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A multi-year, multi-scale analysis of urban sustainability

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ABSTRACT

In an urban world human well-being and global sustainability are connected to cities and the way they function. However, the ability and political willingness of local authorities and urbanites to take action to significantly reduce urban negative biophysical impacts is limited. This manuscript presents the results of a research which aimed to examine the extent to which existing and potential measures within and outside urban boundaries can reduce the urban ecological footprint and advance urban sustainability. It focuses on the town of Ra'anana, Israel, as a case study examined over a decade. It identifies the contribution of different urban activities (e.g., transportation, food consumption etc.) and stakeholders (e.g., urban residents, municipality, the state etc.) to the changes of the urban footprint over time. It then examines the potential contributions of selected measures (e.g., plans, technology implementation, behavioral change, etc.) within and outside the town's boundaries to minimize the urban footprint. The research joins a small group of studies that have examined urban footprints over time and an even smaller number that tried to examine the potential footprint reductions from sustainability actions taken at different spatial scales.

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1. Introduction and background

In an urban world most of humanity's material and energy throughput and waste is directly and indirectly connected to urban activities (Newman, 1999; Kennedy et al., 2007). The role of urban governments and residents in reducing environmental pressure and advancing sustainability has been widely acknowledged. Cities are key source of unsustainability and at the same time critical for advancing sustainability (Alberti, 1996; Rees, 1997; Grimm et al., 2008).

Therefore, a growing number of studies have focused on analyzing the bio-physical dimensions of urban sustainability, including urban resource reliance and ecological impact on geographic locations at various spatial scales (e.g., Grimm et al., 2008; Kennedy et al., 2007; Moore et al., 2013; Newell and Cousins, 2014; Stossel et al., 2015). These studies have emphasized the need to asses and monitor the impacts of specific urban activities, and to propose measures to reduce negative impacts as a means to advance both local and global sustainability. However, the effectiveness of various measures should be assessed. Efforts can then be targeted toward measures with the greatest potential benefits. Furthermore, actions outside the cities' boundaries at the national and international scales may be even more effective for reducing urban environmental impact and advancing urban sustainability. It follows that assessment of urban sustainability should be carried out as a multi spatial scale assessment so that the contributions of measures (policies and plans, technologies etc.) within and outside a city's boundaries are considered. Furthermore, urban sustainability assessment should be carried over time to examine patterns of change and the extent to which implemented measures actually contribute.

One approach increasingly being used to analyze urban reliance and impact on the global environment, and the gap between existing unsustainable urban centers and a more sustainable future is the ecological footprint analysis (EFA) (Mori and Christodoulou, 2012; Newton, 2012). EFA assesses the bio-physical sustainability of human activity by estimating the land and water bodies required in order to produce the resources consumed and to assimilate some of the waste produced by a defined population (Rees, 1992; Wackernagel and Rees, 1996; Rees, 1997). It can be used to monitor progress toward sustainability, to compare the environmental pressure of different cities, lifestyle or technology, and to assess human resource burdens against capacity (Robinson, 2004).

Over the years various studies have assessed urban ecological footprints (a partial list includes these studies: Rees and Wackernagel, 1996; Rees, 1997; Barrett et al., 2002; Collins et al., 2006; Hubacek et al., 2009; Scotti et al., 2009; Wilson and Grant, 2009; Moore et al., 2013). All studies emphasized urban reliance on a global hinterland in order to maintain the required resource supply and emission assimilation. The studies employed the concept of global carrying capacity and highlighted the fact that most cities under study exceeded that capacity. To date two studies focused on Israeli towns (Kissinger and Haim, 2008; Stossel et al., 2014).

Most urban EFA studies have presented a snapshot of a specific point in time without monitoring change over time or examining different actions to reduce a city's footprint. Measurement of EF over time can

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contribute to monitoring progress toward closing the sustainability gap, the present global condition in which humanity's total annual demand on Earth's renewable resources and services exceeds the Earth's capacity to regenerate them (Rees and Wackernagel, 1996). Measurement of the EF over time can reveal a change in the way the city is operating; can be used to explore the impact of different actions on a city's footprint; and assess how much progress urban policies and practices can make toward desired sustainability goals. Only a few studies have analyzed the EF of a city overtime. Du et al. (2006) presented the case of four cities in China (Guangzhou, Ningbo, Suzhou and Yangzhou) over a decade between 1991 and 2001. Browne et al. (2008a,b, 2009) used the city of Limerick as a case study for analyzing the EF of an Irish urban area over time. They analyzed the footprint of specific urban activities in 1996 and 2002 including transportation (Browne et al., 2008a), product consumption (Browne et al., 2008b) and energy consumption (Browne et al., 2009). The results of these studies suggested that despite efforts by municipal governments to reduce environmental impacts local footprints continued to increase over time.

