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Anshuman Khare
Terry Beckman *Editors*

Mitigating Climate Change

The Emerging Face of Modern Cities

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Preface

Climate change has emerged as one of the most challenging political and scientific issues of our times. The Brundtland Report (1987) and Rio Conference (1992) highlighted the significance of local actions as a means of securing global sustainable development. This is further emphasized by the projection by UN-HABITAT, in its publication titled "State of the World's Cities Report 2008–2009: Harmonious Cities," which estimates that 70 % of the world's population will live in cities by 2050.

With ever increasing trends in urban consumption and production practices, a call for action to mitigate Climate Change is often seen as a way to foster sustainable development. Considerable attention is now being paid to determine what urban sustainability would include. Urban transportation, urban housing and containing the sprawl of cities are all small pieces of the puzzle.

Today there is a pressing need to broaden our knowledge and apply new concepts and frameworks to development of modern cities. Building on the foregoing, this book attempts to bring together and discuss concepts, tools, frameworks, cases, and best practices to cope with the emerging challenges faced by cities today. The book is of use to policy makers, city planners, practitioners, and academics who are starting to project what modern cities will need to do in terms of energy efficiency, mobility, planning and design of habitat, and infrastructure and adapting to climate change.

As this topic is relatively new, we received a wide variety of articles from around the world, covering a wide variety of subjects. After careful review, we selected 14 relevant that deal with mitigating climate change in an urban setting. In order to provide some structure to guide readers, we have grouped the articles in three parts: Urban Policies and Practices, Urban Transportation, and Urban Remodeling. Undoubtedly there are other ways that the articles could have been grouped, but in terms of providing depth of coverage in significant areas of interest, this grouping seemed to make the most sense.

Urban Policies and Practices

As the title of this part implies, policies and their implementation into practice by cities can have a profound effect on climate change. That is, policy is a significant tool that cities have at their disposal which can guide and direct broad climate mitigation strategies—if used wisely. We see in this book several examples of how this can come about, and even some of the risks involved.

Coble's chapter, *Is Smart Really So Smart*?, provides an interesting overview of the strengths and limitations of Smart Growth thinking. It shows that despite coming up with seemingly sound methods of mitigating climate change through reducing urban sprawl and following certain land use principles there are good reasons why such approaches might not be very successful.

In the following chapter *Geographic Information Systems* (*GIS*) *as a Tool in Reducing a Community's Ecological Footprint*, Schatz, Walker, de Kroes, Arciniegas, Getz, and Khare present three case studies in the utilisation of GIS-based data in integrated planning at the regional and municipal level. This chapter demonstrates techniques for evaluating the climatic ramifications of design alternatives before they are implemented. The challenge of this powerful tool has been in harnessing the extensive data it can provide planners who either lack expertise or limit its use to the analysis of existing conditions rather than as an assessment of proposed intervention. By drawing on GIS to test hypothetical scenarios in the planning stage, and using well-developed interactive tools to inform stakeholders during the planning process, community and municipal planners, and policy makers can make better informed decisions and develop more effective and comprehensive strategies for the preservation of important ecological resources and the reduction of energy consumption and associated GHG emissions in introducing new—or reorganizing existing—buildings and infrastructure. The development and distribution of these tools and techniques at the very scale of environmental administration (regional and municipal) at which policy implementation typically takes place is critical to the success of our efforts to mitigate climate change.

De Flander's chapter, *Resource-Centered Cities and the Opportunity of Shrinkage*, suggests two unique approaches to mitigating climate change that cities as a whole can take. The first involves a switch from consumption based to resource-based economic assumptions in existing as a city. The second involves a plan for a city to focus on shrinkage and on moving away from denser population structures.

The first of these ideas necessitates quite a significant change in mindset of not only city policy makers, but also businesses and consumers. Typically, one significant way to improve the economy is to increase consumption. However, the activities associated with consumption are also usually the activities that contribute to and increase climate change factors. An alternative approach is to place resources at the center of a city's economic system. This measurement and maintenance of resources rather than consumption changes the focus of policy making such that the overall urban system could change and through that change help mitigate climate change.

The second idea flows from the first, and suggests that cities, as resource focused entities provide their *own* resources, and be less parasitic. To accomplish this, two things must occur: they must shrink, and they must become less dense. Shrinkage allows for the viability of closed systems, whereby a city can reasonably provide many of its own resources. Less dense living allows for the re-purposing of land, buildings, and space to produce resources for the city.

The author contends that the combination of these two approaches will have a profound effect on climate change. The difficulty lies in implementing the approaches.

The final chapter in the part from Cruz, *Understanding Local Government Resilience*: *A Case Study on how the Local Government of Marikina City Reacted to the Flood in September* 2009, is a case study of the local government response of the Philippine city, Marikina to the devastation caused when it was hit by Tropical Storm Ketsana.

This case study stands out from the considerable body of literature on urban climate mitigation and adaptation due to two distinctive features: it explores the reorganization of the local authority in a city that is particularly vulnerable to the effects of climate change, located in a less developed country and therefore lacking many social and economic resources to cope with its effects; and it examines the management of environmental risks before and after they actually materialized. This approach enables a before–after comparison of *changes* in the deployment of policy measures to better cope with these risks (here–flooding) in the future.

The devil's advocate could argue that the author's analysis actually portrays an example of failure rather than success. Despite extensive evidence on the vulnerability of the city and the region, the Marikina municipality did not coordinate its responses effectively *prior* to the tropical storm; and it did not strengthen its institutional capacities *after* the flood. This violation of the precautionary principle is not uncommon in environmental policy, but the failure to implement the necessary changes even *post-factum* is quite unusual.

The study unequivocally focuses on the *institutional* arrangements that enable cities to enhance their ability to cope with climate change. Good climate *governance* entails additional dimensions, such as knowledge-based decision making, transparency and participation, networking and more. It would be instructive to examine these dimensions in a follow-up study.

Urban Transportation

The second part of the book deals with a perennial issue, well known to impact climate change: urban transportation. And as the world's population grows, and that population migrates to urban centers, this particular issue becomes more salient and critical to any efforts to mitigate climate change.

Maitra and Sadhukhan paint a fascinating picture of dramatic growth in the number of private vehicles on the roads in urban India, along with corresponding increases in traffic congestion and harmful emissions in their chapter *Urban Public Transportation System in the Context of Climate Change Mitigation*: *Emerging Issues and Research Needs in India*. Private transportation (i.e., cars and two-wheelers) is becoming increasingly dominant over public transit (e.g., buses). This is a very important and interesting context; India has the second largest population among nations and the country is experiencing strong economic growth. The authors present a concise description of the climate change issues in moving people about in large Indian cities.

This chapter also initiates a discussion on some promising mitigation strategies that could reduce congestion and emissions in urban India. The strategies focus on promoting public transport patronage via increasing capacity and improving service. The authors outline service problems with traditional buses in India; and briefly describe some alternatives, including bus rapid transit (BRT) and various rail-based systems. Maitra and Sadhukhan close by suggesting a research agenda. There is a pressing need for research to guide optimal combinations of BRT and rail systems for various large urban environments in India, and to help forecast demand for public (versus private) transportation based on critical service attributes.

In their chapter, *Emissions Models as a Design Tool for Urban Transportation Planners*, Handford and Checkel suggest that greenhouse gas emission predictions are costly and problematic to produce in current urban transportation planning. The micro-simulations necessary to produce useful predictions are very computer intensive, and thus costly to run. Macro level models do not provide the detail necessary to effectively apply to transportation planning. To address this shortcoming, the authors have developed a transportation emissions' model which includes a simplified micro-simulation. This model is a hybrid of a four-step model and a micro-simulation. The design is such that it can plausibly run on a conventional desk-top computer. Several scenarios illustrate the way this tool can be used for urban transportation planning.

This modeling tool could have significant implications for urban transportation planners. With its lower cost and lower computational requirements than other tools, it can be more readily applied for planning purposes. As cities grow, and urban traffic flows become more complex, this tool will give planners a way to see the greenhouse gas emissions implications of changes and developments to the transportation infrastructure.

In his chapter, *Mobility with the Focus on Mitigating Climate Change in Urban Centers*: *Open Innovation and Pricing as Key Elements for Customer-Focused Strategies and Measures*, Wittmann points out that one of the key contributors to climate change is the use of the automobile to address the general and increasing need for individual mobility. Given that individual mobility needs are at the center of economic and social development—especially in cities—it is important to create a way to mitigate the effect of automobiles on climate change.

Applying consumer behaviour principles to this situation offers a way to impact and reduce the need for individual automobiles. That is, Wittmann suggests that using open innovation approaches will help to determine and address individuals' mobility needs with new products and services. Additionally, he outlines ways in which pricing strategies can be applied to environmentally-friendly individual mobility solutions such that the bottleneck to the use of such solutions is reduced or eliminated.

In their chapter, *An Approach to Tackle Urban Congestion and Vehicle Emission by Manipulating Transport Operations and Vehicle Mix*, Mitra and Pravallika do a great job of examining the urban transportation problem and presenting good arguments for their resolution. The chapter is generally written in ways for a reader who might be unfamiliar with some theories (specifically the technical issues concerning air quality and mobile sources. The central question is explored in depth and a case for vehicle mix model is made. The authors summarize adequately the literatures and the methodologies in support of their work.

Urban Remodeling

The final part of the book takes a look at how the structure of cities can be changed to mitigate climate change. Some chapters examine the impact of programs run by cities with the same goal.

Mark Brostrom, Christian Felkse, and Allan Yee in their research *Climate Change and Cities*: *Mitigation Through the Effective Management of Waste* puts the focus on a relevant issue of everyday municipal services and utilities in developed countries: waste management. Based on the Canadian example from the City of Edmonton, the authors look beyond the classical waste management perspective in terms of resource use and environmental impacts of waste (e.g., overconsumption, soil and groundwater, and air pollution) by discussing the relevance of municipal waste management practices in terms of contributing to and potentially mitigating climate change. Contrasting data on landfill disposal, recycling, composting, and grasscycling this chapter outlines an array of waste management practices that municipalities often have at their disposition to choose from and their respective GHG emissions. Thereby, this chapter sheds light on the impact that municipal utility decisions have in terms of alleviating climate change while at the same time fulfilling their classical service functions.

Puurunen and Organschi take a closer look at US housing in their chapter titled *Multiplier Effect*: *High Performance Construction Assemblies and Urban Density in US Housing*. To repeat in order to emphasize, global urban climate mitigation efforts depend on the reductions of emissions from metropolitan areas of the US. The key in this respect is identifying balanced technical and policy approaches that blend high-density mixed land-uses and transportation. In the low-density suburban metropolitan areas of the US, this is particularly challenging. The high levels of car dependency, as well as the high costs of deploying district energy systems, and the political barriers associated with introducing passive-housing efficiency codes, make the low-density suburban energy landscape in the US particularly problematic in this regard.

The authors do a very good job with analyzing how this issue can be addressed via high-performance multi-family/apartment complexes. The chapter is a strong contribution to a particularly problematic policy and technical issue in the US. The analysis and conclusions contribute to critical understanding of a national-level and global-level urban climate challenge. In particular, the contribution of this chapter to the book is the ways in which high-density residential apartment retrofits can provide an affordable and high-performing alternative to current suburban energy strategies that seem at a loss over which technology, which zoning densities or economic approaches seem useful. The authors summarize nicely the challenge, the existing literature the application of the lifecycle analysis tool.

Ren, Wang, and Chen believe that today's climate change mitigation technique in the residential sector will inevitably serve as tomorrow's means of climate adaptation. Their chapter *Climate Change Impacts on Housing Energy Consumption and its Adaptation Pathways*, demonstrates that facing the global temperature increases predicted by climate models, cities like Brisbane that are situated in heating and cooling-balanced climate zones will require increased energy performance and carbon reduction just to sustain current levels of home energy consumption and CO_2 emissions. This vexing fact is of critical importance to policy makers and planners concerned with the long-term sustainability of the built environment. Because of the extended lifespan of buildings, today's upgrades in the thermal performance of building envelopes and in the energy efficiency of appliances and mechanical systems must be assessed not in terms of current temperatures but against scenarios that account for likely increases in future home cooling demands due to global warming. By providing "adaptation pathways" that independently—or in combination—serve to counter increases in atmospheric temperature and associated energy consumption, the authors have offered a flexible framework and a clear set of tools for mitigating carbon emissions now while reinforcing the benefits of those efforts for the future. The quantitative methodology and resulting assessments that this chapter describes may help to prevent the premature obsolescence of today's energy efficient or carbon neutral home.

Reusswig and Peters in their chapter *European Citizens*, *Carbon Footprints, and Their Determinants*: *Lifestyles and Urban Form*, investigate carbon footprints in several energy domains between and within countries (Germany, Czechoslovakia, and Scotland), urban and rural regions, and different lifestyle groups. The results exhibit distinctive footprint differences the authors trace back to strong and less strong predictors. With focus on urbanity, the analysis elucidates the close interrelationship between energy system, infrastructure, and lifestyle, likewise enablers and constraints. The results of the investigation give a strong indication for the requirement to align public and private investments in a low carbon emitting way in order to enable individuals to transform pro-environmental preferences into greener lifestyles.

Chen, Wang, Khoo, Thatcher, Lin, Ren, Wang, and Barnett discuss Urban Heat Island in their chapter *Assessment of Urban Heat Island and Mitigation by Urban Green Coverage*. Urban heat island (UHI) is a big concern in the context of rapid urbanization and climate change. Urban climate model (UCM) has been applied in the chapter to quantify the potential of urban vegetation in mitigating UHI. The method proposed in the chapter can be used in other cities where UHI is a growing concern in order to quantify the changes in urban land-use required to reduce UHI below certain level. The benefit of vegetation under future climate scenarios has also been modeled to understand its relative change. This will help in urban climate change adaptation planning.

In the final chapter in this part, *Urban Climate Change Mitigation in Mexico City*: *Innovative Solutions in Municipal Wastewater Treatment Plants*, Muñoz presents a case study from Mexico. Waste water disposal is a major concern for mega cities. The disposal and treatment of sludge can produce emissions of greenhouse gases which contribute to global climate change. The potential of emerging technologies for biogas production from waste as a renewable source of green energy has been discussed in this chapter to decrease the amount of greenhouse gas emissions and save energy. The integration of environment policies into the national development plan of Mexico is introduced. The chapter can be helpful to understand start-of-art methods for the production of biogas and bio-hydrogen as green energy source from urban waste and identify the best available technologies for a particular context.

The Way Forward

It is interesting and encouraging to note the number and the variety of concepts that are available in a quest to mitigate climate change. Even beyond those mentioned in this book, there are more ideas being developed and tested around the world, and we expect that to continue. However, as the world's population becomes more concentrated in urban centers it is more and more critical that these ideas and concepts are taken up on a mass scale or are vigorously supported to be implemented on a mass scale.

In some cases this seems to be happening—for example when a transit system is developed or expanded, it will—by its very nature—be taken up by the masses. But why are mass transit systems not priorities in many cities? Why is it so difficult to get support for a solution that can have a significant mitigating effect on climate change? One part of the answer to this is that the citizens—consumers—of the world need to support the changes.

This leads one to an important factor in implementing any of these solutions: the behavior and attitudes of the citizens. That is, in order for these solutions to be implemented successfully and in a large enough manner to truly mitigate climate change, people's behaviors, and attitudes must change. As highlighted in this book, no longer can people think that they are entitled to have their own, personal transportation system—i.e., a car—and can drive it anywhere, anytime in the city; nor can they assume that their actions will not impact anyone else. However, many people behave in a rational economic fashion that focuses on their individual situation, and even from an individual perspective externalities need to be accounted for if climate change is to be impacted.

Therefore future research has many directions to go: the ideas and concepts explicated in this book can be pushed even further through development and application; new concepts that are not even imagined in this work need to be explored, analyzed, and developed; and importantly, researchers need to look at the behavior of people, and find ways to influence that behavior to adopt new technologies, new concepts, and simply accept the fact that their actions have an impact.

Review Process

Submitted chapters were double peer-reviewed by a team of academics and practitioners from around the world. Those chapters that provide a significant contribution to theory and/or practice were accepted for publication.

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With a strong background in institutional analysis and capacity building in sustainable development, environmental policy, and resource management, he now focuses on integrating environmental concerns into other policies, notably EU General Affairs and external relations, including trade, development, foreign affairs, and security policy. He is particularly engaged in strengthening Transatlantic relations and cooperation on environment, climate, and energy security.

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Supporting Networks

Alexander von Humboldt Network for Cities and Climate Change is a Network of researchers and practitioners established in 2010 by the alumni of the Alexander von Humboldt Foundation to inform scientific and policy discourses, promote research and innovations based on exchange, and cooperation among members.

The Online Center for Corporate Stewardship (OCCS) (Athabasca University) is a collaborative online community of corporate stewards who promote the philosophy of corporate stewardship and increase research and effective educational programming in this area. The Center showcases our collaborative research and course offerings. However, the bigger goal is for the Center to become a global nodal point for academics and practitioners to share knowledge, interact, and develop new thinking to pursue the goal of corporate stewardship.

Contents

Part I
Urban Policies and Practices

Is Smart Growth Really So Smart?

Dana Coble

Abstract The world's population has been growing at an exponential rate, increasing demands on energy and resource use and contributing to greenhouse gas (GHG) emissions and pollution. This increase in population has been primarily in urban areas. In developed countries, 75 % of the population already lives in cities and for every 1 % increase in urban population, energy consumption increases by 2.2 % (WBCSD in Energy efficiency in buildings: Business realities and opportunities. Atar Roto Presse SA, Switzerland, 2008). Clearly we are moving towards a crisis if we continue traditional methods of development. So how can cities accommodate this growth in a sustainable manner? One movement to address these issues has become increasingly popular with urban planners, environmentalists and some developers: "smart growth" (Downs, J Am Plann Assoc 71(4):367–380, 2005). This chapter will begin with a definition and overview of smart growth to familiarize readers with its basic premise and will then provide arguments both for and against implementation. Implementations will be reviewed and their results assessed, with a focus on Canadian data. Based on the data reviewed, it is the position of the author that smart growth has not achieved its intended results. This is due to both implementation issues well as with smart growth theory itself. Conflicting planning guidelines, localized authority and consumer preference have been the primary contributors preventing effective implementation, while smart growth theory has a limited approach to environmental and ecological issues. It is suggested that in better engaging stakeholders, transitioning toward regional planning and incorporating complementary initiatives, smart growth would more effectively realize the three objectives of sustainable development.

Keywords Smart growth · Sustainable growth · CaGBC's ten principles · Mixed use development · Residential densities

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1 Introduction

The world's population has been growing at an exponential rate, increasing demands on energy and resource use and contributing to greenhouse gas (GHG) emissions and pollution. This increase in population has been primarily in urban areas. In developed countries, 75 % of the population already lives in cities and for every 1 % increase in urban population, energy consumption increases by 2.2 % (WBCSD 2008).

Clearly we are moving towards a crisis if we continue traditional methods of development. So how can cities accommodate this growth in a sustainable manner? One movement to address these issues has become increasingly popular with urban planners, environmentalists and some developers: "smart growth" (Downs 2005).

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2 Scope and Limitations

Since smart growth principles have only been recently incorporated in many jurisdictions, quantitative data is limited. Three major Canadian cities—Calgary, Toronto and Vancouver—have substantially changed their municipal plans in the last five years and data reviewed is not resultant of current policy. It is also important to note that the literature available is based on findings during different market conditions—prior to the sub-prime crisis in the United States (US) and the global economic downturn. As a result, conclusions may not reflect current realities.

3 Definition

3.1 What is Smart Growth?

There are several definitions of smart growth—likely as many as there are of sustainability. Canada Green Building Council (CaGBC 2010) defines smart growth as "a collection of land use and development principles that aim to enhance our quality of life, preserve the natural environment, and save money over time". The American Planning Association has called it "a way to meet the challenges of sustainability" (Jepson and Edwards 2010). Others simply suggest smart growth is a solution to address the pitfalls of urban sprawl (Downs 2005; O'Toole 2007; Suzuki and Moola 2010)—a phenomena perceived by many to be a primary contributor to increasing GHG emission levels.

Alternative planning models are frequently used to describe smart growth, such as new-urbanism, neo-traditionalism, and walkable communities. Although similar in principle, these models are geared toward individual neighborhoods rather than municipal objectives.

3.2 Objectives

The principles cited by smart growth advocates vary in scope however there are key elements in most. As the CaGBC is a federal organization with a mission to "lead and accelerate the transformation to high-performing, healthy green buildings, homes and communities throughout Canada" (CaGBC 2010), it is appropriate to use its principles as the benchmark to review implemented policies.

CaGBC's ten principles of smart growth include:

1. **Mix land uses.** Each neighbourhood has a mixture of homes, retail, business, and recreational opportunities.
2. **Build well-designed compact neighbourhoods.** Residents can choose to live, work, shop and play in close proximity. People can easily access daily activities, transit is viable, and local businesses are supported.
3. **Provide a variety of transportation choices.** Neighbourhoods are attractive and have safe infrastructure for walking, cycling and transit, in addition to driving.
4. **Create diverse housing opportunities.** People in different family types, life stages and income levels can afford a home in the neighbourhood of their choice.
5. **Encourage growth in existing communities.** Investments in infrastructure (such as roads and schools) are used efficiently, and developments do not take up new land.
6. **Preserve open spaces, natural beauty, and environmentally sensitive areas.** Development respects natural landscape features and has higher aesthetic, environmental, and financial value.
7. **Protect and enhance agricultural lands.** A secure and productive land base, such as BC's Agricultural Land Reserve, provides food security, employment, and habitat, and is maintained as an urban containment boundary.
8. **Utilize smarter, and cheaper, infrastructure and green buildings.** Green buildings and other systems can save both money and the environment in the long run.

9. **Foster a unique neighbourhood identity.** Each community is unique, vibrant, diverse, and inclusive.
10. **Nurture engaged citizens.** Places belong to those who live, work, and play there. Engaged citizens participate in community life and decision-making.

These elements are intended to be applied collectively to achieve results. For example, encouraging growth in existing communities maximizes existing infrastructure and contributes to the preservation of green space; mixed use developments facilitate the use of alternate methods of transportation. In practice however, it may be difficult to achieve these objectives concurrently. For example, preserving natural areas may increase automobile use and/or restrict housing affordability.

3.3 Design Guidelines

The design guidelines of smart growth further assist in understanding how the theory differs from traditional land planning, or "sprawl" as it is frequently called. Litman (2011) summarizes the two approaches, as shown in Table 1.

4 Advocates, Opposition and Ambivalence

There are three primary groups who extol the virtues of smart growth: environmentalists, urban planners and a select group of private real estate developers (CMHC 2005; Downs 2005; O'Connell 2009), however there are a similar amount of special interest groups who are in opposition. The majority of real estate, land development and construction industry members consider growth limitations an infringement on their economic interests; others believe strict zoning regulations violate the property rights of individuals (Litman 2011; O'Connell 2009). In addition, many opponents argue that smart growth design is not congruent with the preferred lifestyles of the majority, nor have the benefits cited by smart growth advocates been realized. The arguments in support of each position, grouped by the three pillars of sustainability—environmental, social and economic—are summarized in Table 2.

Response from the general public has been mixed. Although frequently frustrated by traffic congestion, many approve of smart growth principles in theory but are sceptical of their implementation. As a rule, when smart growth initiatives threaten to directly impact their communities, these initiatives are frequently met with strong opposition (Downs 2005; Grant 2002; O'Toole 2001).

Table 1 Comparison of smart growth and traditional design guidelines

	Smart growth	Traditional growth
Density	Higher-density, clustered activities	Lower-density, dispersed activities
Growth pattern	Infill (brown field) development	Urban periphery (greenfield) development
Land use mix	Mixed	Single use, segregated
Scale	Human scale. Smaller blocks and roads. Attention to detail, since people since people experience the landscape up close, as pedestrians	Large Scale. Larger blocks and wide roads. Less detail, since people experience the landscape at a distance, as motorists
Public services (shops, schools, parks)	Local, distributed, smaller. Accommodates walking access	Regional, consolidated, larger. Requires automobile access
Transport	Multi-modal transportation and land use patterns that support walking, cycling and public transit	Automobile-oriented transportation and land use patterns, poorly suited for walking, cycling and transit
Connectivity	Highly connected roads, sidewalks and paths, allowing more direct travel by motorized and non-motorized modes	Hierarchical road network with many unconnected roads and walkways, and barriers to non-motorized travel
Street design	Streets designed to accommodate a variety of activities. Traffic calming	Streets designed to maximize motor vehicle traffic volume and speed
Planning process	Planned and coordinated between jurisdictions and stakeholders	Unplanned, with little coordination between jurisdictions and stakeholders
Public space	Emphasis on the public realm (streetscapes, pedestrian areas, public parks, public facilities)	Emphasis on the private realm (yards, shopping malls, gated communities, private clubs)

Source Litman (2011)

5 Implementation

Various policies have been incorporated by jurisdictions to encourage smart growth, however many only consider certain components, or apply principles in an ad hoc manner, as opposed to taking the holistic approach recommended by theorists (CMHC 2005; Downs 2005; Song 2005; Staley 2006). Four primary mechanisms municipalities and regions have implemented: the encouragement mixed use development; increased densities; alternate transportation systems; and, establishment of urban growth boundaries. Of 202 US cities surveyed on their smart growth policies, 88.0 % had mixed use zoning, 62.2 % introduced higher density zoning, 56.0 % encouraged transit oriented development and 27.5 % of them had adopted an urban growth boundary (O'Connell 2009). Although exact ratios have not been calculated, Canada has followed in the footsteps of its US counterparts with similar emphases having been incorporated.

Table 2 Arguments for smart growth and traditional growth

	Arguments for smart growth	Arguments for traditional growth
Environmental	Reduces GHG emissions Improves air quality due to less pollution Improves water quality due the preservation of ecological systems Maintains biodiversity and preservation of wildlife species	Static traffic congestion because business suburbanizes as well Better storm water management due to fewer impervious surfaces (sidewalks, alleys, building densities)
Social	Revitalizes existing neighborhoods Greater community engagement Better accessibility for seniors and those under driving age Improves quality of life, less commuting and "chauffeuring" time Mixed housing types allow residents to remain in the community as their housing needs change	More prestige - especially in gated communities More privacy in low density developments Better public services (schools, police) Better neighborhood amenities Larger homes to accommodate traditional families and traditional lifestyles Fewer "undesirables", less crime
Economic	Reduces transportation costs for the public Reduces cost to maintain a smaller lot Reduces infrastructure costs for municipalities Revitalizes existing neighborhoods Mixed housing types provides options for buyers of different income levels Provides for affordable, local food production	More stable property values in homogenous communities Less expensive to develop greenfield sites Greater demand from home buyers, retail and commercial establishments Reduces investment required for costly public transit, which is used by a small percentage of the population, but borne by all taxpayers Protects property rights of land owners

Sources CMHC (2005), Downs (2005), Litman (2011), O'Connell (2009), O'Toole (2007), Suzuki (2003), Suzuki and Moola (2010)

5.1 Mixed Use Developments

Design guidelines and zoning amendments have been added to most Canadian cities' plans to encourage a combination of residential, retail and commercial use, primarily in an effort to revitalize inner city development (Grant 2002; O'Connell 2009). In many cases, mixed use has also meant allowing for a combination of housing types and densities (single family detached, multifamily and rental units) within an area zoned for residential use only. A significant omission from these policies has been industrial zoning. Most industrial zoning continues to be isolated and located on urban peripheries (Grant 2002).

Some suburban areas within city boundaries and in outlying municipalities have also promoted mixed use development but are less common. By 2000, approximately thirty mixed use communities were under construction across Canada (Grant 2002).

Both inner city and suburban mixed-use developments have been applied to individual sites without considering their interconnectivity to current and future development (Song 2005).

5.2 Increased Densities

Increased densities have been accommodated by mixed-use zoning and lot size reduction (O'Connell 2009). Density is also a critical component to support viable public transportation systems. CMHC (2005) suggests densities of twelve units per acre are needed to support public transport, however most zoning allows for densities of seven to eight units per acre. Density is the smart growth initiative that has received the greatest opposition by the general public and policy is less likely to mandate an increase in minimum densities as a result. US zoning verbiage generally puts a limitation on maximum densities as opposed to establishing minimum requirements, making implementation even more challenging.

5.3 Transportation Options

Plans that have encouraged both active (walking and cycling) and public transportation have been adopted by most jurisdictions encouraging smart growth (CMHC 2005). Transit plans have focused on inner city areas, as they have the highest densities to support high quality public transport.

Equal or greater funding for alternative initiatives is a cornerstone of policy, and many plans seek to limit overall road capacity while increasing public transit and improving the environment for walking and cycling (Hubbell and Colquhoun 2006; Toronto 2010; Vancouver 2007c).

5.4 Urban Growth Boundaries

The establishment of an urban growth boundary (UGB), or "greenbelt", is to serve two purposes: contain growth within the boundary's urban core, increasing density; and, designate the boundary itself as a preservation area for agricultural, ecological and/or aesthetic purposes (Ali 2008; Amati and Taylor 2010; Myung-Jin 2004). According to a study by Dawkins and Nelson, as many as one-quarter of municipalities in the US have implemented UGBs (Daniels 2010) with Portland, Oregon, being one of the first cities to have introduced legislation (introduced in 1980). The province of British Columbia created an Agricultural Land Reserve (ALR) in 1974, and although not specifically intended as an UGB, unofficially became one in 1996 through the Livable Region Strategic Plan (CMHC 2005).

Ottawa and Halifax are additional Canadian jurisdictions to have implemented UGBs and, most recently, Southern Ontario. Through its Greenbelt Act adopted in 2005, 1.8 million acres of land has been protected by this province (Ontario 2011).

6 Results

The data indicates that although some positive outcomes have been realized, smart growth policies have not significantly changed the urban landscape; performance has been comparable to cities without growth management policies (Staley 2006). A summary of results relating to CaGBC's ten principles is shown in Table 3.

Table 3 Select cities' realization of CaGBC's smart growth principles

	Toronto	Calgary	Vancouver	Portland
Mix Land Uses	success with inner city redevelopment of industrial sites			
Build well-designed Compact Neighborhoods	greenfield developments remain largely of traditional low-density residential designs			
Provide a variety of transportation choices	automobile use same or greater than 1990			
Create diverse housing opportunities	single family detached remains dominant			
Encourage growth in existing communities	greater growth outside urban core			
Preserve open spaces, natural beauty and environmentally sensitive areas	no policy pre 2004		relatively intact	
Protect and enhance agricultural lands	no policy pre 2004		relatively intact	
Utilize smarter, and cheaper infrastructure and green buildings	no policy	slightly lower infrastructure costs but higher government cost per capita; LEED standards applicable to government buildings only		
Foster a unique neighborhood identity	indeterminate			
Nurture engaged Citizens	no policy pre 2004			

Sources Behan and Lea (2010), CMHC (2005), Davis (2008), O'Toole (2001), Portland (2010), Portland (2012), Vancouver (2012)

6.1 Successes

Positive outcomes have been achieved by redevelopment of inner city sites and land preservation.

6.1.1 Mixed Land Use: Inner City

Mixed-use development has been most successful in the redevelopment of brownfield sites within the urban core. Examples are Vancouver's False Creek Development, Toronto's Harborfront and Calgary's Bridgeland.

It is important to note that these redevelopment efforts are costly and time intensive. For example, the Royal Commission began the planning of Toronto's Port Lands in 1992 with the first phase of construction breaking ground a decade later (Toronto 2008). The Port Lands' master plan is still in public consultation (Toronto 2013). Vancouver's False Creek policy was adopted in 1999 with zoning approvals being finalized in 2006 (Vancouver 2007a) and Calgary's Currie Barracks encountered seven years of delays (Braid 2006).

6.1.2 Natural Land Preservation

Generally, natural and agricultural areas established by UGBs have been preserved (CMHC 2005; Daniels 2010; Portland 2012), although many caution that this may change when development reaches the constraints of the boundary, or when economic conditions make reductions to the boundary more attractive than maintaining preservation (Ali 2008; Amati and Taylor 2010; Daniels 2010).

6.2 Failures

Numerous studies suggest that these policies have done little to contain urban growth, increase densities, or reduce automobile use.

6.2.1 Mixed Land Use: Suburban Areas

Suburban mixed-use has produced less than stellar results and greenfield sites continue to be developed with single-zoned use. One of the first suburban communities to introduce mixed-use land planning was McKenzie Towne, a 2,400-acre development in South Calgary. Its first phase included commercial space the developer could neither sell nor fully rent. High-end homes adjacent to other housing types were also slow to sell (Grant 2002). These results, in combination with higher infrastructure costs associated with the design, incited the developer to revert to a conventional land plan in subsequent phases (CMHC 2005; Grant 2002).

Table 4 Population growth between central city and other CMA regions

Census metropolitan area (CMA)[a]	CMA growth 2001-2011	Central city growth 2001-2011	Non-central city growth 2001-2011	Central city growth as percentage of CMA growth (%)	Non-central city growth as percentage of CMA growth (%)
Toronto	900,167	133,566	766,601	14.84	85.16
Calgary	263,345	217,830	45,515	82.72	17.28
Vancouver	326,563	57,831	268,732	17.71	82.29
Portland, OR[b]	298,128	54,655	243,473	18.33	81.67

[a] includes urban/suburban areas
[b] data from 2000–2010
Note High central city growth for calgary is resultant of a large annexation of land into the municipality
Sources Statistics Canada (2011), US Census Bureau (2010)

6.2.2 Encourage Growth in Existing Communities

In both Canada and the US, areas outside the central cities have been growing at a faster pace than within the cities themselves (CMHC 2005; Cox 2004; Demographia 2004). Studies have calculated suburban areas have accounted for over 95 % of urban growth. Table 4 shows a chart of the urban/suburban growth breakdown for the cities included in Table 3.

Portland, Washington, DC, Minneapolis/St. Paul, Ottawa have all experienced "leapfrog development" to regions outside their UGBs as these regions were not subject to the city's development constraints (Amati and Taylor 2010; Downs 2005; Myung-Jin 2004; O'Toole 2001). For example, of the new housing units constructed in the Portland region in the 1990s, 40 % were built outside the UGB (Myung-Jin 2004).

6.2.3 Increased Densities

Inner city development of infield sites has not compensated for the increase in suburban growth, and densities have not increased significantly as a result. A reduction in household sizes has also prevented the realization of higher densities (CMHC 2005; Cox 2004). Proposed employment nodes at transit stations have been largely unrealized in Calgary due to a lack of implementation strategy, market dynamics and public opposition to increased densities (Hubbell and Colquhoun 2006) and Toronto's employment nodes have been too dispersed to significantly concentrate density (CMHC 2005).

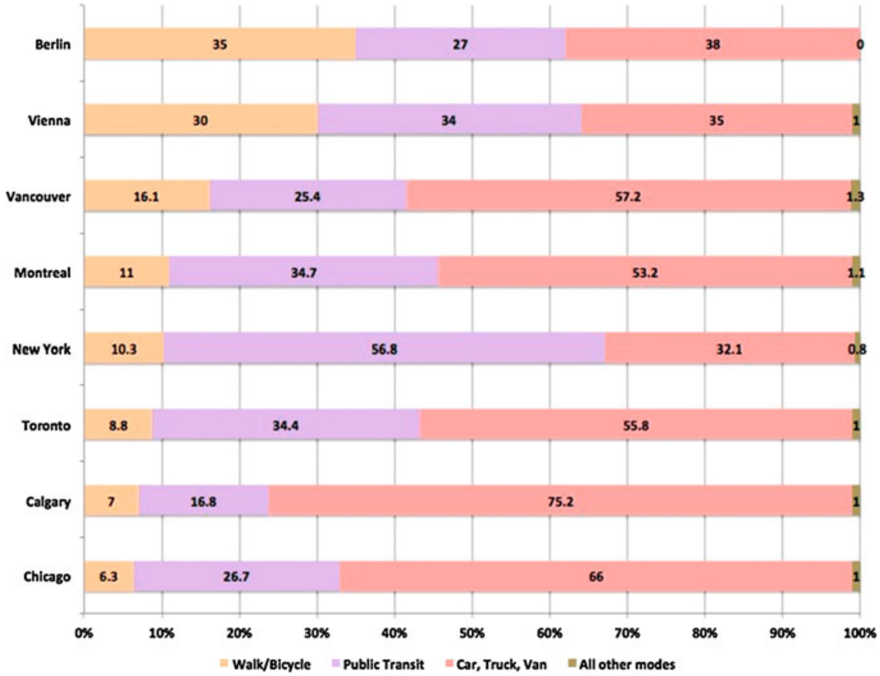

Fig. 1 Transportation modal breakdown (2007)—in percent. *Source* Behan and Lea (2010)

6.2.4 Alternate Transportation Use

Automobile usage remained relatively static in all six regions studied by CMHC (2005): up to 2 % higher in four regions and a similar decrease in the remaining two. Of eight international metropolitan areas studied (Behan and Lea 2010), the Canadian cities had the highest automobile modal share. Automobile use in these four cities ranged between 50 and 76 % whereas the two European cities usage was less than 40 % (see Fig. 1).

Portland's per capita driving increased 20 % between 1990 and 1998, despite a large funding commitment for its light rail system (O'Toole 2007), and an analysis of empirical data over a 20 year period showed no correlation to increased transit use and Portland's urban growth containment policies (Myung-Jin 2004). Light rail additions in many other US communities have also failed to alleviate traffic congestion (Downs 2005).

In addition, industrial areas provide many employment opportunities but are usually isolated from residential areas. They are poorly serviced by public transport and difficult to access by active transportation (Grant 2002). For example, employment in Calgary continues to be concentrated in the east (representing 34 % of the area's employment in 2006) while residential development continues in the west. This has further exacerbated automobile use (Hubbell and Colquhoun 2006).

Because suburban areas are growing at a faster rate than urban areas and automobile use is the primary source of transportation, private transportation use continues to grow.

6.2.5 Diverse Housing Options

In Canadian projects, apartments have higher vacancy rates in communities with apartment/owner housing mixes; apartments above stores frequently end up being leased to other businesses (Grant 2002). For sale detached residential housing continues to represent the majority of new construction (CMHC 2005; O'Toole 2001).

Although housing affordability has remained relatively static in the Canadian cities studied (CMHC 2005), affordability data includes both urban and suburban areas. Several other studies support the argument that UGBs have decreased the availability of affordable housing within the urban core (Daniels 2010; Downs 2005; Cox 2004; O'Toole 2001).

Gentrification of inner city neighborhoods have increased population within these areas, however increased densities or a mix of housing types have not been realized (Grant 2002). The improved desirability of these neighbourhoods also increased housing costs, driving out the working class and contributing to homelessness issues (Barnes and Hutton 2009; Grant 2002). Examples of this are Cabbagetown in Toronto and Yaletown in Vancouver.

6.2.6 Green Buildings and Smarter Infrastructure

Although one of CaGBC's smart growth principles, green buildings and infrastructure are rarely mentioned by other organizations advocating smart growth. Introduction of green building policies have generally been limited to government compliance to LEED (Leadership in Energy and Environmental Design) standards (Calgary 2013; Portland 2012; Vancouver 2007b). Some—including Portland and Vancouver—have provided incentives for green initiatives within commercial development (US Department of Energy 2012; Vancouver 2007b). Energy efficiency in residential construction is currently considered "best practice" by municipalities however, as required standards do not exist in any Canadian city reviewed.

Many regions have upgraded their water and sanitary services but have done so through traditional construction methods. Empirical analysis has determined infrastructure costs in higher density areas are less, but by an insignificant amount (Cox and Utt 2004). The implementation of smarter infrastructure is in review but no formal policies are in place in any city reviewed.

7 Assessment of Results

There are three primary reasons why the majority of smart growth objectives have been unsuccessful: conflicting planning guidelines; localized authority and consumer preference.

7.1 Conflicting Planning Guidelines

Although many jurisdictions have incorporated smart growth principles into their municipal plans, initiatives are still relatively recent. A standardized framework has not been established and implementation has been inconsistent (Jepson and Edwards 2010; Song 2005). Existing zoning regulations must be amended and current infrastructure design altered—processes which are traditionally slow and cumbersome (Downs 2005; Schmidt 2004).

Different departments within municipalities also have different objectives. For example, traffic planners are concerned with efficient vehicle movement and emergency response personnel concerned with site access whereas the higher densities and narrower streets recommended for smart growth design threaten to impede both (Braid 2006).

Federal and/or provincial fiscal policies—such as gas subsidies and road improvement funding—can work against local initiatives by continuing to promote the use of private vehicles (Schmidt 2004). Alberta's economic downturn in the 1990s suspended funding for Calgary's light rail transit for a decade (Hubbell and Colquhoun 2006) with a similar scenario occurring in Ontario (Get Toronto Moving Transportation Committee 2012).

7.2 Localized Authority

Unless the region is considered as a whole, uncontrolled growth in one area will undermine controlled growth in another. This has been clearly shown by the results realized in those areas having established UGBs. Not only are authoritative bodies generally unwilling to give up control of local planning, but the ability to gain consensus across boundaries is difficult (Downs 2005).

7.3 Consumer Preference

It is argued that consumers who prefer alternate modes of transportation will naturally gravitate to higher density or mixed-use developments but that does not mean the creation of these developments will change the behaviours of those who prefer to rely on their cars (O'Toole 2007). As such, increased car use, coupled with increased densities, has contributed to traffic congestion as opposed to alleviating it.

As evidenced by the continuing trend in suburban growth, the majority of consumers—especially those with families—prefer conventional community designs. Absorption ratios are significantly higher in these areas, which encourage developers to continue using traditional land planning models to meet consumer demand (Grant 2002; Cox 2004).

For obvious economic reasons, retail establishments follow residential growth patterns. This, in combination with the popularity of big box stores and one-stop shopping, lower land costs and adequate area to accommodate automobile use, continues to encourage major retailers to invest in the suburbs rather than test unproven business models.

Consumers have proven to be fearful of policies which threaten to decrease the value of their homes (Downs 2005; Grant 2002). For this reason, higher density and adjacent lower-cost housing are two strategies which have received the greatest opposition.

The redevelopment of brownfield sites has been driven by economic interests of municipalities and specialized developers (O'Connell 2009), but has been successful because of consumer preference: these revitalized areas appeal to a segment of the population preferring an active lifestyle close to urban amenities. Also, because these sites are not valued by the neighbouring communities, less opposition has been encountered.

8 Smart Growth and Sustainability

As smart growth principles have generally not realized their intended results, an additional question should be considered: is it an implementation issue or a fundamental flaw with smart growth theory?

The most commonly cited definition of sustainable development is that of the Brundtland Commission (WECD 1987): "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Three types of needs are considered—environmental, social and economic—which are referred to as the pillars of sustainability.

Returning to CaGBC's definition of smart growth, its objectives are to "enhance our quality of life [social], preserve the natural environment [environmental] and save money over time [economic]". The effectiveness of smart growth principles in achieving these objectives follow (refer to Table 2 for a detailed list of benefits cited by proponents.)

8.1 Social

As the majority of the population continues to gravitate to low-density housing, it is reasonable to assume this is their ideal model for quality of life. In implementing increased density, it could be argued that the perceived social benefit of the few is being imposed on the many.

Other social issues, such as providing mixed housing options to facilitate choice and encourage diversity within the community, are supported by smart growth. However it has been shown the creation of diverse housing opportunities does not guarantee housing affordability. Government initiatives specifically addressing affordability issues—either through regulation or market-based incentives—must also be present.

8.2 Environmental

Density in itself does not seem to reduce automobile use (Cox 2004; O'Toole 2007) and despite significant investment in transportation systems, the automobile remains the preferred mode of transportation. This suggests that in theory the combination of density and alternate transportation modes would reduce GHG emissions, but in practice consumers must have sufficient incentive to change their behaviours.

While efforts to reduce GHG emissions through reduced automobile use are admirable, buildings are responsible for over half of all emissions (Pembina Institute 2011; Toronto 2007; Vancouver 2007c). As noted earlier, it is rare that green buildings have been considered a smart growth principle. In light of the significant impact they could have on climate change, CaGBC's inclusion better promotes the environmental objectives of smart growth.

Until a better model is discovered, land preservation is necessary to preserve ecological systems and agricultural land. As innovative technologies to provide sustainable infrastructure solutions are in development stages (Flow 2008) these preservation needs may change, however the general public also places aesthetic value on natural areas. Although the majority of urban planners have concluded acceptable areas cannot be preserved with growth continuing at current rates and densities, there is data which suggests otherwise (Cox 2004; O'Toole 2007) and further study is suggested.

8.2.1 Renewable Energy

One significant principle which is absent in the smart growth model is renewable energy. Perhaps this is because the theory was developed before renewable technologies were considered economically feasible. Today, generating clean energy, to include supplementing energy provided by the grid, are important components of a sustainable urban environment and climate change mitigation. Due to site limitations (shading, obstructions), renewable technologies such as wind and solar power are more effective in lower density areas than higher ones (Boyd 2010). As it may not be desirable to install turbines or solar panels on agricultural or ecological land within a preservation area, lower density development alongside higher density may better support the incorporation of self-generated renewable technologies.

8.3 Economic

When combined with a case for economic vitality, such as inner city brownfield redevelopment, smart growth principles are most successful: these locations do not need preservation; existing infrastructure is maximized; and, the tax base of the city is improved (O'Connell 2009). As noted earlier however, if affordability is to be realized government intervention may be necessary.

The suggestion that money can be saved over time is unsubstantiated. Although costs of municipal infrastructure are slightly higher, the savings (calculated at approximately $40 per year per capita) may not provide sufficient justification to increase densities beyond what is preferred by the majority (Cox and Utt 2004). Furthermore, other infrastructure costs, such as public transportation, traffic calming measures, additional sidewalks and cycling lanes do not appear to be considered in the cost saving calculation.

Transportation cost savings for the public are also in question. As noted earlier, consumer preference will dictate residence location, and economic and personal factors will determine location of employment. Studies have shown UGBs have extended cross-border commutes as there is no assurance a citizen will choose to live close to where they work (Cox 2004; Myung-Jin 2004).

9 Recommendations

9.1 Engage Stakeholders

Dialogue with citizens and the business community is critical. Urban planners may see the benefit of controlled growth, but successful land design is heavily dependent on those who use it. Citizens who are fearful of declining property values and prefer to use their cars will continue to oppose smart growth initiatives. Businesses that derive more economic value by locating in similarly zoned areas will be reticent to try new models.

There are several avenues in which urban planners can encourage participation such as charettes and workshops, surveys (print and online), and focus groups (de

Sousa Briggs 2003; Preskill and Jones 2009). If internal expertise is unavailable to coordinate such initiatives, several independent organizations specialize in public–private engagement. Examples are The Allen Consulting Group, Pace Consulting, and Prairie Wild Consulting. In addition, citizen advisory committees are becoming increasingly utilized by city governments for specific issues and also hold promise in shaping growth plans. These committees are comprised of community volunteers interested in the issues, bringing with them a diversity of expertise and perspective. In their capacity on the committee, not only can they contribute a broad range of ideas, but also liaise between the government and the general public (Courter 2010).

Alliances with NGOs that support active lifestyles, alternative modes of transportation (walking, biking) and community involvement can lend credibility to smart growth initiatives and contribute to changing behaviour. Public–private development partnerships, tax incentives and streamlining permitting/approval processes will encourage the business community to invest more seriously in mixed land use projects.

By fully engaging all stakeholders in a meaningful exchange of ideas, urban planners can more effectively communicate the benefits of smart growth and also shape policy to better serve constituents.

9.2 Transition Toward Regional Planning

As mentioned, smart growth has been defined as a solution to sprawl. Sprawl was created, in part, by a lack of cohesive planning within cities. Without the implementation of regional planning, similar results may be produced when incorporating smart growth principles. Also, regional planning has the potential to eliminate the "leapfrogging" development trend that has undermined the efforts of many cities in their attempts to control growth.

9.3 Incorporate Complementary Initiatives

As mentioned, it has been argued that many jurisdictions have not taken a holistic approach to smart growth. Based on the evidence, it could also be suggested that the smart growth model has not taken a holistic approach to sustainability. Smart growth principles are part of the solution to sustainability but are not all-encompassing. Either additional principles should be added to the smart growth model or smart growth should be combined with other initiatives—such as green infrastructure and clean energy.

Decreased housing affordability continues to plague smart growth developments and can only be solved with changes to public policy. Examples such as restricting the sale (and price) of a percentage of units for low income purchasers and/or reserving a percentage of units for social housing programs would ensure diverse housing opportunities remain available.

CaGBC's principle #8: Utilize smarter, and cheaper, infrastructure and green buildings is a step toward sustainability that is absent in most other smart growth models, however rather than attempting to establish yet another set of guidelines, smart growth models would benefit from partnering with existing initiatives. LEED, Passive House and Living Building Challenge are three programs that have been also been adopted by CaGBC. Both LEED and Passive House focus on building efficiency while Living Building Challenge includes twenty over-arching imperatives—including green infrastructure, water use and net zero energy.[1] Rather than treating each as an independent program, an interrelationship between the four should be established.

10 Concluding Remarks

While smart growth principles do align with sustainability objectives and aim to address climate change through reduced vehicle use, results have been mixed. When evaluated against CaGBC's ten principles, the data reviewed suggests there have been more failures than successes. This is a result not only of ineffective implementation, but also of the theory itself. Smart growth can be part of the answer in working toward urban sustainability but it is not the whole answer. By encouraging meaningful dialogue—among all stakeholders and across regions—the benefits of smart growth can be better communicated, affecting change in consumer behaviour. Dialogue can also provide valuable feedback from citizens and the business community which government can use to create win–win urban planning models. A transition to regional planning will allow these models to be cohesively supported throughout the region. Further, in considering complementary initiatives in conjunction with smart growth principles, government can better align urban development with sustainability goals.

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[1] While it is beyond the scope of this chapter to discuss these existing programs in detail, for further information, visit CaGBC's "Programs" page at http://www.cagbc.org/AM/Template.cfm?Section=Programs

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Geographic Information Systems (GIS) as a Tool in Reducing a Community's Ecological Footprint

Rod Schatz, Doug Walker, Jaap de Kroes, Gustavo Arciniegas, Paul Getz and Anshuman Khare

Abstract A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographically referenced data (Foote and Lynch 2000; Burrough and McDonnell 1998; Bernhardsen 2008). GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data, maps, and present the results of all these operations in real time. In recent times, GIS has become an indispensable tool for city planners in designing urban areas or renewing existing neighborhoods and visualizing the impact of their decisions. To accommodate the growth of cities and to address complex economic, environmental and social challenges, municipalities are broadening the use of local and regional information to assist in more effective decision-making regarding matters of local and regional importance. As this chapter demonstrates, GIS tools can assist municipalities in future planning through design process synthesis and integration, namely the implementation of the land use, transportation, housing, and energy plans. The discussions in this chapter will focus on how this tool can be used to educate and engage audiences in reducing the ecological footprint of a community by touching on issues such as housing transportation development of green spaces and overall ensuring a good quality of

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life for communities. Success stories from North America and Europe highlight the experience of the communities who are using GIS to this purpose.

Keywords Geographic information system (GIS) · Scenario planning · Climate change · Urban planning

1 Introduction

In today's fast-paced and constantly changing world, our industrial society is faced with large scale and difficult problems such as climate change and these problems now require unique solutions and specialized analytical techniques. This is particularly more prominent for our global cities as it relates to their ecological footprints and the impact they have in their contribution to global climate change. Cities are on the frontlines when it comes to climate change since they are society's first point of contact with our designed world and the services they provide both directly and indirectly contribute to climate change as a result of the large population bases they serve.

The United Nations (UN) released a report, stating that the World's cities are responsible for up to 70 percent of the harmful greenhouse gases while only occupying just 2 percent of its land mass (United Nations Human Settlements Programme 2011). Current estimates have approximately 50 percent of the world's population living in global cities (United Nations Human Settlements Programme 2011). The services cities provide vary from community design to operational infrastructure services for subdivisions, transportation networks and other critical infrastructure and each of these service types can contribute dramatically to climate change, principally, if the services are not designed efficiently. In essence, cities provide the core services for human habitation and many cities are beginning to realize their impact on climate change and are searching for solutions to reduce their impact.

The discussions in this chapter will focus on how a Geographic Information System (GIS) can be used to educate and engage stakeholders for reducing the ecological footprint of a city by touching on issues such housing, urban design, transportation, development of green spaces and ensuring a good quality of life overall for communities. This chapter is written with the assumption that the reader is not familiar with GIS technology or its real world application. Consequently, the chapter endeavors to provide some background information on how a GIS functions.

