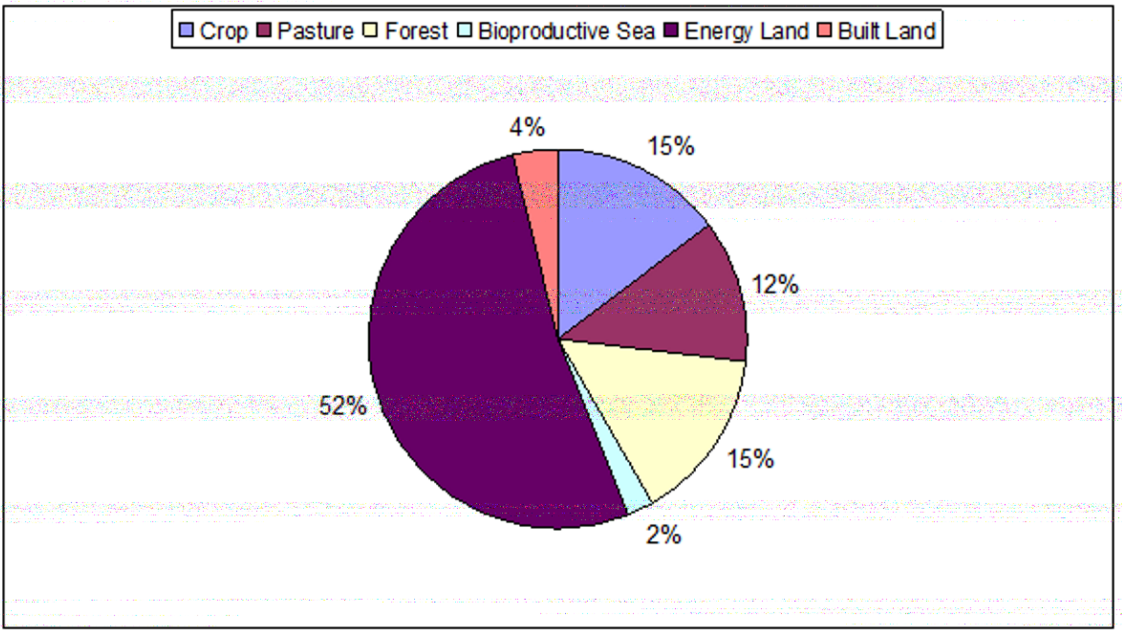


Fig. 7. Environmental footprint balances for *BANES*: Breakdown by land type.

Table 1: Environmental footprints and associated biocapacities of relevant study areas.

	The UNESCO World Heritage City of Bath	**BANES**	**South West of England Region**	**United Kingdom**	**World**
Environmental footprint (gha/cap)	3.48	3.77	5.56	4.71	2.64
Biocapacity (gha/cap)	-	0.67	1.91	1.34	1.71

Sources: Bath – Doughty & Hammond (2004); BANES – current study; South West Region – Chambers *et al.* (2005); UK – Borucke *et al.* (2013); world – Grooten and Almond (2018).