The aim of this manuscript is to examine the extent to which existing and potential measures within and outside urban boundaries can reduce the urban EF and advance urban sustainability. It focuses on the town of Ra'anana, Israel as a case study examined over a decade (2002 − 2012). It identifies the contribution of different components (e.g., transportation, food etc.) and stakeholders (e.g., urban residents, municipality, etc.) to the changes of the urban footprint over time. It then examines the actual and potential contributions of selected measures (e.g., plans, technology implementation etc.) within and outside the city's boundaries to minimize the urban footprint. It also identifies the influence of ‘demand side factors’ (i.e., changes within the town over the research period) and ‘supply side factors’ (i.e. changes in conversion factors, the contribution of new technologies etc.).

2. Methods

This study analyzes the urban EF of the town of Ra'anana, Israel, using the component based EF method for six different consumption components of urban activity: food, electricity, water, material and waste, transportation and built area. The calculation includes resources and energy required in order to produce the products and assimilate waste generated by the town. The calculations were based on the method used in previous urban footprint studies (Kissinger and Haim, 2008; Kissinger, 2013; Moore et al., 2013; Stossel et al., 2014). For full presentation of the calculation procedure see the supplementary materials file.

2.1. The case study

The population of Ra'anana is approximately 69,000 residents (CBS — Central Bureau of Statistics, 2012). The town is classified as 8 out of 10 on the state of Israel socio-economic hierarchy (with 10 being the highest) (CBS — Central Bureau of Statistics, 2006). According to the Israeli CBS — Central Bureau of Statistics (2008) 41% of households include children under the age of 17; 60% of work-aged residents work outside the town; and 75% commute daily by private vehicle.

One of the main reasons the research focused on the town of Ra'anana is that it was previously analyzed by Kissinger (2003) and Kissinger and Haim (2008) using 2002 data. These studies used EF analysis to measure the town's required hinterland and its dependence on overseas ecosystems. The authors distinguished between local and global footprints and found that most of the residents' needs were not provided locally, but rather depended on resources located all over the world. Results showed that the town's footprint should be reduced by half in order to stay within its available local biocapacity (Kissinger and Haim, 2008). The choice to analyze the town's EF between 2002 and 2012 aimed to follow after changes during a significant period since the original study, a period to which most required data was available.

Another reason for our choice to focus on Ra'anana is connected to the small changes in population size during the research period. During the decade covered by this research (2000 − 2012) the town's population has grown by only 0.44%. That low rate is probably the result of the town's high housing prices compared to neighboring towns as well as a low rate of new residential construction. This small change in population makes Ra'anana an interesting case for examining footprint change as the contribution of population growth (a common contributor to growth of activities, material consumption and energy in the town) is very limited.

Ra'anana is usually presented as a show case among Israel's greenest and most sustainable urban settlements. Indeed, the municipality takes action to mitigate the urban impact on the environment and climate change. As part of this effort during the years the study focused on the local authority has advanced recycling programs, singed ICLEI's international convention for climate protection under which it is obligated to reduce its greenhouse gas (GHG) emissions by 20% by 2020. The town is also part of the ‘Aalborg Charter’ of the ‘European Sustainable Cities and Towns toward Sustainability’. The town was awarded with the 2010 national Green City prize, and was the first Israeli town to achieve the ISO 140001 environmental management standard.

2.2. Data sources

We used data sources from four spatial scales: (1) local scale—local data was used when available, mainly for subjects for which the municipality has direct responsibility, such as solid waste disposal and built up area; (2) regional scale—for data on public transportation; (3) national scale—we used the CBS data and data from the Israel electric company, the Israeli ministry of the environment, and Israel's water authority; and (4) international scale—data from the food and agriculture organization statistic database (FAOstat) and the global footprint network (GFN) (for detailed references of the sources for each data category see Table S1 in the supplementary file).

Local authorities tend to trust databases they are familiar with and that describe local realities (Moore et al., 2013), thus we selected local data when available rather than national data. Due to developments in data availability and collection since the first EF study of Ra′anana (2003) we recalculated its EF for the year 2002 rather than relying on data from the previous study.

Footprint analysis over time requires annual consumption data for each studied component, alongside the adaptation of conversion factors for each component and studied year and the specific relevant EF equivalent factors to global hectares. The study comprises three time points, 2002, 2007 and 2012 and the calculation was based on data for each of those years. When data was missing, we used data from the following year. Specific conversion factors were then implemented for the different studied years for each EF component, including: annual yield factors for food; the ‘electricity fuel basket’ of each year, which included different proportions of fuels (e.g., coal, natural gas) and resulted with different EF per unit; transportation emissions factors based on vehicle age and engine size; solid waste composition and recycling rates; energy and materials inputs used for different materials and the supply of water. For the list of conversion factors for each component and studied year see tables S3–S9 in the attached supplementary materials file. Finally, for the EF equivalence factors we used the WWF (2004) for the year 2002, Ewing et al. (2010) for the year 2007 and GFN (Global Footprint Network) (2014) for the year 2012 (see tables S2 in the attached supplementary materials file). The carbon sequestration rates were considered similar throughout the research period and following Borucke et al. (2013).

2.3. Analyzing the potential of various actions

After calculating the urban footprint and analyzing its components the research examined the potential contribution of various measures to reducing the urban footprint for the year 2012.

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