2 What is a Geographic Information System?

A Geographic Information System is a computer-based system designed to capture, store, manipulate, analyze, manage and present all types of geographically referenced data (Foote and Lynch 2000; Burrough and McDonnell 1998; Bernhardsen 2008).

In essence, a GIS links map-related (spatial) data to a storage database of attributes (characteristics about the spatial features commonly referred to as non-spatial attributes). The true power of a GIS comes from its ability to leverage the linked spatial and non-spatial information and perform spatial analysis across map features and attributes to identify spatial patterns in the data that were not evident in its tabular form. These graphical spatial analysis capabilities are what separate a GIS from other information systems such as a Relational Database System (RDBMS).

A GIS allows users to create interactive queries (user-created searches), analyze spatial information, edit data and maps and subsequently present the results of all these operations (Clarke 1986). Most importantly, the real value of a GIS in urban planning related to climate change is its ability to help urban planners and policy makers analyze and visualize the consequences of potential actions. The analysis undertaken with a GIS can be done at a macro or micro level. Further, the problems analyzed could be on a regional level or small-scale study area.

Tomlinson (2003) categorizes the uses of a GIS as a particularly horizontal technology that consequently means it has far ranging application across the industrial and intellectual landscape. Consequently, the use of a GIS is well suited to the use of tracking, monitoring and scenario planning for climate change and local government ecological footprints. A commonly referenced business quote is "What gets measured gets done, what gets measured and fed back gets done well, what gets rewarded gets repeated" [John E. Jones quoted in Williamson (2006)] can be seen as providing the basis of what GIS does. GIS is a powerful tool that can assist local governments with measuring, monitoring and facilitating the creation of continuous improvement cycles that are critical for helping to address climate change issues.

The capabilities that a GIS provides can help to educate the public on climate change issues, enable political decision makers through sound evidence to govern through the creation of effective polices and most importantly, provide bureaucrats with the proper tools to track, monitor and measure the effectiveness of their performance measures to improve their ecological footprints. More importantly, a GIS assists Municipalities with the problem of accessing and sharing data with key stakeholders, which is particularly significant when one considers that Municipalities are charged with effective decision and policy making on behalf of its citizens but citizens need to be included in the process.

In recent times, GIS has become a handy tool for city planners in designing urban areas or renewing existing neighborhoods. To meet the growth goals of cities and to address their complex economic, environmental and social challenges, municipalities are broadening the use of local and regional information that will assist in more effective decision-making regarding matters of local and regional importance.

The factors that have the highest impact in terms of climate change are those that are the highest contributors to Greenhouse Gas (GHG) emissions. Not only are factors such as energy, housing, transportation contributors to GHG emissions, they also come in the way of providing better services and citizens having a better quality of life.

> "Cities are responsible for the majority of our harmful greenhouse gases. But they are also places where the greatest efficiencies can be made. This makes it imperative that we understand the form and content of urbanization so that we can reduce our footprint…understanding the contribution of cities to climate change will help us intervene at the local level. With better urban planning and greater citizen participation we can make our hot cities cool again" (United Nations Human Settlements Programme 2011).

A GIS can map and analyze the geographic distributions of the elements that contribute to GHG emissions. But more importantly, however, a GIS constitutes an excellent mechanism to allowing urban planners, engineers and other community designers with the ability to explore and create "what if" scenarios related to their proposed designs and the design's impact to contributing to the GHG. This means that a Transportation Engineer can use GIS to analyze the potential impact of a road design and its effects on commuter gas usage, noise pollution, and other variables in real time. According to the Intergovernmental Panel on Climate Change (IPCC), worldwide transportation is responsible for approximately 23 percent of the total energy related greenhouse gas emissions (United Nations Human Settlements Programme 2011).

The 2011 UN Report on Cities and Climate Change makes a recommendation that to fully understand and map the impact of cities and climate change, several major factors need to be tracked and measured as these factors influence the total CO_2 emissions of urban areas. According to United Nations Human Settlements Programme (2011), these factors are:

1. city's geographic location—it will determine the amount of energy required for heating, cooling and lighting;
2. demographics—the size of the population base will influence the demand for space and services;
3. city's urban form and space density—larger cities tend to have higher per capita emissions than more compact cities;
4. urban economy—types of economic activities and whether these emit large quantities of greenhouse gases; and finally,
5. other socio-economic factors such as the wealth and consumption patterns of urban residents.

In summary, through the use of a GIS local governments are able to track, monitor and analyze all of these relevant factors highlighted by the UN report effectively and a GIS ultimately allows policy makers to investigate and identify relationships that would not have been evident in the data in its raw tabular form and this can all be done in real time allowing for hypotheses and design assumptions to be tested. Ultimately, the GIS will reveal spatial patterns and allow for a more thorough understanding of how these factors interact in our landscape.

3 Cities and Climate Change GIS Based Scenario Planning: An Introduction

Urban planners, architects and engineers have the most dramatic effect upon designing our built environments. However, very few of them analyze the effect their designs will have upon climate change. Some urban planners use GIS-based applications for the public participation processes to show one design over another, but few are modelling their designs to look at the impact their designs will have on future climate change and to determine if a more optimal design should be considered.

A GIS provides urban designers with the ability to create real time "what if" models that in turn create scenarios or alternatives based on a set of impact assumptions or indicators. The impact assumptions can be economically, socially or environmentally based and can be easily changed to alter the outputs of the model. Common modelling impact assumptions could come from the list of factors identified by the United Nations Human Settlements Programme (2011), or could be the proximity to environmentally sensitive areas, waste water produced, waste water created, energy used per land use zone, density per land use, vehicle kilometers travelled and number of dwelling units created, the list is almost limitless. The impact assumptions list is just a sampling of the numerous indicators that a GIS can model and effectively analyze.

By using a GIS for "what if" modelling, it gives urban designers the ability in real time, through an iterative process, to gain a greater appreciation for all of the variables at play and how they impact climate change or other important effects. A GIS-based modelling approach assists urban designers, policy makers and the general public with education, awareness and most importantly, with understanding the effects a design or policy will have on the environment.

"What if" scenario planning is particularly important when we look to design our 'built world' for optimal efficiencies to reduce our impact on our 'natural world'. The subsequent sections of this chapter will profile three public sector agencies through case studies relative to the use of a GIS based model that was used to increase public awareness, develop climate change plans and ultimately assisted the organizes with furthering their programs in greenhouse gas reductions. Each case study followed a similar yet overall methodology as follows:

1. Statement of project objectives, usually including a description of the planning context and anticipated future needs of the community.
2. Data gathering, including both spatial data and non-spatial data pertinent to the project.
3. Model gathering or creation, in which rules or algorithms are assembled that
    a. suggest how change to the area will occur over time and
    b. estimate the potential impacts of that change regarding climate change and related concerns.

4. Creation of an analysis framework within the GIS that allows planners to suggest alternative choices and policies, and then "see" their likely consequences over time via new maps, charts, tables, and other reports and displays. Planners often base their analysis framework on the concept of scenarios.
5. Collaborative discussion and problem-solving among project stakeholders, using the analysis framework as an interactive support tool.
6. Concluding decisions and a statement of expected outcomes, sometimes called the "preferred scenario."

The three case studies highlight organizations that are looking to ensure the designs they develop for their communities are optimal to reduce CO_2 emissions.

3.1 Interagency Climate Change Scenario Planning Pilot Project on Cape Cod, USA

3.1.1 Problem Statement

In 2010, an interagency working group of United States (US) federal agencies, working through the US Department of Transportation's Volpe Center, commissioned a pilot project to test a new approach to long-term (greater than 20 years) regional planning. The inspiration for this work was to look at climate change from both sides: its causes and, its effects related to transportation infrastructure and land use (United States Volpe Center 2011).

The US transportation sector alone represents approximately 10 % of all energy-related greenhouse gas emissions worldwide (United States Environmental Protection Agency 2007). One way to reduce transportation-related emissions over time is to change patterns of development, which in turn affect the amount of driving people will ultimately do. For example, a landmark study by the Urban Land Institute in 2008 called *Growing Cooler* concluded that compact development can reduce vehicle miles traveled by 20–40 percent compared to conventional, spread out development patterns (Ewing et al. 2008). In this pilot project, GIS-based computer modeling software was configured to estimate the GHG emissions associated with future land use plans being sketched in real time on a map. More compact plans resulted in quantifiably fewer GHG emissions.

3.1.2 Methodology: Tools and Techniques

The pilot project examined how rising sea levels and increased storm surge in coastal areas might affect roads, rail lines, and residential and commercial development in the future. Coastal areas are of particular interest in the United States, where over half the population lives within 50 miles of the coast (United States National Oceanic and Atmospheric Administration 2012).

In the pilot project, Volpe and its partners convened a two-day workshop of local and regional planners who were charged with creating a long-term land use and transportation plan for Cape Cod, the coastal peninsula off Massachusetts. Cape Cod has an area of 1,070 km^2 and a current population of approximately 200,000 with expectations of steady population growth over time.

Workshop participants worked in small groups using real-time and live data in a GIS-based scenario planning application called CommunityViz (Walker and Daniels 2011) where the map scenarios were projected onto large tables. Using infrared pens, participants could draw potential plans for the location and type of new residential and commercial development. The GIS was able to update the model and produce revised results based on the participant's potential plan in real time.

Participants were also able to experiment with new transit stops. As the participants worked, the software ran real-time calculations about their plans' effects on greenhouse gases, the amount of new development in dangerous coastal areas, and a wide variety of other interconnected topics relating to housing, transportation, and environmental concerns (Fig. 1).

3.1.3 Results

The workshop used Scenario Planning, where a number of future alternatives were created and compared to each other to gain insights about the complex system dynamics of a regional plan. Based on those insights, candidate plans were revised and refined through several iterations to create a final solution. One of the clearest findings for participants was that reducing greenhouse gases involves trade-offs against other priorities, all of which need to be balanced. For example, one sample scenario that was estimated to reduce GHG by an excellent 6.2 % compared to the trend also had the unfortunate effect of increasing the percentage of new population in areas vulnerable to sea-level rise from 28 to 44 %. In the end, the refined scenario emerging from the workshop was estimated to reduce GHG 5.3 % compared to the current trend. An added benefit was a population reduction in vulnerable areas and consistent goal tracking on several other goals that included protection of critical habitat areas, rural areas, historic preservation areas, and water resource protection.

3.2 Coastal Resiliency Seminar in Texas, USA

3.2.1 Problem Statement

Following the success of the Cape Cod pilot study, GIS-based table-top scenario based sketching workshops have been gaining popularity thus extending their scope and applicability to climate change outreach and education. In 2011, for

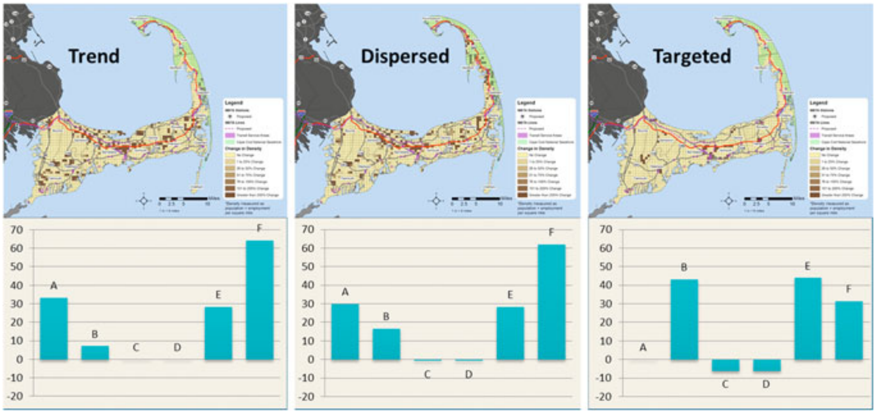

Fig. 1 Example maps and modeling results from Cape Cod pilot project. The maps show three scenarios for growth: trend with a medium level of compactness, Dispersed with low compactness, and Targeted with compact growth in locations carefully chosen to reduce climate change and other impacts. In the *charts*, the vertical axis goes from −20 to 70. *Bars* show modeling results from CommunityViz GIS software for *A* Percent of land area developed (from previously undeveloped or rural). *B* Percent of new population served by transit, *C* Regional percent change in regional vehicle miles traveled compared to trend, *D* Percent change in regional greenhouse gas emissions compared to trend, *E* Percent of new population in vulnerable areas, and F New population in other high priority conservation areas. All data is for illustrative purposes only. (Graphics courtesy of Placeways LLC)

example, Professor John Jacob and Steve Mikulencak of Texas A&M University's Texas AgriLife Extension and the Texas Coastal Watershed Program initiated a project to engage broader community audiences in regional planning and climate change (Mikulencak and Jacob 2011).

Their study, which took on the nickname "Coastal CHARM (Community Health and Resources Model)," focused on the Houston–Galveston region, which is expected to grow by as much as 2.9 million people in the next 25 years. This project shared many themes with the Cape Cod pilot, and it also covered a broad range of topics including groundwater pollution, the encroachment of development on prime agricultural lands and plant and animal habitats, and significant hurricane risk.

3.2.2 Methodology: Tools and Techniques

All of these topics are amenable to GIS-based modeling using CommunityViz (as in this case) or similar tools. Some involve straightforward overlap calculations, such as how many hectares of agricultural land falls under development. Others require more sophistication, and part of the planner's job is to decide how detailed and precise to make the model. For example, it is possible to construct very detailed models of how development affects the way water runoff flows across surfaces and through soils, picking up undesirable contaminants along the way. However, such models require large amounts of detailed data and intense computer processing, which add time, cost, and inconvenience to the process of making planning decisions. As a result, planners sometimes decide to use modeling approaches that are simpler and less precise—though still accurate enough to make informed decisions. In the case of groundwater, for example, it may be enough to estimate the amount of impervious surface introduced by new development and use that as a proxy for the eventual effects on water quality. In this study, an intermediate level water quality model was adopted.

3.2.3 Results

Hurricane risk is widely expected to increase with increasing climate change and is a significant concern to residents of this region (United States Climate Change Science Program, 2008). In one particularly vivid CHARM workshop exercise, for example, participants could overlay hurricane-based flooding on their proposed future development and assess the potential economic damage to houses and infrastructure. The model offered choices of two real hurricanes from the past and one hypothetical hurricane of the future. The level of inundation from each hurricane had been carefully modeled in a separate tool, and summary results were imported to CommunityViz for use in real-time workshop exercises. The location of new development in flood-prone areas was of course the most important factor, but participants were also given tools for varying the use of hurricane-resistant construction techniques. For example, raising the ground floor of a building increases its resistance to storm surge damage, but also increases its construction costs. This exercise helped participants internalize ideas about how a present-day investment in buildings can reduce the risk of future damage and costs (Fig. 2) that may arise from long-term climate change.

3.3 Transitioning to Sustainable Energy, the City of Arnhem, the Netherlands

3.3.1 Problem Statement

Arnhem is a City in the eastern section of the Netherlands located alongside the Rhine River. It is a city with about 150,000 inhabitants living in roughly 65,000 buildings of the City's 77,000 buildings. The City of Arnhem has included in its policy the European Union (EU) goal to reduce greenhouse gas emissions by at least 20 percent by 2020 (European Union 2008). Consequently, this means that about 20 percent of all energy used within the City should be generated in a sustainable way while at the same time a 20 percent reduction in energy use should

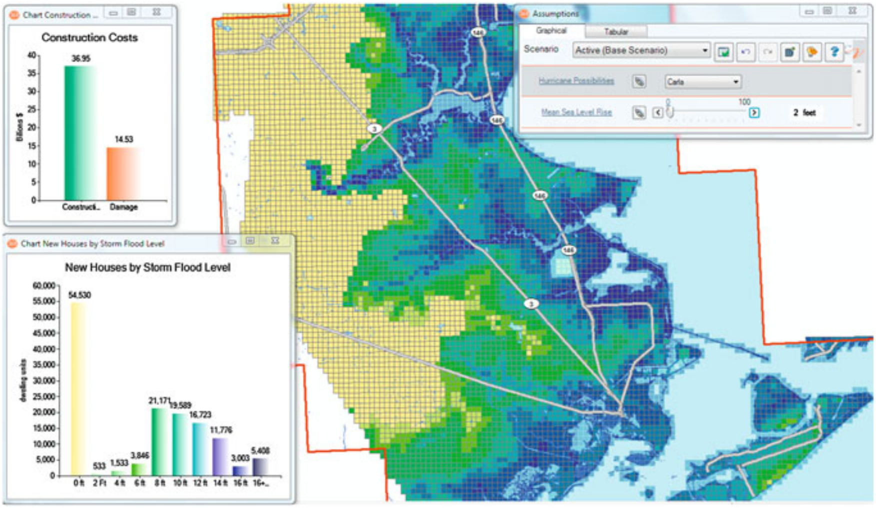

Fig. 2 Screenshot from CommunityViz software being used in the Coastal CHARM model. The hypothetical example was used to illustrate the effects of a possible hurricane on future development in the Houston–Galveston area of Texas. On the map, *darker shades of blue* represent deeper flood inundation (Image courtesy of Placeways LLC)

be achieved by improving energy efficiency. Consequently, a decrease in energy use will result in increasing the chances of being able to fulfilling the objective or reducing energy consumption and ultimately. The ultimate goal that the City set for itself is to be energy-neutral by the year 2050. This means that Arnhem is currently going through a transition from fossil fuels to more sustainable energy sources.

In the Netherlands, fuel prices average above 10 dollars a gallon (the average price is 1.85 euro/liter) and there is a direct link between fuel prices and electricity and natural gas prices. Every year the price of fossil fuels rise by more than 50 cents a gallon in the Netherlands. Additionally, fuel prices rise when the price of oil on the world market increases but prices at the pump do not decline much when the price of oil on the world market drops. These high prices suggest a great motivation to buy cars that use less fossil fuel and similarly, to adapt existing buildings so that they also use less fossil fuel. At present, organizations in the Netherlands such as the national and local governments, energy producers and factories are all undertaking initiatives to stimulate their transition from fossil to renewable sources (CDA et al. 2011; Dutch Ministry of economic affairs, agriculture and innovation 2011).

The transition to greater energy efficiency involves a complex long-term process in which many different stakeholders must act collectively as well as individually. Some actions that may seem simple can actually be quite complicated. For example, a house owner may individually decide to invest in solar panels or added insulation to reduce energy costs. However, what if a person renting a house wants to install solar panels? Does the tenant who makes the investment pay less rent? Or what happens if the building owner pays for the building improvements? Is it an acceptable practice for the tenant's rent to increase? Another example is the use of a geothermal hot/cold storage system, which uses groundwater to store heat in summer and cold in winter for reuse in other seasons. These systems are more efficient and cost effective if they are shared collectively among many houses.

At a municipal level, a pertinent question arises of how to create a collective system to promote positive behaviors and ultimately transition to new energy sources throughout the city. Consequently, is it the role of a municipality to stimulate, coordinate and mediate these types of activities? The challenge and struggle for a municipality is how to promote these initiatives without necessarily having to assist financially in such long-term investment projects. Experience has demonstrated that a municipality can encourage change by formulating the right policies, rules and regulations, organizing informational campaigns and by offering subsidies for certain technology implementations.

3.3.2 Methodology: Tools and Techniques

As a result, the City of Arnhem used a GIS-based scenario-planning tool for sharing information and educating the public to set forth the proper framework to encourage change. Arnhem used their own GIS and data and invited other stakeholders, such as local housing corporations, to share their information that would be used in the same GIS. Arnhem subsequently utilized all of this information to support three core activities:

- monitoring the various energy-saving activities of the stakeholders such as homeowners and businesses;
- evaluating the effectiveness of both completed and planned energy-saving activities; and
- jointly planning coordinated actions among stakeholders.

In this shared ecosystem, the City is only one of the stakeholders. To create trust and promote cooperation with the other stakeholders, the city shares its geographical information and maintains openness on its energy-saving activities and plans. The information from the other stakeholders is essential to the success of coordinated actions and to demonstrate the broader ecosystem. Collaboration of this nature thus involves a new kind of complicated negotiating process in which the municipality cannot tell other participants what to do but has to convince and influence their decisions with solid arguments and additional information, which together shows them that the common interest or greater good is also in their best interests. The role that GIS plays in this type of collaboration process is crucial.

In order to get advice on this process, Arnhem contacted Mapsup, a small European consultancy company that specializes in geo-collaboration and has developed a spatial decision support framework for stakeholder communication. In short, this means that Mapsup provides advice on the use of GIS within a collaborative and strategic communication process that involves many complex and diverse stakeholders. Mapsup starts the collaboration process by laying out steps for the stakeholder communication process by establishing the types of (geographic) information required by each step of the framework and partnering with their clients to form a dynamic project team. Quite often, good communication among stakeholders requires technical data to be presented in such a way that it remains technically correct, but at the same time is understandable for people that lack specialized knowledge. In many cases, special software is developed to facilitate these tasks, but this is not always the case. Choosing the right approach depends on the core objectives being sought, the subsequent processes that are required, the project's requirements and ultimately the capacities of the stakeholder community to handle digital content and GIS tools, which often is more than expected.

To support the actual meetings with the stakeholders, Mapsup and the City of Arnhem made extensive use of a MapTable and scenario planning. A MapTable (Fig. 3) is a 46-inch tabletop computer built in a physical wheeled table, which makes it easy to be transported and moved around and rotate both horizontally and vertically. The MapTable is particularly suited for supporting 'horizontal' and collaborative group work as it allows users to draw and explain their ideas or views on top of an existing map which can display numerous map-based data. Having a group of 10–12 people working horizontally on a MapTable generates insights that can provide more significant results than those obtained by working horizontally with paper or vertically with a portable projector. Next section describes the

Fig. 3 Participants working on a live and interactive GIS based model using a MapTable (Image courtesy of Mapsup)

outcomes from two instances of a policy implementation, where a GIS was used to facilitate the process of communication between stakeholders and presented a variety of scenarios to promote a positive change in behaviors to ultimately reduce GHG.

3.3.3 Result 1: Planning of Major Maintenance of the Arnhem Housing Corporation

The first case deals with non-profit housing corporations that rent out the majority of the houses in Arnhem.

Within Arnhem, there are six housing corporations that own about 6,400 buildings. This constitutes approximately 10 percent of all the buildings in Arnhem. To ensure proper building maintenance, every 30 years the buildings get a major structural overhaul, which includes new doors, windows, roofs and insulation. As a result, this make for an ideal moment to improve the energy efficiency of the structures by improving the insulation materials used and by changing the energy source used to more sustainable or efficient energy sources. Between 2010 and 2040 all the buildings of Arnhem will undergo a major structural overhaul. Normally every housing corporation will do its own structural overhaul planning without considering the planning implications related to the other organizations and obviously the broader local implications that their improvements may or may not have on the community.

The City sought to engage the different stakeholders in a collaborative process in which they would all together look for possibilities to facilitate the energy transition and allow Arnhem to achieve its longer term objectives. The City of Arnhem has its own GIS which organizes all relevant data for the city. This includes data on buildings, addresses and ownership. Furthermore, a report from KEMA (an Arnhem-based energy consulting firm) was used to create a GIS data set that quantified the energy benefits for particular building types of all kinds of new energy sources, such as photovoltaic panels, hot/cold storage, windmills, etc. (Rooth and Schmelzer 2009). Mapsup incorporated these factors into a model that was implemented in CommunityViz. This made it possible to interactively select housing blocks and apply different strategies to these blocks. While doing so, a dynamic chart on the MapTable indicated the influence that the strategy had on the indicators. The result was a clear indication that outcomes of the different strategies created by using the GIS and scenario modeling could be adopted influence change and public perception. Consequently, the discussion among the stakeholders involved focused on the real issue of investment and profit, both in financial and environmental terms, rather than "what's in it for me". This was directly a result of the scenario planning model and communication framework that was developed and implemented.

By showing the possibilities of GIS in combination with scenario-based models, the stakeholders became aware of the importance of sharing their own information, integrating it with information from others in a central repository, manipulating it and then sharing the results. The influence of a GIS to achieve this shift toward a more collaborative attitude became apparent. As a result of this integrated use of GIS, NUON (a large Dutch energy company) one of the project's stakeholders was able to identify the housing corporations that had major structural overhaul plans for housing blocks that were within a certain distance of the district heating system that they managed consequently NUON and the housing corporations were able to explore the possibilities of connecting the housing blocks to the district heating network that exist in the City. Even though the project is still at in its early stages, action by NUON was regarded as an important intermediary result from this project.

3.3.4 Result 2: Visualizing and Monitoring Energy Production and Consumption Data

A second aspect of Arnhem's scenario model dealt with the companies that supply all the electricity, fossil fuels and district heating to the City's inhabitants.

The City of Arnhem is interested in monitoring energy use within its perimeter to see whether the policies for the energy transition have had a positive effect on the community in the short and long term. This is, however, not easy to do for a number of reasons. First of all, by Dutch law, it is not possible to access individual consumer utility usage data due to the existing privacy legislation. Secondly, the energy provider sells energy consumption data per postal code. This is a code that covers approximately 19 addresses on average for the same street. If there are less than five utility connections in a postal code, no information is provided due to privacy concerns. Thirdly, the available data is not directly related to buildings that are located on the street. Data on energy consumption is delivered per connection to the supplier grid, but there may be more than one connection per building (for example, apartment buildings). Even within a building, different parts may have been built at different times and therefore use different amounts of insulation.

The reasons above lead the project team to ponder the following questions:

- How can the consumption of an apartment be compared to that of a single house?
- How can the effect of an implemented policy be monitored and tracked over time?

The City registers information about all buildings in the City, such as year of construction, area and volume of the buildings, different addresses in buildings and their postal code. This is required by Dutch law. Mapsup converted this raw tabular data from postal codes into a map layer. This map was included in the GIS scenario model along with the data available within the Arnhem database. Area and volume per housing unit was added per postal code area. Subsequently, these were divided by the energy consumption and an indication of energy consumption per square meter or cubic meter was obtained. This new information allowed Arnhem to visualize the energy consumption patterns in a meaningful way.

Figure 4 shows a classified energy consumption map for a part of Arnhem with its different postal code zones and corresponding energy values. The colors indicate equal-size intervals for energy use in megajoules (MJ) per square meter per year in that specific zone. Using CommunityViz, the legend of this map was made dynamic, which means its intervals could be interactively adjusted by stakeholders and the colors rendered accordingly (see dynamic legend and dynamic assumptions in Fig. 4). Both the map and its legend proved important during the discussions with stakeholders.

The legend consisted of 9 class ranges, whose size could be defined and/or adjusted by stakeholders in real time. This was done by defining the legend's midpoint value and then the interval size in MJ of the class. For instance, if the midpoint value was set to 550 MJ/m^2/year and the class size was set to 100 MJ/m^2/year, the result would be a legend with it lowest class ending at 100 MJ/m^2/year and the highest at 1,000 MJ/m^2/year. This means that areas with values above 1,000 MJ would be depicted with the same color. This legend proved particularly crucial during the discussion as it enabled stakeholders to analyze the data properly and generate acceptance on the both the quality and usage of the available data. By modifying the legend's class interval size and midpoint value, it was possible to detect large differences in consumption at a municipal level and small differences at a local (district or subdivision) level.

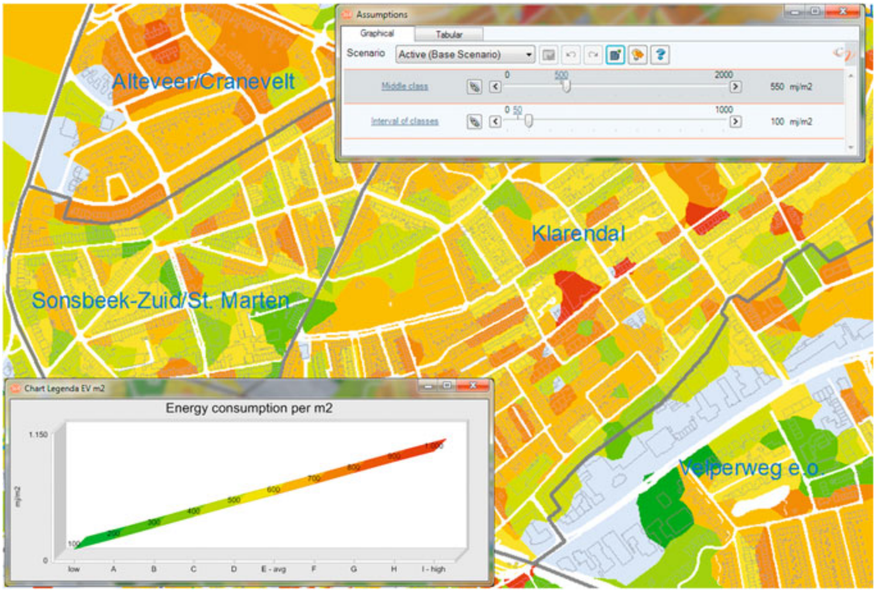

Fig. 4 Map of a part of the city of Arnhem showing energy consumption patterns per postal code zone (Image courtesy of Mapsup). Map legend (*bottom left*) is dynamic as both its class size and middle value can be interactively modified by setting new values on the assumptions window (*top right*). As soon as the legend is modified, the map is automatically redrawn according to the new values on the legend

In consultation with the stakeholders, the energy consumption patterns per district were also visualized in a particular, yet powerful way. They were interested in viewing consumption patterns for a particular selection of postal code zones, which were regarded as ‘active’ zones. The remaining ‘non-active’ zones were thus excluded from the calculations. Users could interactively select and highlight ‘active’ zones using the ‘painter’ tool by touching a target area on the MapTable. The energy consumption of a particular district was then calculated as the sum of all energy use values of the ‘active’ postal area code in that district divided by the total area in m^2 of the active area codes. This ‘active’ district averages were found by users and energy experts to be more reliable than those of each postal area code. The possibility of mapping energy consumption for ‘active’ areas at a district level proved crucial for building consensus and reaching agreements during the discussions. The result was a dynamic map of energy consumption in MJ/m^2/year for ‘active’ postal code areas for each district of Arnhem, where the legend and target areas could be modified at any time and is planned to be consulted and used collectively throughout future stages of the planning process.

Other interesting map layers produced by combining energy consumption data with geographical locations using CommunityViz and considered by stakeholders to be relevant included:

- Consumption with the year of construction, which revealed areas with older buildings and suboptimal insulation policy to stimulate insulation;
- Consumption with consumer lifestyle descriptions, which facilitated finding citizens that might be interested in the energy transition policy; and
- Consumption and address number, so larger groups could be efficiently contacted.

4 Conclusions and Further Research

This chapter introduced the concept of using a Geographic Information System (GIS) as a valuable tool for planning, analyzing and monitoring the sustainable cities of tomorrow. In our discussions here we just focused on climate change even though there are many other benefits of using GIS in urban planning and design. While this chapter highlighted just a few success stories from around the world, it was demonstrated that what gets measured gets fixed. GIS provides powerful visualization and analysis capabilities that set it apart from other computer systems and it should become a valuable part of the climate change toolkit. As cited by the United Nations Human Settlements Programme (2011), cities are responsible for up to 70 percent of the harmful greenhouse gases produced and new creative planning process can have an advantageous effect on reducing GHG’s before designs are even built and affecting our ‘built world’.

Reducing the ecological footprint of a community can certainly be achieved as long as the involved process is regarded as a long-term investment program. An important lesson derived from the experiences of Arnhem city is that the role of a municipality should be to organise the stakeholders and to convince them to share their information. The GIS-MapTable combination allowed for an integration of information that has so far facilitated collaboration, forming of alliances and collective decision making to help the city reach long-term goals related to the transition to sustainable energy sources. The focus of the process should not only entail the issue of reducing the city's ecological footprint, but also how and when to achieve this. Timely joint decisions can help reduce costs and increase benefits. In representing the community, the municipality is the best level for this kind of coordination.

Combining GIS scenario planning with the MapTable made it possible to perform on-the-fly analysis during group meetings and allowing stakeholders to adjust input parameters in real time based on the ideas of the participants. This integration showed that GIS is no longer a back-office tool for map making and spatial analysis, but it is increasingly becoming a front-office communication tool for joint organization, visualization and analysis of spatial information. Additionally, there is no doubt that GIS has an invaluable role in helping our urban designers design more sustainable communities, assisting with educating the general public, allowing politicians to create effective policies based on sound analysis and finally allow local government leaders to properly monitor and track their progress and test their hypotheses in a risk free manner. When it comes to climate change it cannot only help measure and explain impacts, but also be used to sell new approaches to all stakeholders.

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Resource-Centered Cities and the Opportunity of Shrinkage

Katleen De Flander

Abstract Our planet is being anthroposized at high speed with Climate Change and other global environmental damages as its consequence. As home of most consumers, many are looking at cities for solutions. Urban densification is often seen as 'the' way towards more urban sustainability. However, externalities of urban consumption and the complexity of the urban system are mostly left out of consideration, leading to unexpected results. This chapter advocates a transition from consumption-centered to resource-centered cities. In an age of rapid urbanization, this chapter further argues how shrinking cities could unexpectedly function as catalysts for change. A shrinking population and a retreat of the current economic system give shrinking cities the potential for becoming front-running resource-centered cities.

Keywords Resource-centered · Complex systems · Transition · Shrinking cities · Closed cycles

1 Introduction

Climate Change has emerged as one of the most challenging political and scientific issues of our times. With ever increasing trends in urban consumption and production practices, a call for action to mitigate climate change is often seen as a way to foster sustainable development. Considerable attention is now being paid to determine what urban sustainability would include. Is a 'sustainable city' a city that uses 25 or 50 % less energy? A city that is carbon neutral, whether with or without carbon offsetting? A city that doesn't have cars or that has green roofs and

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solar panels? Many cities/neighborhoods/buildings are called ‘sustainable’ or ‘eco’ because they are doing better than mainstream but is this the right approach?

In response to the question “What is the single most important environmental/ population problem facing the world today?” Diamond (2006, p. 498 cited in Frey and Yaneske 2007, p. 61) captures the essence in his answer: “The single most important problem is our misguided focus on identifying the single most important problem!” In other words, the real world is full of interactions and connections. “Complexity science is moving us away from a linear, mechanistic view of the world, to one based on nonlinear dynamics, evolutionary development, and systems thinking” (Sanders 2008, p. 276). Climate Change should therefore be understood as a complex system. Interestingly, cities are as well. Bai et al. (2010, p. 130) indicates that “cities are increasingly recognized as complex adaptive systems[1] that integrate, respond to, and influence a diverse range of social, economic and ecological processes operating across a range of spatial and temporal scales. Connections between urban systems and regional and global change are therefore characterized by significant nonlinearities and cross-scale interactions among slow and fast moving processes”. This understanding avoids us getting on a reductionist track, which deals for instance only with Carbon neutrality. It makes us focus on a broader transition process in cities and recognize not only their nonlinear behavior but also their transformative capacity while staying functional.

2 Myth Busters

Although it is widely ignored, we are not going to solve Climate Change and other global environmental problems within our current economic system. The story that more free markets, more consumption and new technology (these are the ones that created our problems in the first place) are going to save us urgently needs some myth busters. Technology can help, but pretending that we can get away with our current lifestyles because ‘green’ technology will solve everything, is being naive at the very least, especially with an eye on the expected population growth.

> Conventional economics as currently practiced is largely responsible for the increasing strain on global resources. The economic performance of nations is generally measured as gross domestic product (GDP), a large component of which is generated by consumption. The way to increase economic performance is therefore by increasing consumption, which in turn demands increased production. In conventional economics, the productive capacity that produces the goods and services is considered to be a function of human-made capital

[1] ‘Complex Adaptive Systems’ (CAS) are a specific category of complex systems—open evolutionary systems such as a rain forest, a business, a society, our immune systems, the World Wide Web, or the rapidly globalizing world economy—where the components are strongly interrelated, self-organizing, and dynamic (Sanders 2008, p. 275).

> only, excluding non-renewable and renewable natural capital, which is considered to be a free good that cannot be depleted (Daly 2001 cited in Frey and Yaneske 2007). Further excluded are the costs for repair of damage to the environment as a result of production and consumption." (Frey and Yaneske 2007, p. 56)

One of these myth busters is Nair (2010) who describes the role of Asia in reshaping capitalism, arguing that it is realistically impossible for Asia to follow the same path as the developed countries due to mere numerical facts. "The world has reached a stage where economic growth, and in particular trying to maintain it via consumption-driven capitalism, has become the driver of our problems" (Nair 2010, p. 76). "We have to put limits on the use of limited resources. So as well as focussing on the quantity of consumption, we need to look at its quality—what consumption is composed of and what changes can be made to it" (Nair 2010, p. 80). This is of course not a popular viewpoint. Many stakeholders have advantages of staying with the old system, but as Einstein pinpointed: 'You can't solve a problem with the same mind that created it'. A change in mind-set needs to take place where consumption ceases to be at the centre. Instead of consumption, what is truly at the center of everything are resources. Natural capital has made our conventional economic system possible in the first place. Natural resources have also made it possible to develop cities. A failure to recognize that natural resources can be depleted has already lead to the demise of several cities and empires in the past. 'History tells that the destruction of the bioproductive capacity of a city's hinterland through the exhaustion of its fertility and the available water supply has happened quite frequently, leading to the self-imposed collapse of cities' (Frey and Yaneske 2007, p. 80).

> Girardet (1999, p. 17 cited in Frey and Yaneske 2007, p. 85) sees Rome's fate as the direct result of the massive exploitation of its very large hinterland. (next to other major contributing factors such as lead poisoning and plagues). According to Mumford (1984 cited in Frey and Yaneske 2007, p. 85), due to the overexploitation of Rome's hinterland and the damage done to the environment as a result of this, the empire's bioproductive capacity became increasingly smaller and resulted in a shortage of food for Rome's one and a half million or so inhabitants. Mumford sees the disintegration of Rome as the ultimate result of its over-growth, which resulted in a lapse of function, and a loss of control over the economic factors and human agents that were essential for its continued existence. Prosperity and population were declining and the barbarians began to infiltrate the over-extended empire.

Is the same happening to modern cities? The following example shows the massiveness of the problem we are facing in real time: China will build new housing for 400 million people in the next 12 years. If they use brick as the main construction material, they will use all their soil and burn all their coal and they will have cities with no energy and no food (McDonough 2005).

3 From Consumption-Centered to Resource-Centered Cities

As Nair (2010, p. 136) suggests: “The big change will lie in putting values on things humans have long taken for free or nearly free—the environment in which we live and the resources it provides us with […] Putting resource management at the center of policy making will shape how individuals consume, how companies do business, how food is produced and water is used, how the balance of rural and urban is reworked.” Sassen (2010, p. 3) poses the following crucial question: “Are these global ecological conditions the results of urban agglomeration and density or are they the results of the specific types of urban systems that we have developed to handle transport, waste disposal, building, heating and cooling, food provision, and the industrial processes by which we extract, grow, make, package, distribute, and dispose of the foods, services and materials that we use?” Combining Nair’s suggestion with Sassen’s question leads us to an approach that focuses on a transition of our urban systems based on rethinking their resource management. This stands in sharp contrast with the common approach of technological fixes and efficiency improvements. While ‘improving efficiency’ starts from the status quo of the current system, and ends up with a 20 or 30 % ‘less bad’ system, the Resource-Centered City stands for a transition to a new system. Not ‘new’ in the way of building ‘new eco-cities’, but ‘new’ in the way of re-organizing our urban systems.

> The inevitable outcome of the continuing pursuit of economic growth and of increased consumption and production will be an eventual shortage of resources. […] Attempts to reduce resource wastage in the production and consumption process, a Factor 4 approach (von Weizäcker et al. 1998 cited in Frey and Yaneske 2007), will reduce resource consumption but will only buy us time, as this reduction will soon be caught up by increasing population and consumption levels” (Frey and Yaneske 2007).

Another consequence of a resource-centered approach is that it forces us to think about the externalities of urban consumption and the relationship of the city with its hinterland. Because we are offsetting the negative consequences of urban consumption outside the city, they are hidden from the eyes and minds of most of the consumers. Externalities of urban consumption are one of the main causes of inequality, be it rural/urban, rich/poor, North/South. A resource-centered city is not a one-resource exploiting or dependent city but is as far as possible self-reliant when it comes to resources. By tackling consumption at its source, the resource-centered city avoids externalities in the most direct way possible. For instance: “By restricting emissions directly at the source, there would be no need for indirect schemes which tend to reward established companies, in both finance and the energy industry, and have already proved readily open for abuse” (Nair 2010, p. 148).

The rural–urban relationship, or as Sassen (2009) suggests urban and non-urban,[2] in our current consumption-centred cities could in many cases be described as parasitic. Since natural capital and resources are seen as a free good, the urban hinterland is emptied out from natural but also human resources (in the form of cheap labour working in the cities) at almost no costs. On the other hand, expensive products from the city return to rural areas for consumption. Attempts to avoid rural–urban migration or export urbanity to rural areas have mostly failed. An interesting thesis Nair (2010) brings up is that weakening the links between wealth and major metropolitan centres (by switching to a resource-centred approach) could lessen the pressure to create mega-cities and could rework the urban–rural balance.

4 From Consuming to Producing Cities

At the moment, our cities have a linear approach to using resources. Materials, energy, food and water enter the city from its global hinterlands (leaving its traces there in the form of ao. soil degradation, water pollution and deforestation), are partly consumed and the rest leaves the city in the form of waste, wastewater and polluted air (also affecting of course inner city air quality). This means that the externalities of urban consumption are carried by a large number of global hinterlands and for a large part hidden from the urban consumers. If we are to understand and respect our limited resource base, cities need to adapt from a linear to a circular resource use and evolve from consuming to producing cities where waste doesn't exist, resource cycles are closed and impacts on the environment (air, water, soil) are neutral or even positive. At the same time, cities need to reduce the geographies of extraction and environmental damage caused through urban consumption (Sassen and Dotan 2011).

Becoming a Resource-Centered city thus means that cities will have to stop their parasitic behavior and provide their own resources. On the one hand, if markets have to work within set limits of resources, cities will be forced to start harvesting[3] their own resource streams such as rain, wastewater, materials and nutrients. This closing of resource cycles is nothing new. In pre-industrial cities it was (and in some parts of the world still is) normal to collect for instance urban

[2] "Cities have a pronounced effect on traditional rural economies and their long-standing cultural adaptation to biological diversity. Rural populations have become consumers of products produced in the industrial economy, one much less sensitive to biological diversity. The rural condition has evolved into a new system of social relations, one that does not work with biodiversity. These developments all signal that the urban condition is a major factor in any environmental future" (Sassen 2009).

[3] 'Urban Harvesting' is a concept that is based on tracking and harvesting all the resources in the city and bringing them back in an endless resource cycle. Also called 'Urban Mining', definitions may differ including or excluding certain resources and methodologies.

organic waste (also from animals and humans) and reuse its nutrients for food production. Modern cities have forgotten their potential of being part of a resource cycle instead of damaging it.

Making the transition from consuming to producing cities, they will have to find space within their urban fabric to produce resources locally: space for energy, materials and food production, space for water treatment and infiltration. This will need to go much further than by just putting solar panels or urban gardens on top of the roofs. The whole city will need to be activated and re-organized, starting from changes in consumption and production patterns, to re-organizing the urban systems and changing urban land-use (for instance by taking space from car-infrastructure for creating a decentralized water treatment system in the neighborhood). All parts of society will need to be tackled, not just private consumers but also companies, industry and agriculture.

Consequently, in the resource-centered city, not efficiency improvement but re-organisation is key. The starting point is therefore not a product or specific material (as in Life Cycle approaches) but includes exploring the 'function' or 'provided service' for which work is needed; and leaving space for re-organisation and trend-change in the urban environment. 'Shelter' for instance can be provided by a building, also by a building that was initially not meant for housing (re-organising space). If we go a step further saying that this shelter should provide a certain thermal comfort level to the people needing its service, this can be solved in different ways. The shelter can be insulated (material) and/or heated (energy) and/or people can wear more clothes (material + lifestyle change) and/or maybe we need to look at a seasonal building use. Each of these solutions will have a different resource demand and decisions have to be taken looking at the integrated outcome. In a closed-cycle approach, using the energy principle for both energy and materials, Rovers and Rovers (2011) come to the conclusion that against the regular way of thinking, "it seems more efficient to just heat the non-insulated houses with solar collectors instead of growing materials for its insulation". Oswalt and Schmidt (2010) come to a similar type of conclusion: "It needs to be weighed whether the energy expended in optimising the buildings does not outweigh the energy saved for its operation".

By looking at our urban systems through a network of resources (soil, air, water, materials, energy, nutrients), which by nature are highly interconnected (influencing one resource can have both positive or negative feedback on the others), we are forced to take a complex systems approach and avoid the danger of focusing only on one resource, a problem often arising from the compartmentalization in sectors, departments, professions, etc. After all, a change in our food system will probably have a greater effect on our energy consumption than simply aiming for a more efficient domestic energy use. As a repercussion, inter- and trans-disciplinarity becomes a must to realize any successful transition in a complex system. Also production choices in the city will have to be seen from within the interconnected network of resources and priorities will have to be set. For example: producing energy by placing solar panels on fertile soil is not the smartest solution because you block your fertile soil to be used for food production. On the other hand, placing solar panels on existing buildings or placing windmills between food production areas creates a double space function.

So far, instead of rethinking the systems we have developed, systems that resulted in climate change, resource crises and other environmental problems, we are still trying to solve the problems they have created within the same system. A good example is our transportation system that is for a large part based on the car and is a vast contributor to oil dependencies, climate change, health problems, air and water pollution, impervious soils, unliveable cities, etc. Instead of rethinking the system and start thinking in functions ('I need to be mobile') and not in goods ('I need a car'), dependencies on cars are now nurtured under the name of green cars, biofuel or electric mobility and car companies are bailed out in the name of 'saving jobs'. Instead, the focus should no longer lie on increasing consumption, leading to more throughput of resources. Companies will have to find new ways of creating value. There will be a shift from selling products to selling services, which will give a new meaning to product quality, durability and re-usability. There will also be a shift from taxing income to taxing consumption.

The shift from consumption-centered to resource-centered cities is at the same time an important key to mitigate climate change since changing the way we deal with resources will tackle many causes of climate change. When we re-organise for instance our urban food system by re-localising food production and changing our food habits, this will immensely reduce greenhouse gas emissions because it will reduce transportation distances, reduce packaging and reduce industrial agriculture (producing lots of CO_2 and N_2O emissions because of its high energy and commercial fertiliser use). On top of that, land use changes (from forests to industrial animal and food production or because soils have been exhausted by chemicals and fertilisers) can be limited or turned around. Our diets might have to change but we definitely don't have to miss out on variety nor on good nutrition. Another example is the change of our transportation system in and between cities, which is a major contributor to climate change. Tackling the 'car' is a main challenge but who would have believed some years ago that smoking would be prohibited in public spaces? If cities have to become more self-reliant when it comes to resources, the space for car infrastructure in cities will prove to have a lot of potential. A revival of high quality public spaces and public transportation will be crucial to keep the 'mobility' function working and to create new quality of life in our cities by giving again priority to the human scale.

5 The Opportunity of Shrinking Cities: 'Less is More'

I argued that we need a transition from consumption-centered to resource-centered cities. Since producing resources demands space, density plays an important role in balancing out demand and supply in a specific system. In this view, shrinking cities have a clear advantage when it comes to closing resource cycles since through shrinkage processes in cities, "concentrations" can be eased so as to accommodate the principle of closed cycles in the city.

Less dense living is often associated with waste of space and resources, but what if that space would not be "wasted" but used to produce the necessary urban resources instead of scavenging outside the city boundaries. What if a shrinking urban population is the ideal catalyst for introducing a Resource-Centered approach? Maybe the question becomes: how much shrinkage is necessary for a city to be able to close its resource cycles and become self-reliant? Could we say: 'The less people, the better?'

Urban planning and transportation theories such as 'Smart growth', 'Compact City' and 'Urban Intensification' all assert that high-density cities are more sustainable than low-density cities. This is mostly affiliated with the higher petrol use of low-density cities (as for instance many car dependent North American cities), and the greater use of public transportation systems and smaller housing units in denser settlements. However, "the relationship between urban population density and the environment in its broader sense is further complicated by the spatial displacement of environmental costs. Although it is often argued that denser urban settlements make more efficient use of land and other resources, at least some of this can be attributed to their 'ecological footprints' outside the spatial boundaries of the city" (Wackernagel and Rees 1995; Wackernagel et al. 2006, cited in Dodman 2009, pp. 3–4). Most cities import the majority of their resources such as energy, food and materials from outside their city boundaries and are therefore mostly consuming places. Resource depletion, pollution, energy use (for example embodied energy) and waste outside the city can therefore often be linked to the linear resource approach of cities which input and output starts and ends outside of the city. Therefore, taking into account the spatial displacement of environmental costs of dense areas, the statement that "higher density cities are more sustainable" becomes questionable and is clearly based on the current linear city system thinking.

From a resource-centered perspective, we want to internalize these environmental costs by moving from a linear to a circular system. The urban system will need to provide as much as possible in its own resource needs, instead of scavenging outside. This perspective puts density into a whole new light. We are not talking anymore about per capita energy use or per capita CO_2 emissions but about what density means for the city's production capacity and about its resource demand and supply possibilities. Less dense cities have a lot more space for resource production and at the same time, they have less demand for resources (mind the 'rebound effect'[4] which is a perfect example of an unexpected outcome in a complex system). In short, while in the current linear city system thinking, density might be increasing sustainability, from a changed resource-centered

[4] The 'rebound effect' is an unexpected behavioral or systemic response that reduces or even turns around the expected result of for instance an efficiency measure. An example in this context: the beneficial effects of a reduced population leading to less demand for resources could be offset by an increase in personal consumption caused by price decreases of goods resulting from excessive stocks.

system perspective, lower densities bring many more possibilities. Now this is not an advocacy for reducing density everywhere to suburban levels and stimulating urban sprawl. It is however an argument that by changing our system's perspective, the roles can be turned around and 'Less becomes More'. In this perspective, Shrinking Cities show high potential.

6 Density in the Light of Shrinkage

When discussing density in the light of shrinkage, the following points are important:

First, I believe it is important to lose the image of a shrinking city being an empty village that doesn't have enough children to fill a class-room. Many large cities are also shrinking; especially old industrial cities (for instance Osaka, Liverpool, Detroit) are losing population in favor of service cities. Besides this, shrinkage can take different forms. Next to an overall thinning out, we more often see a polarization within the city: from the center to the periphery or from one part of the city to another. This polarization results often in even bigger social and racial segregation and inequalities. Shrinking cities are already a common phenomenon worldwide and will be even more so in the future. "Since years one can observe demographic decline in great parts of Europe. Even on a global scale urban shrinkage is a widespread phenomenon. According to different studies every 6th–4th large city worldwide has lost population in the 1990s" (Wiechmann 2006). While many are focusing their attention on growing (mega-) cities, it has become clear in the last years that it makes a lot of sense to set a parallel focus on current shrinking cities since they are a shape of things to come.

> Even though urban growth will continue to dominate in the coming decades, the number of shrinking cities is continually increasing. An end is in sight, however: around 2070–2100, the world population will reach its zenith and the process of urbanization will largely come to an end. Then the processes of growth and shrinkage will reach a balance, and urban shrinkage will be a process as common as it was before industrialization began. […] Shrinkage will in future be considered as normal a process of development as growth. It will lose its stigma and come to be seen as a scenario that has advantages as well as disadvantages and that leads to distinct forms of renewal and change. In the discourses on the city in the USA the shift in terminology away from 'urban decay' and 'urban decline' towards 'shrinking cities' indicates that such a change in thinking is underway" (Oswalt n.d.).

Second, it is important to realize that urban density in relation to sustainability is usually discussed in the light of continuous growth. This seems logic when looking at the booming mega-cities. However, when discussing this in the light of shrinking, it becomes a whole different issue. We don't have to debate any more if the growing population will be housed by densifying the existing urban fabric, by using inner city brown fields or by developing new peripheral green fields. We are not even in a position to discuss ideal densities for a compact, walkable city and argue against the unsustainable suburban sprawling (although sprawling is one of the main causes of urban shrinkage). Realistically, turning Shrinking Cities into a compact city is often a utopia.