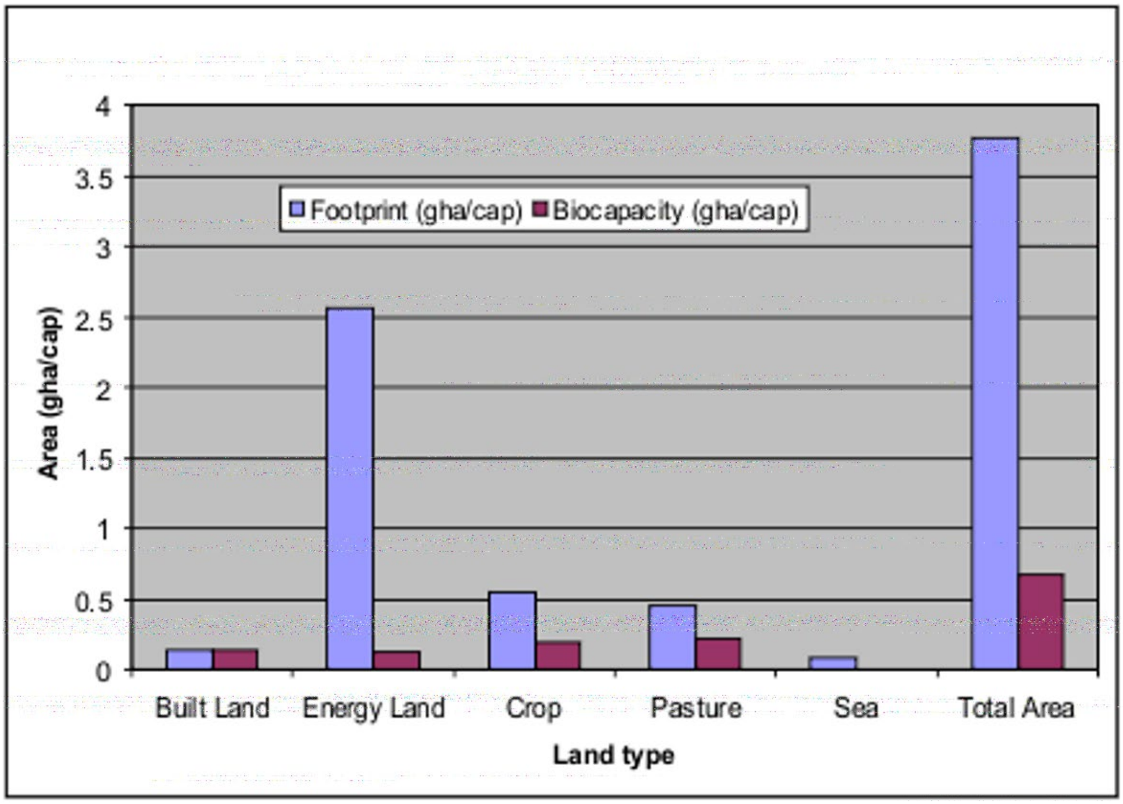


Fig. 8. The ‘ecological deficit’ for *BANES*: Environmental footprint versus biocapacity based on land types.

6.2 Thinking Globally

The global implications of the environmental footprints for Bath & North East Somerset can be assessed by placing them in a wider context. A comparison with the ‘Earthshare’ indicates how close humanity is to achieving '*One Planet Living*' (Desai and Riddlestone, 2002; Eaton *et al.*, 2007; WWF, 2016; Grooten and Almond, 2018). That would require a rate of consumption of natural resources equivalent to 1.71 gha per person (data from Grooten and Almond, 2018; and shown in Table 2). However, the global environmental footprint [*ef* = 2.64 gha/cap (Grooten and Almond, 2018)] exceeds the planet's biocapacity by some 0.93 global hectares per person (Grooten and Almond, 2018). If the rest of the world consumed as much in material terms (and produced the corresponding waste stream) as is currently done in *BANES*, then humanity would need access to the biocapacity of at least an extra two Earth-sized planets to achieve sustainable living. In the same vein, the UK 'standard of living' would require the resources of around three planets (Eaton *et al.*, 2007), the USA five planets, and the *United Arab Emirates* (UAE) ten planets. However, it must be borne in mind that the notion of an *Earthshare* is simply an ethical construct (Eaton *et al.*, 2007) - a value judgement about fair national shares of world environmental impacts.

National and global footprint data published in association with the successive issues of the influential WWF *Living Planet Reports* (Borucke *et al.*, 2013; WWF, 2016; Grooten and Almond, 2018) highlight the global inequity associated with the acquisition of the world's resources (see Table 2). It illustrates that the richer, more developed countries are the primary cause for the current global ecological deficit. It is inevitable that, as the poorer countries aspire to become more industrialised, the vision of a 'better' way of life will result in an even larger global footprint, a growing ecological deficit, and a rising overshoot ratio. A consequence of the rapidly growing world population is the continuing overshoot of available natural resources. In practice, it is unlikely, given the disparity in global wealth and resources between the prosperous 'North' and 'Majority South' (Hammond, 2000; Hammond, 2006), that the different nations of the world will converge towards '*One Planet Living*' during the 21st Century. This would need, for example, a major reduction in energy demand, along with a shift from a dependence on fossil fuel and uranium resources (so-called 'capital' energy sources) to renewable energy technologies (mainly solar-driven, 'income' sources) in both the industrialised and developing nations (Eaton *et al.*, 2007). Only then would humanity be able to secure a low carbon global economy.