Third, urban density in shrinking cities is mostly seen as a problem: costs of basic services and infrastructure are carried by less people and become too expensive or are simply abolished, public funding is reduced, cultural and social activities are abandoned, etc. All this leads to even more people leaving the city. Because many shrinking cities are falling more and more out of the current economic system, they have been ‘spit out’ or have become ‘disposable’ as some local activists call themselves, they often have no other choice than to rely on themselves. We see examples of local food production, places where local currencies have been introduced as a lifeboat to revitalize a local economy, local bio energy production by farmers, space pioneers with new initiatives, etc. These are all attempts to become more self-reliant and at the same time more resilient to outside factors (such as cutting public funds). Although attempts for re-localization are already found in Shrinking Cities, for some reason, making the complete transition has not happened. Why not? One answer could be the ‘Frog effect’. When you put a frog in boiling water, it jumps immediately out of the water because of the shock. If you put him in cold water and bring it slowly to boil, the frog stays and dies. An example of a shock that resulted in action is Cuba. After the country was cut off from 80 % of its food imports and 50 % of its oil imports when the Soviet Union collapsed in the 1990s, Cuba transitioned from an industrial to an organic fossil-fuel independent agriculture in the course of a few years. We could say that shrinking cities are also in a state of shock but since it has been often a gradual process, it didn’t result in action but in a slow death.

Considering the above points, from a resource-centered perspective, density gets a new meaning in the light of shrinkage. With the aim to bring about a resources-based transition, it is more promising to work towards a new system in a place where the old system is already retreating then to change a system that is fully running. Instead of reducing funds, abolishing services and activities in Shrinking Cities, we can switch to a more productive approach to shrinkage. Seeing shrinkage as a catalyst for change, Shrinking Cities can become front-runners in the transition process towards a post fossil-fuel and a resource-centred society. They can become urban labs of how to downscale and re-localize our agriculture, how to dignify food production, how to become fossil fuel independent and decentralize resource production, how to increase quality of life and use the available space for resource production. Not with the aim to create ‘closed cities’ but as catalyst points for a transition that can spread out regionally and beyond.

7 Climate Change Mitigation

It might not be obvious at first sight, but as stated and illustrated before, there is a direct relation between a switch to a resource-centered approach for cities and mitigating Climate Change. As a matter of fact, the relationship is a lot more direct then with some systems that were specifically invented to mitigate Climate Change. For instance, the Carbon-Credits trading system often avoids direct solutions at source by offsetting actions (but also externalities) to other parts of the world while stimulating business-as-usual at source. By tackling urban consumption and its externalities directly, by re-localizing production and urban harvesting and, more generally, by placing resources at the center of urban policy and management, we are tackling several priority areas for mitigating Climate Change, including greenhouse gas emissions, land use change and deforestation.

Shrinkage has the potential to accelerate the process of becoming a resource-centered city. Front running cities have proven their exemplary function by rippling their success to other cities. Think for instance of the innovative public transportation system 'Bus Rapid Transit (BRT) System' that was first introduced in Curitiba and has since then been taken up in several cities globally. This low-cost (to use but also to construct if you compare with expensive subway lines), separate-lanes and high-frequency bus system has effected a modal shift from automobile to bus travel in Curitiba. It also eliminated a great part of the local informal transport mafias and motivated citizens to take a new view on mobility. It was so successful that many other cities around the world have adopted the BRT system. A city that is able to lead change in its urban systems and in the use of it's resources can ripple its success to other cities. In this view, shrinking cities could play an unexpected exemplary role in mitigating Climate Change in cities.

8 Conclusions

In the light of mitigating Climate Change and urban sustainability, this chapter discussed why it is important to start thinking from a resources perspective and why shrinking cities have a high potential following this viewpoint.

A shift from our current consumption-centered cities to resource-centered cities by putting resource management at the center of policy making will shape how individuals consume, how companies do business, how food is produced and water is used, how urban space is activated and how our urban systems are reworked. This will have a major effect on mitigating Climate Change.

Whereas in the 'Smart Growth' debate densification is seen as 'the' way to sustainability (with the main argument that dense cities are more efficient and use less energy per person, however completely ignoring the externalities of urban consumption), a resource-centered approach allows us to look at density in a different way. If we can see the opportunities of shrinking and couple this with the big environmental challenge we are facing in the 21st century, the current shrinking cities can be the front-runners of a system change. Whole new questions emerge such as: 'How much shrinking do we need for the city to be able to close its resource cycles?'

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Understanding Local Government Resilience: A Case Study on how the Local Government of Marikina City Reacted to the Flood in September 2009

Marian Cruz

Abstract In the face of climate change and its impacts, the best response of cities is to improve their resiliency. However, it is interesting to view an organization such as a local government, as one of the means to improve resilience of a city. This study aims to understand organizational resilience, i.e. a resilient local government, as a response to the impacts of climate change. In September 2009, the local government of Marikina City experienced a significant amount of stress when Tropical Storm Ketsana hit the country and devastated not only Marikina, but cities and municipalities in the metro and in the northern parts of the Philippines. The study area was one of the hardest hit by the heavy flood caused by the tropical storm. This sudden shock, which was considered by Philippine scientists as an extreme rainfall event, affected almost all inhabitants of Marikina, damaged houses and interrupted local businesses. This chapter is part of a much broader case study under the Alexander von Humboldt Foundation's International Climate Protection Fellowship Programme.

Keywords Climate change · Resilience · Local Government

1 Introduction

Climate change is a reality and its impacts pose a huge challenge to society. Disasters and disturbances such as flood events have "highlighted the need for urban systems to cope with unexpected shocks" (Resilience Alliance 2007, p. 7).

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Building resilience, therefore, is crucial particularly in areas like cities where presence of humans is abundant (Resilience Alliance 2007).

Local governments hold an important role in both climate change adaptation and mitigation (UNDP and UNEP 2010). In adaptation, the goals are to reduce vulnerability and improve resilience. Resilience is best viewed in a developmental perspective where it builds in time from continuously facing pressures or stress (Sutcliffe and Vogus 2003).

This study aims to understand organizational resilience as a response to the impacts of climate change. The focus of this chapter is on organizational resilience and actions, reactions and response of local government of Marikina, after experiencing Tropical Storm Ketsana. This study is part of a much broader case study of Marikina City that is currently that is being undertaken.

This chapter contains the following sections. Section 2 provides a discussion and description of climate change and organizational resilience. It also describes the resilience approach. Section 3 presents the objectives and methodology of the study. Section 4 describes Tropical Storm Ketsana, the sudden shock that surprised not only Marikina City but the whole country. The effects of Ketsana both at the national and local levels are presented. The local government of Marikina's arrangement on disaster preparedness, management and response before and during Ketsana is described in Sect. 5, and post-Ketsana issues in Sect. 6. Section 7 contemplates on one of the responses or actions made by the local government after experiencing the sudden shock. Section 8 provides a conclusion of the study.

2 Understanding Climate Change and Resilience

2.1 Climate Change and Flood

Studies have tracked the recent historical changes in climate which includes observed increase in global average air and ocean temperature, melting of snow and ice, and rising global average sea levels and occurrence of heavy precipitation in most areas (IPCC 2007). With climate change, comes the occurrence of hazards. Cities can be highly affected wherein their immobility makes them vulnerable to the impacts of climate change (IBRD and WB 2010). Therefore, being a healthy and robust city is really a challenge in these changing times. Local governments have important roles in addressing the complex impacts of climate change by creating the appropriate plans for their services and communities (Lee 2011). City level actors are aware of the importance of their roles and are actively participating in various climate strategies, projects and programs even though the Kyoto Protocol does not explicitly mention their roles and responsibilities (UNHSP 2011).

With the increase in probability of occurrence of intense typhoons is a higher likelihood of flood events. Flooding is a natural phenomenon and if not properly managed and reduced, they can lead to worsening of problems (LGA 2011). The effects of floods in cities are particularly strong because of its population and its immobility (IBRD and WB 2010). According to a study made by World Meteorological Organization (WMO) and the Global Water Partnership (GWP), there are different types of losses due to flood. The first type is tangible direct losses which comprise of loss of things with monetary value, which results from direct contact with flood water. The second type is the tangible indirect losses, which are losses of things which cannot be bought or sold, which resulted from the event but not from direct impact, e.g. loss or disruption of agricultural and industrial productions. The third type of loss is the intangible human and other losses such as loss of life, physical injury and loss of heritage (WMO and GWP 2008).

2.2 Understanding Organizational Resilience

Studies have described resilience in an ecological, sociological, the combined aspects as well as organizational context. This research chapter is geared more on the latter. Weick et al. (1999) and Sutcliffe and Vogus (2003) state that it is not easy to grasp the meaning of social resilience in organizational studies (Hutter 2011). Organizational resilience is a term often used in a wide range of concepts that includes adaptation, capability, competence, and learning concept (Hutter 2011). However, it is often unclear and hard to define (Braes and Brooks 2010). What is even more challenging is using (social) resilience in the context of natural hazards. In his research note, Hutter (2011, p. 2) concludes "only systematic theoretical work and rigorous empirical analysis in the future can provide sufficient certainty about the usefulness of social resilience as understood in organizational studies."

Sutcliffe and Vogus (2003) gave an optimistic view on defining resilience in the context of organizing in the face of adversity. They made an effort to reverse the usual interpretations done in other studies wherein authors see organizational (as well as individual) failures as threat rigidity that when faced with threat, leaders and members of a group respond rigidly and are inflexible. According to the authors, when there is the presence of enabling conditions such as competence, growth and efficacy, then the likelihood of a resilient response, which eventually leads to positive adjustment, is very high.

A positive definition of resilience is when it is utilized in the aspect of development. This is different from another concept of resilience where it is seen as a super entity or otherwise having the ability of a group that can absorb damages and still retain its form (Porac 2002; Sutcliffe and Vogus 2003). Although observed in the context of megacities, Klein et al. (2003) discussed that bouncing back to the original form is undesirable since the entity would be just as vulnerable to the next disaster. Indeed, why should one go back to its original state when improvement is a better option.

Viewing resilience in a development perspective is looking at something that improves "over time from continually handling stress or risks" (Sutcliffe and

Vogus 2003, p. 96). The beauty in this perspective is that it does not promise that groups or organizations (or even individuals) to be perfect. It recognizes both the "possibility of fallibility and the probability of successful coping" (Sutcliffe and Vogus 2003, p. 97). Organizational resilience is defined as "anchored in organizational processes aimed at enhancing an organization's overall competence and growth (especially the ability to learn and to learn from mistakes), and restoring efficacy through enhancing the ability to quickly process feedback and flexibly rearrange or transfer knowledge and resources to deal with situations as they arise" (Sutcliffe and Vogus 2003, p. 104).

Wildavsky (1988) cited in Sutcliffe and Vogus (2003, p. 97) views resilience as adaptability, where it refers to "improvement in overall capability, i.e., a generalized capacity to investigate, to learn, and to act, without knowing in advance what one will be called to act upon". There is the concept of improvement, change, adaptation and of learning from mistakes.

Resilience is also important in the context of sustainability (Brand and Jax 2007). The local government's role for rebounding by learning from its failures and limitations brought by disasters is highly expected by its local constituents. Indeed, the public wants to have a government that is operational and provides service after a catastrophic event such as flood.

2.3 Resilience Defined in the Study

With all the definitions and components mentioned on resilience, this research chapter would envision the term in a developmental perspective as well. Thereby, based on the definitions of Wildavsky (1988), Sutcliffe and Vogus (2003), resilience would be defined in the study as the ability of the local government to rebound from uncertainty by adapting from recurrent disasters such as flood hazards. A resilient local government would now pertain to having the ability to react to changes brought by flood hazards that can be caused by climate change. It also has the ability to rebound and maintain its basic functions.

2.4 Resilience of What and to What Approach

It is quite practical to apply a *resilience of what to what* approach to empirical studies that work with resilience, since the concept gets diluted and increasingly unclear due to many different intentions and wide extensions (Brand and Jax 2007). As the concept is broad, it is important to define resilience in terms of what to what (Müller 2010). A resilience approach calls for assessing both specified and general resilience (Resilience Alliance 2010). For this study, the focus is on the specified resilience where Resilience Alliance (2010) refers it as the resilience of what, to what. It pertains to controlling variables that may have threshold effects which lead to either unwanted or permanent changes in the system state (Resilience Alliance 2010).

Resilience of what. The "of what" part describes the specific element which supposed to be resilient to the identified disturbance (Brand and Jax 2007). Therefore, to answer the resilience of what, it is the organization particularly the local government of Marikina City.

Resilience to what. Resilience Alliance (2010) describes resilience "to what" as disturbances, disruptions and, uncertainties. Here this pertains to flood, particularly the flood event caused by Tropical Storm Ketsana in 2009.

3 Objectives and Methodology

The main objective of this research chapter is to answer the question "what is one of the responses made by the local government of Marikina City after experiencing flood event caused by Tropical Storm Ketsana?" Specifically, it aims (a) to describe Tropical Storm Ketsana, i.e., the sudden shock, and its effects to Marikina City, and (b) to analyze and compare the local government's set-up on disaster preparedness, management and response. The result of the latter objective would be an identification of one of the responses made by the local government of the city after experiencing the sudden shock. The success or the quality of this response will not be assessed in this chapter.

The methods of the study will include a review of related literature on resilience and a description and analysis on the particular flood event that occurred in 2009, and a comparison of the organizational set-up of the local government of Marikina in disaster preparedness, management and response before, during and after Tropical Storm Ketsana.

4 The Sudden Shock: Tropical Storm Ketsana

Background of the study area. Due to its geophysical location and socio-economic conditions such as low maintenance standards for disaster prevention facilities and poor inhabitants living in disaster-prone areas (Nakasu et al. 2011), the Philippines is considered as one of the most disaster-prone countries in the world (ADPC and FAO 2006). According to the 2009 Mortality Risk Index of the United Nations International Strategy for Disaster Reduction, the nation ranks 12th among the 200 countries most at-risk for tropical cyclones, floods, earthquakes and landslides (GOP 2009). An average total number of 19–20 typhoons cross the county each year. These events frequently occur in the months of July to November. Typhoons strike in all major regions of the country however, the Central and Northern Luzon are the most affected areas (GOP 2009).

Metropolitan Manila or Metro Manila, also known as the National Capital Region, is comprised of 16 cities, including Marikina City and one municipality. The area is a floodplain/tidal basin. Typhoon occurrences often result in gentle flooding in low-lying areas which could last for a long period of time in a significant number of towns. Around 40 % of the annual average rainfall is associated with typhoons (GOP 2009). Annually, the country experiences disastrous rainfall events and flooding. According to the National Disaster Coordinating Council, a total of 158 destructive typhoons that resulted in 13,491 deaths have occurred between 1900 and 2008 (GOP 2009).

The Sudden Shock. Although typhoon occurrences are frequent, the nation was still shocked on 26 September 2009 when Tropical Storm Ketsana, with local name "Ondoy," hit the archipelago. The tropical storm produced floods that resulted in tangible losses, both direct and indirect as well as intangible losses. According to the Post-Disaster Assessment or PDA Report, the tropical storm first developed as a tropical depression three days before the disastrous event. In 24 h, a total of 455 mm of rainfall was recorded in one of the stations of the Philippine Atmospheric Geophysical and Astronomical Services Administration, the country's official weather bureau, where about 343 mm of which fell within 6 h. This clearly exceeded the climatological average total rainfall for September which is 330 mm. This was considered an extremely rare of occurrence (GOP 2009). According to the PDA report, the unusual volume of rain produced by Tropical Storm Ketsana caused widespread flooding particularly in the central part of Luzon where Metropolitan Manila lies. It is equivalent to a Category I storm with maximum winds of up to 147 km per hour (GOP 2009).

4.1 Effects of Tropical Storm Ketsana

Tropical Storm Ketsana affected the southwest monsoon and caused widespread flooding in almost all parts of central Metro Manila and Southern Luzon (north of Metro Manila) and some parts of Visayas and Mindanao regions, located south of Metro Manila. A total of 4,901,234 individuals or 993,227 families were affected during this catastrophic event based from the National Disaster Coordinating Council's final report produced in 2009. Twelve out of the seventeen regions of the country were affected by the storm. A total of 16 cities (including Marikina City, the case study area) and 172 municipalities were distressed. Casualties reached up to 464 deaths with 529 reported injured and 37 individuals missing (NDCC 2009). Majority of the deaths were caused by drowning (GOP 2009). The total damage by Ketsana reached PhP 11 billion pesos or around 775.74 million Euros. More than half of the cost of damage was (a) agricultural resource-related wherein around 203,477 hectares were affected and incurred losses of about 392,230 MT of crops such as rice, corn and high value commercial crops; fishery products, livestock/poultry; and facilities for irrigation, fishery and livestock/poultry; and the rest were

(b) infrastructure-related such as schools and hospitals. A total number of 185,004 houses were partially and/or fully destroyed (NDCC 2009).

Ketsana caused extensive flooding in Metro Manila and neighboring Rizal province (GOP 2009). There were three reported landslide incidents in areas in Luzon. The heavy rainfall brought by the tropical storm also prompted the National Irrigation Administration to open some of the gates of major dams (i.e., La Mesa Dam, Ipo Dam, Ambuklao Dam and Binga Dam) which resulted in heavy flooding in areas in Region 3, north of Metro Manila (NDCC 2009). Fifty-seven road sections were impassable to all types of vehicles in five regions, including the 37 road sections in Metro Manila during the peak of the tropical storm due to eroded shoulders, presence of floodwaters and landslides (NDCC 2009).

From 3 to 9 October 2009, seven days after Ketsana, Typhoon Parma entered the Philippines and crossed over Central and Northern Luzon. Based from the Post-Disaster Needs Assessment, both Tropical Storm Ketsana and Typhoon Parma caused substantial damages and losses which were equivalent to around 2.7 % of the Gross Domestic Product or GDP. The two storms account for over 60 % of the GDP (including Metropolitan Manila or the National Capital Region which accounts for about 38 % of the total GDP) and were considered significant in the overall magnitude of their effects (GOP 2009) in the country. The scales of these disasters were magnified because these storms hit highly populated economic centers. These two events were comparable to other major disasters in the world (GOP 2009, p. 15).

Effects of Tropical Storm Ketsana on the Local Government of Marikina City. In the Metro Manila region, Marikina City is reported to be the most heavily affected by flood waters. Although the local government of Marikina City has prior experience with "normal" floods, they were unprepared for the intensity of that rainfall event on 26 September 2009. On that fateful day, the local government convened the Marikina Disaster Coordinating Council (MDCC), which is chaired by the city mayor and is in-charge of responding to calamities and disasters experienced by the city. Rescue 161, the city's local communication and command center, was ordered by the council to deploy rescue operations. Only three of the 16 barangays, the smallest administrative unit in the Philippines, were accommodated by ambulances in the morning of the 26 September. At noon, most of the affected areas were unreachable because of the high flood levels.

5 Local Government's Disaster Arrangement Before and During Ketsana

As early as the 1990s, the local government of Marikina City had undertaken disaster-related initiatives. The vision and plan of the local government for its city is for its inhabitants to have a clean and safe place. To accomplish the plan, the local government (a) reactivated the MDCC; (b) created the Rescue 161, also known as the Disaster Management Office; and (c) established the 5-Minute Quick

Response Time. These initiatives were tied up with different programs that are related to flood control, mitigation and response.

Marikina Disaster Coordinating Council. Even before and during the time of Ketsana up until 2010, the Presidential Decree 1566, series of 1978, entitled "Strengthening the Philippine Disaster Control, Capability and Establishing the National Program on Community Disaster Preparedness," was the very basic Philippine law on disaster management. It mandates all levels of government from the national to the barangay level to organize multi-sectoral disaster coordinating councils. With said decree, communities can mobilize resources and capabilities needed to manage disasters with the presence of disaster coordinating councils. Said councils act as a link with all relevant government agencies and civic organizations (Duque 1999).

The decree provides the creation of the National Disaster Coordinating Council (NDCC). It is the highest policy-making body on disaster concerns and provides advice to the President (WB and NDCC 2005). WB and NDCC (2005) cites important stipulations in the decree, which includes (a) the state's policy on self-reliance among local leaders and their constituents; (b) documentation of plans by government departments and attached bureaus and agencies; (c) execution of planning and operation at the barangay level in a multi-sectoral basis; (d) leadership responsibility lies at the local level particularly on the provincial governor for provinces, city/municipal mayor for towns, and barangay chairman for barangay, the lowest political unit (WB and NDCC 2005).

The organization of the disaster coordinating councils exists from the national to the local levels. At the city/municipal level, the disaster coordinating councils are chaired by the highest elected official which is the mayor and vice-chaired by the station commander of the integrated National Police. The latter also acts as action officer. According to the decree, the council is comprised of members of organic city/municipal officials as well as national officials assigned by the city/municipality. The set-up of disaster management then, according to Duque (1999), is based on the democratic governance of the Philippines. The local disaster coordinating councils also cooperate with central government agencies and civic and non-government organizations whereby it links these relevant groups and mobilize resources and capabilities to manage disasters (Duque 1999).

The Marikina Disaster Coordinating Council (MDCC) was reactivated in the 1990s. It is chaired by the city mayor, vice-chaired by the vice mayor and the action officer is either the city administrator or the city engineer. The council is comprised of (a) damage and needs assessment; (b) central communication and command center; (c) plans and operations; (d) support services; and (e) recovery and rehabilitation. All of which are manned by regular and casual government employees from the different offices of the city government.

The MDCC has three functional stages, i.e., (a) pre-disaster stage, (b) disaster stage and (c) post disaster stage. For the pre-disaster stage, the functions of the Council include ensuring local departmental offices to have plans and defined disaster management roles. The Council is also responsible in conducting researches and studies; compiling and keeping geo-hazards maps which will be useful in land use planning; identifying potential evacuation centers in coordination with the barangay offices; conducting training and seminars related to disaster response; and information, education and campaign on disaster related matters. The Council also has administrative and documentation tasks as well (Marikina City Government 2007). During disaster stage, the MDCC is expected to do a lot of communication and coordination such as oversee actual response; coordinate with other offices like the Barangay Disaster Coordinating Councils and Rescue 161; maintain central communication and command center; and perform documentation. The local government of Marikina is aware of its responsibility during post-disaster stage. Here the MDCC is the lead of the recovery and rehabilitation unit. The Council is also responsible for the damage and needs assessment, recommendation of these evaluations to the City Council for legislative actions and documentation.

6 Local Government's Disaster Arrangement After Ketsana

After the great flood event caused by Tropical Storm Ketsana, changes took place both at the national and local levels. For instance, the Philippine Disaster Risk Reduction and Management bill was passed into law in 2010. It now superseded the Presidential Decree 1566 which has been enforced for the past 33 years. The law aims to strengthen the Philippine Disaster Risk Reduction and Management System by providing for the national disaster risk reduction and management framework and institutionalizing the National Disaster Risk Reduction and Management Plan. The scope of the act includes provisions on development of policies and plans and the implementation of measures on all aspects of disaster risk reduction and management. It also encompasses good governance, risk assessment and early warning, knowledge building and awareness raising, reducing underlying risk factors, and preparedness for effective response and early recovery. With the passage of the new law, there is now a new mandate for the local government units particularly making communities more disaster resilient as well as institutionalizing disaster risk reduction within their functions and operations.

Marikina Disaster Risk Reduction and Management Council. At the Marikina City level, the city's Council passed City Ordinance No. 32 creating the Marikina City Disaster Risk Reduction and Management Council (MCDRRMC). This move reorganizes the current MDCC with an emphasis on disaster preparedness. The importance of the people's right to life and property, incorporation of internationally accepted principles to plan, mainstream disaster risk reduction and climate change policies to all sectoral plans, program and engage civil society groups, private sectors and volunteers in the government's disaster risk reduction programs are considered and incorporated to the local law.

According to the said ordinance, the leadership of the reorganized council is still the same where the city mayor is the head or chairman, the vice-mayor and the city administrator as the vice-chairman and action officer, respectively. Members of the council include city officials, the Bureau of Fire Protection, Philippine National Police, Chinese Volunteer Fire Brigade, non-governmental organizations and people's organizations such as the Rotary Club of Marikina, Red Cross, Marikina Valley Contractors Association, Tzu Chi Foundation, Fil-Chinese Chamber of Commerce, Marikina Valley Medical Society, among others. The manpower of the council is comprised of regular and casual local government employees.

The MCDRRMC has also three function stages, i.e., (a) pre-disaster stage, (b) disaster stage and (c) post-disaster stage. According to the city ordinance, the pre-disaster functions includes formulating policies related to disaster risk reduction and management; approving, implementing and monitoring of plans; and ensuring that disaster risk reduction and climate change adaptation policies and strategies are integrated in the city's development plans, programs and budget. With regards to the disaster and post-disaster functions, the reorganized council has responsibilities over forced evacuation of local inhabitants and to ensure that there is smooth coordination among the government, public and private sectors.

Required Additional Office. With the passage of the Philippine Disaster Risk Reduction and Management Law, one of its mandates is to create the local disaster risk reduction and management office in the lower level, i.e., provincial, city, municipality and barangay levels. This additional office will be under the office of the provincial governor, city or municipal mayor or *punong* barangay or barangay leader based on the law. Further, the law mentions that the office shall be assisted by three staff responsible for administration and training; research and planning; and operations and warning. This mandate was considered by Marikina City. The creation of the Marikina Disaster Risk Reduction and Management Office was included in the City Ordinance No. 32.

7 A Reaction After Ketsana: Local Government's Creation of a Local Disaster Risk Reduction and Management Office

After the occurrence of Tropical Storm Ketsana, the local government of Marikina made several responses and adjustments. A comparison of the local government's disaster preparedness, management and response arrangement before, during and after Ketsana indicates institutional changes. One of the reactions of the local government was to legalize the creation of a disaster risk reduction and management office. Following the Philippine Disaster Risk and Management (DRRM) Act, the local government through the City Ordinance No. 32, passed by the city council, proposed a new office that consists of an administrative and training unit; a research and planning unit; and operations unit. The ordinance also reorganizes the former MDCC into MCDRRMC.

There was no disaster risk reduction and management office before and during Ketsana. There was only the MDCC and Rescue 161. Back then, the former MDCC did not have a permanent technical arm that supports the council. In reference to the earlier studies (Sutcliffe and Vogus 2003) a technical office manned with competent and efficient staff who are willing to learn and have relevant experience on disaster preparedness, management and response may increase the likelihood for the Council to produce more resilient responses or positive adjustments.

The local government of Marikina is currently making efforts to create a local DRRM office that will act as secretariat and technical arm of the MCDRRMC. Consistent with the DRRM Law, the new office will be under the office of City Mayor wherein its main tasks include setting the direction, development, implementation and coordination of disaster risk management programs. It will also be involved in formulating a local disaster risk reduction and management plan which should bein accordance with the higher level framework. According to the City Ordinance no. 32, an important role of a local DRRM office is to design, formulate and program disaster risk reduction and management plan. Said plan should be consistent with the national guidelines and be approved by the MCDRRMC. Other equally important tasks of the office include (a) identifying and assessing hazards vulnerabilities and risks within the city; (b) coordinating risk assessment and contingency planning; (c) operating a multi-hazard early warning system; (d) maintaining database of human resource, equipment, directories and location of critical infrastructures; (e) responding and managing the adverse effects of emergencies and carry out recovery activities; and (f) performing other functions that may be assigned by MCDRRMC.

However, it is should be noted that although, the local government already legalized the creation of such permanent office to assist the MCDRRMC, the (national) Commission on Audit made a recent report that the local government of Marikina has failed to established such office. In addition to this, the auditor also found out that the local government has not approved a DRRM Plan for 2011 with respective Work and Financial Plan. At present, the chief of the City Transportation Management and Development Office is the officer-in-charge on disaster-related matters. In response to this latest finding, the local government of Marikina said that the MCDRRMC has already issued a resolution instructing the use of the five percent calamity fund to implement the provisions of both the national law and city ordinance (Cordon 2012).

8 Conclusion

In the face of hazards posed by the changing climate, a local government that is resilient, such that it reacts and aspires to improve, is important to help cities to be resilient. This chapter examines a case study on organizational resilience, in particular, the response of the local government of Marikina City to the heavy flooding caused by Tropical Storm Ketsana. This chapter has shown that one of the reactions or responses is the legalization of the creation of the Marikina City

Disaster Risk Reduction and Management Office, after a comparison of the local government's disaster preparedness, management, and response arrangement before, during, and after Ketsana. A local government that is resilient, where it reacts and wants to improve is imperative. It helps the city to be resilient to disasters and hazards which are brought about by climate change.

There are, of course, other responses made by the local government of Marikina. However, these are further described and analyzed in a broader case study which is currently being undertaken under the Alexander von Humboldt Fellowship Programme.

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Part II
Urban Transportation

Urban Public Transportation System in the Context of Climate Change Mitigation: Emerging Issues and Research Needs in India

Bhargab Maitra and Shubhajit Sadhukhan

Abstract The transportation sector contributes significantly towards Green House Gas (GHG) emissions which are contributing factors for the global climate change. In developing countries, such as India, the share of urban transportation sector in overall vehicular emissions is significant. The present chapter reports increase in urbanization, growth of vehicle population and characteristics of urban transportation in India. The chapter highlights the need for increasing public transportation ridership as an instrument for reducing traffic congestion and vehicular emissions. The opportunities and challenges associated with urban public transportation systems are identified and the recent initiatives for improvement of urban public transportation system are reported. Finally, the research needs for improvement of public transportation system in urban India in the context of climate change mitigation are highlighted.

Keywords Urban transportation · Public transportation · Vehicular emission · Urbanization · Climate change

1 Introduction

Global warming has started affecting the world climate and taking an adverse shape day by day. Accordingly, global warming and resulting climate change has become a growing concern and threat to civilization (IPCC 2007). There is a dire need to take appropriate measures for mitigation of climate change in order to sustain the

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world as it ought to be. Although there are various reasons for the global warming, the increase in Green House Gas (GHG) emissions is considered as a major reason as GHGs increase the surface temperature of the world resulting global warming (IPCC 2007). The sources of GHG emissions include residential activities, industrial activities, power system, transportation system, etc. (CPCB 2010). The contribution of transportation sector in GHG emission is significant as it produces large emissions of Carbon Dioxide (CO_2), ozone and soot (Berntsen 2004). As per the Kyoto Protocol, the share of transportation sector is about 7 % of the total climate forcing due to its contribution in ozone, soot, and greenhouse gases (GHG) (Kadukula 2008). In 2009, transportation sector was responsible for 23 % of global GHG emissions (ADB 2012). The contribution from transport sector is expected to increase to 46 % by 2035 and 80 % by 2050 (ADB 2012). In Asia, 23 % of global CO_2 emissions are generated from transportation sector, of which the share of road transport sector (both passenger and freight) is 75 % (ADB 2009). Therefore, it is evident that the role of urban transportation, especially in developing countries, is of paramount importance in the context of GHG emissions and resulting global warming which leads to the change of climate. Traffic congestion and resulting GHG emissions are significant in majority of urban areas in developing countries. However, adequate prominence has not been given on improvement of urban transportation system in developing countries to bring down traffic congestion and resulting contribution to GHG emissions.

In India, the traffic congestion and resulting GHG emissions are significant in majority of urban areas. In 2005, the contribution of India in total GHG emissions was about 8 % and it is expected to be about 13 % by the year 2030 (ADB 2009). Therefore, it has become necessary to understand issues related to urban transportation system in India for reducing congestion and bringing down resulting GHG emissions in the context of climate change mitigation.

Traffic congestion and vehicular emissions are influenced by demand, supply and control characteristics of the transportation system. Therefore, improvements of transportation system (say, mitigation of congestion, reduction of vehicular emissions, etc.) may be attempted through various facets of works related to augmentation of supply, management of demand and improvement of control. However, increased public transport usage is considered as an effective instrument for reducing vehicle volumes and thereby bringing down the congestion and resulting GHG emissions in urban areas.

This chapter reviews urban transportation systems in India, justifies the need for improving public transportation system in the context of climate change mitigation and reports recent initiatives taken up by the Governments for improvement of public transportation system in urban India. The chapter also highlights emerging issues and research needs related to improvement of public transportation system as a demand management instrument for reduction in traffic congestion and the resulting GHG emissions. Reduction in GHG emissions through other means such as improved vehicle technology, alternative fuel, etc. are not included within the scope of the present chapter.

The increase in urbanization, vehicle population and road travel in India are reported in Sect. 2, while a review of transportation systems and vehicular emissions in urban India is included in Sect. 3. As the focus of the chapter is on urban public transportation system, Sect. 4 includes the opportunities and obstacles associated with public transportation system in Indian cities. Several initiatives have been introduced by the Government of India and various State Governments for improvement of urban public transportation system. These initiatives are reported in Sect. 5, while Sect. 6 addresses the emerging issues and research needs. Finally, the conclusions of the chapter are highlighted in Sect. 7.

2 Urbanization, Vehicle Population and Road Travel in India

2.1 Urbanization

India is the seventh largest country in the world in terms of its geographical area (CIA 2012). In terms of population, India ranks second in the world (CIA 2012). The present population of India is about 1.21 billion and the share of rural population is 68.83 % (Census of India 2011). In the recent years, the country has achieved GDP growths in the range of 7–8 % indicating a distinct trend of economic development. The country is also experiencing rapid urbanization (Fig. 1). In the last decade (2001–2011), the growth of urban population was 31.16 % as compared to 17.9 % growth of rural population. The number of cities with population of more than one million has increased from 35 to 54 during 2001–2011 and with the present trend of urbanization, the number is expected to increase to 70 by the year 2025 (Census of India 2011). The share of urban population has also intensified from 28 to 31 % during 2001–2011 and likely to be 54 % by the year 2025 (Demographia 2012). The growth of population in Indian megacities is also significant. During the last decade, the capital city, Delhi recorded an average

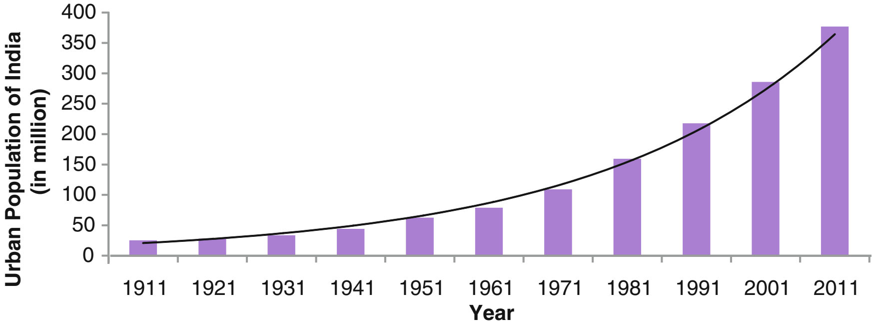

Fig. 1 Urban population of India (*Source* CIA 2012)

annual population growth of 4.52 %, followed by Bangalore, 3.38 % and Mumbai, 2.68 % (Census of India 2011). The population growth rates in other big cities are also momentous. Rapid urbanization caused significant increase of travel in urban areas and made urban transportation a major issue in Indian context.

2.2 Vehicle Population and Road Travel

Over the last few decades, India has experienced substantial growths of vehicle volumes and road travel. During 1980–2004, the share of road sector in the total passenger-km travel increased from 72.2 to 85.8 % and the vehicle population increased by 13.5 folds (Singh 2005). In 2001, the total number of registered vehicles was 55 million while the vehicle population increased to 115 million in 2009 (RTYB 2011). According to statistics provided by the Ministry of Road Transport and Highways (MoRTH), Government of India, the annual rate of growth of vehicle population in India was about 9.7 % during the last decade (2001–2011) (RTYB 2011).

The growths of different categories of vehicle during 1981–2011 are shown in Fig. 2. The category wise vehicle data for the year 2011 are projected from the available yearly vehicle data from 2001 to 2009. During 1981–2009, the number of motorized two-wheelers increased by more than 35 fold, while the number of cars increased by more than 15 fold (RTYB 2011). On the contrary, the population of buses increased only by about 9 fold (RTYB 2011). The percentage share of buses in the overall vehicle population in the recent years is shown in Fig. 3. It may be observed that the share of buses in the overall vehicle population remained only in the range of 1.1–1.4 % during 2001–2009 (RTYB 2011).

Overall, the country is experiencing growth of vehicle population but differential growths are recorded for different types of vehicle. The growths of private vehicles are significantly higher than that of buses. As a result, there is a significant shift in the modal share towards private vehicles.

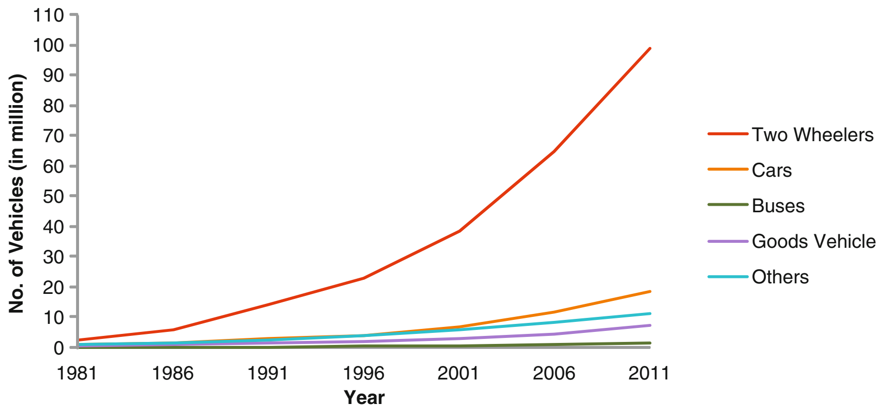

Fig. 2 Growth of different categories of vehicle (*Source* RTYB 2011)

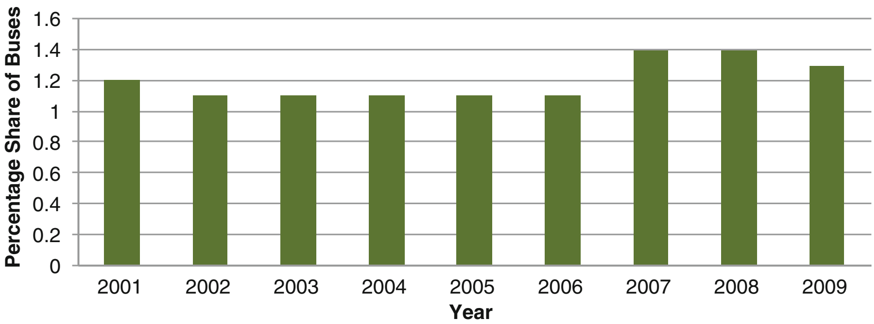

Fig. 3 Yearly statistics (2001–2009) of share of buses as percentage of total number of registered vehicles in India (*Source* RTYB 2011)

3 Transportation Systems and Vehicular Emissions in Urban India

The transportation system in urban India is primarily road based. A few exceptions include some of the metro cities such as Mumbai, Kolkata, Delhi and Chennai where substantial trips are made by the suburban rail or the city rail or even the metro services. However, in these cities the shares of road based trips are also significant.

Traffic streams in Indian cities are heterogeneous in nature, but the degree of heterogeneity varies across different cities. In the megacities, the shares of non-motorized traffic are negligible as compared to the shares of the motorized traffic, while in the medium and small sized cities the shares of non-motorized traffic are considerably higher. Lack of facilities such as pedestrian walkways, bicycle lanes, etc. are prime hurdles towards higher shares of non-motorized traffic in big cities.

The number of registered vehicles in selected metro cities is shown in Table 1. As of March 2009, the 22 metro cities accommodated about 27 % of the total registered vehicles in the country. Delhi, Bangalore, Chennai, Hyderabad and Ahmedabad recorded a registered vehicle population of more than 16.6 million which is about 54 % of the total registered vehicles in all metro cities (RTYB 2011). It may be mentioned that the vehicle population in Kolkata represents only the live vehicles after cancellation of vehicles registered prior to January 1993. Kolkata and other megacities started cancellation of registration of old vehicles every year following judicial interventions aiming to reduce the vehicular emissions. As a result, the growth of total registered vehicles in these cities may not truly reflect the volume of newly added registered vehicles. In reality, significant amount of new vehicles are being registered in all Indian metro cities and the total share of these metro cities in the overall newly registered vehicle population is significant.

The shares of different vehicle types in registered vehicle population for selected metro cities are given in Table 2. It may be observed that among various vehicle types, the share of private vehicles (i.e., motorized two-wheelers and cars)

Table 1 Total number of registered motor vehicles in selected metropolitan cities in India: 2001–2009 (as of March and number of vehicles in thousands) (*Source* RTYB 2011)

Metropolitan cities	Years								
	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ahmedabad	846	899	978	1,075	1,632	1,780	1,451	1,586	1,691
Bengaluru	1,593	1,680	1,771	1,891	2,232	2,617	2,179	2,640	3,016
Chennai	1,257	1,356	1,895	2,015	2,167	2,338	2,518	2,701	2,919
Delhi	3,635	3,699	3,971	4,237	4,186	4,487	5,492	5,899	6,302
Hyderabad	951	1,241	1,319	1,356	1,433	1,522	2,181	2,444	2,682
Jaipur	644	693	753	824	923	1,051	1,177	1,289	1,387
Kolkata	664	801	842	875	911	948	987	573	581
Mumbai	1,030	1,069	1,124	1,199	1,295	1,394	1,503	1,605	1,674
Nagpur	416	459	503	543	770	824	884	946	1,009
Pune	620	658	697	755	827	874	930	1,141	1,153

is significantly higher than that of buses. The economic growth has made vehicle ownership increasingly affordable to middle and upper classes in urban India. The availability of low cost cars is expected to further aggravate the private vehicle volumes in urban India.

Presently, there is no restriction on the usage of private vehicles during different hours in a day or during different days in a week. Therefore, the category wise registered vehicle population is also reflected in the on-road traffic stream. The composition of traffic stream at three major intersections in Kolkata is shown in Fig. 4. It may be observed that the share of private vehicles (i.e. cars and two wheelers together) is in the range of 60–75 %, while the share of buses is only in the range of 4–7 %.

Most of the Indian cities and towns have not been developed following planning principles. The percentage of land allocated for roads in Kolkata, Delhi, Mumbai and Chennai are 5.45, 11.25, 9.5 and 11.13 % respectively (IIR 2009);

Table 2 Private and public transport vehicles in selected metropolitan cities in India in 2009 (as of March) (*Source* RTYB 2011)

Metropolitan cities	Two- wheelers	Cars	Taxi	Buses	Others
Ahmedabad	1,312,601	218,805	6553	17,407	135,680
Bangalore	1,946,767	579,977	111,448	18,176	359,851
Chennai	2,017,816	499,256	58,889	34,491	308,852
Delhi	3,846,721	1,802,251	50,351	41,142	561,702
Hyderabad	1,836,549	417,868	29,436	22,725	375,403
Jaipur	1,035,999	163,479	14,833	18,873	153,528
Kanpur	519,664	73,947	193	691	47,033
Kolkata	173,891	313,900	32,826	6,938	53,693
Mumbai	909,993	484,473	56,958	13,061	209,881
Nagpur	850,276	71,262	2,126	4,160	81,374
Pune	831,029	129,797	10,417	12,800	169,033

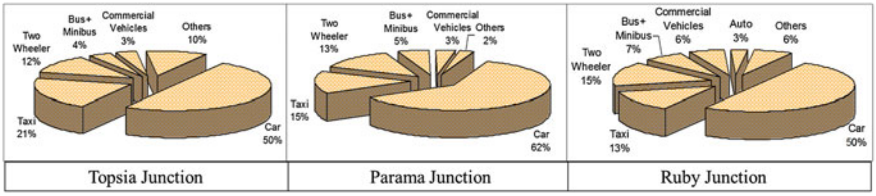

Fig. 4 Composition of traffic stream at selected intersections in Kolkata

while as per Urban Development Plans Formulation and Implementation (UDPFI) guidelines, the land allocation for the transportation should be 15–18 % for metro cities in plain area (ITPI 1996). In other cities also, the land allocated for roads is inadequate. Moreover, roadside activities and encroachment are also common in urban India, which put constraint on augmentation of transport supply. Therefore, with the growth of vehicle volumes, the imbalance between demand and supply of transport and the resulting traffic congestion level are increasing. High levels of traffic congestion have already started affecting the mobility and economic growth of various cities.

The high level of traffic congestion is reflected in the average journey speed of vehicles during the peak period. Average journey speed during peak period in Central Business District (CBD) area of several cities is as low as 10 km per hour or even less. The delay to traffic at signalized intersections has also increased significantly. Highway Capacity Manual 2010 defines six levels of service (LOS) (A to F, where A is the best and F is the worst) for signalized intersections on the basis of the average control delay per vehicle (TRB 2010). Table 3 shows control delay and LOS at different approaches of three major signalized intersections in Kolkata. The amount of control delay per vehicle or the poor level of service clearly reflects the severity of transportation problems in urban areas.

The growth of para-transit modes, especially three-wheelers (called as auto and tempo), is an important feature of urban transport in India. In most cities the bus system is either not fully developed or the quality of service is poor, which has encouraged the large-scale use of three wheelers in urban areas. Most of these three wheelers operate on fixed-routes and serve large number of passengers for

Table 3 Control delay and LOS at different intersections in Kolkata

Intersection	Approach	Control delay (Sec)	Level of service (LOS)
Ruby	Kalikapur	108.4	F
	Gariahat	83.6	F
	Parama	65.4	E
	Anandapur	44.5	D
Parama	Ruby	43.9	D
	Topsia	41.9	D
	Chingrighata	43.6	D
Topsia	Park Circus	35.5	D

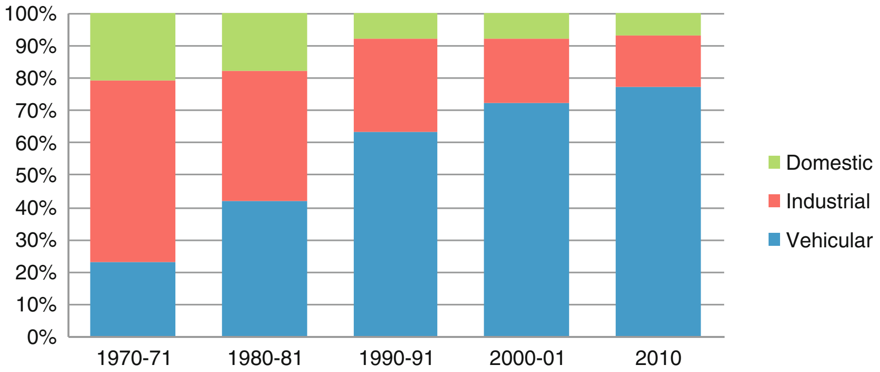

Fig. 5 Sources of air pollution in Delhi (*Source* Govt. of India 2002)

short trips. There is no comprehensive policy to restrict the operation of three wheelers only on selected routes primarily as feeder modes to bus or rail system. Therefore, these vehicles are presently operating indiscriminately in urban areas even as a competing mode to bus and aggravating congestion due to increase in vehicular volumes.

The traffic congestion has also intensified the vehicular emission levels in urban India and as a result the contribution of transport sector in air pollution has increased significantly. The contribution of different sectors in air population in Delhi is shown in Fig. 5. It may be observed that the share of transport sector has increased considerably over the last few decades. In 2002, the contribution of vehicular emission in overall air pollution in Delhi was 72 %. Also, the transportation sector contributed to 76.2 % of CO, 96.9 % of Hydrocarbons, and 48.6 % of NOx emissions in Delhi (Govt. of India 2002).

The pollution loads in different cities are shown in Fig. 6. The quantity of three major air pollutants (CO, HC and NOx) increases drastically with a reduction in vehicle speed (CPCB 2010). Thus, prevailing traffic congestion in Indian cities, particularly during peak periods, not only increases the delay but also increases the pollution levels.

The above discussions indicate that while increase in private vehicle ownership is probably a reflection of economic growth and therefore is desirable, the usage of private vehicles must be reduced, especially during the peak hours, in order to relieve congestion and reduce vehicular emissions in urban areas. In this context, it is necessary to influence the mode choice behavior of urban commuters so as to encourage them to use public transportation services in lieu of private vehicles, which will eventually reduce vehicular volumes and therefore, bring down traffic congestion as well as vehicular emission levels. Among different public transportation modes, city rail or metro rail is capital intensive and the services cannot provide as wide network coverage and door-to-door services as the bus transit. Therefore, bus will remain as an important public transport mode in urban India.

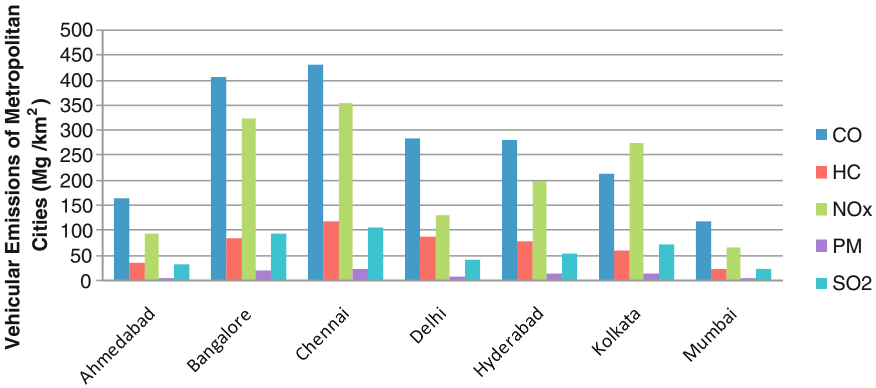

Fig. 6 Air pollution loads in selected major cities (*Source* CPCB 2010)

4 Urban Public Transportation System: Opportunities and Obstacles

It is necessary to improve public transport usage in urban India in order to bring down traffic congestion and resulting vehicular emissions which are affecting the climate change. A key issue is how to increase the public transport patronage in various cities in India. The opportunities and obstacles in this context are mentioned below.

4.1 Public Transport-Opportunities

Public transport users may be classified as captive riders and choice riders. Captive riders are those who do not own private vehicle and accordingly they are completely dependent on public transport for fulfilling their travel needs. Choice riders own private vehicles and therefore, may use public transport only by choice. Presently, public transport in urban India is used largely by captive riders. The growing numbers of private vehicle provide an opportunity to improve public transportation usage by shifting some of these choice riders to public transport. Of course, a higher shift of choice riders to public transport is possible only when the public transportation is improved as per the needs of choice riders.

4.2 Public Transport-Obstacles

There are several obstacles in the process of increasing public transport patronage in urban India.

(a) Overcrowding: In urban India, public transport is highly overcrowded during the peak hours. The discomfort associated with overcrowding of public transport makes it a less attractive alternative to commuters. In Kolkata, both captive and choice riders are found to consider congestion inside buses as a disutility. Interestingly, the Willingness-to-Pay (WTP) of choice riders for getting a seat in lieu of standing at crush load condition is found to be 1.7 times higher than that of captive riders (Maitra et al. 2012). A few other studies in Indian context (MMPG 1997; PhaniKumar and Maitra 2006, 2007) also indicated WTP of commuters for reduction of congestion and/or seat availability inside public transport vehicles.
(b) Poor Quality of Buses: Most of the buses operating in urban India are not attractive in terms of aesthetics and convenience. The noise level is high, the step heights are inconvenient and the appearance is poor. Probably, it is believed that soft factors such as quality of bus are not important in developing countries such as India. The research findings, of course, indicate that trip makers consider 'type of bus' as an important attribute in their choice decision. In Kolkata, the WTP values of captive and choice riders are found to be Indian Rupee (INR) 0.80 per km and INR 2.15 per km respectively for an improvement in the quality of bus (Maitra et al. 2012).
(c) Lack of Reliability and Public Transport Priority: Public transport services are often not reliable and there has been no attempt to improve the reliability of services. Although, no information is available regarding the importance of reliability in the context of bus service in India, but in-vehicle time is found to be an important factor in several studies (MMPG 1997; Phanikumar and Maitra 2006, 2007; Basu and Maitra 2010; Maitra et al. 2012). Practically no attempt has been made to implement bus priority measures in Indian cities for improving in-vehicle time of buses and improving the attractiveness of the bus service.
(d) Lack of Traffic Information: Real time traffic information for buses is not available in Indian cities. On-board travel information is also a missing component in the context of bus service in urban India. A recent study in Kolkata metro city indicates that the WTP of choice riders are INR 2.29 per km for availability of real time bus arrival information at bus stops and INR 1.07 per km for availability of on-board travel information (Maitra et al. 2012). The WTP values indicate that choice trip makers consider availability of traffic information as important factors in the context of bus travel.
(e) Low Fare Structure: Public transport fare is a socio-political issue. As a reasonable share of population even in urban area is from economically weaker section, it is justified to keep the fare as low as possible. But, low fare has been maintained in lieu of the poor levels of hard factors (such as in-vehicle time, waiting time, etc.) and soft factors (such as type of bus, comfort inside vehicle, traffic information availability, etc.) of public transport services. It appears that the low fare alone is unlikely to make the bus an attractive alternative to choice riders.

Adequate investigations have not been carried out to understand what attributes of public transport services need to be improved in order to make public transport an attractive alternative for choice riders. However, the available research works indicate the need for substantial improvement of soft factors and hard factors of public transport service. On the contrary, low fare is the necessity for commuters from economically weaker section. Also, most Governments are not in a position to increase the public transport subsidy which will be required to improve public transport as per the requirements of choice riders but continue the operation with a low fare structure. A clear segmentation of public transportation system appears to be the way out for urban India (Maitra et al. 2012) where two types of bus service (ordinary service and special service) may be operated to serve the needs for captive and choice riders. Ordinary service must have a low fare affordable even by socio-economically weaker section and primarily catering to the need for captive riders, while special service with a high fare but with accounting for both hard and soft factors targeting primarily choice riders.

5 Improving Urban Transportation in India: Recent Initiatives

In the recent years, several initiatives have been taken by the Government of India and various State Governments for improvement of public transportation system in urban India. Some of the major initiatives are mentioned below.

5.1 National Urban Transport Policy

The Government of India proclaimed a National Urban Transport Policy in 2006 (NUTP 2006) inspiring integrated land-use and transport planning in all cities to minimize travel distance and improve the access to livelihoods, education, and other social needs. The policy also emphasized the need for substantial allocation of road space with people, rather than vehicles as its main focus. The policy clearly heartened greater use of public transport and non-motorized modes by offering central financial assistance for such projects.

5.2 Jawaharlal Nehru National Urban Renewal Mission

The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was initiated in December 2005 by the Government of India as a programme to improve the quality of life and infrastructure in Indian cities (JNNURM 2011). The mission aimed to inspire reforms and fast track planned development in identified cities.

The JnNURM set an ambitious target to add close to 15,000 good quality buses in 61 major cities across the country. It intended to provide better public transportation and thereby, reduce traffic congestion and vehicular emissions in urban areas (JNNURM 2011).

5.3 Bus Rapid Transit System

Recognizing the significance of the bus transportation system, some of the Indian cities such as Ahmedabad, Delhi, and Bengaluru have opted for Bus Rapid Transit Systems (BRTS) as a high-quality customer oriented transit. Several other cities are also opting for BRTS in order to boost the share of public transport.

5.4 Other Initiatives for Bus Transport

United Nations Development Programme initiated a five-year demonstration program for operating and testing of fuel-cell buses (FCBs) in Delhi. The major objective was to introduce zero emission and highly efficient bus technology in India for reducing local air pollution and global GHG emissions (FCB Project 2010).

5.5 Metro Rail

Kolkata was the first city in India to have Metro rail in 1984. Subsequently, Delhi and Bengaluru also successfully started operation of metro rail. Various other cities such as Mumbai, Hyderabad, Kochi, and Chennai are also likely to have metro rail system in the near future.

5.6 Sky Bus

Sky Bus is the new rail based mass transit system which was launched in 2003 on an experimental basis for a stretch of 1.6 km in the open area along the railway track near Madgaon station in Goa. Various other cities in India are also considering the possibility of developing Sky Bus system.

5.7 Monorail

The nation's first 20 km long monorail is under construction in Mumbai. Once implemented successfully in Mumbai, it is likely to encourage the use of monorail in other cities in India.

6 Emerging Issues and Research Needs

India has comprehended the need for improving public transportation system in urban areas as an instrument for easing traffic congestion and bringing down vehicular emissions. The country has also initiated steps for improving Public Transportation (PT) Systems. This section presents some of the emerging issues and gaps which need to be addressed through research. The emerging issues and research needs are mentioned below.

6.1 Optimal Public Transportation System

Different types of public transportation system such as BRTS, Metrorail, Monorail, Sky bus, etc. are opted for different cities. There is no rational basis for selecting a particular type of public transportation system for a city. Also, it is unclear if the selected public transportation system is the optimal for the city. Presently, there are no guidelines for selection of optimal type of public transportation system for different cities in India with due considerations to city structure, land use, socio-economic characteristics and user behavior, physical constraints, available public transportation system, fixed cost and variable cost of alternatives public transportation systems, etc. It is necessary to develop guidelines for selection of optimal type of public transportation systems in different cities.

6.2 Travel Behavior and Travel Demand

Travel Demand Forecasting is a key step controlling the economic and financial viability of urban transportation projects. But, in majority of projects, travel demand forecasting is not carried out giving due considerations to the travel behavior of commuters. The quality of public transportation system is a major concern in urban India. It is necessary to identify hard and soft factors of public transportation services which are important to choice riders and include these factors in travel demand model. Also, the benefits likely to be derived from improvement of hard and soft factors should be duly considered in the economic analysis. It is, therefore, necessary to understand the valuation of various attributes of public transport service. Finally, it is necessary to develop guidelines for uniform and rational estimation of travel demands in various public transportation projects in urban India.

6.3 Public Transport Priority

In terms of journey time, road based public transportation system (say, bus system) is generally less attractive than private vehicles. Several works also revealed the importance of journey time in the context of choice of mode or route in urban India. However, no attempts have been made to incorporate bus priority techniques in urban India to improve the journey time of buses and making bus travel an attractive option to car users. It is important to mention that roadway, traffic and control characteristics prevailing in urban India are much different from those in developed countries. For example, traffic in urban India is highly heterogeneous, lane discipline is absent, pedestrian volumes are often very high, road side activities and encroachments are common. The behavior of drivers and road users are also substantially different in India. Therefore, although bus priority techniques are well known and implemented in several developed countries, it is necessary to carry out research to understand suitability and effectiveness of well known bus priority techniques in urban India. Also, it is necessary to develop warrants or guidelines for application of different priority techniques in India.

6.4 ITS Application

On-broad travel information, real time bus arrival information, etc. are important factors of bus service which are likely to influence the mode choice behavior of choice riders. Application of ITS in several ways can be instrumental in improving the efficiency of bus service in urban areas. Unfortunately, ITS application is yet to take place in urban India for improving the efficiency and attractiveness of the bus system. It is necessary to identify the priority domains for the application of ITS in public transportation and develop a framework for implementation of ITS in public transport system.

6.5 Bus Characteristics and Service Attributes

The type of buses (including dimensions, seat capacity, seat orientation, step height, etc.) vary widely in urban India. Also, it appears that no rational basis is followed for the selection of the type of bus for different routes. The service characteristics, particularly the headways (i.e., time interval between two successive buses on a particular route) also found to vary widely in different routes. It is necessary to develop a methodology for optimizing the benefits to commuters through appropriate selection of bus characteristics and service attributes giving due considerations to the operational viability. Eventually, guidelines should be developed for selection of the optimal type of bus and service characteristics based on route and demand characteristics.

6.6 Transfer Facilities

There are inherent deficiencies associated with transfer facilities around bus stops, rail stations and metro stations in urban India. Although the impact of these deficiencies on public transport ridership has not been investigated adequately in Indian context, but these deficiencies directly relate to safety and efficiency of transportation system. It may be mentioned that safety of pedestrians is a major issue in urban India and the role of transfer facilities is extremely pertinent in the context of pedestrian safety. It is necessary to identify hard and soft factors of transfer facilities, investigate their role on public transport ridership and prepare guidelines for development of transfer facilities around bus stops, rail stations and metro stations.

6.7 Feeder System

Appropriate feeder system is a basic necessity for the success of metro rail system. Appropriate feeder system is also important for bus system. In India, there are lacunas associated with planning of feeder system in urban areas. Often, feeder modes (particularly, three wheelers) act as a competing alternative to the mainstream public transportation system. The design of feeder system should account for the behavior of commuters. It is necessary to identify the optimal domain of operation of small feeder vehicles in urban areas considering user cost, operating cost, environmental cost, etc. Also, it is necessary to develop guidelines for design of routes, headway of service, etc.

7 Conclusion

The contribution of transportation sector in Green House Gas (GHG) emissions is significant and the increase in GHG emissions is considered as one of the major reasons for the global climate change. Therefore, the role of transportation sector becomes important in the context of climate change mitigation. In India, the contribution of urban transportation sector in overall vehicular emissions has increased significantly due to rapid urbanization, growth of vehicles, physical constraints associated with road capacity augmentation and growing imbalance between the demand and the supply of transport. It is found that while the growth of private vehicles in urban India has been substantial, the share of buses has not changed significantly. Therefore, increased use of public transportation system is considered as an effective demand management instrument for bringing down vehicular volume, traffic congestion and vehicular emissions in urban India. The opportunities and obstacles associated with urban public transportation systems in India are identified. It is found that the existing public transportation systems generally do not cater to the requirements of choice riders. It is necessary to improve the soft factors associated with public transportation system in order to make public transportation system an attractive alternative for choice riders. The recent initiatives taken up by the Government of India and various State Governments for improvement of urban public transportation system are reported and gaps are identified to highlight the research needs for improvement of public transportation system in urban India in the context of climate change mitigation.

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Emissions Models as a Design Tool for Urban Transportation Planners

Daniel Handford and M. David Checkel

Abstract Urban transportation is a significant contributor of greenhouse gas emissions. Despite this, transportation planning projects are generally not optimized directly for greenhouse gas emission reduction because there are few practical tools available that quantify the impact of specific project features. Ideally, physics-based micro-simulations would be used to evaluate project features within large-scale networks to properly capture local driving behavior and extended traffic shifting effects. This is generally not practical because micro-simulations require excessive computational resources. A transportation emissions model, which includes a simplified micro-simulation, is described. This model micro-simulates transportation emissions across large-scale networks such that emissions from a metropolitan region can be calculated for multiple design options in a few hours on a personal computer. A variety of case studies are presented which demonstrate the utility of practical large-scale micro-simulations for transportation emissions. The requirement for large-area models is shown by scenarios which demonstrate traffic shifting effects due to local changes in network capacity.

Keywords Micro-simulation · Emissions · Transportation · Design · Traffic

1 Introduction

Urban transportation planning is typically focused on optimizing the capacity and safety of transportation systems. While realizing these goals is often thought to achieve reduced exhaust emissions, the environmental impacts of planning

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activities are rarely measured or modeled. This is because of a lack of practical and available tools to quantify the environmental impacts of transportation design. The critical requirement is the measurement and evaluation of environmental impacts of transportation improvement plans. If they can model the environmental impacts of transportation improvement plans, urban transportation planners can significantly reduce climate-changing emissions through appropriate transportation planning and infrastructure design.

The significance of climate-changing emissions from transportation sources is amplified in urban regions. To illustrate, transportation emissions account for 17 % of Canadian greenhouse gas (GHG) emissions (Environment Canada 2010). However, transport sources are more important within cities, contributing about 29 % of total GHG emissions for Edmonton (Bailie and Beckstead 2010) and 27 % for Calgary (The City of Calgary 2011). There are several reasons for this but urban congestion and inefficient traffic patterns are significant contributors. Urban transportation planners develop infrastructure and improve traffic control measures to reduce congestion and this is generally known to reduce emissions. However, most transportation modeling tools do not accurately measure the emissions impact of traffic behavior and thus provide little or no guidance in designing infrastructure or traffic control to reduce emissions. Realistically, to measure the impact of traffic planning on emissions, one requires detailed transportation models that work at the link and sub-link level to measure vehicle behavior as influenced by infrastructure features and traffic controls while also working at the whole- network level to account for the re-distribution of traffic over an entire multi-mode transportation network. Micro-simulation models are required to appropriately model infrastructure features, traffic controls and driver behavior at the link or sub-link level. Simultaneously, modeling must be extended across large-scale regions to accurately account for traffic displacement across other network links and across transportation modes. However, modeling an entire multi-mode transportation network with a micro-simulation is typically impractical due to the computational resources required. While the concept is theoretically possible using a supercomputer, it could only be justified as a research project rather than being routinely applied to optimize transportation system designs.

This chapter describes a traffic emissions modeling tool designed specifically to provide consistent and representative emissions data while operating over a range of transportation models from macro to micro. The tool includes vehicle tractive power and emissions sub-models developed for a range of vehicle types as well as multiple fuel types and energy sources and calibrated over a range from 1990 historical fleets through projected future fleets to 2050. The emissions sub-model can calculate emissions outputs based on the tractive power sub-model's internally generated speed trace or based on external speed traces generated by independent micro-simulation traffic models. More importantly, to provide useful emissions outputs for macro traffic models, the emissions tool has a micro-simulation vehicle motion generator efficient enough to produce vehicle motion models appropriate to each vehicle type on each link of a whole-region traffic simulation. Emissions are evaluated and stored at a link-level resolution so results can be displayed as map-based graphics, providing strong visual feedback on where emissions effects are produced. This enables transportation planners to efficiently evaluate the GHG implications of infrastructure and transportation improvement plans, and allows them to use GHG emissions as a performance measure in their design decisions.

The emissions modeling tool is demonstrated through case studies that illustrate the effects of Policy, Infrastructure, and Traffic Control. Each case study discusses the options available and shows the use of GHG emissions modeling as a design optimization tool.

2 Background

The two most common types of transportation models are four-step models and micro-simulations. Four-step models are macro scale models used to estimate the load or demand that traffic will place on a network and the distribution of that load across network links. Micro-simulations, on the other hand, are used to estimate the capacity of a part of a network by directly modeling vehicle motions and interactions.

Four-step models model the demand characteristic of networks, and generally provide results that include the flow rate and average speed or delay on each link. GHG calculations applied to four-step model results are typically sets of emission factors known as Vehicle Kilometer Traveled (VKT) models, so named because they multiply the number of kilometers traveled by a weighted emission factor in units like kgCO2e/km. This type of analysis generally cannot capture the effects of local design features and driving behavior. Thus, even though a four-step model can provide link level resolution, it cannot be used to accurately predict emissions at the link level, particularly as a function of unique link characteristics. VKT models are most appropriate when applied to the entire network as an aggregated entity (Smit et al. 2008; Barth et al. 2001).

Micro-simulations generally model each vehicle on the part of the network being simulated, including the interactions between neighboring vehicles and possibly the effects of local infrastructure features on driving behavior. This produces a highly detailed record of events on the links being simulated and the result is that even for small networks or parts of networks, the computational effort required of a micro-simulation is large. The level of detail is helpful for emissions modeling because driving behavior can be appropriately modeled and emissions can be allocated geographically. However, simulations at sufficiently large scale to include traffic displacement across the network are generally not practical for day-to-day transportation planning and design activities (Handford and Checkel 2011).

The model described in this chapter uses a hybrid approach. Four-step model-based results for a whole network are used as the basis to generate representative micro-simulations on each link. These micro-simulations are then used to model fuel consumption and emissions. This methodology resolves emissions at the link level, captures driving behavior as affected by congestion and link design features, and also captures traffic shifting since large networks can be simulated. It allows for very large-scale analysis with micro-simulation accuracy while running rapidly enough on conventional desktop computers to provide for practical, day-to-day analysis of transportation design options.

3 Model Description

This section outlines the structure of the model, as well as the methodologies used in the sub-models.

3.1 Model Structure

The modeling tool used for this study consists of three parts or sub models; a simplified micro- simulation model, a tractive power model, and a power-based emissions model. The simplified micro-simulations use four-step Transportation Demand Model (TDM) link volume and speed results as inputs so the micro-simulations can be based on a macro-scale TDM analysis that accounts for traffic distribution across the network. The micro-simulations model generates appropriate vehicle speed traces or trajectories for each class of vehicle on each link and these are then passed to the tractive power model. Vehicle power is calculated at each time step in each trajectory and passed to the emissions model. That model uses power-based functions, (calibrated for vehicle type, year and ambient conditions), to calculate the fuel/energy consumption and emission rate at each time step. The inventory tool can then integrate over the trajectories, and sum the results for each vehicle type and link as well as creating network-wide inventories.

As an alternative starting point, speed trace data from experimental data, micro-simulations such as VISSIM or user defined vehicle trajectories can be used as input to the tractive power model. While such data sets typically don't cover a sufficient network area for whole-region analysis, this flexibility of inputs allows for a direct comparison between conventional, interaction-based micro-simulations such as experimental data, PTV's VISSIM model and the built-in simplified micro-simulation model. Figure 1 shows a flow chart for this model's application using the simplified micro-simulation and for use with other user-defined vehicle trajectories.

3.2 Simplified Micro-Simulation

The simplified micro-simulation model generates realistic vehicle trajectories for each vehicle type on each link being modeled, based on input provided by results from a macro-scale TDM, (such as EMME for example). Figure 2 shows the

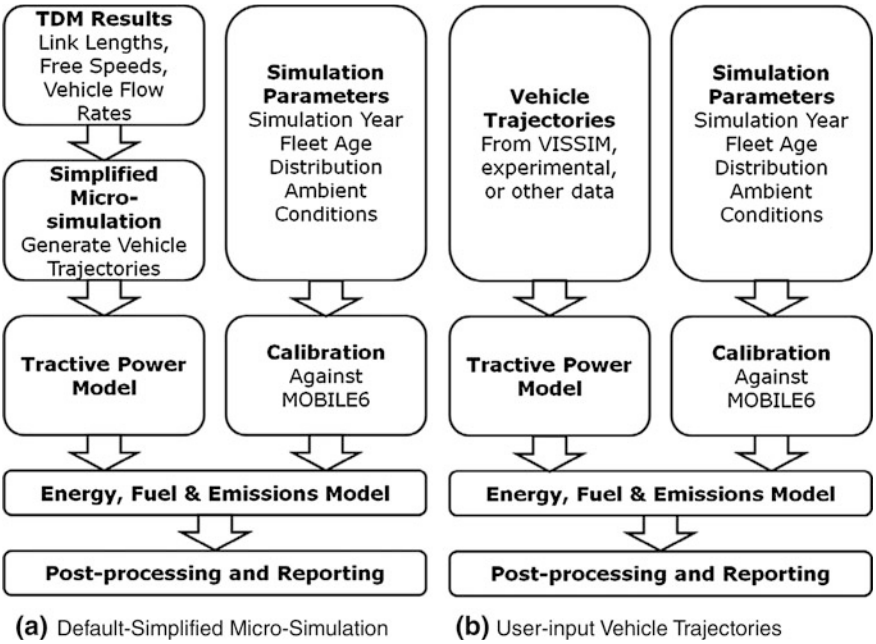

Fig. 1 Simulation flow chart. The emissions tool by default uses four-step travel demand model (*TDM*) results to generate vehicle trajectories (**a**), or can model the emissions based on vehicle trajectories specified by other means (**b**)

Fig. 2 Inputs and outputs for the simplified micro-simulation

inputs and outputs of the simplified micro-simulation. Rather than model each individual vehicle interacting with neighboring vehicles, the simplified micro-simulation finds a vehicle trajectory that satisfies the link length and average speed, while attempting to follow rules which emulate real traffic. For example, vehicles will attempt to travel at the free speed, and will slow or stop as necessary to make the average speed correspond to the specified delay on that link. This method has several advantages for simulating transportation emissions. The use of vehicle trajectories rather than average speeds or other aggregated network parameters means that driving behavior and vehicle power demand can be modeled appropriately, including using link-specific parameters like speed limits, gradients and the like. The use of a single vehicle trajectory for each class of vehicle on each link rather than modeling each vehicle and its interactions with others makes the simulation fast enough to be run on conventional computers, even when considering multiple design options or parameter optimizations. The vehicle trajectories, once generated by the simplified micro-simulation or entered as user-defined parameters, are passed to the tractive power model.

3.3 Tractive Power Model

The tractive power of each vehicle is calculated at each time step of the vehicle trajectory. It is a function of the vehicle trajectory (acceleration and speed), of link parameters (like gradient) and of class-specific vehicle properties, (frontal area, drag coefficient, rolling resistance coefficient, and mass). Tractive force is calculated as the sum of the forces required to overcome the vehicle's resistance to motion and to provide the acceleration. Tractive power is the product of the tractive force and vehicle speed. A physics-based model following that of Sovran and Bohn (1981) is used as the basis for vehicle tractive force. This model includes rolling resistance, aerodynamic drag resistance, and acceleration:

$$F = M\frac{dV}{dt} + R + D$$

where F is the tractive force, V is the vehicle speed, M is the vehicle mass, R is the rolling resistance, and D the aerodynamic drag. Rolling resistance and drag are further described by:

$$R = (r_0 + r_1 V)Mg$$

$$D = C_D A\frac{V^2}{2}\rho$$

where r_0 and r_1 are static and speed-variable coefficients of rolling resistance, V the vehicle velocity, g the acceleration of gravity, C_D the drag coefficient, A the vehicle frontal area, and ρ the density of the air through which the vehicle travels. Many models assume that rolling resistance is not a function of speed and set r_1 equal to zero (Society of Automotive Engineers 2003; Heywood 1988); this assumption is generally valid for speeds less than 110 km/h and is used in the proposed model. Ultimately, the tractive power model takes the following form:

$$P = M\frac{dV}{dt} + (r_0 + \sin\theta)Mg + C_D A\frac{V^2}{2}\rho$$

where θ is the angle representing the slope of the roadway.

3.4 Fuel Consumption and Emissions Model

The vehicle tractive power trace is used to calculate the instantaneous emission rate of each pollutant through a set of fuel consumption and emission functions. The functions used are based on correlations to chassis dynamometer testing done at the University of Alberta (Busawon and Checkel 2006; Checkel 1996). The functions return fuel consumption and emission rates in units of g/s given inputs of power p, in kW, and vehicle speed v, in m/s, and molar mass M. Carbon dioxide is calculated based on the conservation of the mass of carbon in the fuel and the exhaust, allowing for carbon monoxide and unburned hydrocarbons. The fuel consumption and emissions functions are calibrated to the MOBILE6 dataset based on:

- vehicle class and fuel type
- simulation year and ambient temperature
- fleet age distribution
- electricity supply properties (for grid-charged plug-in-hybrids and electric vehicles)
- hybrid and electric vehicle market shares.

The data sources used to calibrate the fleet are selected based on availability and relevance. Canadian fleets, (as modeled in the studies presented here), are calibrated to:

- the MOBILE6 model for emissions sources including running, evaporative, cold start, and brake and tire particulates
- the NRCan transportation database for fuel consumption
- the market share estimates of NRCan, and
- electric grid emission factors from LCA (Life Cycle Asssessment) studies for the relevant grid.

This calibration allows for an accurate representation of user-defined vehicle fleets; it also allows users to investigate the impacts of changes to the vehicle fleets such as might occur with technological changes or policy initiatives like green incentives.

4 Case Studies

The model described here is used to calculate emissions for various simulation scenarios. The scenarios include changes to the vehicle fleet composition, changes to transportation infrastructure, and changes to traffic control measures. These scenarios demonstrate the utility of using large-scale transportation micro-simulation to estimate emissions.

4.1 Case Study of Policy Application

The first two scenarios presented investigate the potential effectiveness of using publicly funded incentive programs to reduce the GHG emissions of the vehicle fleet. One scenario considers the use of incentives to encourage scrapping old vehicles (>10 years) in favor of new vehicles; the other considers the use of similar incentives to encourage the purchase of hybrid vehicles rather than conventional gasoline vehicles. The two scenarios both model three-year programs beginning in a major Canadian municipality (Edmonton) in 2013, with the incentive set at $3,000 per vehicle. Essentially, a limited number of drivers are given a monetary incentive in the amount of $3,000 if they chose to participate in the program by purchasing a new vehicle with reduced GHG footprint. The programs are assumed to have an incentive budget of $45,000,000 and thus provide incentives to 15,000 vehicle owners, distributed evenly over the three years to 5,000 vehicle owners per year. These scenario conditions allow for a comparison between the two hypothetical incentive models and demonstrate the utility of modeling emissions with a dynamic fleet. These alternatives are chosen to illustrate that this type of analysis can be used to inform policy makers of the effectiveness of such public programs.

The base case for both scenarios is a macro-scale TDM for the City of Edmonton on a typical fall weekday. It is estimated that there are approximately 746,000 active light duty vehicles and that 37,300 of those are new vehicles. The traffic demand is assumed to increase at a rate of 2 % per year and this analysis does not account for any increases in road capacity.

The first scenario models accelerated scrappage rates using new vehicle purchase incentives. For each of the three program years (2013–2015), an additional 5,000 new vehicles are introduced into the fleet, and 5,000 vehicles aged more than 10 years are retired. It is assumed that there would be sufficient demand for the incentives. Figure 3 shows the evolution of the fleet age distribution from the base year through to 2018.

The second scenario models the introduction of a hybrid vehicle incentive program. For this scenario, the fleet age distribution remains unchanged, but for each of the three years of the program (2013–2015), the number of new hybrids brought into the fleet is increased by 5,000 as a result of the incentive program.

The results of these new vehicle incentive studies are shown in Fig. 4. The introduction of more efficient technologies with fleet turnover is expected to lower CO2 emissions for a fixed amount of traffic but the rising trend of the baseline case shows that this is overcome by the anticipated 2 % yearly increase in traffic demand. Both the scrappage and hybrid incentive programs have the potential to reverse that trend and reduce the overall CO2 emissions over the three-year program period. For the parameters chosen, the hybrid incentive program provides a greater effect CO2 emissions than the scrappage program. The anticipated end of the programs in 2015 results in an upward inflection in their emission trends as the

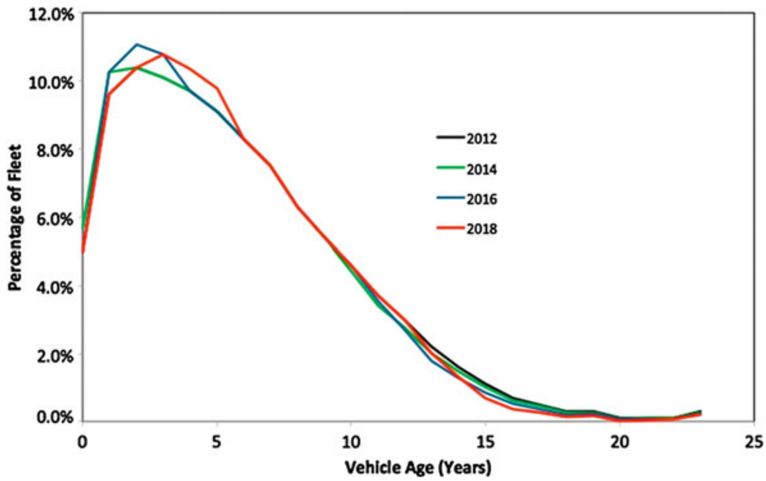

Fig. 3 Fleet age distribution for scrappage incentive program starting in 2013

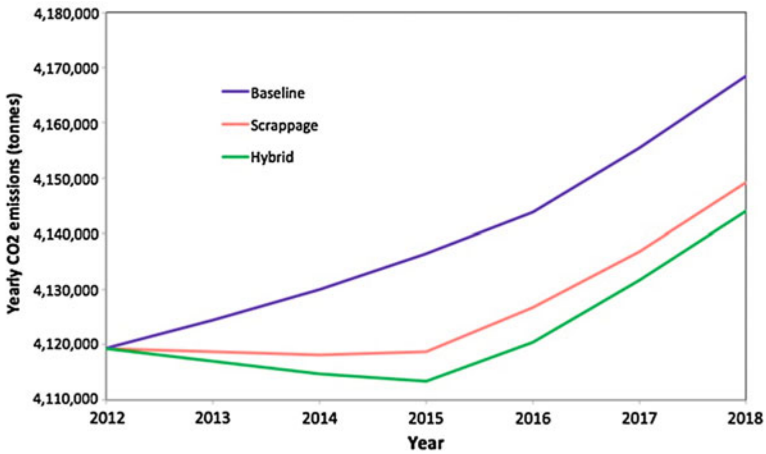

Fig. 4 Effect of two incentive programs on estimated yearly tailpipe CO2 emissions in Edmonton for light duty vehicles. Baseline model reflects normal fleet replacement rates combined with a 2 % increase in traffic per year

fleet continues to turn over and age with replacement strategies reverting to the baseline conditions.

In general the objective of policy makers is to mitigate the largest quantity of GHG possible for their given budget. This type of analysis lends itself well to this goal; the program budget and emissions mitigated can be used to calculate the cost of reducing GHG's on a $/tonne basis, and then compared to alternative projects. The cost effectiveness of the programs outlined in these studies is summarized in

Table 1 Estimated CO_2 emissions savings for the scrappage and hybrid models, and their cost effectiveness over the three years of the program and three concurrent years

	Scrappage Model (kg)	Hybrid Model (kg)
2012	–	–
2013	5,860	7,550
2014	11,800	15,300
2015	17,700	23,100
2016	17,200	23,500
2017	18,700	23,900
2018	19,100	24,300
Total (6 years)	*90,300*	*118,000*
Program cost	*$45,000,000*	
Mitigation cost ($/tonne)	*$498*	*$382*

Table 1 for the assumed parameters, the hybrid incentive scenario at $382 per tonne is more effective than the scrappage incentive scenario at $498 per tonne. However, both programs are relatively expensive compared to typical carbon prices ranging around $15 per tonne based on energy conservation programs. The ability to estimate the emissions savings and cost effectiveness of potential GHG reduction programs allows policy makers to compare different concepts and use their budgets as effectively as possible.

4.2 Case Studies in Infrastructure Design

This case studies the emissions effects of infrastructure changes by investigating the closure of a major urban bridge. The study illustrates the importance of large-scale simulations that capture traffic shifting effects as well as local congestion.

The study focuses on the effects of closing a bridge on a major artery into the downtown zone of Edmonton, Canada. Figure 5 shows maps of link-based specific emission rates for the two scenarios: (a) with the bridge open, and (b) with the bridge closed. The primary consequences of a bridge closure are that traffic must use alternative river crossings, and that the increased loading will cause congestion at these points. A secondary effect is that some travelers will choose alternate modes of transportation such as public transit and the vehicle kilometers traveled on the network will decrease. This mode-shifting effect is captured by mode choice model implemented in the four-step TDM used to generate the two cases. These suspicions are confirmed by the results shown in Table 2. The importance of traffic shifting and the necessity of large-scale modeling is illustrated by presenting results for a range of study boundary radii. While the regional model does not show a significant change in average speed, travel (VKT), or GHG emissions, the traffic volumes within a 0.5–1 km radius of the bridge are significantly lower, and vehicle travel is both slower and less efficient. The results indicate that, for this

Table 2 Relative increase of GHG emissions, average speed, and traffic (VKT) for the bridge closure scenario

	Relative increase due to bridge closure			
Radius (km)	GHG (kgCO2e) (%)	Average speed (kph) (%)	VKT (%)	GHG (gCO2e/VKT) (%)
0.5	−63.7	−11.1	−67.4	11.3
1	−12.5	−2.5	−19.4	8.6
1.5	−4.2	−3.4	−7.8	3.9
2.5	*−1.7*	*−0.6*	*−2.8*	*1.2*
5	−0.7	−0.5	−0.9	0.3
10	−0.1	−0.1	−0.1	0.0
Region	−0.1	0.0	0.0	0.0

The bridge is at the center of the expanding radius that bounds the simulation

case, a minimum radius of 2.5–5 km from the closed bridge would be required to capture traffic shifting effects, mostly of traffic onto alternative bridges. (This radius would be different for other cases depending on the traffic volume crossing the bridge and the capacity and proximity of alternative routes). In this case, the displacement of some vehicle trips to light rail transit roughly balanced the increased distance traveled by vehicles detouring around the closed bridge so, on a city-wide basis changes in vehicle mileage and CO2 emissions were minimal. This result would have been difficult to foresee and to confidently predict without the capability to model both traffic and emissions on a whole-network basis.

4.3 Case Studies in Traffic Control Measures

The following two scenarios relate to traffic control measures; increasing the speed limit on a major freeway, and changing from signalized intersections to free flowing interchanges on a ring road. Each of these case studies includes a baseline case and the altered case where, effectively, the capacity of a major artery is increased and traffic is likely to shift towards that artery. These case studies demonstrate the advantages of large-scale micro-simulation models for a complete understanding of the transportation issues being modeled.

In the first case study, a major suburban freeway crosses a metropolitan region outside the inner core in the East-West direction. The speed limit is 80 km/h (kph) baseline, and the effects of an increase to 90 kph are studied. With lower travel time on the freeway, some traffic that would otherwise use nearby roads is attracted to the faster flowing freeway. The problem is studied using three boundaries to demonstrate the importance of large-scale modeling. The narrowest boundary is only the freeway, the second includes roads in the immediate vicinity and the largest includes the entire metropolitan region. The three boundaries are shown graphically in Fig. 6. Figure 6 also illustrates the resulting link traffic

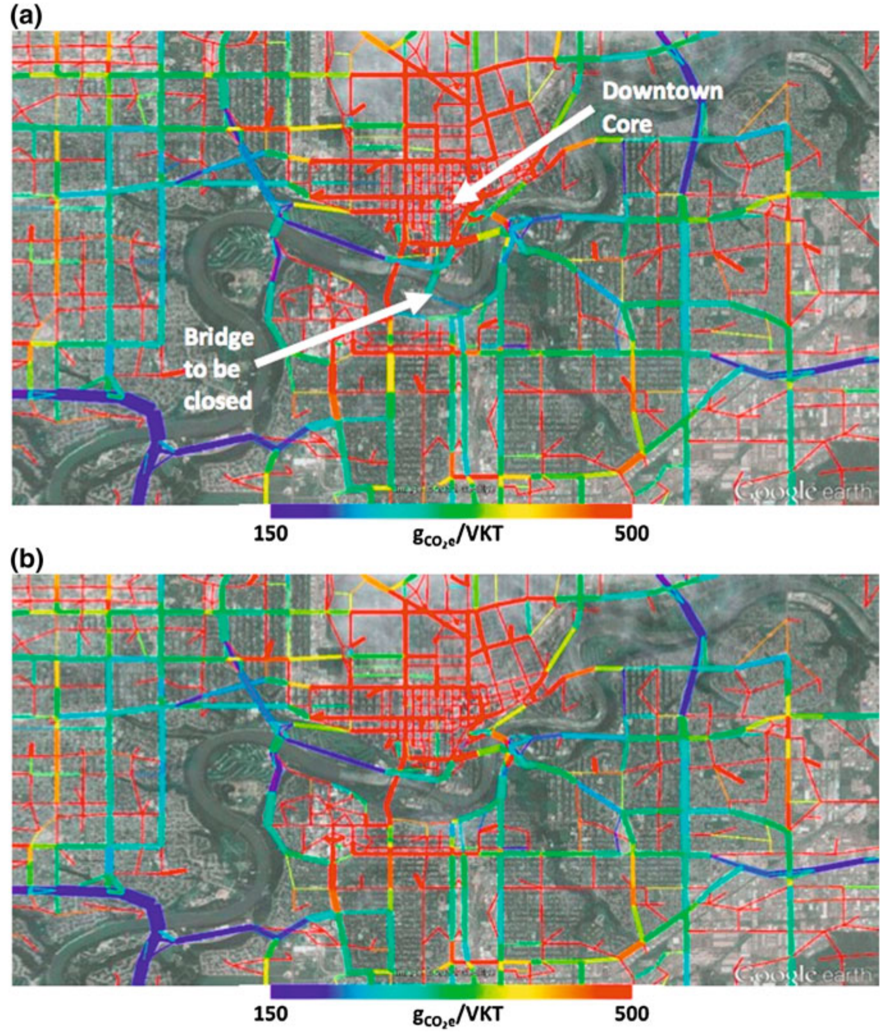

Fig. 5 Bridge closure case study models showing distance specific GHG emissions: **a** is the base case with the bridge open, and **b** is the case with the bridge closed. Line width shows traffic volume, and color shows CO2 specific emission rate (see *scale*)

volumes (as line width) and the specific CO2 emission rates (as line color). Table 3 provides numeric results for the three different boundaries.

Considering only the freeway, a higher speed limit produced faster travel (by 5 %) and a marginally lower specific CO2 emission rate (by 1 %) because of vehicle efficiency and smoother flow. However, the increased traffic on the link (up by 7 %) raised overall CO2 emissions along the freeway by 6 %.

The extra traffic using the freeway is displaced off lower-speed, less-efficient links but must also drive further to access the freeway. Does this result in greater

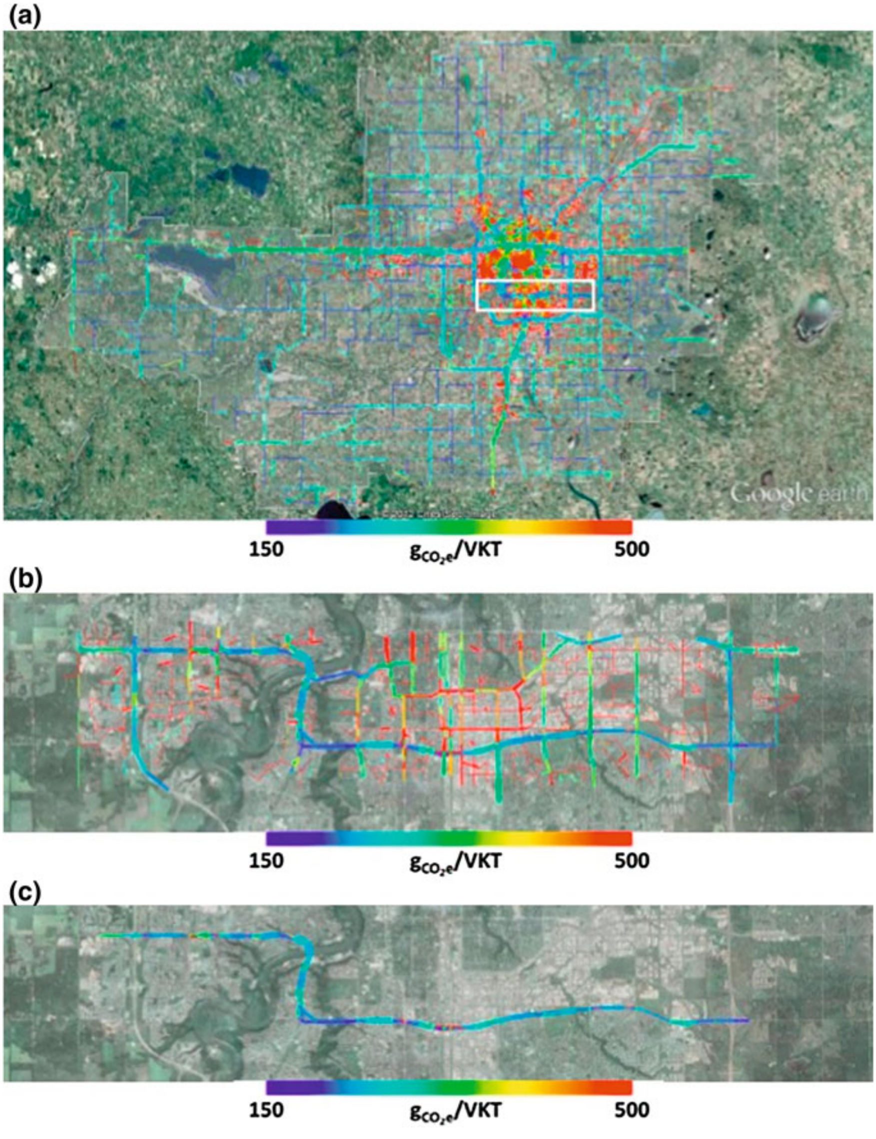

Fig. 6 Baseline case with 80 kph speed limit, showing the model boundaries: **a** Metropolitan region with freeway vicinity shown in *white box*, **b** Freeway and vicinity links, and **c** Freeway only

or lesser CO2 emissions? The study is repeated with broader boundaries to capture the effects of traffic displacement. At the freeway + vicinity level, overall travel rises by 2 % with a corresponding 1 % increase in CO2 emissions. This now covers about 3 times as much travel as the freeway itself and the result is interpreted to indicate that the extra travel of getting vehicles to/from the freeway still

Table 3 Model results for weekday peak hour travel of an increased speed limit on trans-urban freeway

Speed Limit (kph)	GHG (kgCO2e)	Average Speed (kph)	VKT (km)	GHG (gCO2e/VKT)
Freeway only (Fig. 6c)				
80	78,211	59.94	338,181	231
90	82,641	62.88	361,426	229
Absolute increase	*4,430*	*2.94*	*23,245*	–
Relative increase	*5.7 %*	*4.9 %*	*6.9 %*	*−1.1 %*
Freeway and vicinity (Fig. 6b)				
80	367,740	49.01	1,015,172	362
90	372,105	49.88	1,037,268	359
Absolute increase	*4,365*	*0.87*	*22,096*	–
Relative increase	*1.2 %*	*1.8 %*	*2.2 %*	*−1.0 %*
Metropolitan region (Fig. 6a)				
80	2,445,858	53.98	6,703,818	365
90	2,445,944	54.15	6,707,263	365
Absolute increase	*86*	*0.17*	*3,445*	–
Relative increase	*0.0 %*	*0.3 %*	*0.1 %*	*0.0 %*

provides an overall increase in CO2 emissions. However, at the urban region level, (encompassing 19 times as much travel as the freeway), the effect of reduced demand on other links across the region becomes apparent. As a result, the overall travel distance and overall CO2 emissions still increase by a marginal amount but less than indicated by the freeway vicinity itself.

The second scenario in traffic control measures examines changing a section of a major outer ring road from signalized intersections to free flowing interchanges. The distance specific GHG emission maps are shown in Fig. 7 and the numeric results in Table 4. This type of development on a high-speed outer ring road is expected to improve travel times and Table 4 confirms the average speed improvement both locally (5 % for the ring road and vicinity) and over the whole metropolitan region (0.6 % which is significant). The efficiency of the vehicles on the network is also improved as is indicated by reduced distance-specific GHG emissions (3.2 % lower in the vicinity and 0.3 % averaged over the entire region). However, given the peripheral nature of the outer ring road, vehicle mileage increases significantly to access that increased capacity and thus overall traffic volume (measured by vehicle kilometers travelled) increases significantly (by 6 % for the vicinity and 1 % over the urban region).

The end result of this study is a significant increase in GHG emissions for the region as a consequence of increased ring road capacity. This result can be troublesome for a transportation planning department; it reduces average network travel times, but increases the GHG's emitted on the network. However, the city in question is growing rapidly so projections into the future with a larger urban footprint and higher traffic show that, in the future, these infrastructure improvements alleviate congestion that would otherwise raise GHG emissions even further.

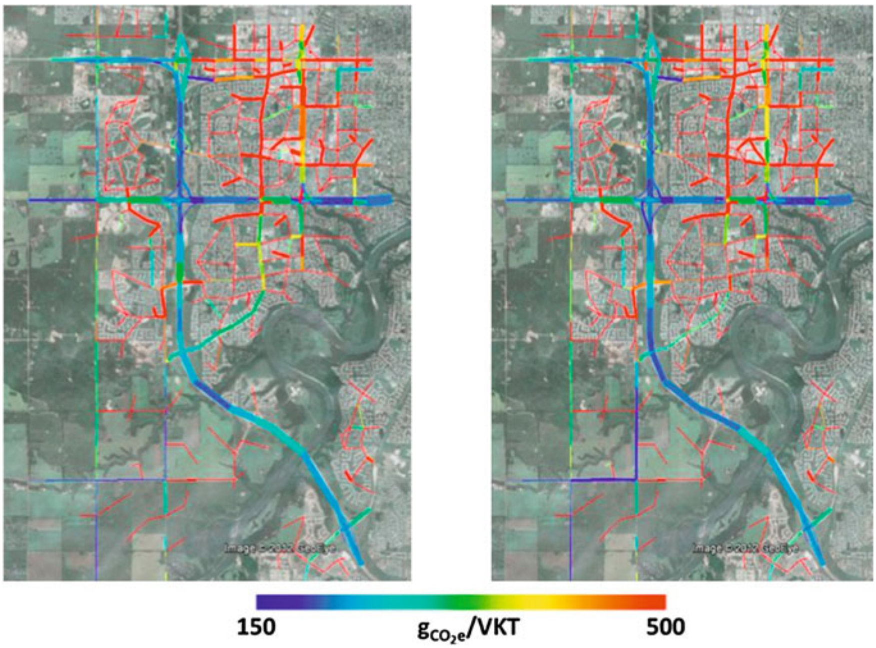

Fig. 7 Baseline case for outer ring road with signalized intersections (*left*) and free flowing interchanges (*right*)

Table 4 Model results for outer ring road section with signalized intersections and with interchanges, for both the near vicinity and the metropolitan region

	GHG (kgCO2e)	Average speed (kph)	VKT	GHG (gCO2e/VKT)
Outer ring road and vicinity				
Signalized	155,652	50.34	421,263	370
Interchange freeflow	160,345	52.76	448,146	358
Absolute increase	*4,693*	*2.42*	*26,883*	–
Relative increase	*3.0 %*	*4.8 %*	*6.4 %*	*−3.2 %*
Metropolitan region				
Signalized	2,308,021	53.98	6,703,818	344
Interchange freeflow	2,321,847	54.3	6,764,181	343
Absolute increase	*13,826*	*0.32*	*60,363*	–
Relative increase	*0.6 %*	*0.6 %*	*0.9 %*	*−0.3 %*

5 Conclusions

The approach illustrated in this chapter has been to apply simplified micro-simulations to large-scale transportation planning studies to rapidly calculate emission inventories for transportation networks in a way that responds to design choices at the project level. The advantages of this approach have been illustrated with a series of case studies showing the ability to respond to policy choices, infrastructure design parameters and traffic control parameters. The modeling tool described is flexible and generates both numeric values and visual output. Both can be used to inform decision makers of the environmental impacts of various transportation and GHG management strategies. The case studies in this chapter have focused on GHG reduction potential but the model also includes criteria pollutants like smog precursors and particulates where the localization of impacts might be even more important.

Case studies illustrated the evaluation of policy choices such as green incentives for hybrid vehicles or vehicle scrappage, providing a means of evaluating the cost effectiveness of proposed programs. Traffic control strategies and plans can also be evaluated for their environmental impact, and the change in overall emissions as well as any shift of emissions between modes can be captured. Infrastructure designers can use large-scale micro-simulation to model the impacts of their design concepts. Furthermore, the simplified micro-simulation used for this study allows for the rapid turnover of such design studies and optimizations with conventional desktop computers.

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Mobility and Mitigating Climate Change in Urban Centers: Open Innovation and Pricing as Key Elements for Customer-Focused Strategies and Measures

Jochen Wittmann

Abstract Global demand for (individual) mobility and motorization is increasing rapidly. Mobility is important to economic and social development, especially in urban centers (Döhmel 2008). But mobility is also considered a main reason for accelerating climate change in the form of CO_2 emissions (IPCC 2007). Politicians, media, NGOs and (city) governments identify mobility as a core domain to design and launch strategies and measures mitigating climate change in urban centers. In recent years, strategies and measures incorporated were often less effective because customer needs and demands were not met sufficiently and the costs of (individual) mobility were increased by regulations and taxation. The leading idea of this paper is to design a conceptual framework, whereby open innovation approaches and pricing as key elements are applied to customer-focused strategies and measures mitigating climate change in urban centers.

Keywords Mobility · Urban centers · Open innovation · Pricing · Life-cycle concepts

1 Introduction

Global demand for (individual) mobility and motorization is increasing rapidly. Mobility is important to economic and social development, especially in urban centers (Döhmel 2008). But mobility is also considered a main reason for accelerating climate change in the form of CO_2 emissions (IPCC 2007).

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Politicians, media, NGOs and (city) governments identify mobility as a core domain to design and launch strategies and measures mitigating climate change in urban centers. In recent years, strategies and measures incorporated were often less effective because customer needs and demands were not met sufficiently and the costs of (individual) mobility were increased by regulations and taxation.

The customer of individual mobility must stand at the center of considerations. The inclusion of open innovation approaches is necessary to identify customer needs in an early planning and developing stage of strategies and measures mitigating climate change in urban centers.

Pricing is another key element, because affordability and value for money of products and services are considered a bottleneck to the widespread use and acceptance of environmental-friendly individual mobility solutions.

The leading idea of this paper is to design a conceptual framework, whereby open innovation approaches and pricing as key elements are applied to customer-focused strategies and measures mitigating climate change in urban centers.

2 Basics of Mobility with the Focus on Mitigating Climate Change in Urban Centers

2.1 Climate Change

2.1.1 Basics of Climate Change

Climate change is considered as one of the most significant developments that heavily damages environments; with particularly strong impacts on urban centers. Climate change is often used as a synonym of global warming, which is based on the increase of the average temperature of the atmosphere and the oceans. This is probably a consequence of mainly anthropogenic activities like the burning of fossil fuel, deforestation as well as intensively conducted industrial farming, which lead to an increase of "Greenhouse gases" (GHG), e g. CO_2 emissions (Kaiser and Kürzinger 1994, p. 107).

Twenty five percent of energy-related CO_2 emissions are caused by transportation including 10 % by cars and vans (Döhmel 2008). The trend based on growing motorization and mobilization, especially in emerging markets (e.g., BRIC: Brazil, Russia, India, China), could be summarized as "more people, more wealth and more energy demand" (Döhmel 2008, p. 28).

The stark truth is that liquid fuels remain a "conditio sine qua non" for transportation. Fossil fuels hold a share of more than two-thirds of world energy consumption and embody the dominant resource of energy in 2030 (Döhmel 2008).

The "polylemma", rising motorization and mobilization, remaining significant dependency on fossil fuels, the acknowledgement that (individual) mobility is value-adding means that mitigating climate change in urban centers, remains a big global challenge and requires the early participation of customers and stakeholders to find the right strategies and measures on the level of urban centers.

The core target of mitigating climate change is to design and prioritize strategies and measures, which support sustainable mobility and prevent or reduce further burdens on environmental-friendly individual mobility.

2.1.2 Strategies and Measures for Mitigating Climate Change

The discussion about strategies and measures for mitigating climate change takes place on global, continental, national, regional and local levels.

Strategies focus on

- the development and use of cleaner, less GHG emitting technologies as well as
- the increased attention on energy efficiency and
- the increased use of renewable energy.

These can include increased attention on mobility with CO_2-neutral or CO_2-reduced emission objectives, e.g., through CO_2-emission based taxation of vehicles or pollution-oriented congestion charge. Acharya et al. point out that "… regulation of pollution—one of the most classic problems of externalities in economics—deals with it much the same way: The polluter pays for its contribution" (Acharya et al. 2011, p. 137). Tributsch (2008) argues that a CO_2-free emission strategy is not preferable for a sustainable future, but there is an urgent need for the development of technologies which are able to adequately balance the circulating CO_2 amount in the atmosphere.

In general, measures considering the impacts of mitigating climate change differ between short-, mid- and long-term (see Table 1). Examples of measures mitigating climate change in urban centers are:

- public transport solutions and motility solutions (Hilmola 2011), which like in Freiburg (Germany) are preferred by city planning and policy.
- mobility services like car sharing in urban centers as an alternative to public and individual mobility solutions.

Table 1 Key mitigation technologies and practices by sector "transport" (IPCC 2007, p. 20)

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialized before 2030
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport cycling, walking); land-use and transport planning.	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.

There are also examples of applied strategies and measures mitigating climate change that are at this time not economically and environmentally advantageous in practice and an improved coordination between the stakeholder groups might be necessary.

The introduction of E10 fuel, which has a content of 10 % instead of 5 % biofuel, in Germany in 2011 uncovered an information gap about the usability of this fuel for car engines. The result was that customers mostly reject the E10 fuel. Despite the lower price of the E10 fuel the added value for the customers was not viable because of the risk of engine damage and a general lack of information.

Another example is the introduction of fuel efficient buses in New Delhi, which led to higher ticket prices. The consequences were on the one hand, that people with higher incomes changed towards individual mobility solutions, e.g., auto scooters, motorcycles and cars. On the other hand, mostly low-income commuters could not afford the bus trips anymore and switched to motility solutions, e.g., walking and cycling, with longer transportation times (Tiwari 2003). The positive effect of a CO_2 emissions reduction measure went into reverse, because of increased traffic by cars.

A potential solution is to define concerted strategies and measures which meet customer needs and include specific incentive systems. But the accurate measurement of CO_2 emissions or the carbon foot print of the urban center is an important prerequisite to support local measures (Liu et al. 2011).

2.2 Urban Centers

2.2.1 Basics of Urban Centers

According to the UN, 50 % of the world population in 2020 will live in urban centers. This will be especially noticeable in urban areas of emerging markets and developing countries like Mexico City, Mumbai, and Kolkata with much more than 10 million inhabitants (Van der Ploeg and Poelhekke 2008).