6.3 Acting Locally

6.3.1 Environmental Footprints and Community Activities

Once a footprint is calculated for a defined population it can be used as a planning, monitoring and educational tool (Wackernagel and Rees, 1996; Bond, 2002; Chambers *et al.*, 2005). Indeed, the *Centre for Alternative Technology* (with a 'mission is to inspire, inform and enable people to achieve practical solutions for sustainability', and based near the west coastal town of Machynlleth in Wales) produced a novel environmental footprinting activity (CAT, 2006) aimed at both local adult communities and school pupils. A set of 'flashcards' are employed to represent stages of production, use and disposal of various human activities, including materials and products. This small group (of 3-6 people) exercise seeks to raise awareness of their impacts and stimulates a discussion around patterns of consumption. Footprint datasets can also be employed to help model scenarios, and to investigate the environmental impact of different human activities. It has certainly proved to be a valuable and effective tool for educators: presenting complicated and detailed statistics as a simple and visual concept (CAT, 2006; Eaton *et al.*, 2007). The footprint indicator can consequently be used for the following purposes [see, for example, Bond (2002)]:

- as an indicator of environmental impact for lobbying decision makers;
- to promote behaviour change at an individual level;
- to illustrate how shifting consumption to less resource-intensive items reduces environmental impact;
- to illustrate that global footprints can be affected by the sum of local activities; and
- to link products to their global footprint and promote markets for sustainably produced goods and services.

Once the impacts on the footprint have been defined, local policies, strategies and initiatives can be developed and prioritised. By updating data sources, the footprint might then be used as a monitoring tool (Eaton *et al.*, 2007). The footprint consultancy *Best Foot Forward* (acquired by the 'sustainability activator' *Anthesis* in 2013) took a leadership role in conducting footprint surveys for a range of companies, local authorities and regional bodies in the UK (Chambers *et al.*, 2000; Chambers *et al.*, 2005). Changes in the footprint can be re-examined annually or biannually. However, the role of proxy data in determining the footprint must be kept in mind. If a significant proportion of the data employed is extracted from aggregate data sources for energy and trade flows, then the local footprint will be relatively insensitive to variations 'on the ground'.

6.3.2 BANES Environmental Footprints, Local Strategy and Sustainability

The biocapacity estimates for *BANES* (0.67 gha/cap) illustrate that, at this local level, the demand for natural resources and waste assimilation (i.e., reflected in its footprint of $ef = 3.77$ gha/cap) is greater than supply. Table 2 provides a comparison of both the *per capita* footprints and biocapacity estimates for *BANES* with that for the surrounding region of the South West of England, the UK as a whole, and the World (as well as the core City of Bath). It can be seen that *BANES* has a slightly smaller biocapacity *per capita* than the UK, although the corresponding footprint is also smaller. In order for all the study areas represented in Table 2 to have the potential to be sustainable in terms of 'one planet' lifestyles, the footprints and biocapacities of the various locations would need to be brought into balance, i.e., the elimination of their 'ecological deficits'. *BANES* is rather farther away from this notion of sustainable living than the UK generally, which is a factor it has in common with many cities and urban areas. Its main practical contribution towards sustainability might therefore be to reorganise itself, over time, from a community exhibiting rather 'linear metabolism' to something closer to the spirit of the Girardet's circular metabolism for cities (Girardet, 1992; Girardet, 1999) [see Fig. 3 (b) above]. That is, one having greater resource efficiency [or a so-called 'circular economy' (*Ellen MacArthur Foundation*, 2013; Cooper *et al.*, 2017; Cooper and Hammond, 2018; EC, 2020)] in terms of the reduction in demand, the reuse of goods, and their recycling (see also Table 3), i.e., 'reduce, reuse, recycle, recover'.

Table 3. The possible prioritisation of strategies aimed at reducing the environmental footprint components of *Bath & North East Somerset* (gha/cap).

Component	**Typical Contribution (%)**	**Possible Strategies**
Built Land	**4**	* Adoption of sustainable construction principles. * Redevelopment of unused land that could be made bioproductive.
Direct Energy	**30**	* Adoption of energy efficiency measures. * Investment in renewable energy technologies, where cost-effective.
Food	**26**	* Encourage use of more locally produced products, thereby reducing 'food miles'. * Support the use of allotments and private vegetable gardens.
Materials & Waste	**30**	* *Reduce* - resource-efficient manufacture and transportation of goods. * *Reuse and recycl*e - focus on recycling and composting, as well as the reuse of materials and products. * Encourage use of materials derived from sustainable sources. * Minimise 'embodied carbon and energy' in construction and other materials.
Transport	**10**	* Encourage more sustainable transport methods and better public transport – 'green' transport planning. * Reduce private car travel to work – car pooling, 'park and ride', cycling, walking, and home working.
Water	**~0**	* Improve water efficiency.