Urban centers are defined as agglomerations of housing, commercial buildings and industrial sites, which can be cities or clusters of cities and villages around them. The often used term “mega-city” is misleading, because it is focused on one metropolis like London and excludes similar densely populated areas like the German Ruhr area. London is the capital and the commercial center of Great Britain as well as the focal city of Greater London. The Ruhr area is an agglomeration of middle-sized cities like Dortmund and Essen with less than 1 million inhabitants and with no dominant center like London.

The UN also includes agglomerations with more than 10 million inhabitants like Osaka-Kobe-Kyoto not focusing on one dominant city like Tokyo and Mexico City (UN 2006). In this context, a comparison of urban centers as networks is viable. These networks exist with both a polycentric (Ruhr area) and monocentric

(Greater London) structure. This also has impacts on the population density and efficiency of individual and public mobility media

2.2.2 Functions of Urban Centers

Urbanization is accelerated by globalization and digitalization, especially in the BRIC countries. Urban centers are living and working places as well as places for shopping and sightseeing. They attract people from urban centers and the areas around them as well as tourists and business people from all over the world.

Mobility and motorization follow these developments. This has strong impacts on urban centers, where mobility of persons as well of ideas and knowledge increase rapidly. Urban centers are therefore also places of agglomeration of knowledge, which is nurtured by the establishment of higher education opportunities and centers of research and development like universities and business research and development. Urban centers are also places of cultural life and leisure, which are more attractive to people with higher incomes. Florida emphasizes that a rich cultural environment attracts people from the creative class, which bring business opportunities to urban centers (Florida 2005).

All these aspects lead to a higher attractiveness of urban centers, which often promise people living in the countryside a higher living standard and opportunities. This fosters further migration to urban centers. Despite severe disadvantages of urban centers like congestion, air pollution and the higher costs of commuting and living, "people and firms settle in big cities in search of better jobs, the need for face-to-face interaction, and the stimulation of the buzz of learning from each other" (Van der Ploeg and Poelhekke 2008, p. 7). Another aspect is the higher relevance of the "home effect" in urban centers, which means that larger markets attract larger businesses and industries, because firms want to be near their clients (Krugman 1991).

These determinants of urban centers are mirrored by mobility aspects as well as requirements by stakeholders of urban centers.

2.3 Mobility

2.3.1 Key Terms

The term "mobility" is used colloquially in different ways, e.g., in the broader sense it is equivalent to the term locomotion. It is therefore necessary to define the following related terms mobility, motility, transportation, traffic and locomotion in order to specify the different terms in the core topic (see Fig. 1).

The differentiation between motility and mobility (in the narrower sense), which are both forms of **locomotion**, improves the understanding of the topic significantly.

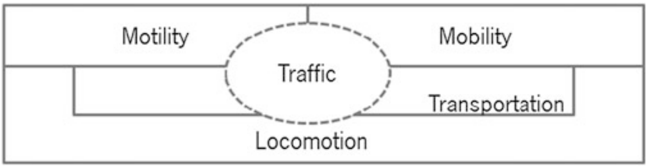

Fig. 1 Key terms

Motility is actively executed locomotion using a person's own power. Examples are locomotion on foot or by bicycle, which can be executed individually, independently and privately.

Mobility is defined as passively conducted locomotion without using a person's own power. For example, in a car or a bus, which can be executed individually, independently and privately, but also publicly, automatically and by a driver/ chauffeur.

The **mobility media** can be driven by oneself (car, motor-cycle) or by drivers (bus, train, plane) or automatically (subway, tram, elevator, escalator). They are mostly of non-human and non-animal nature, but of technical nature. There are also **motility media** like bicycles and trishaws/rickshaws.

Traffic is the connectivity and intensity of the movement of motility and mobility media in an area. **Transport/Transportation** means the (motility)/ mobility of persons and goods in an individual and public manner (individual/ public transportation) on land, sea and air. Individual and public transportation on land are the primary focus of this paper.

The different application of motility and mobility is dependent on needs, requirements, legal caveats, and economic restrictions. These are respectively influenced by (city) governments, enterprises and the people themselves (stakeholders). Weidlich and Haag (1999) point out the relevance of transaction costs, which are essential for the decisions about the use of mobility and motility media (intermodality aspects) exemplified on a park-and-ride system in the Chinese city of Nanjing.

Private households as well as profit and non-profit enterprises and countries have different objectives in using mobility as a value-adding factor. For example:

- **Industrialized countries** focus on maintaining their international (economic) competitiveness.
- **Emerging markets** try to reach international (economic) competitiveness.
- **Private households** participate socially and focus on self-regulation and self-realization.
- **Enterprises (profit and non-profit)** reduce their (environmental) complexity, e.g., reduction of transaction costs, and acquire competitive advantages through the build-up of business competencies.

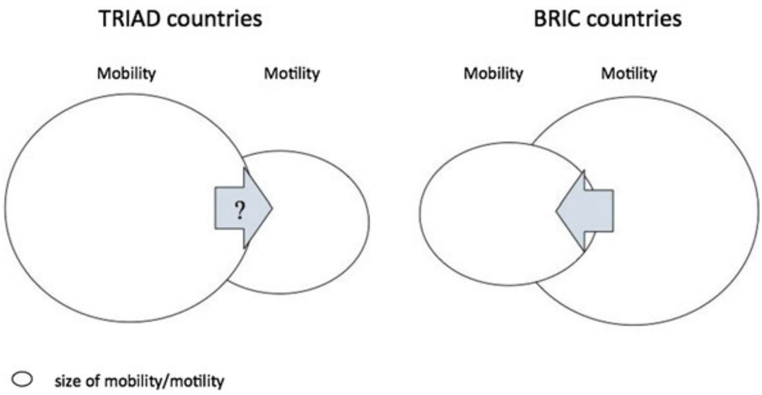

Fig. 2 Trends of mobility and motility

2.3.2 Trends of Mobility and Motility

Motorization and mobilization of people in emerging markets is growing rapidly and the requirements for mobility are changing significantly. Figure 2 shows different trends of locomotion in Triad countries—EU, NAFTA and industrialized countries in Eastern Asia (ADL 2009) and BRIC countries (virtual example).

In Triad countries the size of mobility is on a high level, which can be underlined by the density of cars per 1.000 inhabitants in comparison to BRIC countries; e.g., Germany with more than 500 cars per 1.000 inhabitants contrasted with China with 3 cars per 1.000 inhabitants (Döhmel 2008). The amount of motility is much larger in BRIC countries, where the bicycle is, like in India and China, still the core medium for locomotion. There are also examples in industrialized countries, where public transportation and especially motility media are preferred; e.g., in Freiburg/Germany, a small university city with fewer industrial sites and therefore not representative for urban centers, but a model for future developments. The IPCC recommends these measures, too (see Table 1).

2.3.3 Stakeholders and Customers of Mobility

There are many stakeholders in urban centers, whose interests must be considered concerning mobility issues, e.g., commuters, tourists, inhabitants, enterprises and local governmental administrations. These stakeholders often have diverging interests, which the city government and its agencies (including city council) have the task of coordinating and canalizing them into political decisions. This may be coordinated with higher political government levels, if necessary. The (city) government must adequately recognize the requirements and needs concerning mobility of the stakeholders.

Stakeholders of mobility can be distinguished by different criteria; e.g., socio-demographic or life-style, preferences or needs. The following two studies take these criteria into account. Both studies have a different focus on demands in context of urban centers and on mobility needs. The terms “customer” and “stakeholder” are used synonymously in this context.

Study by Sternlieb and Hughes (1988)

Sternlieb distinguishes between three core groups of inhabitants in a New York City study: upper class, middle class and lower class (Sternlieb and Hughes 1988). These different groups of stakeholders have different expectations and needs towards the urban center. Different requirements for mobility in general are also relevant for these groups.

The **upper class residents** focus on the urban conditions as a field for investment (real estate, business). The upper class residents are mostly focused on individual mobility, because (urban) mobility means on the one hand business-oriented flexibility and on the other, status, individuality and prestige as an expression of life style and wealth (Van der Ploeg and Poelhekke 2008).

The **middle class residents** mostly live in suburbs and outskirts, where living is more affordable than in the urban center. They prefer transportation solutions and also individual mobility solutions, which comply with their mobility requirements as commuters and consumers.

The **lower class residents**, who often live near the city center in subsidized residential areas, focus on public transportation systems like buses and subways. In emerging markets and developing countries, lower class people often living in slums or non-official housings are forced to walk or use a bicycle to go to work (Tiwari 2003).

Study by Arthur D. Little

In a study about mobility in 2020 Arthur D. Little, a consulting firm, identified different customer types of mobility (ADL 2009). The study distinguishes between several types of mobility customers in Triad markets (ADL 2009):

- **Greenovator** reflects/internalizes socio-ecological impacts on mobility and demands innovative and sustainable mobility solutions.
- **Family cruiser** counts on growing demand for mobility in a rising fragmented personal environment (family, friends, peers, colleagues).
- **Silver driver** starts proactive, motivated in the third phase of life. He is experienced in mobility products and favours a high quality consciousness/ product awareness.
- **High-frequency commuter** is characterized by high everyday mobility distances/frequencies and is focused on mega-cities in the future.
- **Global jet setter** is dependent on global mobility needs because of his job requirements/demands and counts on exclusive premium mobility services/ support.

Table 2 Customer types of mobility in Triad and BRIC markets (ADL 2009)

TRIAD markets	Greenovator	BRIC markets	Basic
	High-frequency commuter		
	Silver driver		Smart basic
	Family cruiser		
	Low-end mobility		Premium
	Sensation seeker		
	Global jet setter		Miscellaneous

- **Sensation seeker** considers mobility as a symbol of (personal) freedom, fun and life-style, status and prestige.
- **Low-end mobility user/consumer** has rigid mobility budgets, a need for affordable mobility solutions. He is ready to downgrade his mobility demand.

In BRIC markets other customer types of mobility are representative. These are basic, smart basic and premium customers (see Table 2):

- **Basic customer** demands basic mobility and needs simple and cheap mobility solutions. He focuses on local products.
- **Basic smart customer** prefers affordable mid class products, which he can individualize to his needs and requirements.
- **Premium customer** is focused on status, reputation, prestige and comfort and intends to differentiate as a societal winner and to be considered as a successful person.

In developing countries basic mobility users are dominant (Tiwari 2003).

The different segments of Triad regions have the following shares in the total market (see Fig. 3): Greenovator 27 %, Silver driver 24 %, High-frequency commuter 24 %, Family cruiser 11 %, Low-end user 8 %, Sensation seeker 4 % and Global jet setter 2 %.

In contrast, the segments of BRIC markets are divided into Basic customers 48 %, Basic smart customers 43 %, Premium customers 4 % and Miscellaneous 5 %.

According to ADL (2009) it is necessary to mirror customer types of mobility with financial restrictions which occur in buying decisions of products and services related to mobility (see Table 3). An essential prerequisite is the financial budget restriction, which influences price sensitivity considerations. In this context the concepts of cost of ownership and cost of usership receive relevance.

2.4 Profile of Requirements of Customer-Focused Strategies and Measures Mitigating Climate Change

A framework is relevant and important for defining the requirements of customer-focused strategies and measures mitigating climate change in urban centers.

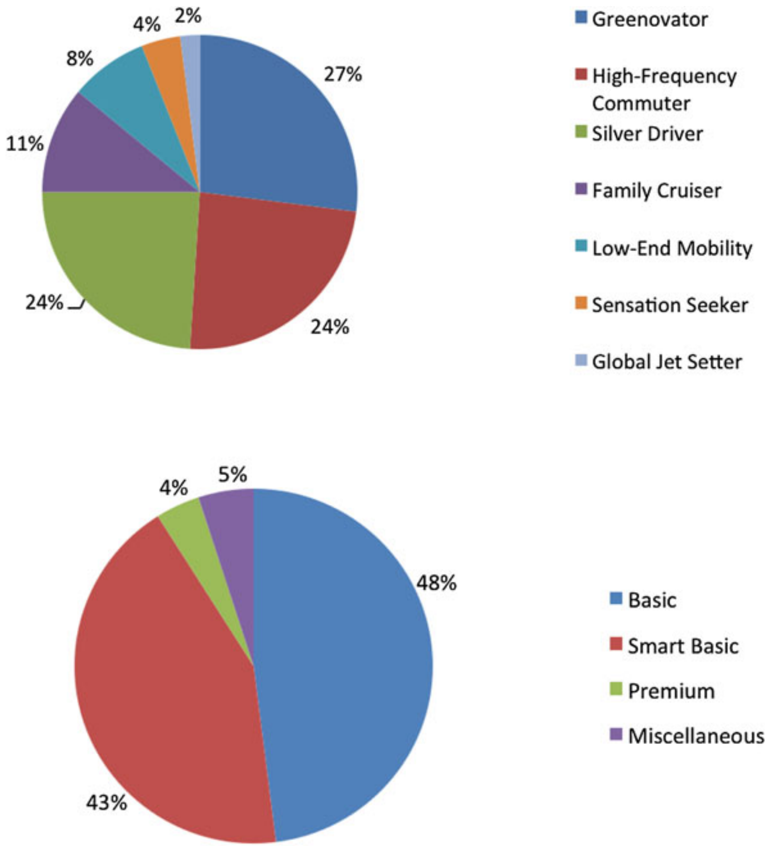

Fig. 3 Customer segments of types of mobility (ADL 2009)

One of the biggest problems arises, because the stakeholders are not integrated and do not participate in the planning phases, designing and selecting strategies and measures mitigating climate change in urban centers (Tiwari 2003).

Therefore it is necessary to include these interests in defining, planning and executing phases of projects. These groups of stakeholders have different needs and requirements as customers of mobility, which requires methods to identify these specific requirements and needs. In this matter, open innovation approaches can be helpful.

It is also essential to point out that each urban center has generally accepted strategies and measures, but also specific ones due to the specific conditions that differ between urban centers in Triad and BRIC countries. The pricing of mobility goods and services emerges as a critical step towards identifying and prioritizing strategies and measures mitigating climate change in urban centers (see Fig. 4). It is also necessary that cost-benefit ratios are applied based on available information.

Table 3 Customer's mobility preferences and price sensitivity (virtual example)

	ADL study		Estimate of:			
	Customers of mobility	Share (%)	Price sensitivity	Individual mobility	Public mobility	Motility
TRIAD markets	Greenovator	27	Low–medium	Medium	Medium	High
	Family Cruiser	11	Medium–high	High	High	Medium
	Silver Driver	24	Low–medium	High	Medium	Low
	High-Frequency Commuter	24	Medium–high	High	High	Low
	Global Jet Setter	2	Low	High	High	Low
	Sensation Seeker	4	Low	High	Low	Low
	Low-End Mobility	8	High	Low	High	High
BRIC markets	Basic	48	High	Low	High	High
	Smart Basic	43	High	Medium	Medium	Medium
	Premium	4	Low	High	Low	Low
	Miscellaneous	5	–	–	–	–

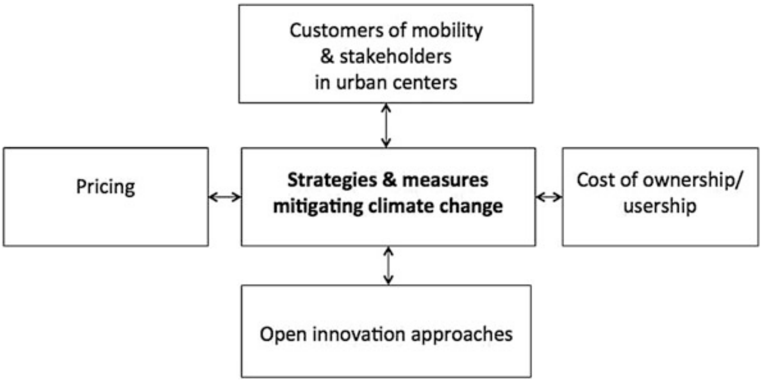

Fig. 4 Framework for mitigating climate change through pricing and open innovation approaches

3 Key Elements for Customer-Focused Strategies and Measures

3.1 Open Innovation Approaches

The identification of customer requirements and needs for products and services is essential for designing effective strategies and efficient measures for mitigating climate change in urban centers.

Different forms of (potential) customer participation are possible. Repurchasers and re-users are also important stakeholders with a high grade of loyalty (Dichtl and Peters 1996). Open innovation is the way in which new ideas, technologies, or other elements of innovation from external sources are brought into a profit or non-profit organization resulting in new products, services and processes (Chesborough 2003). Open innovation approaches focus on the capacity of potential and regular customers with different degrees of participation in an innovation process (Hippel 2005). In this context innovations range from technological, financial, environmental, infrastructural, and social to organizational innovations.

Open innovation is a promising approach to solve the problem of customer integration and participation. Open innovation approaches are commonly used in organizations, which "have to learn how to maintain or modify their organizational boundaries and how to reproduce or develop their strategic knowledge" (Pénin et al. 2011, p. 27).

Open innovation approaches must be applied by planning and decision units of (city) governments and other stakeholders. These institutions are often organized and connected with each other like a network. Cooperation and coordination instead of confrontation and competition are a high priority in this fluid environment. The organization managing the innovation process builds the focal organization in a polycentric network involving other organizations and (potential) customers.

Open innovation approaches include different methods, which enable or increase the participation of (potential) customers within the product and service initiation process. Open innovation approaches are launched either network-hierarchical or network-heterarchical. The open innovation approaches here focus on mobility-related products and services.

The relevant approaches for this analysis are the lead-user concept, the crowdsourcing approach and the concept of innovation with (virtual) communities, which includes netnography as a specialized search method (Füller 2006), as follows:

- **lead user** (network-hierarchical),
- **crowdsourcing** (network-heterarchical),
- **innovation with communities** (network-hierarchical) and
- **hybrid form** (network-quasi-heterarchical).

Network-heterarchical means in this context, that the initiative for customer integration into the innovation process is organized by the (potential) customers themselves.

Network-hierarchical means in this context, that the initiative for customer integration into the innovation process is organized by the (focal) organization of the network.

Network-quasi-heterarchical means in this context, that network-hierarchical as well as heterarchical methods are applied like innovation with communities in combination with crowdsourcing. Example: The focal organization of a network

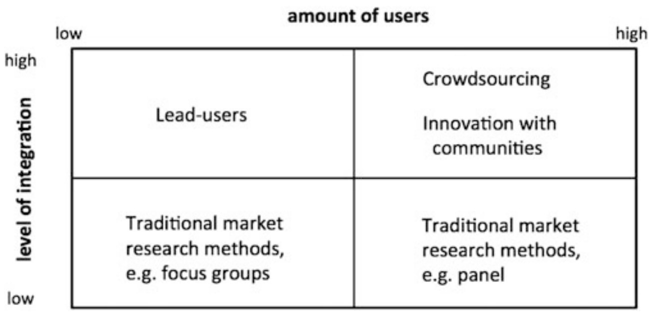

Fig. 5 Open-Innovation-Matrix

installs a (virtual) communication platform, where crowdsourcing teams are welcomed for interchange.

Moreover the grade of participation is different between open innovation approaches and traditional market research methods (see Fig. 5). The closer participation and strong identification with the organization of the open innovation approaches lead to early identification of prospective customer needs and requirements and involvement in the innovation process of the focal organization. These are essential to launch in early planning and designing stage strategies and measures for mitigating climate change in urban centers.

The **lead-user approach** focuses on so-called lead-users, who are people with a strong ability to forecast customer needs in advance (Lilien et al. 2002). They are directly integrated into the process of idea finding and selection. The lead-user concept is characterized on the one hand by a high grade of customer integration and on the other hand by a small amount of integrated (potential) customers, where the communication process is non-anonymous.

Crowdsourcing is a method, where spontaneously, a group of people agree on orchestrating their activities in order to reach a common goal like creating software, e.g., Linux software.

The method of **innovation with (virtual or online-)communities** describes a dialogue between an organization and its (potential) customers. This is also a tool of connecting to others in order to receive valuable information about the organization's products and services. These dialogue platforms, often internet-based, are also used for testing, brainstorming, idea finding and innovation management. They could be open networks as well as networks which limit access only to (potential) customers. Crowdsourcing and the concept of innovation with communities contain many more users, and the communication process between the company and the users can be anonymous or non-anonymous.

Hybrid form of open innovation approach is, for example, about building an open government, which is based on the considerations of open innovation. It is an important step to incorporate more transparency, participation and collaboration

Table 4 Preferences for open innovation and life-cycle concepts by customers of mobility (virtual example)

	ADL study		Open innovation preference	Cost of ownership (co)/ usership (cu) preference
	Customers of mobility	Share (%)		
TRIAD markets	Greenovator	27	All	Both
	Family Cruiser	11	Innovation with Communities (IwC)	co
	Silver Driver	24	Lead-user	co
	High-Frequency Commuter	24	Crowdsourcing (CS)/ IwC	co
	Global Jet Setter	2	Lead-user	Both
	Sensation Seeker	4	Lead-user	co
	Low-End Mobility	8	IwC	None
BRIC markets	Basic	48	IwC	cu
	Smart Basic	43	CS	Both
	Premium	4	Lead-user	co
	Miscellaneous	5	–	–

between governments, enterprises and people, who act as customers (McDermott 2010). Nam gives a good example of how to integrate crowdsourcing with online-communities, which participate in an open government approach. He refers to the open government concept of Seattle, which also includes mobility topics, e.g., www.ideasforSeattle.org (Nam 2012).

This shows that open government methods with open innovation approaches can be applied successfully on the regional and local level of metropolitan areas (Table 4).

Traditional market research methods can support open innovation approaches, but they cannot replace them. Traditional market research methods only have a low level of integration, e.g., the empirical study should be non-biased and independent and therefore focus groups and panels should be (scientifically) independent with a smaller degree of customer integration and more anonymous.

3.2 Pricing and Life-Cycle Concepts

3.2.1 Pricing

Strategies and methods for mitigating climate change in urban centers have strong impacts on the prices and on the value for money of mobility products and services. Different methods of pricing are relevant, like target value pricing (Wittmann 2008).

The pricing process is defined by a system of organizational rules, structures and measures, which are established in order to set or implement prices (Wübker 2005). The pricing process is often more decisive than the pricing decision, which depends heavily on organizational conditions and cultures (Beckert 2011).

In competitive markets it is necessary that the price of the product and service contain a higher "value extraction" than competition (Wittmann 2008). A prerequisite is a competitive advantage of the product and service, which can be priced. Innovations play a significant role in the pricing of strategies and measures for mitigating climate change, which must fit with these topics.

In general, a price premium in automotive domains is justified by competitive advantages based on higher quality, a higher grade of comfort, more driving pleasure/fun of driving, sportiness and prestige. These are mostly emotional-related features of a vehicle, so-called benefits according to Lancaster (Lancaster 1966). But rational features, characteristics according to Lancaster, like ecological items (Wittmann 1998), are not often linked to price premiums today in automotive domains.

Therefore it is a "condition sine qua" non to apply customer-focused methods, like open innovation approaches, to identify the right features which allow the inclusion of price premiums for ecological products and services.

It is also necessary to take into account a dynamic view on the pricing issue, because environmental advantageous products and services are mostly of multi-use or repetitive use. Therefore capable concepts for application are, on the one hand, the cost of ownership concept, especially for products, and on the other hand the cost of usership concept, especially for services.

Another important aspect is the differentiation between the technical and the owner's view of the life cycle of the product, which may not be congruent and are characteristic of durable goods. Multi-use aspects have impacts on environmental issues, too. Life-cycle considerations are therefore essential to understand pricing and influence customer's economic decision making.

3.2.2 Life-Cycle Concepts

Life-cycle concepts are important instruments to show the interdependencies between cost of ownership and cost of usership. A study by KPMG, a consulting firm, points to the shift from cost of ownership to cost of usership for mobility solutions in urban centers (KPMG 2012). Therefore the idea is to link pricing with these two concepts.

The cost of ownership and usership approach helps improve the design and prioritization of tailored strategies and measures mitigating climate change in urban centers.

Cost of Ownership Model

Initially the concept of cost of ownership is applied in capital goods industry, e.g., the construction industry, where long life-cycles are relevant for the economic feasibility of the goods (Taylor 1981). Wittmann illustrates the application of the cost of ownership model to the automotive industry in connection with a target pricing approach (Wittmann 1998). The cost of ownership concept focuses mostly on product ownership and refers to motility- and mobility-related products, including hybrid ones, like pedal electric cycles (Pedelecs).

In the cost of ownership model an ecological price premium can be considered when the product bears competitive advantages in ecological features in comparison to a competitor's product. This premium can be justified by savings on fuel costs and taxes related to mobility, for example. This is also important for the owner's view of the life cycle of the product, when significant cost, tax and fee reductions can be realized over time because of the ownership of an ecological vehicle (see Fig. 6).

According to a KPMG study, customers are, for example, aware of technological obsolescence with ecology-driven technologies of vehicles (KPMG 2012). These concerns must be taken seriously, because these have impacts on the re-use of the vehicle and consequently on the resale value. It is also worthwhile to think about a relaunch of ecological product features or a bundling of features and services to upgrade the product for further resales when a total life cycle of more than 25 years in industrialized countries and more than 35 years in developing countries is appropriate (Mildenberger and Khare 2000). The realization of an ecological price premium is also necessary for resale value.

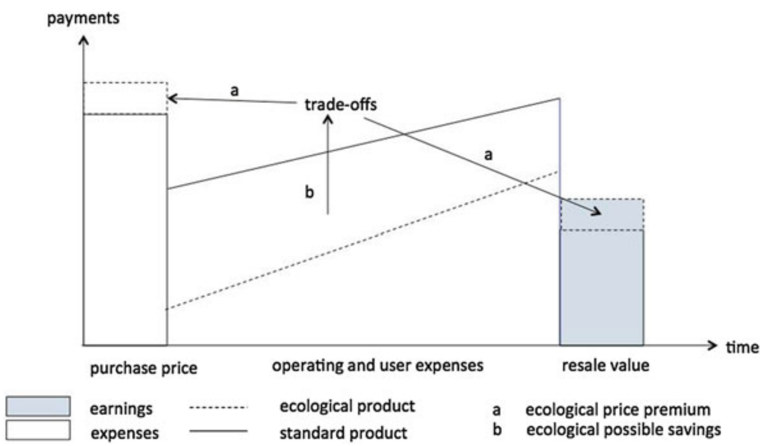

Fig. 6 Model of cost of ownership

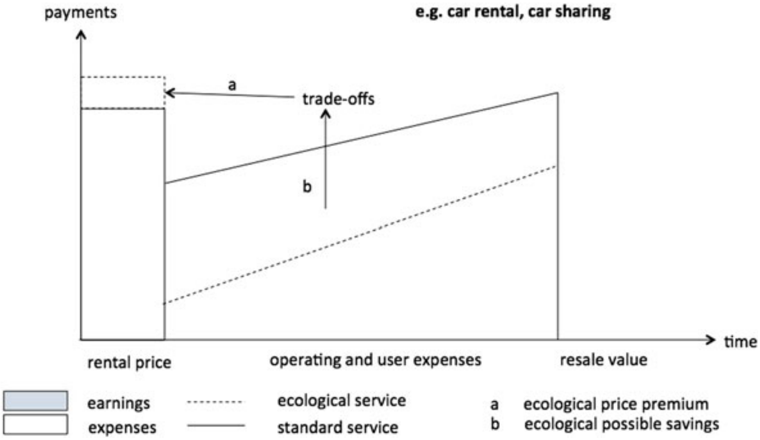

Fig. 7 Cost of usership model

Cost of Usership Model

The cost of usership model focuses on different individual and public services, which are divided into motility services, mobility services and combined ones (e.g., Rent-a-bike service in combination with railway transportation by Deutsche Bahn). These services are offered by public and private organizations, like taxi companies, bus and railway companies, car and bike rentals.

Car-sharing concepts should be included, which could be an innovative form of individual mobility in urban centers, but they probably compete with established and well-organized car rentals and taxi companies, too. In case of car sharing or car rental e.g., the rental price premium can be justified by savings on fuel cost between an ecological and a standard vehicle (see Fig. 7). A resale value does not occur in the case of mobility services. Similar to the cost of ownership model the price premium can be justified by ecological (product) features.

3.2.3 Evaluation Approach

In the following section the advantageousness of several alternatives of mobility solutions is analysed based on using a net present value formula (see Appendix 1). It is necessary to consider two life-cycles of customers in this simplified example, where one initial cash flow is equivalent to the resale value of the former owner. This enables a comprehensive view on buying decisions of durable (mobility) products and services.

In this context the initial cash flow at the beginning is interpreted as price for a product. The following cash flows per year are costs of usage and fixed costs, like tax, insurance and service costs. Two vehicles (A, B) have different fuel consumption rates. Both vehicles are used consecutively by two owners over 3 years each. In the first step, the value shares for both vehicles after 3 years of ownership are 70 % and after 6 years 30 % of the new vehicle price (period p = 0). In scenario Ia the cost differences caused by different fuel consumption rates (A: 7 l/ 100 km; B: 7.5 l per 100 km) can be compensated by a 3 % price premium for A. In scenario IIa the price premium for A is theoretically 5 % due to a fuel consumption rate advantage of 1 l/100 km.

In a second step (scenarios Ib/IIb), the value shares for both vehicles after 3 years of ownership are (A: 70 %, B: 65 %) and after 6 years (A: 30 %, B: 28 %) of the new vehicle price (period p = 0). The presumption is that a higher fuel consumption rate of vehicle B leads to lower value shares, because of higher user expenses. Owner 1 of vehicle B receives a lower net present value than owner 1 of vehicle A due to the lower resale value of his vehicle and the price premium for vehicle A. Owner 2 of vehicle B realizes higher savings because of the lower price of the used vehicle B, which compensates for the higher fuel consumption costs over the life-cycle of vehicle B. The incentive to buy vehicles with higher fuel consumptions rates (and higher CO_2 emissions) is attractive when the value shares of these vehicles are significantly lower than of the environmental-friendly vehicles like vehicle A in this simplified example. In contrast the total net present value (comprehensive view) over two owner cycles is still more advantageous for vehicle A than for vehicle B.

The adjusting lever to change customer behaviour, for example, lies in policies of (city) governments to introduce pollution-oriented congestion charges or to give preferential access to inner cities for environmental-friendly vehicles. Concerted activities are necessary by (city) governments, stakeholders and automotive industry to control strategies and measures for mitigating climate change in urban centers. The open government approach, as for example in Seattle, can be helpful to exchange ideas with customers of mobility in urban centers (City of Seattle 2012).

4 Conclusion and Outlook

The linkage between open innovation approaches, pricing methods and the cost of ownership and usership approaches are a prerequisite to identify and design customer—focused strategies and measures for mitigating climate change in urban centers.

One of the biggest problems arises because stakeholders are not sufficiently integrated and thus do not typically participate in the planning and designing stages (Tiwari 2003).

The participation and integration of (potential) stakeholders of mobility into the development process of products and services could lead to improved design and prioritization of customer-focused strategies and measures, which target mitigating climate change in urban centers. The open government approach is also necessary as it includes customer needs in political decision making. This is easy on resources and leads to effective, accepted and durable decisions that contribute positively to mitigating climate change.

Bellmann (1990) argues that producers and customers of vehicles are focused on the product less than on the total life cycle and its holistic perspective. This would be less a technical and economic problem than a cultural and mental problem. Therefore, the early participation of relevant stakeholders in the design and prioritization of strategies and measures for mitigating climate change in urban centers can lead to a more sustainable use of individual mobility solutions.

Appendix 1

Cost-benefit scenarios of vehicles of two owner's life-cycles with different gas consumption rates (virtual example)

		scenario I a			scenario I b		
	vehicle	A	B		A	B	
NPV	total	-49,300 €	-49,300 €	price / costs difference [%]	**-49,300 €**	-49,900 €	price / costs difference [%]
	owner's cycle 1	-29,200 €	-29,200 €		**-29,200 €**	-30,600 €	
	owner's cycle 2	-26,700 €	-26,800 €		-26,700 €	**-25,700 €**	
period	0	-39,000 €	-38,000 €	3%	-39,000 €	-38,000 €	3%
	1	-4,300 €	-4,500 €	-4%	-4,300 €	-4,500 €	-4%
	2	-4,300 €	-4,500 €	-4%	-4,300 €	-4,500 €	-4%
	3	-4,300 €	-4,500 €	-4%	-4,300 €	-4,500 €	-4%
sale	3	27,300 €	26,600 €	3%	27,300 €	24,700 €	11%
resale	4	-27,300 €	-26,600 €	3%	-27,300 €	-24,700 €	11%
period	4	-4,300 €	-4,500 €	-4%	-4,300 €	-4,500 €	-4%
	5	-4,300 €	-4,500 €	-4%	-4,300 €	-4,500 €	-4%
	6	-4,300 €	-4,500 €	-4%	-4,300 €	-4,500 €	-4%
sale	6	11,700 €	11,400 €	3%	11,700 €	10,640 €	10%
value share	owner's cycle 1	70%	70%		70%	**65%**	
	owner's cycle 2	30%	30%		30%	**28%**	

		scenario II a			scenario II b		
	vehicle	A	B		A	B	
NPV	total	-50,000 €	-50,200 €	price / costs difference [%]	**-50,000 €**	-50,800 €	price / costs difference [%]
	owner's cycle 1	-29,700 €	-29,700 €		**-29,700 €**	-31,100 €	
	owner's cycle 2	-27,100 €	-27,300 €		-27,100 €	**-26,100 €**	
period	0	-40,000 €	-38,000 €	5%	-40,000 €	-38,000 €	5%
	1	-4,300 €	-4,700 €	-9%	-4,300 €	-4,700 €	-9%
	2	-4,300 €	-4,700 €	-9%	-4,300 €	-4,700 €	-9%
	3	-4,300 €	-4,700 €	-9%	-4,300 €	-4,700 €	-9%
sale	3	28,000 €	26,600 €	5%	28,000 €	24,700 €	13%
resale	4	-28,000 €	-26,600 €	5%	-28,000 €	-24,700 €	13%
period	4	-4,300 €	-4,700 €	-9%	-4,300 €	-4,700 €	-9%
	5	-4,300 €	-4,700 €	-9%	-4,300 €	-4,700 €	-9%
	6	-4,300 €	-4,700 €	-9%	-4,300 €	-4,700 €	-9%
sale	6	12,000 €	11,400 €	5%	12,000 €	10,640 €	13%
value share	owner's cycle 1	70%	70%		70%	**65%**	
	owner's cycle 2	30%	30%		30%	**28%**	

	average fixed costs p.a.	average total km p.a.	gasoline price € per litre (l)	discount rate
vehicle	A	B	A	B
owner's cycle 1	1,500 €	25,000	1.6	10%
owner's cycle 2	1,500 €	25,000	1.6	10%
fuel consumption rate l/100 km	scenarios I		scenarios II	
owner's cycle 1	7	7.5	7	8
owner's cycle 2	7	7.5	7	8

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An Approach to Tackle Urban Congestion and Vehicle Emission by Manipulating Transport Operations and Vehicle Mix

Sudeshna Mitra and P. Krishna Pravallika

Abstract Emission from motorized vehicles is a major source of air pollution in urban areas. However, it varies significantly with vehicle technology, type of fuel used, operating conditions, vehicle mix, etc. Understanding the relationship amongst congestion levels in terms of Level of Service (LOS) policies, emission levels and traffic compositions is important for effective policy development for pollution reduction. This study adopted an integrated optimization model to understand this complex relationship with the help of suitable performance indices considering total emissions, fuel consumption, vehicle delays as well as capacity utilization of an intersection in Kolkata, India. SYNCHRO, a transportation operational analysis program is used to develop all the possible LOS thresholds. Twelve different traffic compositions are considered by modifying the share of vehicle categories. Emission inventories are generated using MOBILE, SYNCHRO and CRRI methods of emission calculation. To validate the emission inventories developed from these models, concentrations of the two major pollutants, Suspended Particulate Matter (SPM) and Oxides of Nitrogen (NO_x) are collected from the intersection site using High Volume Air Sampler. Estimation of emission for base case by MOBILE yielded closest results with that of actual emissions estimated by the High Volume Air Sampler at the site. While comparing the performance indices, for the Kolkata intersection, LOS B is found to be the most effective operating point for combined emissions, fuel consumption and traffic congestion (delay at the intersection) point of view. There is also evidence that reduction in emission is associated with decreased share of motorcycles.

Keywords Urban congestion · Vehicle emission · Operating condition · Vehicle mix · Emission at urban intersections

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1 Introduction and Background

Road transportation consumes a major share of the total energy used by the transport sector. In developing countries motorized vehicles primarily use fossil fuel, thereby significantly contributing towards air pollution. The principal pollutants from the transport sector responsible for adverse health effects include lead, various types of particulate matter, oxides of nitrogen (NO_x), volatile organic compounds (VOCs), carbon monoxide, ammonia and sulphur dioxide. However, the proportion of these various pollutants depend on a number of factors, including vehicle technology, quality of fuel as well as the driving conditions. When countries go through an economic growth, there will always be a growth in vehicular traffic. Recently in India, similar trend is seen and the growth of vehicular traffic on roads has been far greater than the growth of the highways; as a result the main arteries in small and major cities are facing capacity saturation leading to increased delay, congestion and air pollution. As mentioned by Ramachandra and Swetmala (2009) the transport sector in India consumed about 16.9 % (36.5 million tonnes of oil equivalent) of total 217 million tones of energy in 2005–2006. Major share of this energy demand is satisfied by sources such as coal and fossil fuel (diesel and petroleum) resulting in vehicular emission and air pollution. According to TEDDY, India (2006) road transport; rail and air transport are responsible for 80, 13 and 6 % of total emissions respectively. In addition, vehicular emissions account for about 60 % of the greenhouse gas (GHG) from various activities in India (Patankar 1991).

It is a fact that between year 1951 and 2002 the vehicle population in India grew at a compound annual growth rate (CAGR) of close to 11 % compared to CAGR of 4.3 % in total road length. Composition of vehicle population in India in the year 2004, the latest year for which the data is available, reveals preponderance of motorized two-wheelers (M2W) with a share of more than 71 % in total vehicle population, followed by cars with 13 % and other vehicles (a heterogeneous category which includes 3 wheelers, trailers, tractors etc.) with 9.4 %. As the M2W vehicles are used intensively due to affordability as well as ease in manoeuvrability in congested and narrow roads, the problem of local air pollution is increasing rapidly due to their highly polluting two-stroke engines.

While there are many ways to reduce road transport related air pollution, the common measures in practice are fuel quality improvement, use of alternative fuels, improvement in vehicle technology, traffic management and control strategies as well as travel demand management through innovative policies. In his study Badami (2004) took an approach of ‘‘value-focused thinking’’ for policy-making related to this complex problem of congestion and vehicle emission with specific reference to motorized two-wheelers. He chose this particular vehicle type since they play an important role in transport air pollution but also provide affordable mobility to millions of Indians with few other attractive options. Using a multi-objective framework, he concluded that primarily three different approaches such as catalytic conversion, vehicle engine technologies, and fuel and oil quality improvements would likely satisfy objectives related to M2W vehicle emissions.

There is also substantial research available on the impacts of transportation improvements on traffic flow and demand. However, most of the literature does not evaluate these impacts on emissions. Studies focusing on the effect of traffic operational characteristics on vehicular emission are limited. In a paper by Cobian et al. (2009) a travel demand forecasting model was developed for Grover Beach, California (CA). The outputs from planning model such as the demand in terms of number of trips by modes were analyzed in emission models to determine the relationship between the target LOS thresholds and emissions produced. The network was modeled for both roadway link LOS and intersection LOS conditions. For roadway links, the overall lowest amounts of emissions were released at the LOS B threshold and the greatest incremental decrease in emissions occurred between LOS D and C. At intersections, the lowest emissions point was LOS A and the largest incremental decrease occurred between LOS D and C. When considering the feasibility of implementation of LOS thresholds, LOS C was determined to be the most effective operating point for emissions. Pandian et al. (2009) did a comprehensive review of existing literature to examine traffic and vehicle related factors influencing vehicular emissions near intersections. They pointed out the fact that most studies found vehicular exhaust emissions near traffic intersections were largely dependent on fleet speed, deceleration speed, queue time in idle mode with a red signal time, acceleration speed, queue length, traffic-flow rate and ambient conditions. However, they concluded that traffic flow, vehicle and road characteristics have profound effect on vehicular emissions at urban intersections. For example, they concluded that cars contribute more to CO emissions whereas heavy-duty vehicle emits more PM, while two-wheelers contribute to HC and NOx emission. This is an important finding since it has strong influence on total emission and would vary with vehicle mix. Most studies have also concluded that older and vehicles with more mileage are associated with increased vehicular emissions. Vehicle emission also varies by a vehicle make and engine capacity; and generally speaking CO emissions reduce with higher engine capacity. Fuel use is influenced by vehicle size and weight, which also influence higher CO2 emissions. The emission of other pollutants typically, but not always, increases by size and weight (Kim 2007). Finally, vehicle load often increases the fuel consumption and produces more emissions for a given vehicle on an individual basis or for groups of vehicles on an average basis.

Two other studies by Gokhale and Khare (2004) and Gokhale and Pandian (2007) focused on the relationship of traffic flow and emission at urban intersections. They used simple semi-empirical box models for traffic intersection based on routinely available traffic flow information and meteorological data. With these they predicted an hourly average CO concentration. However, a major limitation of the work is consideration of traffic flow-density relationship at intersections rather than delay, which is more appropriate for such locations. This is due to the fact that at intersections, idle emission due to delay should be of interest and vehicle speed is not an important factor in deciding emission at intersections. Sturm et al. (1997) and Husch (1998) suggested use of SYNCHRO, a macroscopic traffic simulation model for compiling emission inventories after suitable adjustments for type of emission. These studies used advance emission models that account for start-up emissions, roadway types etc. by using advanced MOBILE6 model. These models have the capability to account separately for startup emissions and running emissions and are better to be used for more realistic estimation. While absolute value of emission using such models may vary based on location of study due to fuel quality, results from these models provide strong basis at least for comparison purpose across various scenarios.

Based on the literature review it is evident that there are some studies that focus on estimation of vehicular emissions based on traffic flow rate and speed data. There is also some evidence that vehicle type is given importance in estimation and finding ways to reduce emission. However, there is a few, if not any, studies that focused on intersection level traffic operational characteristics, vehicle composition and their implications on emission to form suitable operating policies. For example, it is possible that certain vehicle mix at certain operating condition will result in lowest emission. Also, increase in certain vehicle types will increase emission to a higher rate than at certain operating conditions. With these in mind, it is considered important to understand the effects of LOS policies i.e. congestion levels, and vehicle mix on emission levels in order to take a step towards policy formation for reduction in emissions and delay at intersections—where pollution is generally very high due to idle emission. This study focuses on an approach by showing how urban traffic congestion and vehicle emission are interrelated and how the problem may be tackled by manipulating traffic operations and traffic composition in mixed traffic condition. The work is demonstrated with a case study from urban India. Comparisons are done by changing both traffic compositions as well as level of congestions to check if there exists a most effective traffic composition and operating condition that will lead to lowest emission. A performance indicator is also developed by considering the effect of congestion through the measure of level of service (LOS), pollutant emissions and fuel consumption for each traffic composition. The interrelation between major players of vehicle related air pollution provides insight about the complexity of the problem and helps us formulating effective policies to reduce air pollution from transport sector. In summary the objectives are:

- To establish a direct correlation with congestion level and emission i.e. to explore the relationship among (1) traffic composition, (2) LOS and (3) emission and
- To compare the impact on emission for various vehicle composition and congestion level (LOS) in mixed traffic.
- To determine the most effective operating policy in heterogeneous traffic.

2 Methodology

There are two broad ways by which emission inventories may be obtained from a road network or intersection. They are either by using empirical or semi-empirical models, or by analyzing air samples from the location of interest. In this study both methods are used. For data collection a signalized intersection in Kolkata, India was selected. At this location, traffic volume counts, signal timing and delay experienced by the vehicles are obtained for a week during peak and off-peak time. Using High Volume air Sampler (HVS), emission inventories are also collected at the site. These air samples are analyzed and utilized to compare with emission estimation from the empirical models. A total of three different empirical emission estimation models—MOBILE, SYNCHRO and CRRI are used for this purpose acknowledging their advantages and disadvantages. Results from these models are compared with the data obtained at the site, to identify the operating condition that matches closely to real data and has been considered as the base case. While it is anticipated that the estimates from these three models will vary significantly due to their underlying assumptions, the main purpose of this study is to capture the effect on vehicular emission due to modification in operating conditions and vehicle mix. As a result the incremental change rather than the absolute values are of importance for this study. With this in mind, all the above mentioned emission software are used, even though the first two were developed in the USA. CRRI method was developed by Central Road Research Institute of India and by far is the only available emission estimation model for India. The steps followed in this study are given below.

2.1 Traffic Data Collection

The first step of the study was to perform traffic volume count at intersections. For this purpose counts are taken for three different time periods viz. morning peak hour, evening peak hour and off peak hour. Vehicles are classified in five broad categories such as cars, HV/Trucks and buses, Auto Rickshaw (AR) (motorized three-wheelers), Motorcycles (MC) and Bicycles (BC)/Cycle Rickshaws (CR). In addition to the turning movement data, information about current signal phase, cycle time, startup loss and queue lengths are also measured at the site. A summary of the vehicle mix at this intersection is shown in Fig. 1. The codes 1, 2, 3, 4 and 5 are represented by Cars, HV/trucks, MC, BC and AR respectively.

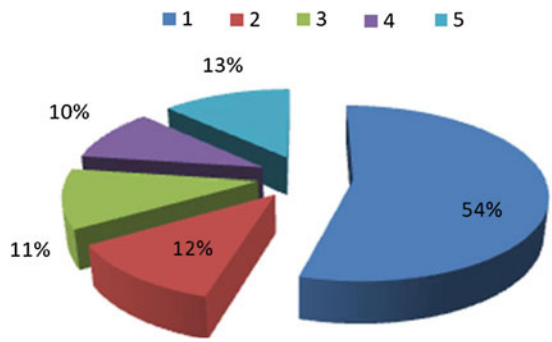

Fig. 1 Observed vehicle mix at an Intersection, Kolkata. The codes 1, 2, 3, 4 and 5 represent Cars, HV/trucks, MC, BC and AR respectively

2.2 Emission Measurement with High Volume Air Sampler

High Volume Air Sampler (HVS) is used to find out the concentration levels of Particulate Matter (PM), Oxides of Nitrogen (NO_x) and Sulphur dioxide (SO_2) at the intersection site. Volumetric filtration using a microfiber filter is used to measure PM. Laboratory analysis is carried out by Gravimetric method of weighing the mass of the particles (PM) deposited on the microfiber filter. For measurement of NO_x and SO_2, volumetric sampling of air through a collecting medium at a known flow rate for a specified time was used. Colorimetric method using spectrophotometer was used in the laboratory to analyze these air samples taken at the intersection in Kolkata.

2.3 Dispersion Model

A simple box model is developed based on the study of Gokhale and Pandian (2007) to estimate the dispersions at the intersection. It is assumed that the emissions disperse uniformly in the box, therefore constant throughout the box. The box height refers to the plume height (Z) which is assumed to be 5 m. The dispersion of pollutants emitted with in the box depends upon the meteorological parameters such as wind speed (u, m/s) and direction (θ degrees). The emissions (Q) at the traffic intersection are calculated from the concentration values (C) using the following equation suggested by Dirks et al. (2003).

$$C = \frac{Q}{Z * U * \boldsymbol{Sin\theta}} \quad (1)$$

Vehicle wake factor and background concentration values which are part of the original equation are omitted as the data for these values are not available.

2.4 Emission Calculation by MOBILE

The US Environmental Protection Agency (US EPA) developed Mobile Source Emission Factor Model (MOBILE) a computer program that estimates emission factors for gasoline and diesel fueled highway motor vehicles. The MOBILE emission model was developed based on laboratory dynamometer driving tests for vehicles. The two different versions of MOBILE, MOBILE5 and MOBILE6 differ significantly in their input requirements and the output structures. In this study MOBILE5b is used for estimating running and idle emission factors for pollutants such as CO, NO_x, VOC and HC. PM emissions factors (idle and running) are estimated using MOBILE6.

2.5 Emission Calculation by SYNCHRO

SYNCHRO is transportation operational analysis software for modeling and optimization of traffic signal timings. It implements the Intersection Capacity Utilization (ICU) 2003 method for determining intersection capacity. This method compares the current demand to the intersections ultimate capacity. SYNCHRO also estimates emissions based on fuel consumption, which utilizes various vehicle and fleet characteristics such as cruise speed, total signal delay, vehicle miles travelled and total stops per vehicle etc. Based on inputs on traffic volume, signal timing details, optimal signal timing can be obtained. From this analysis it is also possible to obtain average delay, number of stops, fuel consumption, as well as estimates of CO, NO_x and VOC emissions. The analysis from SYNCHRO provides information on v/c ratio, delay, intersection capacity utilization, intersection LOS and ICU LOS. The SYNCHRO emissions model based on fuel consumption is as follows:

$$F = TT * k_1 - TD * k_2 + ST * k_3 \tag{2}$$

where

$k_1 = 0.075283 - 0.0015892 * S + 0.000015066 * S^2$
$k_2 = 0.7329$
$k_3 = 0.0000061411 * S^2$

and

F fuel consumed in gallons
S cruise speed in mph
TT vehicle miles traveled
TD total signal delay in hours
ST total stops in vehicles per hour

With the fuel consumption known, the emissions produced are determined using the following formulas:

CO	F * 69.9 g/gal = Carbon Monoxide Emissions (grams)
NO_x	F * 13.6 g/gal = Nitrogen Oxides Emissions (grams)
VOC	F * 16.2 g/gal = Volatile Oxygen Compounds Emissions (grams)
F	Fuel Consumption (gallon)

2.6 Emission Calculation by CRRI Method

The CRRI method (Ravinder et al. 2010)which is proposed for a road network for the prediction of emissions from automobiles is as follows:

$$E_i = \sum_i (Veh_j * D_j) * e_{ij} \tag{3}$$

where,

E_i	is total emission of pollutant i (g/day),
Veh_j	is the number of vehicles of type j,
D_j	is distance traveled by vehicle type j,
e_i, j, km	is the emission factor for pollutant i for vehicle type j (g/km)

CPCB 2000 emission factors are used in this method.

2.7 Traffic Composition and LOS Variation

Since one of the aims of this work is to correlate emission with LOS and traffic composition, the starting point was the base case. It is improved by adding capacity and deteriorated by reducing capacity to get all the possible LOS cases. Once the LOS variation is taken into account and the corresponding variation in emissions is noted, the next task is to check for variation with various vehicle-mixes. Again the starting point for that was the base case vehicle mix and after that various hypothetical vehicle mixes as shown in Table 1. A total of twelve different traffic compositions with varying percentages of three major vehicle categories such as cars, motorcycles and heavy vehicles are considered. After that emission estimation was done for each of these traffic conditions at various LOS to find the combined effect of congestion and vehicle mix.