Source: adapted and updated from Eaton *et al.* (2007) with data for *BANES* (extracted from Table 1).

The simplest means of prioritising the impact of local activities is to use the component breakdown of the footprint (such as that illustrated in Fig. 6). Local planning and development strategies could utilise such footprint data provided it is based on detailed analysis of the collated results. Table 3 depicts possible strategies for reducing the environmental footprint (adapted and updated from Eaton *et al.*, 2007) of Bath & North East Somerset, together with the weighting of each component obtained from the present data (see again Fig. 6). Many of these interventions are consistent with the strategies advocated by the *BANES* Environmental Sustainability Partnership [ESP] (2012). This reinforces the case for using environmental footprints as an indicator of progress towards 'sustainability' as advocated by Desai and Riddlestone (2002) at the *Bioregional* consultancy. Indeed, Eaton *et al.* (2007) suggested their adoption to monitor the take-up of recycled and/or traditional materials in construction, as well as improved energy efficiency in building design and layout. This reflects one of the largest of the footprint components: '*Materials and Waste*', including as it does embodied energy (Hammond and Jones, 2008; Hammond and Jones, 2011a).

The *BANES* community and geography has many sub-regional strengths (*BANES* Council, 2017), but its image of a richly varied district in the South West of England conceals a range of economic, environmental, and social challenges. Indeed, development proposals are considered by the Council with a presumption in favour of sustainable development. Consequently, the *BANES* Sustainable Community Strategy addresses social, economic and environmental challenges in the light of six key drivers (*BANES* Local Strategic Partnership, 2009): *Climate Change*; *Demographic Change* (including the impact of an aging population); *Inequalities* (a number of deprived communities within the sub-region); *Locality* (greater local democracy, the provision of local accessible services, more local food production, and enhanced sustainable local energy production); *Growth* (in housing and employment); and *The Economy* (with increased local employment, less overall commuting, and a strong low-carbon business sector). Clearly, not all these drivers are reflected by the community's environmental footprint components (see again Fig. 5 and 6). However, in terms of what the *BANES* Council describes as the 'climate emergency', it recognises the need to secure lower carbon lifestyles, reducing the community's dependence on fossil fuels, and ensuring climate change resilience, particularly the face of potential flood risk. They also understand the necessity of adopting environmentally-friendly practices, such as making buildings more energy efficient, increasing the use of renewable energy, reducing car use, and growing more local food. However, planning constraints are in place on listed buildings, constructed from Oolitic limestone mined beneath Combe Down (see Section 4.2 above), within both the historic core of Bath (see Fig. 4) and some of the outlying areas (Hawkins, 2011). These restrict the adoption of energy efficiency and renewable energy interventions, because changes in the appearance and fabric of such historic buildings are limited. The *Direct Energy* component accounts for 30% of the footprint (see Fig. 6), as does that for *Materials and Waste* [which includes an important 'embodied energy' element (Hammond and Jones, 2008; Hammond and Jones, 2011a)]. *Food and Drink* is then the next largest component at 20%, followed by *Transport* at 10%. [The significance of the *Food and Drink* sector is similar to the result found by Cooper and Hammond (2018) in their assessment of potential UK '*circular economy*' interventions.] *BANES* Council and its predecessors have themselves a good track record in terms of UK developments in encouraging more sustainable transport and in waste recycling (see again Section 4.2 above), although much more could be done to bring it up to Northern European levels of provision. EFA potentially provides a basis for monitoring across the various components against planned targets going forward. Even so, in the aftermath of the COVID-19 pandemic of 2020, it is likely that the UK Government will encourage a 'green recovery' and what has here been described here as more 'circular metabolism' within its urban communities.