Table 1 Traffic composition cases

Case	% of Cars	% of MC	% of HV/T
1	10	10	80
2	20	20	60
3	30	30	40
4	40	40	20
5	80	10	10
6	60	20	20
7	40	30	30
8	20	40	40
9	10	80	10
10	20	60	20
11	30	40	30
12	40	20	40

2.8 Integrated Optimization Model

The next step in this study was the development of an Integrated Optimization Model (IOM), similar to Li et al. (2004) where a total of four Performance Indices (PI) have been developed. The functions for optimization are aimed at improving traffic quality by improving the level of congestion, which is measured by LOS and to reduce emissions, fuel consumption and vehicle delays. With the help of PI functions the effect of traffic composition on the emissions and traffic congestion are investigated and demonstrated. Since delay at a signalized intersection is the measure of LOS, it is used as the index of traffic quality whereas the amount of fuel consumption and exhaust emission of vehicles at an intersection are measures of emission and used for calculating the indices. Emissions are either considered as total emissions; or PM and NO_x are considered as two separate indices. Although this was done so that measured NO_x and PM may be used for PI computation, PI_2 and PI_3 should be given priority over the PI_1 and PI_4 since they consider total emission as opposed to emissions from two pollutants only. It is also important to point out that in calculating the indices normalization is very important due to the difference in unit. This is done by taking ratios of each of the parameters compared to the base value rather than the absolute value of the parameter. Different weights are assigned to these ratios to show the significance of a particular factor over the other. The sum of these ratios adds up to 10, i.e. the upper limit of the indices is 10 and this corresponds to the PI value for base case. PIs for other LOS as well as traffic composition may be compared with the base case, which is highly congested and operating presently at the worst LOS. The following are the four PI functions defined in the IOM:

$$PI_1 = \left(\alpha \times \frac{D}{D_I}\right) + \left(\beta \times \frac{CU}{CU_I}\right) + \left(\gamma \times \frac{F}{F_I}\right) + \left(\delta \times \frac{NO_x}{NO_{xI}}\right) + \left(\varepsilon \times \frac{PM}{PM_I}\right) \quad (4)$$

$$PI_2 = \left(\alpha \times \frac{D}{D_I}\right) + \left(\beta \times \frac{CU}{CU_I}\right) + \left(\gamma \times \frac{F}{F_I}\right) + \left(\zeta \times \frac{TE}{TE_I}\right) \tag{5}$$

$$PI_3 = \left(\eta \times \frac{D}{D_I}\right) + \left(\theta \times \frac{TE}{TE_I}\right) \tag{6}$$

$$PI_4 = \left(\iota \times \frac{D}{D_I}\right) + \left(\kappa \times \frac{NO_x}{NO_{xI}}\right) + \left(\lambda \times \frac{PM}{PM_I}\right) \tag{7}$$

where,

D	Intersection signal delay
CU	Intersection Capacity Utilization
F	Fuel consumption
$NO_x = NO_x$	emissions
PM	PM emissions
TE	Total emissions (NO_x, PM, CO, HC and VOC)

α, β, γ, δ, ε, ζ, η, θ, ι, κ and λ are the corresponding weights of the indices having values 3, 1, 2, 2, 2, 4, 5, 5, 4, 3 and 3 respectively.

A simple logic is followed to determine the most effective operating condition that may be implemented for maximum benefit. This is explained as follows:

- If LOS A resulted in the lowest PI values, it was disregarded because for the most part implementing a LOS A policy threshold is not feasible since it requires an unrealistic capacity of infrastructure to be built.
- The point at which the lowest PI is obtained is compared with the point where the greatest incremental decrease in PI occurred. Two scenarios could occur:
- If the points matched, then it is considered as the most effective LOS threshold and would be the targeted operating condition for a particular traffic composition.
- If the points did not match, then the point with greatest incremental decrease in PI is considered the most feasible option and the corresponding LOS would be suggested for a particular traffic composition.
- Once the best operating condition is obtained then the traffic composition needs to be modified to check the effect of different mix of vehicles on emission, fuel consumption and traffic congestion.

3 Results and Discussion

The emission inventories developed using MOBILE, CRRI and SYNCHRO methods are compared to that of HVS method. MOBILE yielded the closest estimate of emissions compared to others. Even then emission estimation from MOBILE resulted in 20 % overestimation and that from CRRI method is

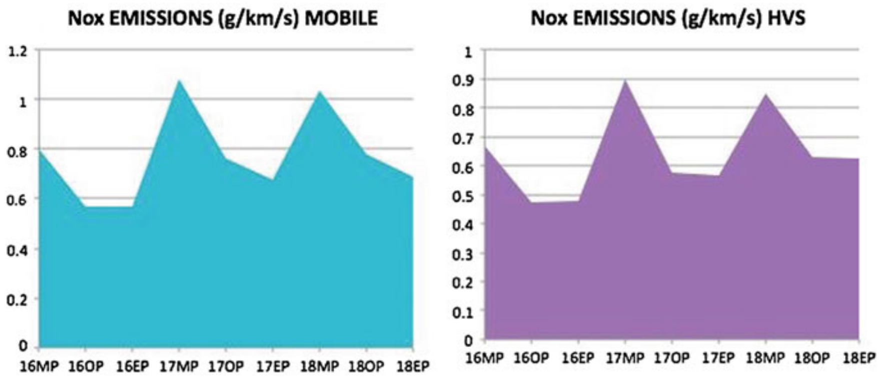

Fig. 2 Comparison of NOx emission from MOBILE and HVS

overestimating more than half of the HVS estimates. On the other hand SYNCHRO underestimated emission compared to HVS. Hence, for modeling purpose MOBILE is used. Figures 2 and 3 show comparison of outputs from MOBILE and HVS. Here it is worth mentioning that HVS provides concentration rather than direct emission. Concentration near road intersection may vary both due to emissions and meteorological characteristics. As identified by Dirks et al. (2003), it is possible to predict the effect on concentration as a result of a 10 % increase in traffic flow for a particular wind speed at a particular time of day. It is also true as identified that the emission rate is not only affected by the increase in the vehicular population but also by constantly changing traffic flow patterns and vehicles' driving modes. In addition, the nature of the vehicular flows also affects the rate and nature of the dispersion of pollutants in the vicinity of the road, influencing the pollutant concentration (Gokhale and Pandian 2007). Hence, it is quite complex to simulate the exact effect even using existing commercial models. As a result, a higher value of error is accepted with the primary objective of comparison of results across various scenarios.

The current or the base operating condition at the Kolkata intersection indicated a LOS of F, during peak hour with cycle failure. The average delay per vehicle was more than 2 min and there were oversaturated queue in all of the approaches except one. To improve this operating condition, hypothetical changes are made in terms of adding more capacities and optimizing the signal timing. After that all of the four performance index values are computed and shown in Table 2 for the existing traffic composition. LOS threshold selection by comparing the incremental changes is also shown in Table 2.

Although the lowest PI values occurred at LOS A, the largest incremental decrease in PI values (by PI_2 and PI_3) occurred between LOS C and B. Considering the feasibility and implementation of LOS thresholds, LOS B is determined to be the most effective operating point when a combined effect of emissions, fuel consumption and traffic operational parameters are considered.

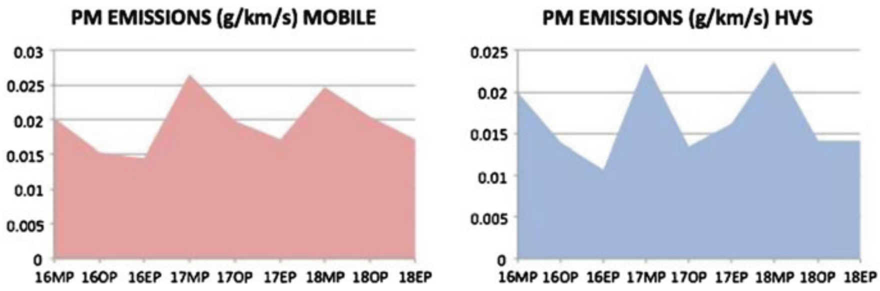

Fig. 3 Comparison of PM emission from MOBILE and HVS

Table 2 LOS threshold selection

ICU LOS	PI function values				Incremental decrease in PI values				LOS Threshold
	PI_1	PI_2	PI_3	PI_4	PI_1	PI_2	PI_3	PI_4	
A	4.195	2.797	2.312	4.675	0.431	0.521	0.508	0.353	A
B	4.626	3.318	2.82	5.028	1.626	2.038	2.273	1.576	B
C	6.252	5.356	5.093	6.604	0.675	0.849	0.941	0.65	C
D	6.927	6.205	6.034	7.254	0.037	0	-0.189	-0.13	D
E	6.964	6.205	5.845	7.124	0.709	0.892	0.989	0.683	E
F	7.673	7.097	6.834	7.807	0.808	1.01	1.111	0.771	F
G	8.481	8.107	7.945	8.578	1.519	1.893	2.055	1.422	G
H	10	10	10	10					

Once the PIs are obtained for all of these traffic compositions, they are plotted against a varying traffic composition for a various LOS thresholds.

Since, LOS B yielded best operating scenario it is discussed here in detail. Comparing various traffic compositions for LOS B, and corresponding PI values from Fig. 4, it is clear that case #5, #6 and #4 resulted in the lowest PI values.

It is also observed that no matter what PI criteria is adopted these vehicle compositions results in lower PIs. If LOS is also considered with traffic composition, the general trend observed is an increasing PI with drop in LOS. The traffic compositions for the best cases are as shown in Table 3.

Based on the results the following observations are made:

- It is very surprising that very high percentage of cars—as much as 80 % resulted in the lowest PI. However, when compared with other vehicles it is observed to contribute lesser than heavy vehicles and even lesser than motor cycles.
- PI value of case 9 (10 % Car, 80 % MC and 10 % HV) is the worst case of traffic composition in most of the LOS plans, which shows that MC are worst and contribute the most when the combined effects of congestion, emission and fuel consumptions are taken into account.

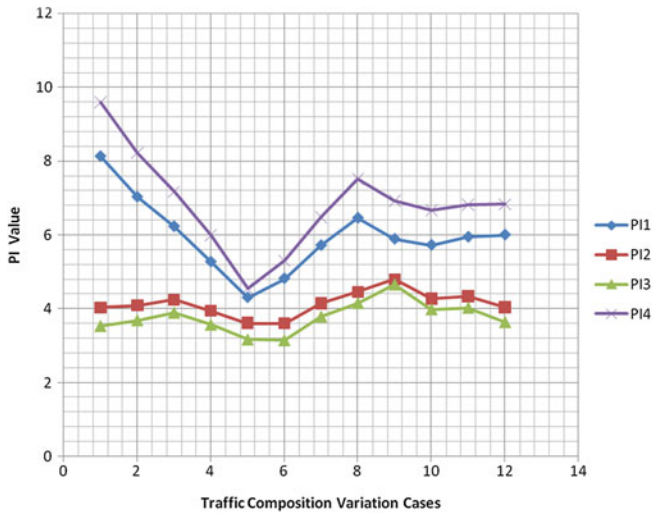

Fig. 4 Variation in performance index with traffic composition for LOS-B

Table 3 Best cases of traffic composition

Case	Car %	MC %	HV/T %
5	80	10	10
6	60	20	20
4	40	40	20

- It is also observed that case 9 is worse than the case 1 (10 % Car, 10 % MC and 80 % HV) where HV are the dominating share. This gives some indication that MC's are more polluting compared to even the HV.
- When cases 5 to 9—where composition of motor cycles gradually increase are closely observed, it is quite interesting to note with increase in MCs there is significant increase in total emissions. This again gives some hint that vehicle emissions greatly depend on MC traffic composition.
- When case 4 (40 % Car, 40 % MC and 20 % HV), case 7 (40 % Car, 30 % MC and 30 % HV) and case 12 (40 % Car, 20 % MC and 40 % HV) are compared, it shows that, with 10 % and 20 % shifts of traffic composition from MC to HV, the gain in PI is marginal. Comparisons across these three cases also indicate that keeping percentage of cars constant, small changes in MC and HV share will not result in significant gain in congestion, fuel consumption and emission. However, an important conclusion from this observation is that the total emissions can further be improved if the HV switch to alternative fuels like CNG—which is relatively easy for government to enforce.

4 Conclusions and Recommendations

In this study traffic volume and emission data are collected at a signalized intersection in Kolkata. The emission inventory obtained at the site is validated with that obtained from empirical models. Interrelationship among traffic composition, operational quality in terms of LOS and emission levels are explored. An integrated optimization is adopted to find the best operating condition. Based on the results following conclusions can be drawn:

- In mixed traffic condition, composition of traffic plays an important role for overall performance in terms of traffic operations, fuel consumption and emission.
- From the study of an urban intersection, it is observed that higher share of motorcycles are generally worse than higher share of heavy vehicles, not only from the point of view of pollution, but overall operations and fuel consumption.
- A gradual increase of motorcycle traffic in the traffic composition showed significant increase in total emissions.
- There was also some evidence that with 10 and 20 % shifts of traffic composition from MC to HV, there is no significant increase in total emissions. This indicates that even with increase in heavy vehicles increase in emission is not high.
- It is also observed that the highest share of the heavy vehicle is not as bad as the highest share of motor cycles from the view point of the performance index used in this study. Hence, it may be concluded that a higher share of heavy vehicle would be better from passenger transport point of view, and emissions from such vehicles can further be improved if HVs switch to alternative fuels.

The policy implications and the measures that may be suggested based on the results and observations are as follows:

1. Since MCs are one of the most polluting vehicle categories its usage has to be carefully assessed through better government policies. For example, in small cities where the share of MCs is generally very high, electric MCs may be encouraged through government incentives. Also, a government mandate to upgrade engine type from two-stroke to four-stroke would also help alleviate emissions from MCs.
2. HV, though contribute higher share of emission, it is found to be better than MCs. However, for further improvement, it will be better to convert the heavy vehicles mainly the trucks and public buses to alternative fuels like CNG. Innovative policies in terms of tax benefits may be an effective incentive to trucking companies who use alternative fuels over traditional fuels. This will be successful only through effective government intervention.
3. Last but not the least, it is clear from this study that a better public transport infrastructure will result in improved carrying capacity by reducing personal vehicle usage, reduction in congestion as well as overall emission.

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Part III
Urban Remodelling

Climate Change and Cities: Mitigation Through the Effective Management of Waste

Allan Yee, Mark Brostrom and Christian Felske

Abstract This discussion places the various components of the City of Edmonton's waste management system within the context of its environmental strategic plan and its follow-on implementation document for managing greenhouse gas emissions. The concept of a waste management hierarchy which integrates social and environmental considerations into a framework that can be used for decision making alongside financial affordability is also presented. The evolution of Edmonton's current waste system is described and then various chains of reasoning and detailed methodologies are discussed for quantifying the reductions in greenhouse gas emissions associated with a number of waste activities that the City currently practices or advocates. The real life examples provided demonstrate that practices resulting from decisions made following the principles of the waste management hierarchy can also be expected to yield benefits in terms of reduced emissions.

Keywords Waste management hierarchy · GHG emissions · Municipal solid waste management · Climate change mitigation policy landfill gas · Composity · Recycling · Grasscycling

1 Introduction

Climate change is truly a challenging modern day problem for society to address. Anthropogenic greenhouse gas emissions (GHG) are produced by almost all activities of modern society and, as more and more of the world's population

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concentrate in cities and they become larger hubs for commerce and social gathering, they naturally also become the focal points for greenhouse gas (GHG) emissions associated with energy consumption, manufacturing and generation of waste materials. But cities are also the level of government most directly involved in providing services to residents and hence, they are uniquely situated to continue providing those services while adjusting their operations to cope with climate change. If cities are contributing significantly to climate change, then cities must also be part of the climate change solution. This is evidenced by the numerous municipal networks and collaborations, at both the national and international level, that are attempting to address climate change at the local level, including the Federation of Canadian Municipalities Partners for Climate Protection (FCM, n.d.), the Global Cities Covenant on Climate (World Mayors Summit on Climate Change 2010), in which the City Edmonton participates, and the C40 Cities Climate Leadership Group (C40 Cities, n.d.), which is a network of the world's megacities taking action to reduce GHG emissions.

This chapter discusses the climate change policy context for the City of Edmonton identified in the City's Environmental Strategic Plan, The Way We Green (City of Edmonton 2011). This policy and implementation plans, such as the City operations Greenhouse Gas Management plan (City of Edmonton 2012), provide the direction for Edmonton to become carbon–neutral within its own operations and ultimately, to become a carbon–neutral[1] community. It will then provide an overview of greenhouse gas emissions produced by the City's delivery of services to the citizens of Edmonton before demonstrating, in depth, with performance results and emissions calculations, how the effective management of waste at the municipal level can be a part of a comprehensive climate change solution.

2 Context of Waste Management in City of Edmonton Climate Change Mitigation Efforts

2.1 Climate Change and Solid Waste Corporate Policy Context

The City of Edmonton recognizes reducing GHG emissions on a community wide basis and specifically from the delivery of municipal services to citizens as strategic priorities. The Way We Green goal that "Edmonton is a carbon neutral city" is further articulated through the following two objectives: "City of Edmonton operations are carbon–neutral, causing no net increase to greenhouse gas concentrations in the atmosphere", and "The Edmonton community is carbon neutral,

[1] "Carbon–neutral refers to achieving net zero carbon emissions by balancing a measured amount of carbon released with an equivalent amount sequestered or offset, or buying enough carbon credits to make up the difference." City of Edmonton (2011, p. 67).

causing no net increase to greenhouse gas concentrations in the atmosphere" (p. 55). The Way We Green was approved by Edmonton City Council in July 2011. While it is understood that carbon neutrality is a long term goal that will take decades to achieve, it is also recognized that becoming a carbon neutral city will be required in order to become a sustainable and resilient city, two overarching aspirations in The Way We Green.

With respect to solid waste, a complimentary goal contained within The Way We Green is "Edmonton generates zero waste," meaning in practical terms that the per capita generation of materials requiring landfill disposal or burning from both the residential and non-residential sectors will be continually decreasing (ZWIA 2004). It will become apparent in this chapter that achieving a zero waste goal will support the City's quest to become carbon neutral.

2.2 Greenhouse Gas Emissions from City Operations

The City of Edmonton, through its provision of municipal services to citizens and businesses, produces GHG emissions. Emission amounts are typically derived from the energy used in a specific operation and in the case of landfill emissions from methane generated by the decomposition of waste. Table 1 provides a breakdown of which operation generate emissions.

Approximately 17 % of emissions from City of Edmonton operations come from landfill and composter operations. If we include emissions from energy used in buildings and waste collection vehicles that are used to manage municipal solid waste, then this increases to over 21 % of the total City operations inventory.

3 Municipal Waste Management

3.1 Waste Management Decision Making

Modern urban solid waste management systems need to be planned, designed, developed and operated in an integrated and holistic manner. For cities, the degree of their involvement in various aspects of waste management (i.e., whether they

Table 1 2011 city operations' greenhouse gas inventory

	Buildings emissions	Muni fleet emissions	Landfill emissions	Composter emissions	Streetlights emissions	Forest (sink)	Total
2008 (T CO_2-e)	207,000	24,000	47,000	14,000	68,000	−3,000	357,000
% of total	58	7	13	4	19	−1	100

own, operate or control infrastructure for collecting, processing or disposal of all solid waste streams generated in the jurisdiction or only deal with certain components of it) is site specific, but in general, the more involved the municipality is, the greater the potential for system integration. The separation of the total waste stream managed by a municipality into different components that are handled in different ways, for example, will have profound implications on how their collection systems are organized, and how different transfer, processing and disposal facilities are sited, designed, constructed and operated. The financial implications of each option also need to be considered in terms of the overall costs and revenues for the overall waste management system. Vesilind et al. (2002) raise the example of how increased recycling activities can have a negative financial impact on landfill revenues and point out that many landfill costs are fixed, regardless of whether any waste is disposed of at the site.

In line with the interdependent and interlocking nature of the various methods of waste management, is the concept of an integrated waste management hierarchy which provides both a social and environmental framework, in concert with financial considerations, for making decisions. In simple terms, the hierarchy, variations of which are also commonly known as the 3 Rs or the 4 Rs, ranks the desirability of 4 methodologies, or means, for managing waste. When fully implemented, the end goal of "zero waste" to landfill will be achieved.

The waste hierarchy can be shown in a pyramidal form as per Fig. 1, or it can also be associated with a Moebius loop illustration (the ubiquitous international recycling symbol) to emphasize the iterative and cyclical nature of the process. At the top of the pyramid, or hierarchy, is the notion that thought should first be given to reducing waste at the source or production level. Examples of this would include the industrial light weighting of packaging materials for transporting and storing consumer goods prior to consumption or even better, efforts aimed at reducing consumption or production in the first place. Differences in packaging levels can often be considered an expression of global cultural differences and environmental consciousness.

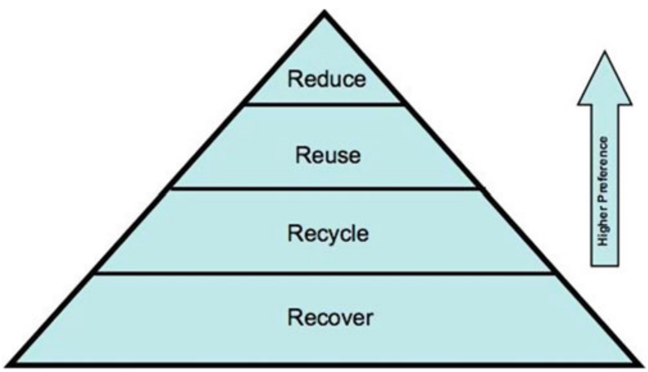

Fig. 1 Waste management hierarchy: the 4 Rs

Once everything practical, at a given point in time, has been achieved at the source reduction level, the next logical step, descending downward in the pyramid, would be to focus on the reuse of materials, as for example, the manufacture of more durable goods, or the use of goods by successive sets of consumers. The end goal here is to keep goods produced from virgin materials as long as possible in the user chain. Established examples would include second hand clothes or furniture outlets or the increasing opportunities for reuse of working TVs or computers, which are discarded by some as waste due to technological advances, but which can be still be used by others, as the performance of the equipment itself hasn't been impacted.

The recycling of materials which cannot practically be reduced or reused, and which could nominally be considered waste, is the next downward step in the hierarchy. Examples here would include the recycling of packaging materials into new products, or the transformation of organic waste into soil amendments through biological treatment systems such as composting and/or anaerobic digestion. The direct production of green chemicals or biofuels through thermal conversion of waste feedstocks by gasification or pyrolysis systems can also be considered recycling. At the forefront of these efforts is the concept of closed-loop-recycling, wherein, akin to the local food movement, the sourcing of recyclable feedstocks, their transformation, and the subsequent consumption of the resulting products is all carried out within a local region, hence avoiding the need for broader sourcing and distribution requiring fossil fuel consuming transportation systems.

The recovery of the energy value of a waste through traditional energy-from-waste systems, such as mass burn combustion facilities, represents the final descending step in the hierarchy at the bottom of the pyramid in Fig. 1. This form of waste treatment is especially popular in high-density population areas in Europe and Asia where large quantities of waste are generated within a small footprint and landfill disposal is geographically not possible or significantly hindered.

Only when all of the above possibilities in the hierarchy have been exhausted should waste then be disposed of through landfilling. As landfill disposal remains globally the most widely employed waste management practice, all 4 Rs described above are collectively known as landfill diversion activities.

A number of sources (Pichtel 2005; Tchobanoglous and Kreithe 2002) tie the concept of the 4 Rs to work the US Environmental Protection Agency carried out in the late 1980s and early 1990s when there was a perceived landfill crisis in the United States. This viewpoint however, may be a bit too limited and parochial in nature. Rathje and Murphy (1992) in his eminently readable treatise on garbology, places the methodology, if not the hierarchy, of the 4 Rs in perspective thusly:

> There are no ways of dealing with garbage that haven't been familiar, in essence, for thousands of years, although as the species has advanced, people have introduced refinements. The basic methods of garbage disposal are four: dumping it, burning it, turning it into something that can be useful (recycling), and minimizing the volume of material goods—future garbage—that comes into existence in the first place (this last is known technically in the garbage field as "source reduction"). Any civilization of any complexity has used all four procedures simultaneously to one degree or another.

As the impacts of reduction and reuse activities are more difficult to quantify, statistical information systems have concentrated more on measuring activities around recycling, energy recovery and the landfilling of waste materials. The drivers for more waste diversion from landfill disposal are many fold, and include legislation and regulations, technology development, socioeconomic factors, regional and international issues, environmental protection and the increased resource value of waste (Wichuk et al. 2012). However, it remains difficult to explain waste management trends globally based on specific drivers. Spatially, there still exist tremendous variations in the strategies and methodologies used for handling waste. For the countries of the European Union (EU 27), Fig. 2 shows the fraction of waste treated by category in 2009 (Eurostat 2011).

Historically, the overall trending of the waste treatment categories across the EU is shown in Fig. 3 (Eurostat 2011). For comparison, an equivalent trending graph for the United States is shown in Fig. 4 (USEPA 2011). The comparison is somewhat obscured as the European data set includes residential, industrial, commercial and institutional (ICI) and construction and demolition (C&D) waste data while the waste data from the latter is excluded from the U.S. graph. There is also a difference in the units of measurement (million metric tonnes versus million U.S. tonnes) on the two figures. The trend however in both graphs is clear: based on total waste generation numbers over the last two decades, more material is either being recycled, composted, or recovered for energy. On the other hand however, the amount of waste going to landfill disposal has been decreasing in Europe while remaining constant in the US.

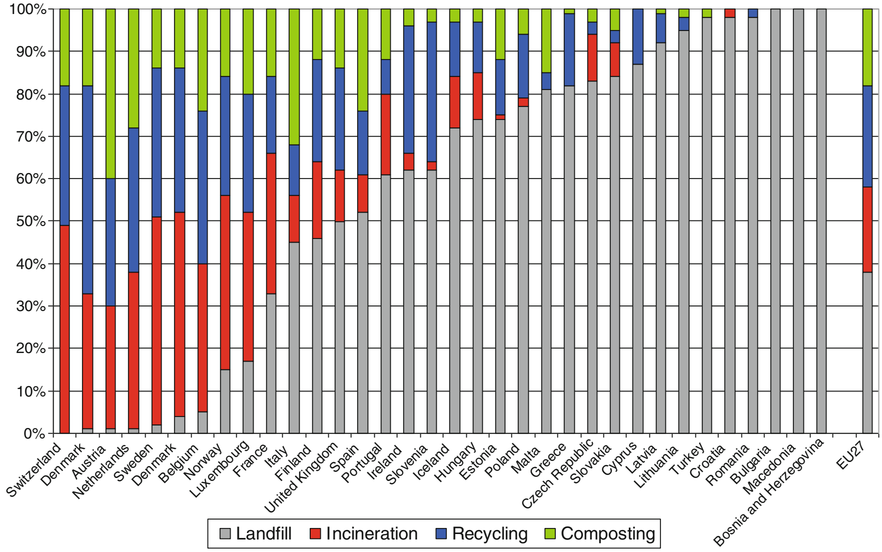

Fig. 2 Waste treatment in EU by country and category 2009 (Eurostat 2011)

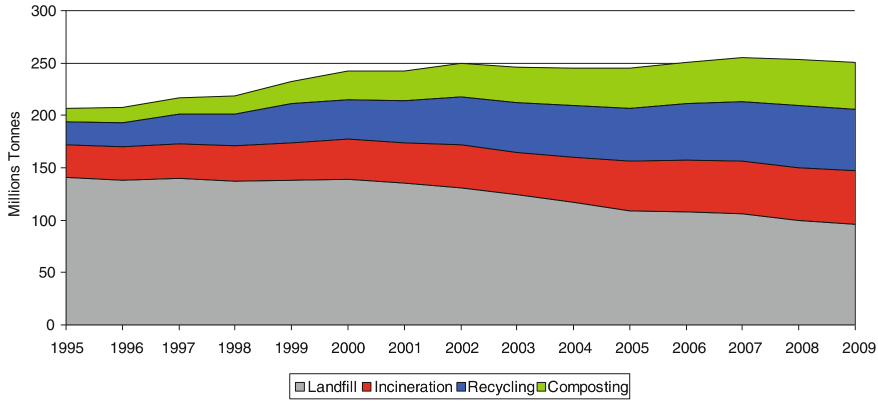

Fig. 3 Historical trends in EU-27 waste management 1995–2009 (Eurostat 2011)

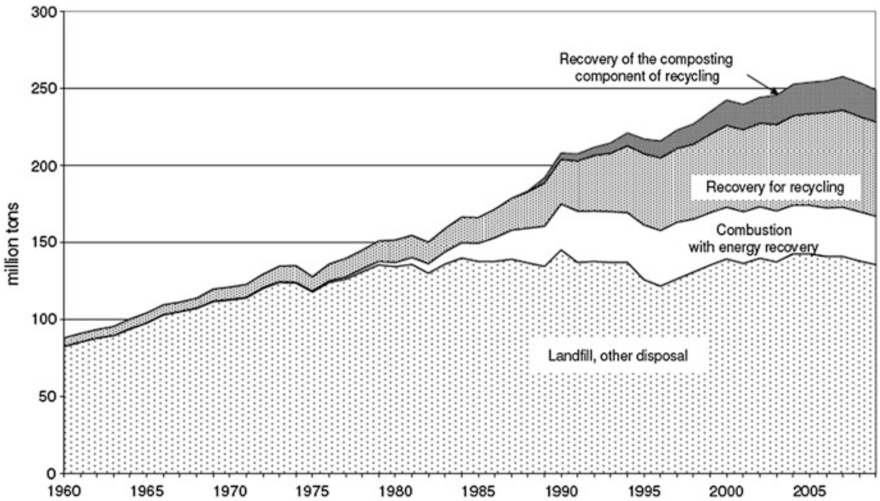

Fig. 4 Historical trends in U.S. waste management (USEPA 2011)

3.2 The Carbon Emissions Effects of Waste Management

Waste management activities have both direct and indirect benefits on GHG emissions and mitigation strategies. How this can be achieved can be summarized as below. The development and widespread acceptance of the waste management hierarchy predates, by a decade or so, major international concerns about carbon emissions on climate change, but in general, decisions made following the former will be consistent with expectations of reductions in the latter.

The reduction of production and consumption of products will result in less GHG emissions through the avoidance of energy inputs involved in the extraction, transportation and transformation of virgin materials required in manufacturing or, through material substitution in a recycling scenario, replaced with less energy intensive recyclable feedstocks. The recycling of paper (wood fibre), for example, will result in the lower harvesting of trees for pulp production.

Efforts to divert organic waste from landfill disposal will basically avoid altogether the generation of GHGs such as methane and carbon dioxide in the anaerobic conditions prevalent in a landfill. A high fraction of these emissions can be avoided through the separate collection and processing of these materials in, for example, a composting facility to produce a soil amendment. A somewhat less efficient way of reducing the emissions generated will be through their subsequent collection and combustion in a landfill gas (LFG) collection and destruction system.

The waste management industry is placing increasing focus on the production of energy (heat and/or power) from waste processing plants such as traditional energy-from-waste mass burn facilities or anaerobic digesters specifically designed for treating organic waste. This resulting displacement of more traditionally produced energy has the potential to slow down the depletion of fossil fuel resources as well as the offsetting of GHG emissions associated with the extraction and processing of those resources.

The proper management of waste in accordance with the waste management hierarchy carries with it a number of associated environmental benefits including a reduction of GHG emissions. While the trend in Europe has seen a significant emissions decrease from 69 to 32 M tonnes CO_2-e between 1997 and 2007 (ISWA 2009) from waste management activities, this has not been the case in Canada. Canadian waste related emissions represent about 3 % of the total GHG emissions in the country and have been stagnant for a couple of years now at around 20.7 M tonnes CO_2-e per annum. In part, this can be attributed to still increasing waste generation rates and the fact that landfill disposal, with or without LFG capture, is still the predominant Canadian methodology for managing waste (Statistics Canada 2010).

Over the past two decades, the City of Edmonton has implemented an integrated waste management system and has been able to reap the ensuring environmental and social benefits, including significant reductions in GHG emissions. While the latter was not the primary driver for the decisions made and the programs and infrastructure developed, the associated GHG benefits are quantifiable, to various degrees, as will be demonstrated in the remainder of this discussion.

3.3 City of Edmonton Waste Management System

3.3.1 Historical Perspective

In the late 1980s and early 1990s, the City of Edmonton was facing a waste management dilemma in being unable to site and develop a new landfill. Historically, since its incorporation as a City in 1904, Edmonton had been able to establish and operate various waste management facilities (landfills and incinerators) within City limits. For the municipally owned and operated landfills, each one had held about 2 M tonnes and had lasted for about 10–15 years. The City's last such site, the Clover Bar Landfill, had been developed in the mid 1970s and had been anticipated to provide a longer term disposal solution because the site footprint and landfill design had been sized to hold some 12 M tonnes. But, the development of Clover Bar also coincided with an economic boom for the City and so, by the end of the decade, over a million tonnes a year of waste (much higher than originally projected) was being received at the site for disposal. In the early 1980s, the City thus began searching again for another site on which a landfill could be developed. Public attitudes had shifted in the interim however, and it was discovered that this time around, a much higher quotient of NIMBY'[2] ism prevailed amongst the various parties in the Edmonton region in proximity to any potential site being considered. In the end, after considerable time and effort, the City's landfill search proved unsuccessful.

Thereafter, over the course of a year culminating in 1993, and following an integrated hierarchical approach, the City developed an alternative Waste Management Strategic Plan that shifted the emphasis away from landfilling towards other waste diversion methodologies. Intended to cover a time span of 30 years, the plan essentially stated that the most technically, economically, environmentally and socially viable alternatives to landfilling were municipal scale composting and residential recycling. In the time that would be required to develop/expand the facilities and programs to support these alternatives, the City would continue to make use of the remaining landfill space within City limits while also seeking to contract for long term external landfill capacity. Concurrent with all this would also be the use of social marketing tools to develop more community focused waste programs aimed at engaging citizens in the active application of the 4 Rs. As well, the underlying collection system would also need to be revamped to support the other plan components. Finally, the development of a detailed financing plan would be required to be able to afford all of the above.

3.3.2 Edmonton's Current Waste Management System Components

Implementation of the Waste Management Strategic Plan over the course of the 1990s and the beginnings of the 21st century resulted in the City developing a municipal scale composting operation for residential municipal solid waste (MSW) consisting of an enclosed mechanical plant and supporting outside processing area and a purpose built materials recovery facility (MRF) for sorting residential recyclables. All of these facilities were centrally sited at the Edmonton Waste Management Centre, a 226 hectare site also encompassing the Clover Bar

[2] NIMBY, an acronym for Not In My Back Yard, meaning a general attitude amongst residents of opposing various types of development in relative proximity to their location.

Landfill, a landfill gas (LFG) plant, 32 hectares of working lagoons for wastewater treatment biosolids and a mechanical treatment plant for landfill leachate.

More community focused programs developed in the same time frame included a community volunteer training program (the Master Composter/Recycler program, 21 years old as of 2012 and still going strong), the establishment of demonstration sites for home composting, construction of community drop off depots (Eco Stations) for household hazardous waste and bulky items and ongoing outreach programs for school tours, promotion of grasscycling, home composting, residential recycling and reuse fairs for collected household items not normally considered part of the residential recycling stream.

4 Carbon Emissions of Current Edmonton Municipal Waste Management Practices

This section discusses the chain of reasoning and various methodologies for determining the GHG emissions and relative emissions of some of the larger scale waste management practices that the City of Edmonton is either currently engaged in or actively promoting. We start with an activity at the bottom of the hierarchy (gas recovery from landfill), both because landfilling is the most common waste management activity that municipalities have historically been involved in, and the background landfill gas discussion also provides the theoretical baseline comparison for calculating emissions for other practices that are higher up in the hierarchy.

4.1 Landfill Gas Capture

The largest contribution to the carbon footprint of most municipal waste management systems comes from the emissions generated by the landfilling of organic materials in the waste stream. By comparison (see the calculations in Sect. 4.4.1), the emissions generated by the upstream extraction and consumption of fossil fuels used in the collection of waste is a relatively minor contributor. Carbon dioxide (CO_2) and methane (CH_4) are the two principal constituents of landfill gas (Tchobanoglous 2002), with the remaining trace gases (BTEX, siloxanes and other non methane organic compounds) having no greenhouse gas (GHG) consequences.[3] As the CO_2 component of LFG is considered biogenic, methane thus becomes the main GHG of concern when considering the carbon footprint of most waste management practices.

[3] Greenhouse gas effects are considered to be the atmospheric absorption and emission of radiation within the thermal infrared range of the atmosphere.

Worldwide, about 6 % of the total methane in the atmosphere can be attributed to the emissions from landfills (Augenbraun et al. 1997). Technically, the accurate measurement of methane emissions from a landfill is notoriously difficult, as the exercise is rife with potential errors including those generated by instrumentation limitations, weather factors (wind, precipitation) and topography as well as the quality of the capping, actual surface emission variations caused by differences in subsurface moisture and waste characteristics, and seasonal and diurnal cycles. By default then, practitioners usually revert to reliance on the accepted Intergovernmental Panel on Climate Change (IPCC) formula to determine L_o, (methane generation potential) which represents the amount of CH_4 that can theoretically be produced from landfilling a tonne of waste (Environment Canada 2012). The equation for L_o is provided below:

$$L_o = MCF \times DOC \times DOC_f \times F \times (16/12) \times 1,000 \text{ kgs } CH_4/\text{t } CH_4 \quad (1)$$

where:

L_o	CH_4 general potential, kgs/t of waste
MCF	CH_4 correction factor, fraction
DOC	degradable organic carbon, t C/t of waste
DOC_f	fraction of DOC that dissimilates under landfill conditions
F	fraction of CH_4 in landfill gas
16/12	stoichiometric factor for conversion of CH_4 to carbon

The MCF term is used to account for differences between "managed" landfills (those with properly engineered liner and capping systems) and "unmanaged" landfills. For the former, the default MCF value will be 1.0, while lower MCF values will be used for unmanaged sites without a tight capping system wherein a larger fraction of the waste in the upper layers can degrade under aerobic or anoxic conditions and thereby result in a lower calculated unit value for L_o.

Of the other variables, DOC is the fraction of degradable organic carbon in the waste stream that is amenable to biochemical decomposition, and can be determined through waste classification audits adjusted by another IPCC equation. This is further modified in Eq. 1 by the DOC_f term, which is the fraction of DOC that will actually degrade under landfill conditions.[4] Finally, the fractions of CH_4 and CO_2 in LFG will each vary over time from 0.4 to 0.6, so by default, F is usually set at 0.5

For a given mass of material *M*, landfilled in a given year *x*, L_o times *M* will yield the total amount of CH_4 that can be generated from that mass. Applying a first order decay function (e^{-kt}) to that value will then provide a time distribution to that total mass of methane (Environment Canada 2012). This IPCC sanctioned methodology, (IPCC 2006) commonly referred to as the Scholl Canyon model (from the pioneering research on landfill gas emission conducted at the Scholl

[4] A waste stream with a higher overall lignin content from wood, for example, is not as amendable to decomposition under landfill conditions as a waste stream with a higher fraction of food or paper.

Canyon Landfill located in the City of Glendale in Los Angeles County, California), is summarized in Eq. 2:

$$Q_{T,x} = kM_xL_oe^{-k(T-x)} \tag{2}$$

where:

$Q_{T,x}$ the amount of CH_4 generated in the current year (T) by the waste Mx,
Kt CH_4/year
X the year of waste input
M_x the amount of waste disposed of in year x, Mt
K CH_4 generation rate constant,/year
L_o CH_4 generation potential, kg CH_4/t waste
T current year

The kinetic methane generation rate constant, *k*, is primarily a geographically dependent constant varying with precipitation and temperature.[5] Moisture within a landfill provides an aqueous environment necessary for the anaerobic processes responsible for landfill gas generation as well as acting as a transport mechanism for making nutrients available to anaerobic microbes. Tables of *k* values have been developed for all of the various climate zones around the world. What these indicate is that methane generation is much higher and is exhausted more rapidly (to the $M \times L_o$ limit) in wet, tropical climates (Bangkok, for example) than in a more temperate dry zone such as Edmonton, Alberta, Canada.

By varying T in Eq. 2 above, a series of values for Q is obtained which will define a curve showing how the annual methane emissions from landfilling a quantity of waste in a single year reduce over time. For a landfill operating over a period of years and receiving varying annual amounts of waste, spreadsheets can be used to add up the corresponding values from individual curves to yield a composite curve representing the annual quantities of methane that will be generated both during the active life of a landfill and post closure. Schematically, this is illustrated in Fig. 5. The end result is that for any given year in the timeline of a landfill, a value, (albeit a model value) can be obtained for the methane emissions from that landfill. Technically, during the operating life of the site, the emissions from the annual energy inputs used for the operation of the site (grid power for operating a scale facility, natural gas for space heating, fossils fuels used by landfill equipment, etc.) should also be calculated and added to the total. In practical terms, values for the latter can be derived by multiplying the recorded quantities of the commodities consumed by their respective emission factors. Emission factors are representative unit values relating the quantity of an emission of a GHG with an activity (the extraction or combustion of a fuel, for example) associated with the release of that emission. The tonnes of methane emissions from

[5] More so with the former than the latter, as the temperature of the waste in the interior of a landfill will not vary nearly as much as ambient air temperatures. Nutrient availability and pH will also affect *k*, but neither variable is considered be a limiting factor within most landfills.

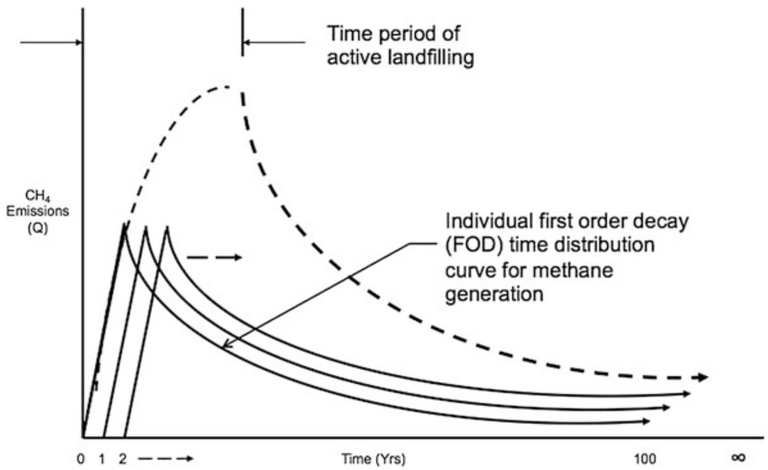

Fig. 5 Summation of individual *FOD curves* over time

a landfill are multiplied by the accepted 100 year global warming potential (GWP) of methane to obtain the equivalent tonnage in terms of CO_2 (commonly written as CO_2-e). GWP is the amount of heat trapped by a GHG in the atmosphere relative to an equal mass of CO_2 over a given time period.

The GHG emission effects of a landfill can be mitigated through the installation and operation of a LFG gas capture system. Essentially, this consists of a network of gas extraction wells placed over the footprint of a site and interconnected with piping. Negative pressure is applied from suction blowers to capture and transport LFG from the extraction wells, through the piping network, and to a central point where the gas can be processed for straight combustion through flaring or for various energy recovery purposes such as heat or power generation, co-generation, or upgrading to vehicle fuel or pipeline quality natural gas standards. Unlike the modeling exercise previously described that is used to predict the methane generated each year from a given site, the extraction of the same from an installed LFG capture system is actually measured through instrumentation. U.S. waste industry sponsored research (O'Brien 2008) suggests that gas capture efficiencies[6] from installed capture systems will average over 90 %. City of Edmonton experience (D. Labutis, Capital Power, personal communication, various dates) suggests this is overly optimistic, and that long term, the figure is much closer to the USEPA default value of 75 % (USEPA 2004).

Modern landfills also have engineered cover systems consisting of a natural, synthetic or combination cap overlain with a soil cover. In conjunction with site grading, the cap is designed to exclude, as much as possible, external moisture

[6] Exact definitions vary, but for present discussion purposes, capture efficiency in a given year is considered to be the quantity of LFG captured as a percentage of that generated amount for that same year as calculated by a first order decay model.

from penetrating to the waste in the interior of the site while the soil layer is meant to sustain vegetative growth that will mitigate against surface erosion and moisture penetration through evapo-transpiration. As a side effect, soil microbial metabolism in the vegetative layer will also serve to oxidize a portion of the methane emissions diffusing through the upper surface of the site. Methane cover oxidation will vary with a variety of factors (soil type and depth, climate, temporally with the seasons, etc.). Both the IPCC (2007a) and USEPA (2004) recommend using a default value of 10 % of the non-captured LFG for estimating cover oxidation.

4.1.1 City of Edmonton Comparative Emissions for LFG Capture

The initial installation of a gas collection system at the City's Clover Bar Landfill occurred in 1991 and the system began operation in 1992. The physical evolution of the piping network then proceeded apace with the continued development of the site. Current active operation of the extraction system is in accordance with the methane content of the gas. When the latter drops below a pre-set value, valving is used to shut off the flow from those areas of the network where the gas originated from (to let them recover[7]) and draw instead from another part of the network. As of 2012, the LFG flow from the site is some 65,000 standard m^3/day, at an average methane content of 52 %.

Extracted LFG is conveyed to an on-site plant located directly south of the landfill, where it is cooled and filtered to remove moisture, particulates and other contaminants and then compressed for use. For a number of years from original construction, the processed gas was conveyed by pipeline to a nearby power generating station where it was used as a fuel supplement to natural gas for producing electricity. After the latter facility was converted to a peaking station operating only intermittently, the generating utility (then EPCOR, now Capital Power) installed a number of portable generators adjacent to their LFG plant. Electricity is now generated on-site from the extracted LFG and fed into the provincial power grid.

Clover Bar Landfill was closed to general waste disposal in late 2010 and its remaining capacity is currently reserved only for internal City emergency use. As of the end of 2011, Clover Bar had received some 13.5 M tonnes of waste. For that year, the City's Scholl Canyon model indicates that the site should have generated 8,122 tonnes of CH_4. Applying a 100 year GWP factor of 21 for methane[8] to that

[7] Declining CH_4 content in LFG is a potential indication that oxygen from atmospheric air is being advectively drawn down into the landfill interior from the operation of the suction blowers and serving to suppress the anaerobic methanogenic microbes responsible for CH_4 production.

[8] An outdated 100 year IPCC GWP figure of 21 for CH_4 is used in this calculation only for the purposes of comparison with Capital Power's supplied numbers for calculating carbon offsets from the LFG operation where the use of that number is enshrined in Provincial legislation. In the Alberta Offset System, where LFG is captured and combusted by flaring, a *direct* offset can be claimed, where it is used to displace fossil fuels for energy purposes, an additional *indirect* offset

figure yields potential emissions of 170,562 tonnes of CO_2-e. In comparison, Capital Power's figures for 2011 indicate they extracted 6,384 tonnes of CH_4 from Clover Bar. Based on the 2011 operating up time of their LFG power generation operation and the fraction of the captured methane that was used to generate electricity versus straight combustion by flaring, this equates to some 161,865 tonnes of CO_2-e for a net difference of 8,697 tonnes of CO_2-e. By applying a 10 % factor for cover oxidation multiplied by a 100 year GWP figure of 21 to the estimated 1,768 tonnes of LFG not captured from Clover Bar in 2011, we obtain a net difference in GHG emissions of 32,848 tonnes of CO_2-e.

4.2 Composting

In the hierarchy of waste management, composting can be considered to be a recycling activity wherein generated organic waste materials are captured and transformed into a beneficial product. In simplified GHG system terms, the basic composting process can be schematically represented by Fig. 6, which is an adaptation from the Clean Development Mechanism offset protocol for composting (CDM 2005). Note that emissions from transportation can be considered outside of the system boundary if, as in many instances, the composting operation is co-located with a landfill or transfer station. In both the landfill disposal and composting cases then, the transportation emissions would be the same. Similarly, the composting system boundary specifically excludes any emission reductions from biomass or soil carbon sequestration from the subsequent use of the finished product. This is because for the latter, compost can be used for a wide variety of uses and though much specific research in this area has been conducted (see, for example, Brown et al. 2011), neither the science nor the carbon accounting methodology for this is as well understand or accepted as for the composting process itself.

The GHG emissions from a composting operation can be quantified in terms of the upstream extraction and consumption of the energy inputs into it as well as the process GHG emissions (excluding biogenic CO_2 emissions) coming from the activity itself. The emissions can then be compared to a baseline case where the same materials would have been otherwise disposed of in a landfill. In this sense, the methodology described herein follows the methodology used in a carbon offset system (e.g., the Alberta Offset System (AOS) or an offset system that would employ project offset protocols developed by the Climate Action Reserve) wherein the emission differences between the baseline and the activity are the avoided emission offsets. It is not as restrictive as the latter however, because more weight

(Footnote 8 continued)
can also be claimed. The emission effects of additional energy inputs into the system (diesel fuel, parasitic power, etc.) must also be factored into the exercise.

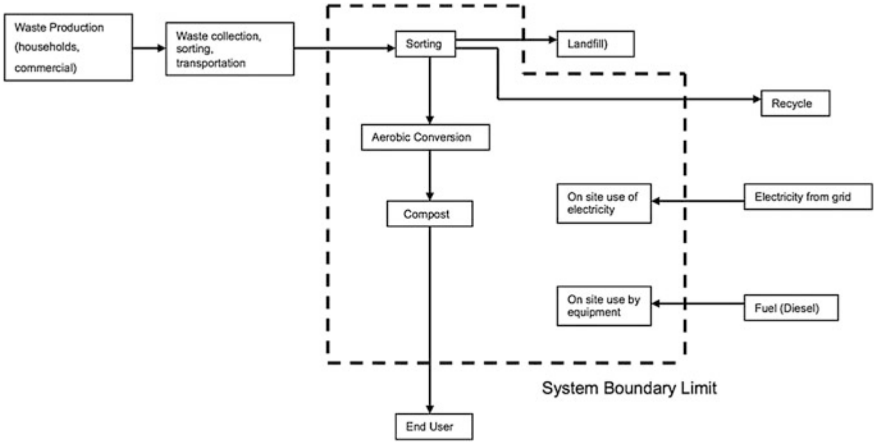

Fig. 6 Basic composting system boundary, inputs and outputs [Adapted from CDM (2005)]

can be given to the science of GHG emissions versus being encumbered by other factors that also bear consideration in an offset system. Some desirable IPCC/ISO 14064 based carbon accounting qualities (permanence, additionality, quantifiable, reality/actuality) would remain the same (WCI 2010) but regulatory risk, for example, would be of greater concern in the latter. The results that come from applying a *k* value in the Scholl Canyon model for the continental dry zone that Edmonton is in show that only 92 % of the ultimate methane generation potential ($M \times L_o$) of a waste would be reached in a local landfill in a 100 year time frame. Composting that waste rather than disposing of it (in a landfill without a LFG capture system) would permanently avoid those emissions entirely. Allowing an offset credit now for all of those potential future avoided emissions over that long a time frame however, poses some degree of regulatory risk. What if some future technology (or legislatively mandated LFG capture), as is commonly argued, came along to negate all or part of those baseline emissions? Or what if the voluntary offset practice evolved, within a short time frame, into a widespread business-as-usual activity? The Climate Action Reserve protocol for composting projects (Climate Action Reserve 2010) allows only a baseline crediting period of 10 years for avoided LFG emissions from the activity.[9]

On the opposite side of the ledger, it can be argued that there is already a degree of conservativeness and accounting for uncertainty in existing offset systems through the use of a 100 year GWP for methane and one that may also be outdated and lower (as in the Alberta Offset System) than current IPCC documentation to boot (IPCC 2007). CH_4 is a short lived atmospheric gas and has a large heat trapping effect for only a brief period [8.4 years (IPCC 2007)] before largely

[9] In fairness however, LFG capture has been mandated in the U.S. for all sites above a certain tonnage size, although this measure was legislated in the mid 1990s under the U.S. Clean Air Act Regulations for public health and safety, rather than GHG reasons.

decaying and converting to CO_2 and water. Over a 20 year time horizon then, the 2007 IPCC 100 year GWP value for CH_4 of 25 equates to a GWP value of 72 versus CO_2. Recognition must be given however, to the fact that a 100 year GWP time horizon is the accepted international standard.

4.2.1 City of Edmonton Comparative Emissions for Composting

Edmonton's composting operation is more complicated than the basic system shown in Fig. 6 and reference should instead be made to Fig. 7. The overall facility consists of an enclosed mechanical plant and an outdoor processing area. The mechanical plants receives a feedstock of organic rich waste derived from a collected stream of mixed single and multi-family residential municipal solid waste fed through a pre-processing (sorting) plant. Separation of contaminants is carried out in two separate steps inside the mechanical plant and these materials (deemed primary and secondary residuals) are hauled away to landfill disposal at a site without LFG collection. The limitations of the separation technology used means that a portion of both residual streams will also unavoidably contain organic material. In the interim, compost product coming out of the mechanical plant is placed in the outdoor area and further processed to cure it. Final physical screening of the cured compost is carried out to prepare it for marketing and distribution and the contaminants removed in this step, deemed tertiary residuals and also unavoidably containing organic material, are likewise hauled away to landfill disposal.