7. CONCLUDING REMARKS

7.1 Summary of the Present Findings

The environmental footprints of the Unitary Authority of Bath & North East Somerset (*BANES*) in the South West of England (UK) have been estimated. It represents an example of sustainability assessment on an urban scale, together with the surrounding 'bioregion', from which lessons can be drawn in a wider context. The environmental footprint is measured in terms of global hectares (gha) required *per capita* (gha/cap). Thus, the overall footprint for *BANES* was found to be 3.77 gha *per capita*, which is well above its biocapacity of 0.67 gha *per capita* and the 'Earthshare' of 1.80 gha *per capita*. The corresponding biocapacity was 116,800 gha (or again 0.67 gha/cap), which gives an ecological deficit of 3.10 gha/cap. Uncertainties in these estimates were found to be around ±13%. The biocapacity was lower than the UK average primarily because 48% of the land area is of the least bioproductive type (i.e., pasture). EF values were disaggregated into various components: *Built Land*, *Direct Energy*, *Food & Drink*, *Materials & Waste*, *Transport*, and *Water* consumption. This component-based approach has enabled the examination of the *Manufactured* and *Natural Capital* elements of the 'four-capitals' model of sustainability (Ekins, 1992) quite broadly. *Direct Energy* use was found to exhibit the largest footprint component (a 31% share), followed by *Materials & Waste* (30%), *Food & Drink* (25%), *Transport* (10%), *Built Land* (4%), and then the *Water* footprint (~0%). Carbon dioxide emissions (the dominant GHG) for the bioregion were found to be 1.182 Mt of CO_2, or 6.76 tonnes CO_2/cap. The *Energy Land* required to sequester CO_2 emissions made up 52% of the total footprint for land. Such data provides a baseline against which to assess policies and planning strategies for future development.

7.2 Footprint Analysis for Sustainability Assessment, Stakeholder Engagement and Urban Planning

Environmental footprint analysis (EFA) is a 'static' process that provides a measure of aggregate environmental burdens or sustainability at some specified date (or year). It is a valuable technique in a toolkit of measures that can aid the, albeit the partial, assessment of sustainable development. Beck *et al.* (2010) recognised such footprints are key to urban sustainability assessment, although they recognise that there are other burdens that need to be evaluated. Environmental footprints are, for example, arguably weak in terms of social inequalities or poverty within and between different countries and societies (Hammond, 2006). EFA therefore need to be supplemented by the use of additional measures to account for these broader elements of human welfare. Indeed, Satterthwaite (1997) devised a set of criteria for urban sustainability, including health and sanitation, recreational facilities, and numerous other aspects of social provision. In a variant of the environmental footprint approach, Frantzeskaki and Kabisch (2016) trialled a stakeholder consultation process to examine urban environmental governance in Rotterdam (The Netherlands) and Berlin (Germany). They suggested that this was beneficial for policy officers, urban planners, practitioners and scientists, who could thereby learn from each other. EFA can similarly be used as an effective pedagogic device, or awareness raising tool, for illustrating human resource use and waste generation (Hammond, 2006), employing a simple measure (land area) that advocates view as readily understandable. The results of the present study provide baseline footprints that could be used as planning, monitoring, or educational tools. It may assist the communities of *BANES* (and elsewhere) to assess how they are reducing environmental burdens and improve sustainability of different sorts "on their patch".

Here a mixed 'compound'/'component' EFA has provided a footprint that is based around activities that can be directly related to the material inputs and waste outputs linked to specific communities. Each footprint component represents a broad policy category that can be analysed separately (see Fig. 6 and Table 1). It is important, however, to take into account the associated uncertainties of each footprint when putting the results in practice. Improved local footprint calculations could be achieved by obtaining comprehensive local statistics (Eaton *et al.*, 2007). The accessibility of local data is, on the whole, improving and local and central government authorities are beginning to recognise the need for such information. An example of the use of EFA for planning purposes in the regional context of the South West of England was provided by Chambers *et al.* (2005), who employed both proxy data extracted from national statistics and information collated from local sources. In an ideal world, the aim would be to move consumption and pollution patterns from those associated with 'linear metabolism' (resources in, emissions/wastes out) to a 'circular' one in which much greater efforts are made to 'reduce, reuse, recycle, and recover' (Girardet, 1992; Girardet, 1999; Doughty and Hammond, 2004; Eaton *et al.*, 2007). The application of footprint data of the type estimated here, but on a year-on-year basis, would assist the *BANES* Council (and similar local authorities) in monitoring the achievement of many of the climate change, environmental and sustainability components of their evolving community strategy (see, for example, *BANES* Local Strategic Partnership, 2009; *BANES* Environmental Sustainability Partnership, 2012).

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stabilising hazardous 18th and 19th Century mine workings on the outskirts of UNESCO World Heritage City of Bath (see Section 4.2 above). But he has contributed here in an academic capacity. Thus, the views expressed in this paper are those of the authors alone, and do not necessarily reflect the views of their collaborators or the policies of the research funder.

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