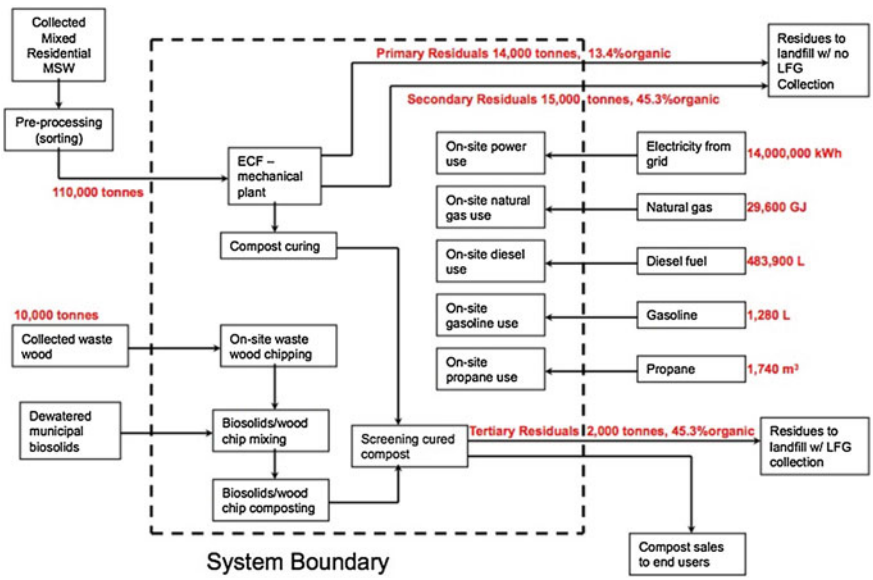

Fig. 7 Edmonton composting facility system boundary, inputs and outputs

The outdoor area is also used for the separate composting of a dewatered municipal biosolids and waste wood chip mix. Biosolids are the anaerobically digested residues from the City's wastewater treatment process. To condition them for composting, they are gravity thickened and then mechanically dewatered in centrifuges to a 23–25 % solids consistency. Since their baseline fate is not landfill disposal, biosolids processing (as much as possible, given the technical limitations of current data management systems) is excluded from the carbon accounting for the GHG emissions from the composting operation. However, the carbon accounting *does* include the emissions inputs and outputs from the composting of the wood chips that are mixed with the biosolids in the operation. The chips are derived from waste wood, which would have been disposed of in a landfill in the baseline alternative to composting.

The energy inputs into the composting operation are electricity from the grid (for aeration blowers, conveyors, and turning and screening equipment), natural gas for space heating of the mechanical plant, diesel fuel for mobile equipment (loaders, screeners, and turners) gasoline for light duty passenger trucks and propane for winter heating of an outdoor crew trailer. Representative, but surrogate numbers for all of the energy inputs and mass quantities in the City's composting operation are also shown on Fig. 7. Using these numbers, the emissions for the operation are obtained by multiplying the various energy input quantities by their respective emission factors (Alberta Environment 2008) and 100 year GWP factors to transform everything to tonnes of CO_2-e. To this are added the calculated process emissions from the composting process as well as the emissions that will result from the landfilling of the organic residuals culled out of the operation. All of this is summarized in Table 2.

For the alternative baseline case of landfilling the materials composted, we can run through the standard methodology for calculating L_o (Eq. 1 in Sect. 4.1) with the following values: MCF = 1 for a managed site, DOC for City mixed MSW = 0.19, DOC_f = the IPCC default of 0.77 and a CH_4 fractional f = 0.5. Multiplying the resulting L_o by the mass of material composted and subtracting 10 % of that product number for cover oxidation at the hypothetical destination landfill site, we obtain a GHG emission figure of 263,340 tonnes of CO_2-e.

The date of the landfilling baseline should be considered when discussing the additionality[10] differences in emissions from the City's composting operation. Certainly prior to the commissioning of the processing facilities involved in 2000, all the collected MSW feedstocks would have been landfilled.

On the regulatory side however, the Alberta Offset System considers 2003 to be the earliest allowable baseline year for offset projects. To rationalize this, a discounted or adjusted baseline approach was adopted for use in the end in the first version of the Alberta composting protocol (currently under regulatory review)

[10] Additionality is considered, in this case, to be the reasonable expectation that the materials composted would have been disposed of in a landfill if the composting project had not been developed. See Pacific Carbon Trust (n.d.).

Table 2 GHG emissions from Fig. 9 composting process

	Item	Amount	Emission	Emissions factor[a]	Emissions (kg)	Emissions[b] (kg CO_2-e)
Energy inputs						
Production	Electricity	14,000,000 kWh	CO_2e	880 kg/MWh	12,320,000	12,320,00
	Natural gas	785,353 m^3	CO_2	0.133 kg/m^3	104,452	104,452
			CH_4	0.0026 kg/m^3	2,042	51,048
			N_2O	0.00007 kg/m^3	5.50	1,638
	Diesel fuel	483,900 L	CO_2	0.138 kg/L	66,778	66,778
			CH_4	0.0109 kg/L	5,275	131,863
			N_2O	0.000004 kg/L	1.94	577
	Gasoline	1,280 L	CO_2	0.138 kg/L	177	177
			CH_4	0.0109 kg/L	13.95	349
			N_2O	0.000004 kg/L	0.01	1.53
	Propane	1,740 m^3	CO_2e	0.368 kg/L	640,320	640,320
Combustion	Natural gas	785,353 m^3	CO_2	1.891 kg/m^3	1,485,103	1,485,103
			CH_4	0.00049 kg/m^3	385	9,621
			N_2O	0.000049 kg/m^3	39	11,468
	Diesel fuel	483,900 L	CO_2	2.17 kg/L	1,321,047	1,321,047
			CH_4	0.0000133 kg/L	6.44	161
			N_2O	0.0004 kg/L	194	57,6841
	Gasoline	1,280 L	CO_2	2.83 kg/L	3,622	3,622
			CH_4	0.00018 kg/L	0.23	5.76
			N_2O	0.000031 kg/L	0.04	11.82
	Propane	1,740 m^3	CO_2e	1.544 kg/L	2,686,560	2,686,560
Energy input subtotal						*16,205,923*
Process emissions						
	MSW and wood chips	120,000	CH_4	0.004 kg/kg	0.48	12,000
			N_2O	0.0003 k/kg	0.036	10,730
Process emissions subtotal						*22.73*
Residuals handling						
	Primary	residuals	14,000	CH_4		164,675
4,116,882						
	Secondary	residuals	15,000	CH_4		596,465
14,911,628						
	Tertiary	residuals	2,000	CH_4		79,529
1,988,217						
Residuals handling subtotal						*21,016,727*
GHG emissions from composting process total						*37,222,672*

[a] Emission factors as published in *Quantification Protocol for Aerobic Composting Projects*, Alberta Environment (2008)

[b] Conversions made using 2007 IPCC 100 year GWP numbers of 25 for CH_4 and 298 for N_2O

based on the 20 % of the organic material that the best statistical information available indicated was already being diverted away from landfill disposal at the 2003 baseline date (Alberta Environment 2008).

Further complicating the baseline discussion in the City's case is the issue of the destination landfill. At the time the switch to composting was made, most of the residential MSW was being disposed of in a contract landfill without LFG collection while the City was trying to conserve the remaining disposal capacity at its own Clover Bar site which did capture LFG. In comparing baseline emissions to composting emissions therefore, a pro-rating calculation was required to accommodate the capture of LFG for the fraction of the waste that would have been disposed of at Clover Bar in the absence of the composting project.

Putting aside the above however, in a simplified comparison assuming a baseline destination landfill without LFG capture (Clover Bar Landfill would have been closed in 2007 if the historical ratio of waste disposed in it had been retained for all of the waste subsequently processed through the composting operation) as per the analysis above, the City's waste composting operation in a typical year will result in reduced GHG emissions of 203,409 tonnes of CO_2-e over landfill disposal for 120,000 tonnes of input solid waste processed.

4.3 Residential Recycling

Recycling seeks to substitute materials culled from the waste stream for the use of virgin materials in the production of new goods and products. At the manufacturing end, recycling can be carried out both from internal sources (e.g., off-cuts of paper or gypsum board from production being reused in new production) or from materials sourced from further along the consumer chain. Transformation of materials from one type of product into another in recycling is also common: for technical reasons, old tires or asphalt roof shingles will not go back into new tire or shingle production. Similarly, it may also be more economically viable to turn post consumer plastic drink bottles into fleece clothing rather than more drink bottles.

Depending on the materials and their eventual transformation, municipalities typically are only involved in part of the recycling chain. For residential waste, that municipal involvement will be in the development and operation of systems for collecting that material and perhaps the sorting of it for marketing purposes through material recovery facilities (MRFs). Thereafter, there is a long chain of additional agents (brokers, primary processors, shippers, etc.) involved before culled material gets into the hands of the end user of that material in manufacturing and then eventually, the end consumer of the manufactured product. For construction and demolition (C&D) waste recycling, the chain may be considerably shorter between the collection and sorting effort and the end use of the material.

In terms of GHG emissions, recycling will cast a wider net than the simple avoidance of CH_4 emissions from the landfill disposal of the materials being recycled. There will be this effect with the recycling of biomass based organic materials such as paper and cardboard. Beyond this however, there also be another emissions reduction effect with the above organics as well as with recalcitrant organics (plastics) and non-organic materials, such as steel and aluminum, which do not degrade anaerobically to yield CH_4, and this will be through the lower energy consumption from the avoided extraction and processing of virgin materials. A carbon baseline for recycling a material would then involve the quantification of the emissions from the extraction and processing of a quantity of virgin resources used in the manufacturing of an end product as well as the avoided emissions that would result from the landfill disposal of an equivalent quantity of the recycled material that would displace the virgin material as feedstock. For the comparative case, the emissions would be from the manufacturing of the end product using the recycled material.

The devil is in the details however. The general logic of the reasoning above may be straightforward, but the execution of it will not be. For a municipality, such as Edmonton, operating a collection system and a MRF, complications arise from the sheer diversity of recyclable materials collected, what types and grades of recyclable commodities they can be sorted into, the volatility and cyclical nature of the markets for these commodities (regular switching between end purchasers is not uncommon), the downstream steps involved in their potential resorting and reprocessing into some sort of virgin resource replacement feedstock, potential uses of the feedstock for manufacturing consumer products and some conflicting drivers. A simple example of a commodity mainly being recycled into the same commodity can be used to illustrate some of this. The recycling of newsprint will reduce the harvesting of trees for pulp production. Two of the grades of old newsprint that are commonly recycled into newsprint again are ONP6 and ONP8. The latter is a higher grade that has less contamination by other acceptable papers ("outthrows"—coloured inserts, magazines, sunlight aged product), or non paper materials, or is less soiled or wet. Extra sorting efforts (and costs) are involved in producing ONP8 at a MRF versus ONP6. The trade off is that, depending on markets, ONP8 can then likely go to a regional or at least a North American paper mill for re-pulping, de-inking and then into being fed as a fibre supplement into newsprint production, versus having to be shipped to an overseas market where it may be economically viable to resort it again before reaching a paper mill. In North American mills, it is a more accepted operating practice that the contaminants in ONP feedstock will end up being discarded through the re-pulping process. Some primary drivers for a MRF operator/owner are the minimization of their operating (sorting) and shipping costs for market acceptable commodities while, at the same time, maximizing their revenue for those same commodities. What are likely not drivers for them are factors tangential to the recycling process such as carbon emissions. The out of pocket costs of transportation are somewhat disproportionate to the GHG emissions associated with them (see the calculations in Sect. 4.4.1); part of that comes from the additional interactions required between the various agents involved (brokers, various haulers) to arrange a complex haul to a distant destination involving different modes of shipping such as truck, rail and ocean freighters. At the intermediate processing end, the GHG emissions associated with a local paper mill may also be more than from a distant mill if a higher fraction of the power from the regional grid is from coal fired plants versus less emissions intensive power (from, for example, hydroelectric sources) generated at the more distant location. Further downstream of the paper mill again, the mill owner will have a variety of customers for his rolled paper products, each with their own destination and process specific energy inputs and emissions.

On the carbon accounting side, some of the emissions factors associated with the various links involved in the recycling of a particular material at a given point in time may be known to a municipality, but it is highly unlikely that they all will be. In general, the higher the number of links in the cycling of a waste product to a new consumer product, the more unknowns there will be. For well-established systems with well-established pairs of recycled and displaced inputs (e.g., aluminum from virgin bauxite ore and aluminum beverage containers), relatively robust emission factors have been developed (Recycling Council of Alberta 2011). This is not the case with all recyclable commodities in all recycling chains. To date, due to the complexities involved, the volatility of the destination markets and the unknowns that likely would have resulted in calculation materiality errors of greater than the standard 5 %, the City of Edmonton has not attempted to quantify the reductions in emissions associated with its MRF operation.

A quantification protocol for recycling in a carbon offset system can be developed following along the lines of the reasoning discussed herein. An intent to develop document covering such a protocol was filed in mid 2011 with the Alberta Offset System (AOS), and a draft technical seed document was written, but as of Fall 2012, this has not yet progressed to the technical review and public consultation stages.[11] While the somewhat artificial boundaries of the AOS on a recycling protocol (the feedstock materials and the end products they are recycled into must both come from within Alberta) may simplify the accounting, they would also result in capturing the carbon effects of only a fraction of the materials culled for recycling within the province. Recycling is a worldwide activity, with some commodities and intermediate products crossing regions and international boundaries with impunity and a true carbon accounting should reflect this.

4.4 Grasscycling

Grasscycling, wherein property owners leave the clippings on their lawn when they mow, can be considered a top of the hierarchy waste reduction practice. For public spaces such as parks and sportsfields, grasscycling is the norm. Decades of cultural conditioning in suburban North American however, have made it much more common for single family residential households to collect their grass

[11] See: http://carbonoffsetsolutions.climatechangecentral.com/offset-protocols/current-alberta-protocols-submitted-review.

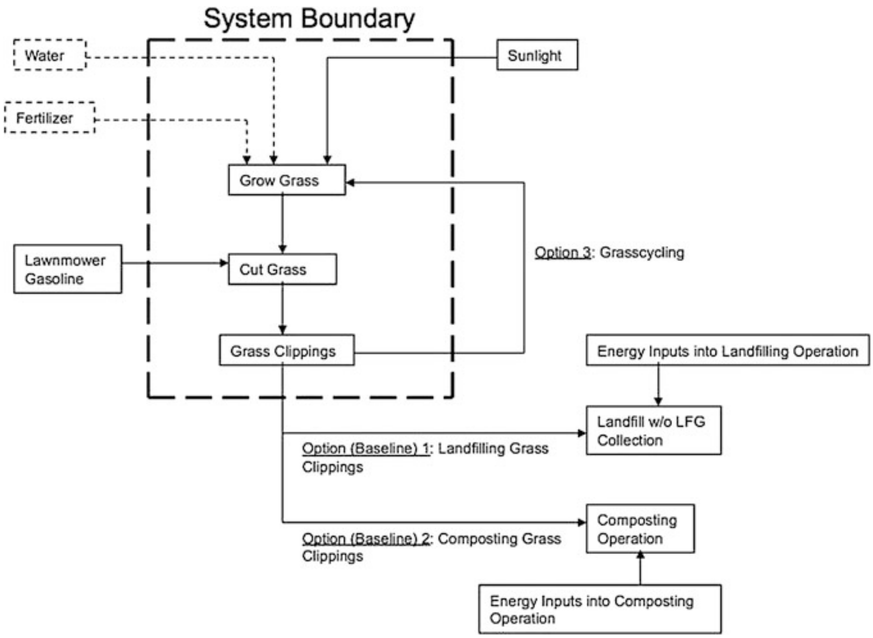

Fig. 8 The residential grass cultivation system

clippings and then set them out for solid waste pick up. In both Canada and the U.S. where other options exist, various provincial and state jurisdictions have virtually mandated residential grasscycling through the enactment of yard waste collection and/or landfill bans.

The City of Edmonton (and the province of Alberta) has opted not to go down the route of banning yard waste and has instead taken a social marketing approach to encourage both home composting and grass cycling. Over the 15 plus years that the City has been promoting grasscycling, the popularity of the practice has grown to the point where the most recent local survey data from the end of 2011 indicates that it is now practiced by about 50 % of the single family households in Edmonton. Whether that can be attributed entirely to the City's efforts or because those efforts were confluent with other factors, such as the wider spread availability of suitable lawn mowers, or noted savings in fertilizer or water use, is a moot point. The end result has been the same.

Intuitively, it would appear to be self evident that grasscycling should result in a reduction in residential GHG emissions. Leaving grass clippings on a lawn will result in the material not being gathered and adding to the quantity of household waste set out for collection. This should further result in a reduction in the energy inputs required in operating the collection system as well as more downstream effects in the reduction of the energy inputs required for processing the clippings and/or transferring and disposing of them in a landfill. Quantitatively, using basic data and making some reasonable assumptions, the carbon footprint of grasscycling can be roughly calculated. Figure 8 shows, in simple terms, how the residential grass cultivation system can be viewed: during the growing season, the inputs into the system will be sunlight, water and perhaps some fertilizer. It will be the resident's choice as to whether or not they apply fertilizer to their lawn or water it (hence the dotted lines in Fig. 8) to supplement any naturally occurring rainfall. Once the grass grows to a height where it becomes unsightly or unruly, it is cut. The options for the clippings will then be threefold: to leave them on the lawn where they degrade aerobically (the same assumption can be made for clippings processed in a home composter) or to gather them up and set them out for waste collection. For the purposes of this analysis, the assumption is made that the two options inherent with the collection of the clippings will be to either compost them centrally or to transfer haul them to a landfill for disposal. Under the grasscycling option, the CO_2 emissions from the aerobic decomposition of the clippings on the surface of the lawn can be considered biogenic.

4.4.1 City of Edmonton Comparative Emissions for Residential Grasscycling

As of 2009 (the latest year for which data is available), the City was responsible for collecting the waste from roughly 180,000 single family households. From the literature (Robinson et al. 1993) correlated with internal waste classification data, we obtain a total mass of grass grown/average yard size of 250 m^2 equal to 354 kgs (or 63,720 tonnes City wide) over the typical Edmonton growing season of April through October.

If we assume that the grass is mown, on average, every two weeks (this will vary with the actual time of the season, hours of daylight, and precipitation) with a gasoline powered lawnmower (the percentage of push mowers and electrically powered mowers versus gasoline units in the residential sector is considered insignificant) consuming 0.2 L/cutting,[12] this equates to 14 or 15 cuttings/season and a total of 540,000 L of gasoline consumed. Using published emission factors for the consumption and upstream extraction and processing of gasoline for internal combustion engines (Alberta Environment 2008) and the GWP numbers for CH_4 of 25 and N_2O of 298 respectively (IPCC 2007), we can then calculate the yearly GHG emissions from the residential mowing of grass in Edmonton to be 1,758 tonnes CO_2-e.

One potential emission input into the system not factored into the calculation is the application of potable water to a lawn to supplement natural precipitation over the course of the growing season. This is due to the wide variability of seasonal rainfall in Edmonton in recent years as well as the continuing trend in the City towards less residential watering of lawns as a matter of habit.

[12] From an informal poll of various City Waste Management staff.

For grasscycling, one of the documented effects on lawn care is the fertilizer value of the clippings. Reliable accurate data on this is difficult to obtain, however the following approach can be taken to try and quantify the avoided emissions associated with this. From an electronic data source (Starbuck 2003) we obtain an estimate that grass clippings will provide about 25 % of a lawn's fertilizer requirements. Some slow release lawn fertilizers commonly available in the Edmonton area have an N–P–K formulation of 28–4–8.[13] Since lawn fertilizer application rates are based on nitrogen, we can apply the seasonal recommendation of 2 lbs N/1,000 ft^2 with this formulation (Murakami et al. 1999) on the average Edmonton lawn size of 250 m^2 (2,691 ft^2) to determine that this represents 19.2 lbs (8.8 kgs) of fertilizer. 25 % of this value is 2.2 kgs.

However, not every single family Edmonton household uses lawn fertilizer. Assuming that 50 % do (the same local percentage as those that do not practice grasscycling), this represents 198 tonnes of fertillzer. A recent popular source (Berners-Lee 2011) pegs the GHG emissions for manufacturing fertilizer as ranging from 1–4 tonnes CO_2-e/tonne of product. If we assume an average figure of 2 tonnes CO_2-e/tonne of product, 198 tonnes of lawn fertilizer consumed will then represent GHG emissions of 396 tonnes CO_2-e.

As there is more uncertainty involved in the logic and various factors used in the above calculation on the potential reductions in GHG emissions resulting from the fertilizer value of the clippings, the figure obtained is, conservatively, not included in the comparative discussion below.

In contrast to grasscycling, the GHG emissions from transportation need to be accounted for when that material is collected and either composted or landfilled. Collection of a season's worth of clippings of 63,720 tonnes, in City mid-sized residential tandem collection vehicles with a 6,500 kgs payload capacity and an average fuel efficiency of 2.5 L of diesel fuel/km for an average round trip of 80 kms from a residential collection route to the City's waste transfer station will require the consumption of 313,700 L of diesel fuel. That amount of diesel multiplied by the published emission factors for the production and consumption of diesel (Alberta Environment 2008) as well as the 2007 IPCC 100 year GWP numbers for CH_4 and N_2O respectively, will then yield GHG emissions of 1,024 tonnes of CO_2-e.

For composting that material, we can apply the composite emission factor associated with the City's composting operation from 3.4.2.1 (0.31 tonnes CO_2-e/tonne of material composted) and multiply it by the season's mass of grass clippings to yield emissions of 19,753 tonnes of CO_2-e. Added to the collection emissions calculated previous, we obtain a total of 20,777 tonnes of CO_2-e for the central composting of the clippings.

For landfilling the grass clippings, the emissions for further transfer hauling the material to disposal need to be quantified as well as the emissions from the operation of the landfill and finally, the GHG emissions resulting from that

[13] Pro Turf 28–4–8 or Agrium's Nu-Gro Landscape 28–4–8.

material being resident at the site. For the transfer hauling, by assuming the use of CIty tractor trailer units with an average payload of 20 tonnes, a fuel efficiency of 0.6 kms/L and a round trip distance of 160 kms to the destination landfill, we obtain a figure of 2,774 tonnes of CO_2-e.

For the emissions from landfill operations, we can assume the use of a mid sized loader and a compactor operating for 3,000 h a year and with an average diesel consumption of 10 L/h of operation. We can then pro-rate the resulting emissions by the 7 months of the year (April through October) during which grass is generated locally. The results will be conservative because the equipment will also be used for the landfilling of waste other than grass clippings during the summer months. Similarly, we can assume that a landfill scale house will consume about the same electricity (7,800 kWh) and natural gas (160 GJ) and generating the same emissions as an average local single family house [7.5 and 7.9 tonnes CO_2-e, respectively (City of Edmonton 2009a, b)]. For electricity, we can pro-rate the annual consumption and emissions by the 7 months of the year during which grass will be generated. For natural gas however, we differ slightly in that it is assumed that it will only be used for space heating during the two opposite end months (April and October) of the grass growing season. Assigning the emissions from the scale house operation to the landfilling of grass is again, a conservative estimate, as other waste will also be received at the site during the grass growing season. Running through the emissions calculations for the landfill operations as per our methodology, we obtain relatively modest operating emissions of 120 tonnes of CO_2-e.

For landfill disposal of grass clippings, we can calculate L_o as for the composting analysis in 4.2.1, but with an adjusted DOC garden waste value of 0.17 (Environment Canada 2012). Multiplying the resulting L_o by the mass of clippings and subtracting 10 % of that product number for cover oxidation at the site, we obtain a GHG emission figure of 125,119 tonnes of CO_2-e. By adding this to the component amounts calculated previously, our total figure for GHG emissions from landfilling a years worth of grass clippings is thus 129,037 tonnes.

Graphically, the relative emissions from grasscycling clippings, centrally composting them or disposing of them in a landfill without LFG collection are shown in Fig. 9. The numbers and analysis provide an indication of the large differences in GHG emissions that can be achieved from a relatively simple community focused waste reduction measure. Grasscycling is voluntary, the emissions differences are real, they are quantifiable and they would pass an additionality test, though no one owns them and they certainly would not be claimable as offsets. And while the social marketing message for grasscycling may not entirely focus on reductions in GHG emissions, it adds to the cultivation of a synergistic environmental ethic that perhaps will also see additional climate change benefits in improving home energy efficiency or greater public transit ridership.

In a larger context, Fig. 9 can also be viewed as an indicator of the relative emissions that could arise from various management options that can be taken with a given waste material. For this particular example, the higher in the waste management hierarchy the option is, the higher the potential reduction in avoided emissions. Using the specific numbers shown, if the rightmost bar is taken as the methane

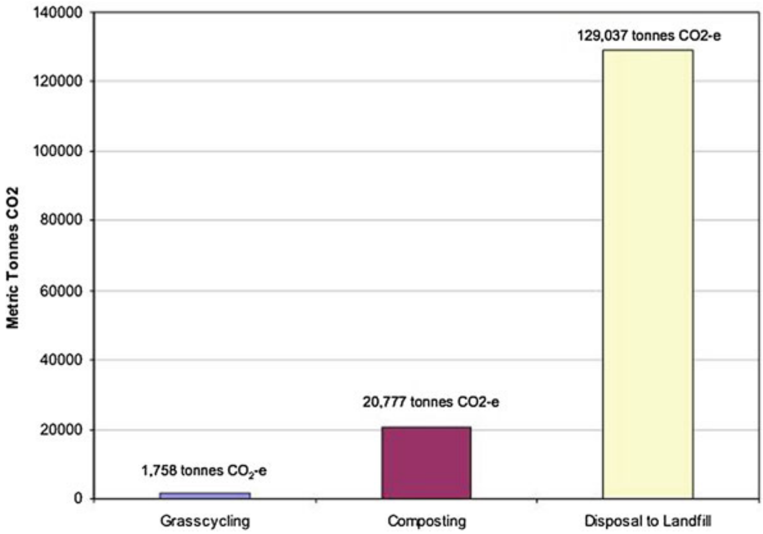

Fig. 9 Relative GHG Emissions for residential grass management in edmonton

emissions (129,037 tonnes CO_2-e) that would result from landfilling 63,720 tonnes of waste grass clippings, then a *waste recovery* activity with a LFG capture system that is about 75 % efficient[14] would reduce those emissions by 96,777 tones CO_2-e. Similarly, composting those materials, as an even more preferable *waste recycling* activity, would reduce the emissions by a higher 108,260 tonnes CO_2-e, and finally, grasscycling, as a top of hierarchy *waste reduction* activity, would yield the largest emission reductions at 127,279 tonnes CO_2-e.

4.5 Future City of Edmonton Waste Management Endeavours

In 2006–2007, Edmonton took the opportunity to conduct a mid term review of its 30 year Waste Management Strategic Plan. Operation of the composting and recycling facilities was allowing the City to divert some 60 % of its residential waste stream from land disposal. Technical progress in a number of waste processing areas had been made however, and a technology review indicated that the window of opportunity was now there for developing infrastructure and facilities

[14] Setting aside some of the project specific carbon accounting nuances arising from the various energy inputs involved in what is actually done with the captured LFG.

to deal with additional components of the waste stream that are non-compostable or recyclable.

Accordingly, the City, with a number of private sector partners, is currently involved in developing and integrating a number of other waste diversion projects at the Edmonton Waste Management Centre as follows:

- A gasification and biofuels facility that will take processed components of the waste stream formerly landfilled and generate a synthesis gas, or syngas, at low temperature and pressures. The syngas (primarily CO and H) then becomes feedstock for the further manufacturing of methanol and ethanol, with the additional recovery of a high CO_2 content gas that can be liquefied and sold for industrial uses. To support this process, the City has developed a pre-processing (sorting) plant to separate out the dryer recalcitrant organics (plastics, rubber, some paper and wood) from the mixed residential waste stream as well as a plant to transform that material, along with contaminated wood and residuals from the composting and MRF operations, into a refuse derived fuel (RDF) for gasification. The private sector partner, in the interim, is proceeding with the design and construction of their gasification and biofuels facility. Scheduled commissioning of the entire process is slated for 2013.
- A facility for the manufacturing of paper from waste office grade paper and textiles, and glass blocks from glass intended for recycling. The City's support for the endeavor is the collection and delivery of the paper feedstocks from City offices, textiles from drop off recycling depots and glass from the MRF operation. Any subsequent return of paper product from the private sector partner's facility to the City then transforms the activity into a local example of closed-loop- recycling. As with the gasification/biofuels facility, commissioning of the paper plant is scheduled for 2013.
- A sorting facility for mixed loads of C&D waste to salvage reusable materials such as wood, cardboard, clean drywall (gypsum board),metals, concrete and asphalt shingles from various private and public construction and renovation projects. Some of these materials will be processed on-site for use in the composting or gasification operations (wood and drywall), or ongoing site development (crushed concrete) or fed into other existing local recycling operations (asphalt shingles). Commissioning of the mixed C&D sorting facility will be completed in 2012.

As the above projects reach fruition and full operation, the overall waste hierarchy target for Edmonton's waste system will see landfill diversion of some 90 % of the residential waste stream over which the City has direct flow control. As per the discussion in Sect. 4, methodologies can also be developed and applied to quantify the resultant reductions in GHG emissions from implementing these projects. For additional diversion of the ICI components of the total waste stream, it is envisioned that additional system planning and development efforts will be required in terms of commercial waste collection or adding on and integrating complementary technologies (such as anaerobic digestion) to increase total processing capacity.

5 Summary and Conclusions

This discussion has placed the various components of Edmonton's waste management system within the context of the City's environmental strategic plan and its follow on implementation document for managing GHG emissions. The concept of a waste management hierarchy which integrates social and environmental considerations into a framework that can be used for decision making alongside financial affordability has also been presented. The evolution of Edmonton's existing waste system has been described and then various chains of logic and detailed methodologies have been presented for quantifying the reductions in greenhouse gas emissions associated with a number of waste activities that the City either practices or advocates. For recovery practices such as capturing landfill gas and for a specific recycling activity such as composting, the methodologies discussed are generally well established and accepted. This is not the case for the handling of residential recyclables, where the length of the handling chain and the variety of options for the processing of culled materials makes the exercise of reliably quantifying emission reductions much more difficult. Finally, an example has also been provided for determining the avoided emissions resulting from grasscycling as a waste reduction activity. This last example has also been used to illustrate the notion that the higher in the waste management hierarchy a management option is for a given waste material, the greater the potential reduction in GHG emissions.

For analyses of this type, the question always arises as to how far into the weeds should one delve in terms of the life cycle analysis of an activity? Certainly more detailed considerations can be carried out to look at emissions associated costs and benefits on both the upstream and downstream side to include issues of fabrication, demolition, product usage and so on. In an offset protocol, many of these sources and sinks would likely be deemed to be negligible, immaterial, self-cancelling, or having too many unknowns to be able to properly quantify. The intent herein has been the presentation of approaches that are logical and strike a reasonable balance between completeness and availability of information. Numbers used in calculations (emission factors, global warming potential values) will come and go, and will continue to be updated as our understanding grows of the manmade contributions to climate change. What matters more in the end is the chain of reasoning used to be able to quantify those contributions and determine how they can be mitigated.

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Multiplier Effect: High Performance Construction Assemblies and Urban Density in US Housing

Eero Puurunen and Alan Organschi

Abstract The suburban house—an emblem of the 20th century American Dream—has come to symbolize unsustainable excess in the new millennium. For the homeowner, the single family home is increasingly burdensome to finance and maintain; for planners and policy makers, suburban sprawl has undermined efforts to limit land consumption and mitigate anthropogenic greenhouse gas (GHG) emissions. While the link between sprawl and transportation emissions is well-established, the atmospheric impacts in the construction and operation of single-family houses are acknowledged but not as well understood. Using a readily available lifecycle assessment tool and building modeling software, this study compares the carbon emissions of low- and high-density housing morphologies and weighs the lifecycle *embodied energy costs* against the *operational energy benefits* of increasing thermal performance in the building envelopes of each housing type. The assessment shows that in spite of increasing energy demands embedded in the materially and technically intensive construction of high performance assemblies, the adoption of these techniques in both the house and multi-unit apartment dramatically reduces lifetime GHG emissions. However, the initial toll of building high performance houses—measured in emissions and extrapolated as construction costs—is burdensome to the environment and homeowner alike. As an alternative, high performance apartments can be built at a carbon and dollar cost only marginally higher than that of conventionally-constructed multi-unit dwellings, with a per-unit lifetime GHG footprint that is one quarter of that of a standard house. The economic and land-use efficiencies of enhanced construction assemblies deployed in dense urban residential development create a multiplier effect in potential GHG reduction; a critical factor for contemporary environmental planning and policy.

Keywords Housing · Urban density · Passive house · Building assemblies · Life-cycle assessment

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1 Introduction

The built environment—individual buildings and, by extension, large scale aggregations of buildings and their infrastructural systems—may be understood as a man-made thermodynamic system through which energy is directed to provide shelter and sustain human settlement. A building harnesses that energy through the organization of physical material in two primary stages of its lifecycle: (1) As embodied energy expended in the extraction, processing and transport of materials; the manufacture of building assemblies; in the construction and maintenance of the building and its necessary infrastructure; and, at the end of its lifecycle in demolition and disposal or recycling of material. (2) In the direct energy consumed in a building's operation as it works to manage environmental heat loss or gain (insulation, heating and cooling), maintain tolerable and healthy interior air quality (ventilation), and to provide safe and convenient interior conditions (artificial illumination and electrification). From a thermodynamic standpoint, the efficiency of this constructed environment might be understood as the relationship between the initial energy the system harvests from the environment and the useful work this energy is able to accomplish.

In creating some of the most sublime artifacts of our technological culture, the processes of building and urbanization have also produced physical by-products and engendered human behavior that has contributed significantly—both directly or indirectly—to the degradation of land, wetlands and oceans, and the atmosphere through the increase in impermeable surface and the resulting heat absorption and disruption of the hydrologic cycle, habitat destruction and loss of biodiversity, solid waste production, the dissemination of toxins and pollutants and, our primary concern here, climate change driven by anthropogenic greenhouse gas (GHG) emissions. The built environment is a significant contributor to these emissions. The global building sector is estimated to be responsible for approximately one-third of global energy related GHG emissions (Levine et al. 2007). The Intergovernmental Panel on Climate Change also estimates that the building sector has the highest potential of all sectors to reduce GHG emissions cost-effectively, with lifetime cost savings (Levine et al. 2007).

Housing construction practice in the U.S. since World War II has been defined principally by the development of the suburban single-family house (Sarkar 2011). This approach to housing production, made possible by significant timber stocks, relatively cheap and efficient construction techniques, and wide availability of inexpensive land has also been supported by indirect subsidies provided by a Federal arterial highway system and artificially suppressed U.S. fuel costs (Graetz 2011). The development pattern based on the detached house has hardened into conventions ingrained in current regulatory structures, land-use policies, and demographic patterns. By defining the spatial structure of American housing, these conventions have inflected U.S. transportation policy, and transformed the American landscape.

In the foreseeable future, however, certain pressures might suggest a reconfiguration of planning policy and land use. As heightened ecological concerns constrain greenfield and open-space development, rising energy costs burden the operation of the single family home and the use of the automobile. Additionally, stricter performance requirements in US building codes will call for more materially and technologically intensive construction techniques. In the near future, the freestanding home, the icon of American domestic privilege, will become increasingly costly to build and maintain and may prove to be—for much of the US residential market—an unbearable means of housing.

Although U.S. building codes currently lag far behind their European counterparts in their energy performance standards, it is likely that American energy regulations, based on recent historical trends in the residential construction sector, will become stricter (see: http://www.energycodes.gov/adoption/states). Within a 50-year time-frame, as regulatory requirements evolve to demand greater energy efficiency in building assemblies and mechanical systems, nearing current Passive House standards (see Sect. 3.2 for definition), the role of embodied energy consumption will increase as both a critical percentage of the life-cycle GHG impact of the housing stock and as an implication for "first costs" in housing production. Although per-square-foot energy consumption in newly constructed homes will decrease as a result of the increased efficiency of the building envelope, the initial costs of building, as both a percentage of a building's life-cycle costs and as absolute per-square-foot construction costs, will rise.

This chapter compares the environmental impacts—in the form of direct and embodied emissions and associated land-use impacts—of two opposing US housing types: the low-rise, low-density suburban single family house and mid-rise urban multi-family housing. By isolating and modeling construction assemblies of both conventional and high performance building envelopes for each housing type, our study seeks to illuminate the relationship between new, more materially intensive construction systems and the associated potential lifetime environmental benefits of density. Figure 1 presents a proposed model for residential neighborhood.

2 Overview of Related Research

It is well known that the residential sector plays a large role in energy use and emissions of greenhouse gas (GHG). In the United States, 23 % of primary energy[1] use is directly related to heating (including cooking and hot water) and to electricity use in dwellings (EIA 2011). In terms of GHG emissions, this direct residential energy use accounts for 17 % of total U.S. GHG output (EPA 2012). In addition to the direct emissions required for heating and electricity, the

[1] Energy contained by unprocessed "raw" fuels, such as coal, oil, or natural gas.

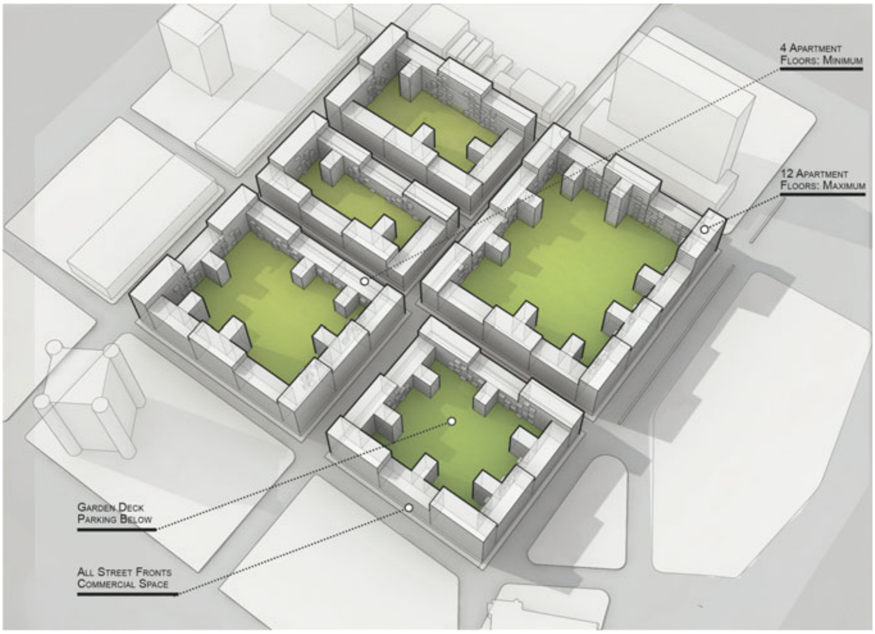

Fig. 1 Future of American housing? Proposed model for residential neighborhood

construction and maintenance of dwellings requires a large carbon expenditure. For demand-side GHG control, emissions associated with buildings are thus one of the most important targets alongside transportation emissions.

2.1 Factors Driving Residential GHG Emissions

Methodologies for studying the GHG impacts of buildings, and the factors driving these impacts, can be divided into two categories. The first consists of statistical methods, which look at data from large national surveys or local household surveys. The second consists of more detailed life-cycle assessments (LCAs) of individual buildings.

Statistical studies encapsulate characteristics of a large number of buildings or households and, in so doing, isolate driving factors behind residential GHG emissions. A statistical study can, for example, control for income while looking at the impact of housing type. A number of recent statistical studies have studied the driving forces behind residential GHG emissions. Some of the causal relations are more obvious. Increased dwelling floor area, which needs to be heated and cooled, leads to higher household emissions (Andrews 2008; Holden and Norland 2005). Living in extreme climates (cold or hot, rather than moderate) has a similar effect (Ewing and Rong 2008). Higher household income and lower energy prices are also associated with increased direct residential consumption (Ewing and Rong 2008). Statistical studies from cold climates (comparable to the Connecticut case study presented later in this chapter) indicate that well-insulated homes perform better than poorly insulated ones and that multi-family dwellings are more energy and carbon efficient than their single-family counterparts (Andrews 2008; Ewing and Rong 2008; Holden and Norland 2005; Randolph 2008). Statistical studies, however, typically ignore the embodied portion of emissions, hence leaving the lifetime analysis incomplete.

A life-cycle assessment (LCA) which analyzes every stage of the lifetime of a building can quantify both embodied and operational emissions. On the downside, LCAs are labor intensive and LCA studies generally assess only a handful of buildings at most. Due to the inherent specificity of LCA results, some caution is necessary when extrapolating larger scale impacts. With this in mind, the following are some LCA results particularly relevant to this chapter. A rare example of a LCA study that directly compares a single family house to a multi-family building (Norman et al. 2006) indicates that on a per-capita basis single-family houses are 2.5 times more GHG intensive than apartments over their lifetime. When measured on a per square meter basis, this factor shrinks to 1.5. This study includes emissions embodied in infrastructure along with the buildings. When comparing conventional buildings to buildings of high-energy performance, the overwhelming result is that high-performance buildings have lower emissions over their lifetime (Gustavsson et al. 2010; Ramesh et al. 2010; Sartori and Hestnes 2007). Many studies compare buildings in terms of energy use, rather than GHG emissions because the choice of energy source (coal, oil, biomass etc.) has such a large impact on operational GHG emissions. According to Gustavsson et al. (2010), the embodied energy share of the total lifecycle energy demand is 6–13 % for a conventional residential building and 25–30 % for a high-performance building. This indicates that with increasing energy efficiency, the relative importance of embodied energy grows. Sartori and Hestnes (2007) put the respective shares at 3–30 % (conventional) and 14–100 % (high performance).[2] One of the interesting findings of this study is that a zero energy building, which satisfies all of its annual operational energy needs on site (such a building has an embodied energy share of 100 %), is not as energy efficient over its lifetime as alternates that rely solely on better insulation and other passive measures. In other words: increasing energy-efficiency during construction is GHG-efficient only up to a tipping point beyond which the initial embodied GHG burden cannot be off-set by decreased operational emissions over the building lifetime.

[2] This meta-analysis of existing studies includes some office buildings alongside with residential buildings.

3 Case Study: Impact of Dwelling Type and Envelope Energy Performance on Lifetime Greenhouse Gas Emissions

As the preceding section indicates, the current norm of American housing, the single-family house, is a rather inefficient dwelling unit in terms of its lifetime energy use and its GHG impact. The study presented here looks at alternatives to the typical American house and aims at describing the GHG reduction potential of these alternatives.

3.1 Assessed Dwelling Units

To investigate the influence of dwelling type and envelope performance on lifetime GHG emissions, this study creates a four-way comparison that includes two houses and two apartments. For each dwelling type (house and apartment) a version built according to current construction standards and a version built according to a high performance standard is considered. Figure 2 shows exterior wall assemblies for each of these dwelling types. A more detailed description of the building assemblies can be found in the appendix.

The case study dwellings are located in the southern part of the state of Connecticut in the northeastern United States. This factor has importance only as it relates to climatic conditions and some of the specific characteristics of the

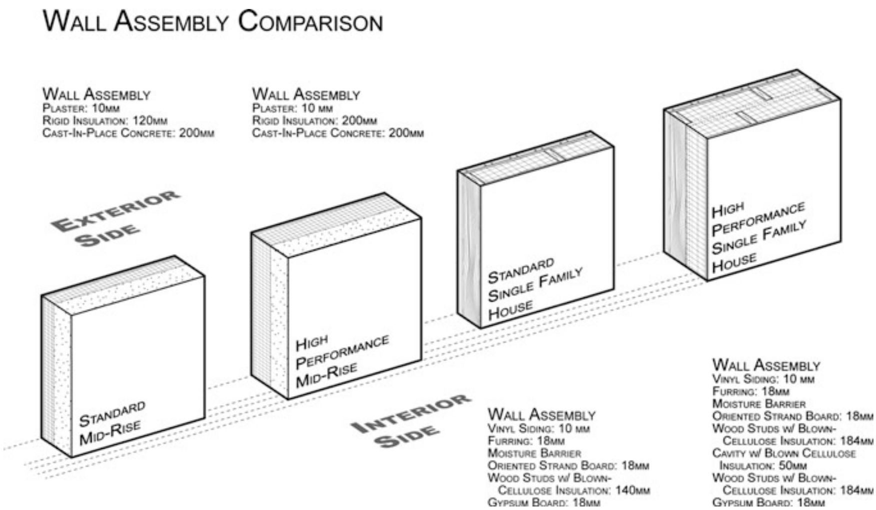

Fig. 2 Exterior wall assemblies for the four case study dwelling types

construction industry in the region (the latter factor influences emissions embodied in the construction process).

The case study house, a gable-roofed, two-story house shown in Fig. 3 is a simplified approximation of a typical suburban house in Connecticut. This house has 198 m^2 of living space (not including basement or attic)—a number adopted from the median size for a single-family house in Connecticut.

The characteristics of the case study apartment unit represent an average taken from apartments shown in Fig. 3. The apartment building type chosen is not typical for the U.S., but a model of urban living more common in Europe. Current U.S. regulations and practices have led to the dominance of "double-loaded corridor" type in the mid-rise (4–12 stories) housing market. In this building type apartments are lined on two sides of a long, central corridor. Elevators and fire stairs are located at certain intervals along this corridor. Only the end apartments can reach through the building (a requirement for effective cross-ventilation) in a double-loaded corridor building. In the apartment building type presented here, most units reach through the building and all of the units have a somewhat direct connection with the exterior through an elevator and stair core serving groups of three or four units per floor. The average size of an apartment unit in this layout is 150 m^2. While smaller than the case-study house, these three or four bedroom

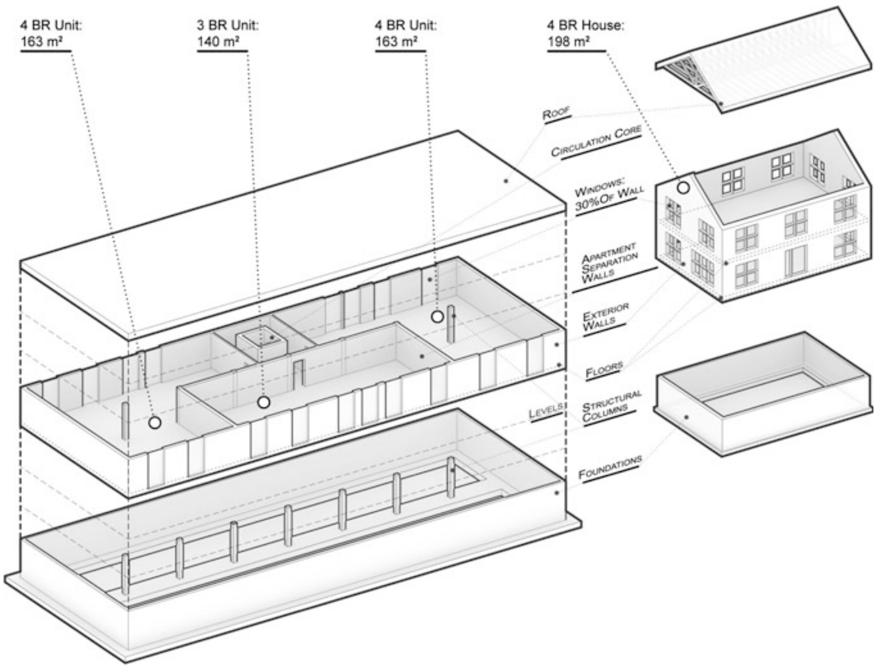

Fig. 3 Building elements included in the embodied GHG assessment. Calculations for the apartment where based on the complete neighborhood shown in Fig. 1

apartments are considerably larger than the U.S. average for apartments (EIA 2005), making the comparison against the case study house more even based.

3.2 LCA Methodology

The lifetime GHG impact of each dwelling type was estimated for a 50-year lifetime. The assessment was limited to emissions associated with building construction and operation: site, infrastructure, or transportation emissions were not considered.

Embodied GHG emissions were assessed with the Athena Impact Estimator. This free life-cycle assessment tool, which is developed by the Canadian Athena Sustainable Materials Institute, estimates environmental impacts of typical construction materials and assemblies in North America. The assessment includes life-cycle stages of material extraction and manufacturing, transportation and on-site construction, as well as maintenance and replacement. At the end of life, Athena Impact Estimator takes account of demolition and removal and disposal for those structural materials that are currently land filled.

Estimates for operational energy (heating and electricity) use were based on a statistical analysis of data from recent U.S. residential buildings (for standard house and apartment) and requirements set by the Passive House standard (for high performance house and apartment). This voluntary standard which originates in Germany aims at creating buildings that minimize heating energy use, relying primarily on the heating effect of human bodies and electrical appliances. The standard sets limits also for electrical consumption. Details on this standard can be found on websites of Passive House organizations (www.passiv.de and www.passivehouse.us).

The LCA methodology for estimating both embodied and operational emissions is explained in greater detail in the Appendix.

3.2.1 Building Elements Included in the Assessment

Figure 3 indicates building elements that were included in the embodied GHG assessment. Structural and envelope systems for the two dwelling types are approximations of techniques typical for each building type in the American North–East. The house is built with a technique that dominates the U.S. housing market, a light wood framing and sheathing system composed of slender timber "studs" and engineered wood sheathing. The apartment building has a cast-in-place concrete frame. The amount of thermal insulation assumed for the standard dwellings was derived from examples of buildings built according to recent code requirements. The amount of insulation for the high performance dwellings was derived from Passive House certified buildings. Due to a lack of American examples of appropriate multi-family buildings, our study made use of examples of Passive House apartment building construction in Germany.[3] Impacts of elements that were omitted in the assessment are discussed in the appendix.

3.3 A Bi-product: Land Use Comparison

To illustrate the land use impact of single-family housing, we created the comparison shown in Fig. 4. A small section in the town of Hamden was chosen to represent a typical Connecticut suburban neighborhood of single-family houses. Both house and property sizes in this neighborhood are very close to Connecticut median sizes (192 and 1,442 m^2 respectively). The counterpart to this sprawling neighborhood is a fictional mid-rise neighborhood developed in the blocks of the historic 9th Square neighborhood in New Haven, Connecticut—a small city of approximately 140,000 inhabitants, 70 miles northeast of Manhattan. Figure 1 shows this proposed development in its downtown New Haven context. It must be mentioned, for clarity's sake, that we are not advocating the total erasure of current urban fabric in the historic 9th Square neighborhood. Rather, we aim to merely illustrate a residential density appropriate for a small American city. Storefront spaces indicated in Fig. 1 were not included in the land use comparison.

4 Results

As Fig. 5 indicates, a standard house is by far the highest polluting option in the four-way comparison. Its emissions over a 50 year lifetime are 1.6 times larger than those of a standard apartment, 2.6 times larger than those of a high performance house, and 3.9 times larger than the emissions of a high performance apartment. In terms of embodied emissions, the jump from the standard house to the high performance house is dramatic. Over the lifetime, a high performance house embodies 1.5 times the emissions of a standard house. The standard apartment, on the other hand, has 18 % lower embodied emissions than the standard house. The difference in embodied emissions between the two apartment types is negligible. This is due to the fact that a large majority of the embodied emissions of the apartment stem from the concrete frame of the building. Hence some added insulation does not have a large impact on the total embodied emissions.

As shown in Fig. 6, the ranking of dwelling types in terms of their overall GHG footprint does not change if the comparison is done on a per square meter basis.

[3] According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard, Germany and Connecticut belong to the same climate zone.

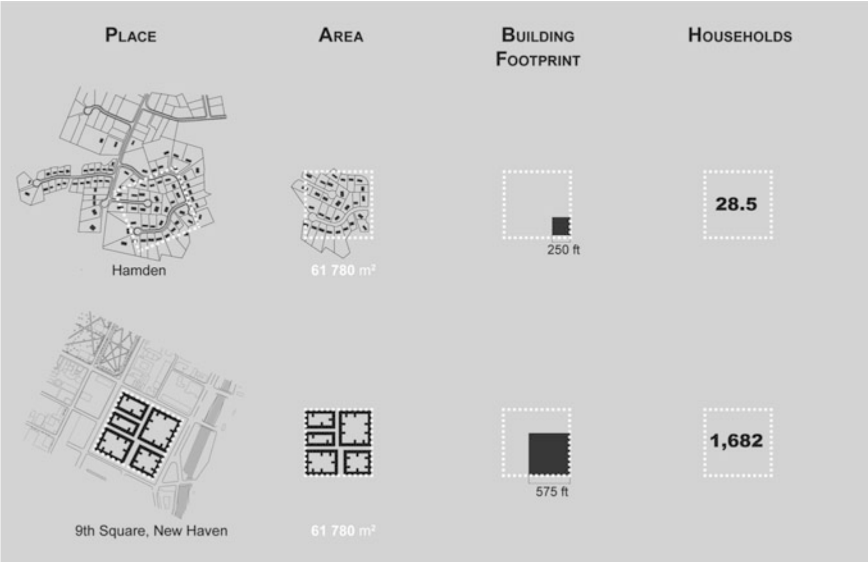

Fig. 4 Comparison of typical sprawling Connecticut neighborhood and a high-density mid-rise neighborhood

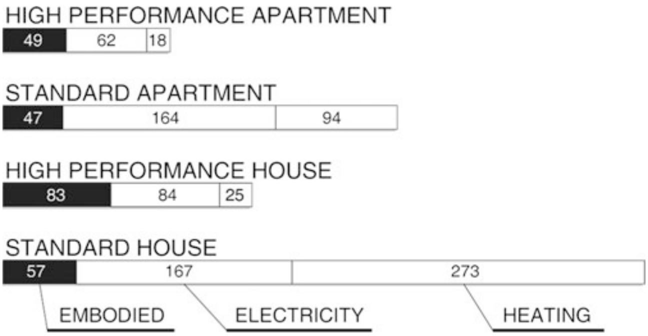

Fig. 5 Total emissions per household in CO_2 equivalent metric tons

GHG emissions for the apartments would hence be lower than their counterpart houses even if all the dwellings had the same floor area. Because operational energy for the high performance dwellings was adopted directly from the Passive House standard, there is no difference in heating and electricity emissions between the high performance dwellings.

Fig. 6 Total emissions per square meter in CO_2 equivalent metric tons

4.1 Land Use Comparison

If one takes the physical footprint of the 9th square and lays it over the Hamden neighborhood, one can conclude that 28.5 households fit within this area (as indicated in Fig. 4). As designed, the 9th Square mid-rise neighborhood houses 1,682 families. If you take the household density of the Hamden example and calculate how much land area is needed to house 1,682 families at this density, you arrive at the comparison shown in Fig. 7. The land area necessary to house 1,682 families within a sprawling district is 59 times the size of the 9th Square.

5 Discussion

The results of our assessment of lifecycle GHG emissions in both the suburban single family house and its higher density urban counterpart corroborate similar findings that show a dramatic lifetime benefit in switching from standard building envelopes to those with high thermal performance (see Sect. 2.1). It would be easy to conclude on the basis of our findings that the current strategy of choice for designers, engineers, and builders who are concerned with the impacts of buildings on climate change—to ratchet up the performance of the materials and assemblies they employ—is a common sense approach to carbon reduction in the built environment. However, the highest performing enclosure systems, as deployed in Passive House design, which for the purposes of this analysis was used as a reasonable approximation of building regulatory requirements for thermal performance in an energy-scarce building environment of the future, come with notable embodied energy costs and GHG emissions.

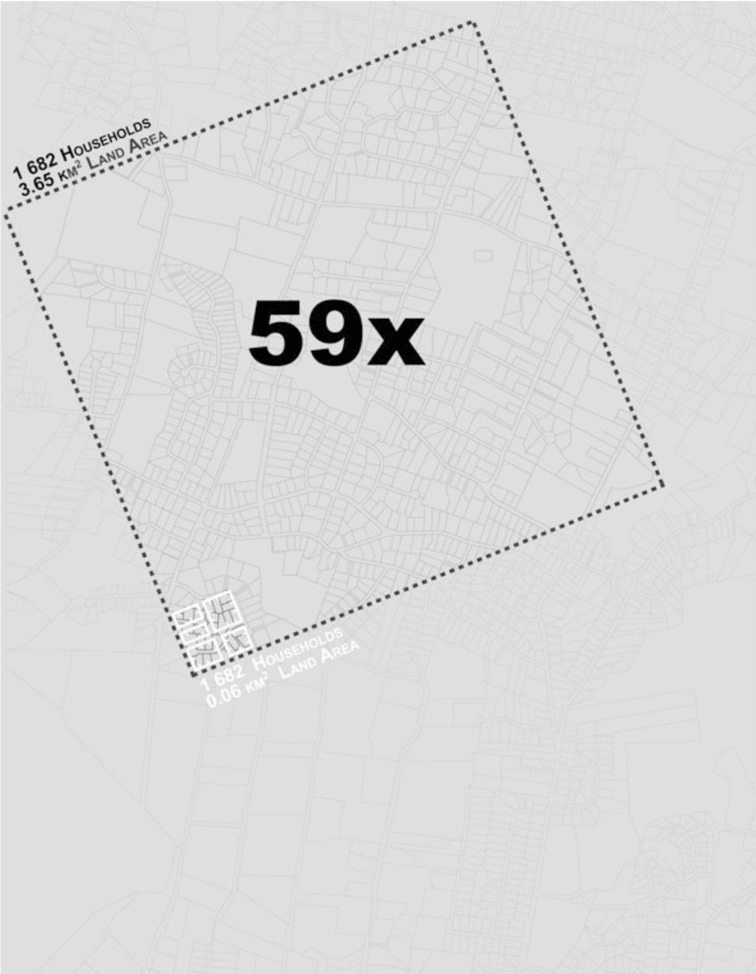

Fig. 7 Land area required to house 1,682 families in the case study sprawling neighborhood is 59 times the size of proposed high-density neighborhood

5.1 Costs of High Performance in the Single Family House

As we turn to the increased performance of materially and technically intensive building systems as a solution to residential emissions, we shift the balance between embodied and operational emissions within the lifecycle GHG equation. Put plainly, the use of more material, and the associated emissions of its extraction, transport, processing, assembly, maintenance, and ultimately, disposal or reuse, will demand a greater share of all of the emissions associated with dwelling. Although our study substantiates the assumption that a single-family-house, constructed with the material intensive assemblies of the Passive House system, still outperforms the conventionally built house in overall energy consumption and GHG emissions, the increase in performance exacts a significant upfront penalty for the homeowner and darkens the broader global carbon outlook. At the level of the housing unit, with embodied emissions serving as a fair proxy for construction costs, the financial burden of building a high performance, energy and carbon efficient single-family house may be unbearable for average American incomes. At the global scale, at a time when the immediate mitigation of atmospheric carbon is an increasingly critical priority, concentrating emissions at the beginning of the building lifecycle during construction—in essence what the high performance house does—is counterproductive to efforts to limit anthropogenic global warming.

The problem of frontloading carbon emissions in the lifecycle of the single-family house is compounded by other significant factors when we consider the ongoing proliferation of the individual house across the American landscape. By looking beyond the boundaries of the energy system analyzed in this chapter—the building envelope and lifecycle building emissions—we find that any potential long-term benefits of increasing performance in the freestanding house are quickly offset by other important carbon impacts that attend sprawl: the continued degradation of greenfield land and the loss of carbon stocks in plants and soils; reduced efficiencies in electrical power due to transmission losses (Andrews 2008) and in heating fuel due to the expenditure of energy in its transport within an attenuated distribution network; the embodied emissions of roadway, bridge, and tunnel construction and repair and the operational emissions of unabated daily vehicular travel. The current low residential density of typical U.S. cities creates local transportation systems that are almost solely based on the private car and makes the daily commute of a typical American the longest in the world (Kenworthy 2008). These impacts, best assessed quantitatively in other past (and hopefully future) studies, begin to suggest that the benefits of increased performance in the construction of the individual house may be outweighed by the societal and environmental impacts, as well as the costs to homeowners, of sustained suburbanization.

5.2 Building Performance Benefits in High-Density Housing

Our study shows that, in terms of operational GHG emissions per housing unit, an apartment building clearly outperforms a house. That operational GHG emission reductions are achieved through the aggregation of housing units under one roof in a cold climate can be readily predicted with basic volume to surface area calculations: with its reduced surface of exterior envelope required to enclose it, an apartment tends to be more thermally efficient than a house. A more noteworthy finding is the relatively low GHG cost of upgrading an apartment building from standard envelope assemblies to high performance assemblies. Our study indicates that while the cost of these upgrades is negligible over the lifetime of an apartment building, it is very significant for a house—nearly doubling embodied emissions. Our lifecycle assessment of high performing building enclosures deployed in a dense urban development demonstrates a multiplier effect, in which the performance benefits are amplified by the inherent thermal efficiency of multi-unit housing. Just as increased energy efficiency is most effective at higher residential densities, embodied emissions reductions are compounded when less surface area of high performance building envelope is used to house more people.

As we look for paths toward significant GHG reductions in the residential sector, high performance apartment buildings are an appealing option. They can deliver low household GHG emissions at a low initial cost, making the shift to high performance construction techniques more financially tolerable and, as a result, more likely.

5.3 Other GHG Emissions Benefits in High-Density Housing

Other benefits of residential density and urbanized housing lie outside the scope of this study but parallel the advantages found in the material and performance efficiencies of the shared building envelope. Several studies identify economies of scale found in more concentrated human settlement and confirm the reduction of emissions derived from them. Urban density allows for the development of more contained, efficient, and sustainable infrastructure. The employment of efficient energy supply and transportation systems, such as district heating and cooling and rail-based public transportation only becomes affordable once critical density thresholds have been surpassed (see e.g. Cervero 2004).

One perceived disadvantage of concentrating buildings and roadways as urban developments—the Urban Heat Island (UHI) Effect—may actually provide passive benefit during the heating season in cold climates. The UHI effect raises ambient temperatures around buildings, shrinking the thermal gradient between unheated exterior surfaces and heated interiors (Ewing and Rong 2008). These potential benefits of condensing housing are all based on the same principles of optimizing the built environment as a system that considers the overall balance of embodied and operational emissions; material investment and operational return.

5.4 Questioning Density

Concerns about the GHG reduction strategy of increasing urban density range from the quantitative to the qualitative and seek to assess negative effects or offsets as density reaches thresholds of tolerability—the attendant impacts on health, sanitation, air quality, and the atmospheric and hydrologic effects of large continuous surface areas of heat-absorbing, impervious material.

Some studies have questioned the effectiveness of carbon reduction strategies in the face of human behavior. A Norwegian study by Holden and Norland (2005) shows that if long-distance leisure travel by car and plane is added to everyday travel, inner city households have just as high carbon footprints as suburban residents. In effect, lower local travel needs are off-set by much higher long distance travel needs. Heinonen et al. (2011) discuss a related finding in a Finnish study: inner city residents have the highest carbon footprints, when consumption of all consumer goods is taken into account. Rather than calling into question the GHG benefits of urban density, these studies appear to confirm the consistent finding that increasing wealth tends to increase individuals' carbon footprints (as discussed also in Lenzen et al. 2008).

It is difficult to account for the variations in occupant behavior in the lifetime operational emissions of a house. Obviously, our quantitative assessments and the policies and plans that rely on them must assume some amount of human transgression of our models, measurements, and predictions. The agency of designers and policy makers lies to some degree in their ability to modify lifestyle through design and to a much greater degree in their implementation of energy efficient assemblies and mechanical systems (Salat 2009). Occupant behavior within or outside the home may ultimately determine individual carbon footprints. As one American energy consultant Andy Shapiro quipped, "There are no zero-energy houses…only zero energy families." (Solomon and Malin 2011).

5.5 Impact of Carbon Sequestered in Buildings

Another important point relates to the carbon sequestration potential of buildings. Our life-cycle assessment did not include the immediate benefit of the carbon storage capacity of the wood products used in the typical construction of the suburban house. Had it been accounted for, the suburban house would have fared somewhat better in the assessment, taking advantage of the carbon offset. The exact duration and magnitude of this sequestration effect depends on assumptions made about the building lifespan and end-of-life disposal or reuse of materials. Even in the worst case scenario, where the sequestered carbon is released by burning the wood after a short lifetime, a timber framed building is typically more carbon efficient than a concrete or steel framed building (O'Connor and Dangerfield 2004; Petersen and Solberg 2002; Upton et al. 2008). That the built environment might become, in its material and structure, a carbon sink drawn from a renewable source (timber) is a significant observation that bears more research, experimentation, and assessment (Oliver and Mesznik 2006). At the moment, the use of light wood framing in the U.S. is limited by regulatory codes to four stories. Mid-rise buildings like those modeled for the urban housing blocks in our assessment, are typically structured in steel or concrete. New heavy timber construction systems like laminated wood veneer and cross-laminated timber (CLT) panels, currently in use in Europe and Canada, have the capacity to bear the significantly higher structural loads of mid-rise buildings, resist failure in fire, and, most relevant here, sequester carbon throughout the lifespan of the building. Had our studies analyzed mid-rise wall assemblies using CLT, the emissions advantage would have tipped even further toward the mid-rise high density-housing alternative. The introduction of CLT construction techniques to the American mid-rise construction industry promises notable benefit in the mitigation of atmospheric carbon. Further engineering and regulatory analysis and life cycle assessment of GHG emissions in mid-rise timber wall assemblies should be undertaken.

5.6 Cultural Arguments Against Urban Housing

Finally, it is beyond the capacity of this chapter to address the philosophical and cultural arguments that have been made against the urbanization of housing in the United States. These reactions are bound inextricably to the history of a nation with abundant land resources and reinforced by long accepted American planning practices and commercial real estate interests. We acknowledge that for many Americans accustomed to the wide availability of relatively inexpensive land and acculturated to the notion that a sense of domestic well-being and safety can only be guaranteed by a buffer of private exterior territory, city life may seem distasteful. This has, of course, important implications for American policy makers considering the viability of new planning strategies and development mechanisms. But problems of political and economic feasibility must be weighed against the mounting empirical and quantitative evidence that the sprawl of human settlement causes both global and regional environmental impacts such as soil and fresh water acidification and ozone depletion. According to a recent multi-national study the threat on the global ecosystem caused by biodiversity loss associated with ever expanding human settlements is on par with the threat of global warming (Hooper et al. 2012). One of most startling results of our study was a by-product of our methodology, the comparative mapping of the land areas required to house families in the suburb and the mid-rise city (Fig. 7). Architects, builders, planners and policy makers might consider the land resources exploited in the platting of cities and suburbs as part of the overall embodied emissions equation of the built environment. Our stark graphic analysis simply depicts, in quantitative terms, the voracious consumption of greenfield land areas under the current suburban planning and development regime, the equivalent, in terms of ecological resources—habitat, soil quality, and biomass—of fouling potable water in a drought.

6 Conclusion

With the puncture in 2008 of the huge “housing bubble” in the U.S. economy and a growing realization that the freestanding house is, for most parts of the country, no longer a secure personal investment and commercial finance instrument; with the spreading structural fragility of an extensive infrastructure that now barely—and at great cost—supports existing sprawl; and with the slow thawing of American's historically chilly relationship with cities, a critical opportunity for planners and policymakers, as well as individual homeowners, has arisen in the United States. Once a major exporter and consumer of the building morphologies, development practices and investment models of invasive sprawl, Americans must now reassess the once shrinking city as a source of higher living standards, a site for new lifestyles, and a means to mitigate anthropogenic climate change.

In 2013, as the U.S. economy begins its "post-bubble" recovery, described in the familiar parlance and economic metric of "increased housing starts", Americans face a critical choice and a formidable challenge: whether to treat their smaller, shrinking cities as just one more (albeit large) material possession to be ignored and discarded or, alternatively, to recognize their endowment of *embodied* potential. We can choose to understand our undervalued and underutilized urban centers as land area to build on intensively, avoiding further destruction of habitat, carbon bearing soils and plants, and complex natural hydrologic systems. We can exploit urban infrastructure as an existing system for the delivery of services: energy in the form of heat and electrification, potable water supply and waste removal and treatment, and transport. By focusing only on the increased enhancement of our own homes' thermal performance, we fail to understand the overall system of energy consumption and carbon emissions in the construction and operation of the buildings we occupy and the land we consume. We are missing a vital chance to rebalance our use of land and material in our quest for shelter and comfort.

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7 Appendix: Study Methodology in Detail

7.1 Embodied Emissions

Embodied GHG emissions were assessed with the Athena Impact Estimator (from here on: Athena). This life-cycle assessment (LCA) tool has a built-in life-cycle inventory (LCI) of different construction materials and assemblies that respond to regional differences in construction practices in North America. The LCI for New York City was used in this study because it is the closest geographic match. Athena GHG assessment does not account for carbon sequestered in any material. More detailed assumptions of Athena as well as LCI reports can be found at http://www.athenasmi.org/our-software-data/impact-estimator/.

The assessment was done for a 50-year lifespan and all dwelling units were assumed to be owner occupied (this decision has an impact on assumptions that Athena makes about building maintenance).

7.2 Building Assemblies

Table 1 shows building assemblies used in the LCA.

7.3 Omitted Building Elements

The most notable omission in the embodied GHG calculation is the impact of gravel fill at foundations. While an important factor when looking at an individual building, the effect is small when comparing two or more structures. An apartment building is likely to need more fill but its impacts are divided between a large number of apartments. Other omissions include the mechanical and plumbing systems, and elevators. Since a full basement was included for both dwelling types, it can however be assumed that there is ample space for mechanical rooms. The GHG impact of building systems can be presumed to be negligible. In a LCA of a concrete apartment building Pasanen et al. (2011) estimate that elevators and mechanical equipment represent 0.2 % of the total weight of the building. Partitions (except the ones dividing apartments) were also excluded since they would have close to a matching GHG impact in both the apartment building and the house.

7.4 Operational Emissions

Operational emissions for the standard house and the apartment were estimated on the basis of U.S. data found in the Residential Energy Consumption Survey (RECS) 2005 (EIA).[4] Average per square meter annual energy consumption was first derived for each dwelling type and this figure was then multiplied by the size of each dwelling. Basement or garage floor areas were not included for either dwelling but stair halls were included in the apartment building. Data included from RECS was narrowed to dwellings in cold climates (at least 6,000 heating degree days per year) and dwellings built since year 2000.[5] Calculated in this manner, annual per-square-foot heating energy consumption for the house and the

[4] RECS 2009 energy data was not available at the time of writing.

[5] RECS does not have enough data to warrant the use of New England data alone.

Table 1 Assemblies used in the LCA

	High-performance high-rise apartment			Standard performance high-rise apartment		High-performance single-family house			Standard performance single-family house	
		Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters		Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters
Exterior wall	(Exterior)	Plaster	10	Plaster	10	(Exterior)	Vinyl siding	10	Vinyl siding	10
		Rigid insulation	200	Rigid insulation	120		Furring	18	Furring	18
	(Interior)	Cast-in-place concrete	200	Cast-in-place concrete	200		Moisture resistant building wrap		Moisture resistant building wrap	
							OSB	18	OSB	18
							Wood studs w/blown cellulose insulation	184	Wood studs w/rock wool insulation	140
							Cavity w/blown cellulose insulation	50		
							Wood studs w/blown cellulose insulation	184		
Basement wall	(Interior)	Cast-in-place concrete	300	Cast-in-place concrete	300	(Interior)	Gypsum board	18	Gypsum board	18
		Rigid insulation	150	Rigid insulation	50		Rigid insulation	150	Rigid insulation	80
							Cast-in-place concrete	200	Cast-in-place concrete	200

(continued)

Table 1 (continued)

	High-performance high-rise apartment			Standard performance high-rise apartment		High-performance single-family house			Standard performance single-family house	
		Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters		Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters
Floors		Cast-in-place concrete	200	Cast-in-place concrete	200		Plywood	18	Plywood	18
							Wood I-joist	240	Wood I-joist	240
Basement slab-on-grade	(Top)	Cast-in-place concrete	100	Cast-in-place concrete	100	(Top)	Slab-on-grade	100	Slab-on-grade	100
		Rigid insulation	200	Rigid insulation	50		Rigid insulation	100	Rigid insulation	50
Foundation footings		Cast-in-place concrete	1,500 × 500	Cast-in-place concrete	1,500 × 500		Cast-in-place concrete	600 × 300	Cast-in-place concrete	600 × 300
Roof	(Top)	Ballast	20	Ballast	20	(Top)	Asphalt roofing		Asphalt roofing	
		EPDM membrane		EPDM membrane			Underlayment		Underlayment	
		Rigid insulation	300	Rigid insulation	220		Blown cellulose insulation	800	Blown cellulose insulation	300
		Cast-in-place concrete	200	Cast-in-place concrete	200	(Bottom)	Gypsum board	18	Gypsum board	18
Windows		30 % window to exterior wall ratio		30 % window to exterior wall ratio			30 % window to exterior wall ratio		30 % window to exterior wall ratio	
		Aluminum frame		Aluminum frame			Aluminum frame		Aluminum frame	
		Double glazing with low E silver argon fill		Standard double glazing			Double glazing with low E silver argon fill		Standard double glazing	

(continued)

Table 1 (continued)

	High-performance high-rise apartment		Standard performance high-rise apartment		High-performance single-family house		Standard performance single-family house	
	Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters	Material or product type	Thickness or dimensions in millimeters
Apartment partitions	Gypsum board	18	Gypsum board	18				
	Gypsum board	18	Gypsum board	18				
	Steel stud with rock wool insulation	92	Steel stud with rock wool insulation	92				
	Gap	20	Gap	20				
	Steel stud with rock wool insulation	92	Steel stud with rock wool insulation	92				
	Gypsum board	18	Gypsum board	18				
	Gypsum board	18	Gypsum board	18				
Elevator core	Cast-in-place concrete	200	Cast-in-place concrete	200				

apartment is 595 and 228 MJ respectively. Electricity consumption was estimated at 222 MJ for the house and 296 MJ for the apartment. With no specific data for common area energy use available for Connecticut, these same figures were used for the stair halls of the apartment building.

Energy consumption for the high-performance dwellings were taken directly from the stipulations of the Passive House standard. For both dwelling types, annual per square meter heating energy consumption was estimated at 54 MJ. Electricity consumption was estimated at 112 $MJ/m^2/a$ on the basis of the maximum total primary energy consumption (divided between heating and electricity) of 433 $MJ/m^2/a$ and estimated 30 % efficiency in electricity production.

Operational GHG emissions were estimated on the basis of the fuel mix for heating in the U.S. North–East and Connecticut electricity emission factors. Carbon equal global warming potential factors of 25 for methane and 298 for nitrous oxide were used. It was assumed that the carbon intensity of both heating fuels and electricity production would be decreasing over time: by 2.4 % annually for electricity and 0.8 % for heating over the full lifetime.

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Eero Puurunen has practiced as an architect and urban planner in the United States, China, and Finland. His work, ranging from single-family houses to district plans, focuses on sustainable development with a particular emphasis on environmental issues. In 2007 he won a Holcim award in sustainable construction for his urban design proposal for one of Shanghai's old neighborhoods. Mr. Puurunen has conducted research on sustainability assessment methods in urban planning and is participating in the development of an assessment tool for Finnish cities. He currently teaches environmental design at Yale School of Architecture. Mr. Puurunen carries master's degrees in architecture and urban planning (Aalto University) and environmental design (Yale University).

Alan Organschi is principal and partner at Gray Organschi Architecture, a design firm recognized for its innovative conception and implementation of projects that range from the adaptive re-use of damaged buildings and neighborhoods to the development and implementation of low-impact assembly systems for ecologically delicate sites. As a member of the Yale School of Architecture faculty, he coordinates Yale's first-year graduate housing studio which culminates each spring with the student construction of an affordable house in the city of New Haven. He is also a lecturer in building technology and an area coordinator at the graduate school. He has lectured publically on architecture, technology, and sustainable urban renewal. Mr. Organschi's current research includes prototype development for high-density, high performance wood housing in the U.S., conducted under the auspices of the Hines Research Fund for Advanced Sustainability in Architectural Design.

Climate Change Impacts on Housing Energy Consumption and its Adaptation Pathways

Zhengen Ren, Xiaoming Wang and Dong Chen

Abstract Australian household energy consumption contributes about 13 % to the total national greenhouse gas (GHG) emissions, and thus, to climate change. At the same time, climate change will in turn impact the total energy consumption and GHG emissions from the residential sector. This study investigated the potential impact of climate change on the total energy consumption and related GHG emissions of housing in Brisbane, Australia (a heating and cooling balanced climate region) and identified potential pathways for existing and new residential buildings to adapt to climate change by simulations in terms of the resilience to maintain the level same as or less than the current level of total energy consumption and GHG emissions.

Keywords Household energy consumption · Climate change · Adaptation pathways

1 Introduction

It is now widely acknowledged that global warming is very likely the result of increasing greenhouse gas concentration due to human activities such as the use of fossil fuel and deforestation. Climate change mitigation and adaptation are two general approaches in response to global warming. Climate mitigation is designed to reduce GHG emissions and in return to reduce the global warming impact. Climate adaptation is designed to adjust actions in the society to cope with climate changes that are already happening or are the likely consequences of current GHG emissions (The Royal Institute of British Architects 2011).

40 % of the world's energy is consumed by the building sector which resulted in one-third of the global greenhouse gas emissions (Nethad 2009). The Inter-

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governmental Panel on Climate Change (IPCC) identified that reducing energy consumption of the building sector and its associated greenhouse gas (GHG) emissions has one of the highest benefit-cost ratios among many possible mitigation measures across different sectors (Levine et al. 2007).

Australian household energy consumption contributes about 13 % to the total national greenhouse gas (GHG) emissions, which is not the largest contributor to GHG emissions in Australia, but it is one of the fastest growing sources (Australian Bureau of Agricultural and Resources Economics and Sciences 2011). The total heating and cooling energy consumption in cold regions may benefit from global warming, meanwhile it will increase in cooling dominated or space heating and cooling balanced regions (such as Brisbane and Sydney in Australia) due to significant increase in cooling energy consumption. Therefore, in these regions climate adaptation measures should be properly considered in both building design and operation stages to reduce energy consumption and carbon emission.

This study presents the likely extent of total household energy consumption and GHG emissions under climate change in Brisbane using the recent developed method by the authors (Ren et al. 2011a). The impact of global warming on total energy consumption and GHG emissions was discussed for both representative existing and new housing. It was demonstrated that in Brisbane the potential contemporary mitigation strategies for residential buildings (such as improving energy performance of a building envelop, using higher energy efficient equipment and appliances), if implemented immediately, become adaptation strategies as global warming reaches 4 °C for existing housing and 2 °C for new housing. Further adaptation strategies (such as the applications of renewable energy for hot water and daily electricity usage) are required as global warming becomes higher.

2 Impact of Climate Change on the Total Energy Consumption and Carbon Emissions

To analyse climate change impact on energy consumption and carbon emissions, the methodologies of predicting future weather and the total household energy consumption and associated carbon emissions were developed (Ren et al. 2011a). The future weather data were constructed using the ‘morphing’ methodology developed by Belcher et al. (2005), in which hourly weather data for the current climate is adjusted with the projected monthly mean changes from atmosphere–ocean general circulation models (AOGCM). The total energy consumption and associated carbon emissions were estimated by the AusZEH design tool (Ren et al. 2011b, 2012), which included energy use calculation modules for space heating and cooling, hot water, lighting and other appliances.

The majority (80 %) of Brisbane dwellings are separate houses (DEWHA-Department of the Environment, Water, Heritage and the Arts 2008). Figures 1 and 2 illustrate two detached single-storey houses of different sizes and

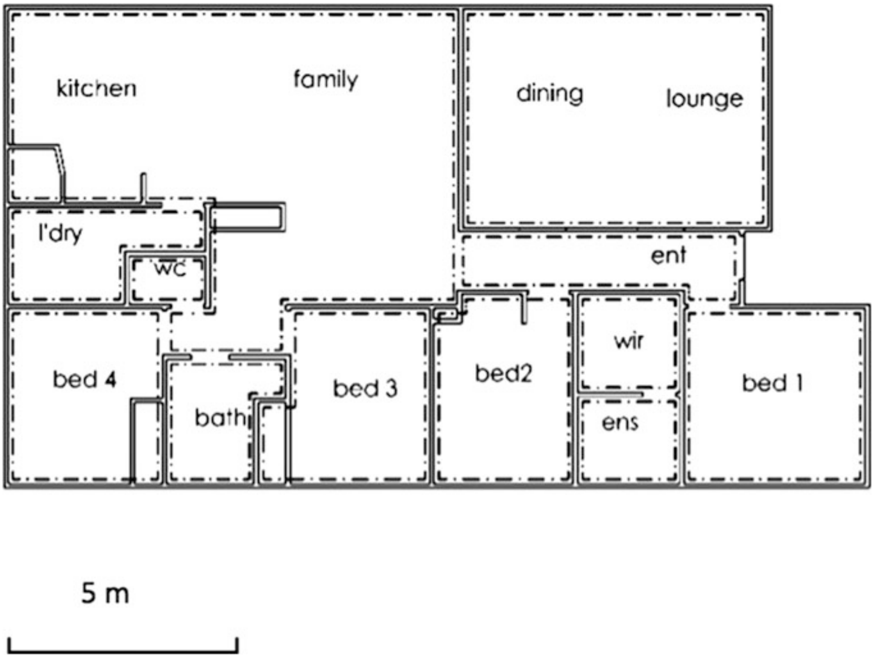


Fig. 1 The floor plan of House 1

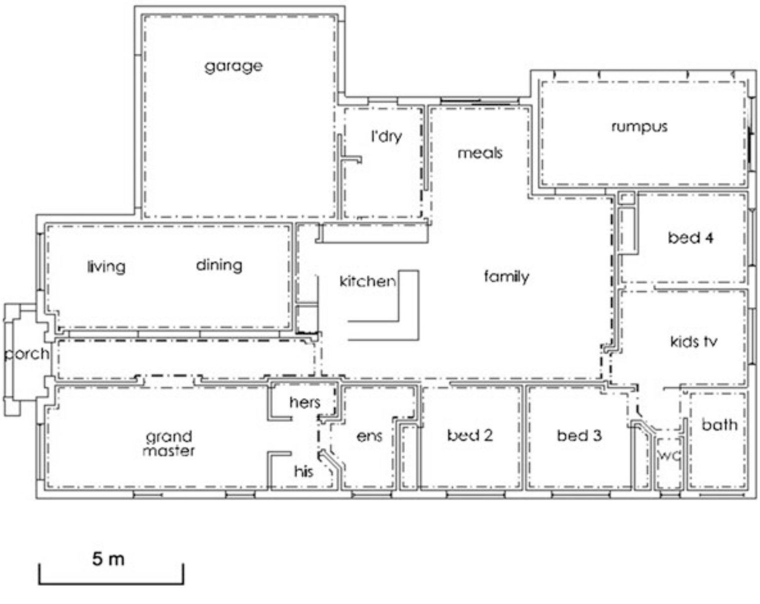


Fig. 2 The floor plan of House 2

constructions. The houses were selected from two of the eight sample houses previously used for energy rating software accreditation by Nationwide House Energy Rating Scheme (NatHERS 2012). 'House 1' has a gross floor area of 160 m^2 (conditioned floor area of 140.75 m^2) that is equivalent to the average floor area of the national detached houses built before 1990 (DEWHA 2008). 'House 2' has a gross floor area of 263.4 m^2 (conditioned floor area of 207.4) that is equivalent to the average floor area of the national detached houses built after 2004 (DEWHA 2008).

In this study, the floor plans for both houses were maintained whilst various changes of wall insulation, ceiling insulation, window types, infiltration controls etc. were used to achieve energy ratings of 2, 5 and 7 star house energy efficiency in Brisbane.

Among the houses, 'House 1' with 2 stars was selected to represent existing housing stocks built before 1990, and 'House 2' with 5 and 7 stars represent new housing stocks that satisfy current energy standard and likely future energy performance requirements respectively (Horne et al. 2005). Reverse cycle electric heat pumps with ducted central systems are assumed to be used for space heating and cooling. The energy coefficients of performance (COPs) of these systems were assumed to be 2.5, which complies with the Minimum Energy Performance Standards (MEPS) of 2006–2007 (DCCEE—Department of Climate Change and Energy Efficiency 2012). Energy efficient compact fluorescent lamps are used for lighting.

A 2010 survey found around 32 % of Brisbane homes used natural or LPG/bottled gas (Milles 2010). In this study, two fuel resources are considered:

- Electricity intensive: electricity was used for all the equipment, systems and appliances.
- Gas intensive: natural gas was used for water heating and cooking, and electricity was used for other equipment and appliances.

Considering that lighting, water heating and other household appliances are insensitive to global warming, climate change impact on residential building energy consumption and carbon emission is dominated by its impact on space heating and cooling (H/C) energy use (Ren et al. 2011a). Consequently, understanding the climate change impact on space heating and cooling energy use and carbon emission is important for the development of proper adaptation pathways for residential houses.

Figure 3 shows the projected heating and cooling energy consumption for 2 star 'House 1' and 5 star 'House 2' in relation to the global temperature increase on the basis of three AOGCMs (see Table 1) in Brisbane. The average values from the three AOGCMs were shown in red lines. The results revealed that the increase in the total H/C energy consumption prevails in the heating and cooling balanced regions (such as Brisbane) due to significant increase in cooling energy consumption. The total H/C energy consumption of 2 star 'House 1' was projected to remain almost unchanged until the global warming reaches 1 °C, meanwhile, for 5

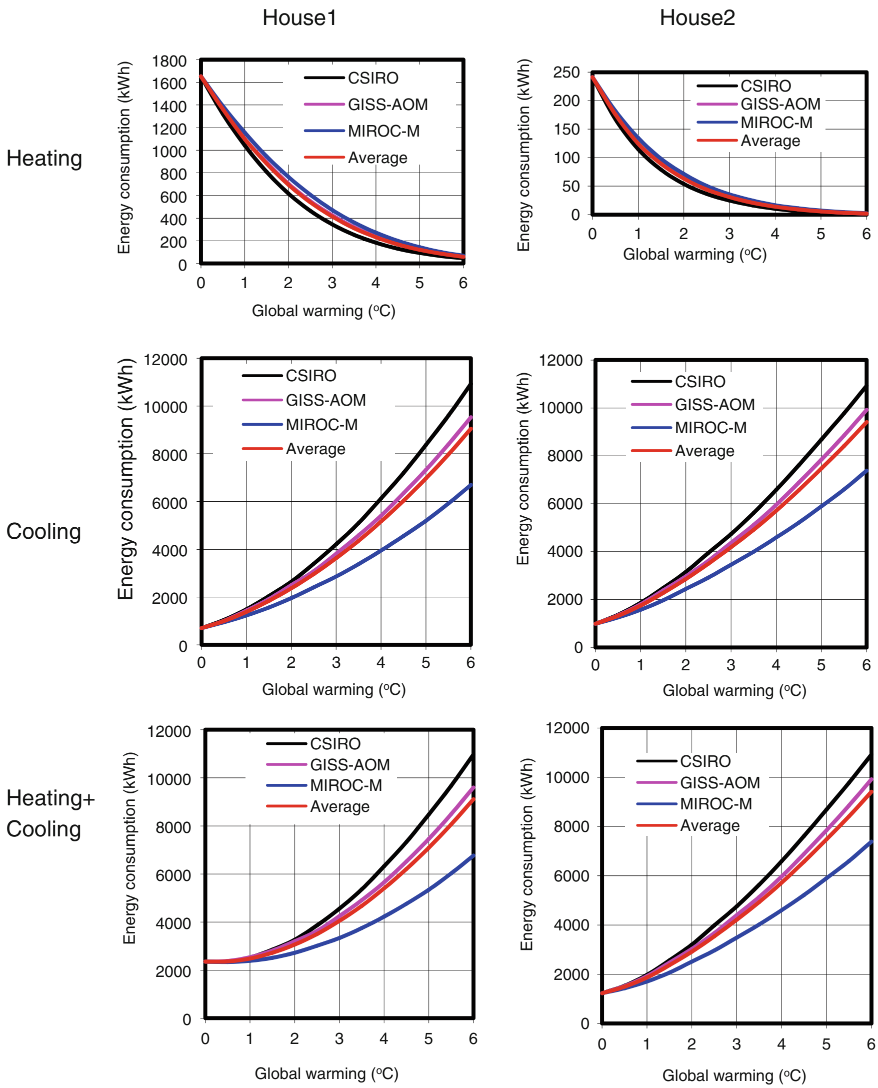


Fig. 3 Sensitivity of changes in space heating and cooling energy consumption (kWh/year) to the global warming for 2 star House 1 and 5 star House 2 in Brisbane (electricity intensity)

star 'House 2' it was projected to increase immediately with globe warming. This shows high energy efficient buildings are more sensitive to global warming.

In Brisbane, as shown in Fig. 4, the future total energy consumption of retro-fitted 5 star 'House 1' in response to 3 °C global warming is projected to be higher than the 2 star "House 1" under the current climate. With only a 1.5 °C global mean temperature increase, the future total energy consumption of an upgraded 7 star 'House 2' will surpass that of a 5 star "House 2" under the current climate.

Table 1 Models used for predictions of future local climate change

Model	Developer
CSIRO-MK3.5	Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
GISS-AOM	National Aeronautics and Space Administration, Goddard Institute for Space Studies, USA
MIROC-M	Centre for Climate System Research, National Institute for Environmental Studies, and Frontier Research Centre for Global Change, Japan

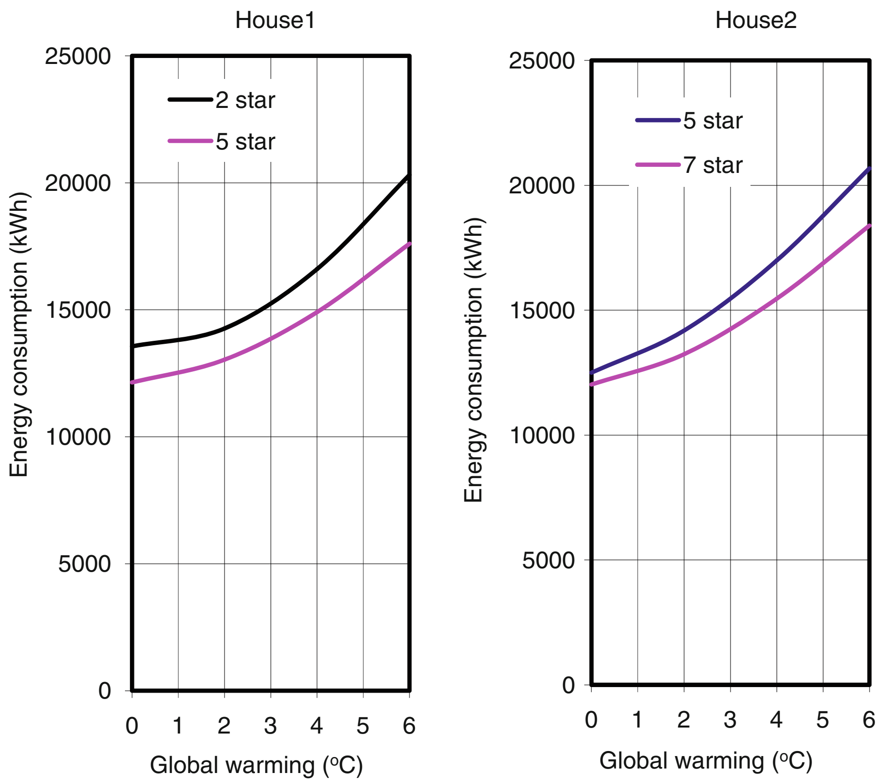


Fig. 4 Sensitivity of the total energy consumption to global warming for House 1 with 2 and 5 stars and House 2 with 5 and 7 stars in Brisbane (gas intensive)

Meanwhile, Table 2 revealed that in Brisbane, considering 6 °C global warming, the total carbon emissions of 5 star 'House 2' are projected to be around twice as much as those under the present climates. The total carbon emission of retrofitted 5 star 'House 1' at 6 °C global warming is even higher than the 2 star house under the current climates.

Table 2 The reduction of total carbon emissions for Houses 1 and 2 by increasing envelop energy efficiency

Energy use type	House 1			
	Present-day climate		Global warming increases by 6 °C	
	Total GHG emissions of 2 star	Reduction in GHG emissions 2 → 5 star	Total GHG emissions of 2 star	Reduction in GHG emissions 2 → 5 star
Electricity intensive (Tonne/year)	11.01	1.42	17.77	2.65
Gas intensive (Tonne/year)	8.46	1.42	15.22	2.65
Energy use type	House 2			
	Present-day climate		Global warming increases by 6 °C	
	Total GHG emissions of 5 star	Reduction in GHG emissions 5 → 7 star	Total GHG emissions of 5 star	Reduction in GHG emissions 5 → 7 star
Electricity intensive (Tonne/year)	9.95	0.46	18.13	2.22
Gas intensive (Tonne/year)	7.40	0.46	15.58	2.22

Considering the uncertainties in future global warming due to variable potential global carbon emissions in the future (a set of 40 emission scenarios defined in IPCC's Special Report on Emission Scenarios (SRES) (IPCC 2000), three carbon emission scenarios were selected in this study, i.e. A1B, A1FI and 550 ppm stabilisation scenarios, representing medium emissions, high emissions and the emissions under policy influences (IPCC 2000). With A1B, A1FI and 550 ppm stabilisation emission scenarios, the corresponding global CO_2 concentration and global warming projections can be obtained by the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC), developed by Wigley's Group in USA (Wigley et al. 1996). From the global CO_2 concentration and global warming projections obtained by MAGICC for a given emission scenario, climate changes in Australia with different Atmosphere–Ocean General Circulation Models (AOGCMs) can be simulated using OZClim (Wang et al. 2011), which is a climate change projection software developed by CSIRO. Then climate change impact on total energy consumption and GHG emissions can be predicted. Figure 5 shows the average total energy consumption from the three AOGCMs model varies with the global warming at the given emission scenarios of AIFI, A1B and 550 ppm respectively in Brisbane.

It can be seen that the total energy consumption for the existing 2 star 'House 1' and new 5 star 'House 2' in Brisbane will increase apparently starting from 2030

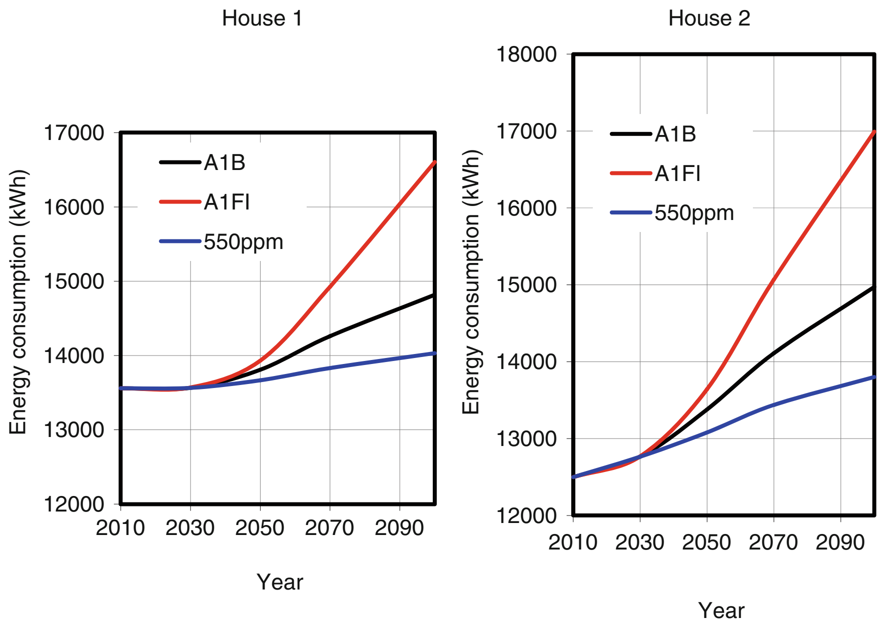


Fig. 5 Prediction of total energy consumption in Brisbane to 2100 (gas intensive)

given the high carbon emission scenario A1FI and medium emission scenario A1B. Particularly after 2050, they will increase linearly. From present to 2100, the total energy consumption will increase around 23 and 9 % for 'House 1' given emission scenarios of A1FI and A1B, respectively, and 36 and 20 % for 'House 2' for the high and medium emission scenarios. From present to 2100 given medium emission scenario A1B, energy consumption for space heating and cooling of 'House 1'(in kWh/m^2 of conditioned floor area per annum) will increase from 17 to 29 kWh/m^2 (e.g., increase by 71 %), and from 6 to 20 kWh/m^2 (e.g., increase by 233 %) for 'House 2'. They will increase by 142 % for 'House 1' and 394 % for 'House 2' from present to 2100 given high emission scenario A1FI. Considering their conditioned floor areas, the increase in the total annual heating and cooling energy consumption of 5 star 'House 2' is projected to be 4,915 and 3,406 kWh for 2 star 'House 1' from present to 2100 given high emission scenarios A1FI. It is clear that attentions should not only be given to low level energy star rating existing housing, but also to large 5 star new houses for adaptation strategy.

3 Climate Adaption Pathways

In general, there are three main practical approaches to reduce the energy consumption of residential houses in Australia if occupant behavioural changes are not included (Ren et al. 2011):

1. Demand reduction by improving energy performance of building envelops;
2. Applications of energy efficient appliances; and
3. Installation of renewable energy, such as solar PVs, wind turbines, solar hot water, etc.

There is an additional approach to reduce carbon emissions of houses, that is:

4. Fuel switching: switching to appliances that use alternative low greenhouse gas emission energy sources.

As shown in Table 2, in Brisbane, it can reduce 2.55 tons of GHG emissions yearly for 'House 1' and 'House 2' switching fuel from electricity to natural gas for water heating and cooking. Energy efficient compact fluorescent lamps have already been used for lighting (see previous section). In addition to these two options, the other measures will also be considered in this study to enhance adaptive capacity in response to global warming as following:

- The existing houses are retrofitted from 2 to 5 stars, and new houses constructed to satisfy 7 star requirement instead of the current standard of 5 stars. Modifications implemented for the houses to achieve above energy star rating are listed in Table 3;
- MEPS of the ducted air-conditioning systems are upgraded from 2.5 (MEPS 2006–2007) to 2.75 (MEPS 2010–2011);
- The 'average' energy performance household appliances based on the DEWHA report (DEWHA 2008) are replaced with the best energy performance appliances available on market. The change reduces about 25 % energy consumption of average household appliances (Newton and Selwyn 2010);
- Solar PVs are installed as an on-site renewable energy supply in connection with a grid electricity network.

Table 3 Modifications of House 1 from 2 stars a to 5 stars and House 2 from 5 to 7 stars

House 1 (2 to 5 stars)	House 2 (5 to 7 stars)
Ceiling 55 % R1.0 insulation upgraded to 100 % R2.0 insulation	*Ceiling* R4.0 insulation changed into R3.5
External Wall Brick veneer upgraded to brick veneer with R1.0 insulation	*External wall* brick veneer with R2.0; insulation upgraded to brick veneer with R3.0 insulation
	Windows timber frames with single glazing changed into aluminium

Adaptation pathways for existing houses are discussed assuming three levels of global warming, i.e., 2, 4 and 6 °C. As shown in Fig. 6, in order to maintain the future energy consumption of an existing house in its service life (i.e. ‘House 1’ in 2 stars) no more than the current levels, the house in Brisbane is only required to be retrofitted to 5 stars if global warming reaches up to 2 °C. However, as the global warming increases to 4 °C, it requires the houses be retrofitted to 5 stars together with high EE air-conditioning and high EE household appliances to fully counteract the effect of 4 °C global warming. As the global warming increases to 6 °C, all four procedures for ‘House 1’, i.e., retrofitting to 5 stars, use of high EE appliances and air-conditioning and the adoption of on-site solar PVs, are required for houses in Brisbane to maintain the future electricity consumption no more than the current level. The size of solar PVs is determined by the local average daily electricity production, which is 4.2 kWh/day for 1 kW PV in Brisbane (Clean Energy Council 2011).

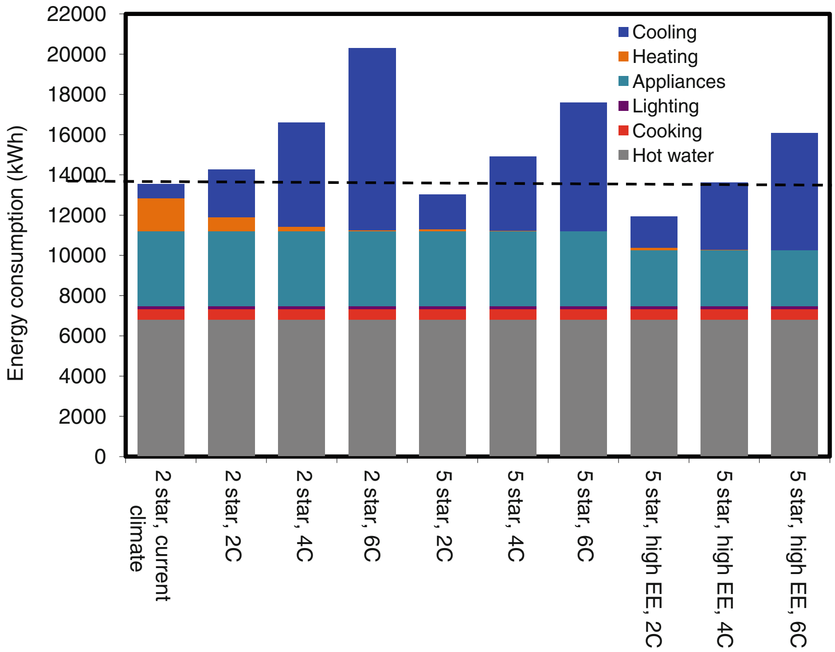
It is understood that earlier adoption of those adaptation measures will reduce the house energy consumption to less than the current level and thus contribute to climate change mitigation. In fact, considering average house service life of over 50 years, the current results further support that house energy rating standard today should be carefully designed for future global warming as pointed out by the authors (Wang et al. 2011).

As shown in Fig. 6 and Table 2, to maintain the future energy consumption of new houses no more than current levels as global temperature increases to 2 °C, the houses are required to satisfy the energy performance requirement of 7 stars, along with the use of high EE air-conditioning and appliances in Brisbane.

As the global temperature increases to 4 °C or more, all the four options described previously has to be implemented to keep energy consumption of a new house no more than the current level. In comparison, these implementations are only required for existing houses when global temperature increases up to 6 °C as discussed above. This again indicates that new high energy efficient housing is more sensitive to climate change.

The adaptation pathways analysed here is carried out for different global warming temperature scenarios. As mentioned above, to consider the uncertainties in future global carbon emissions, the analysis can also be made for the future years under the different carbon emission scenarios. It should be noted that the simulation results here project the potential average changes in the energy consumption centred at the future year and should not be viewed as the determinative energy consumption for a specific year in the future.

As shown in Table 4, to maintain the energy consumption of existing and new houses in 2030 no more than current level under high carbon emission scenario A1FI, the 2 star existing ‘House 1’ is required to be retrofitted to 5 stars and the 5 star new ‘House 2’ be upgraded to 7 stars. This building envelope improvement of ‘House 1’ can still be applied to achieve the targeted energy consumption in 2050. For the new ‘House 2’, to achieve the targeted energy consumption in 2070, the three options (built 7 stars, high energy efficient air-conditioning and appliances, and installing smaller PV) are required.



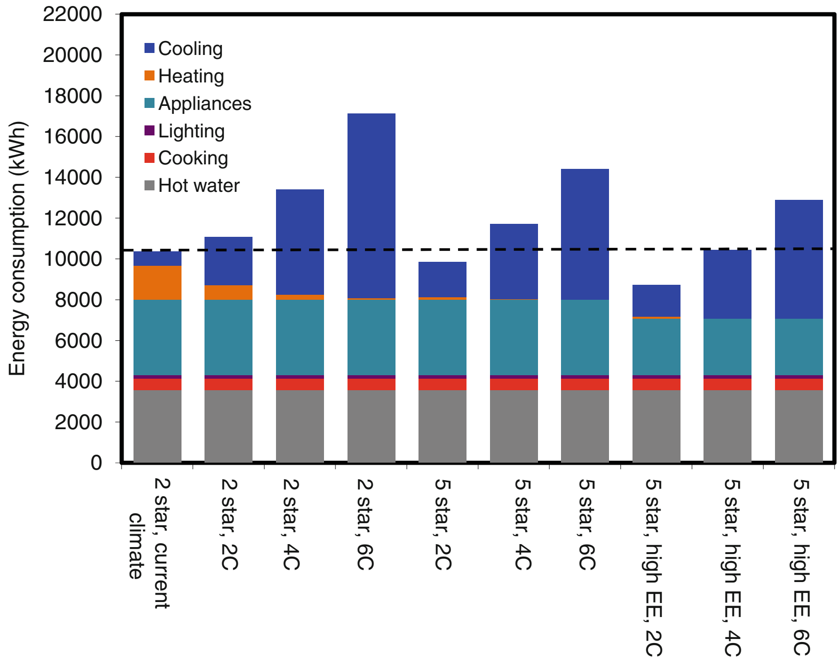


Fig. 6 Evaluation of the total energy consumption to global warming through the measures of building energy efficiency, high EE (air-conditioning and appliances) and on-site solar PVs for House 1 and House 2

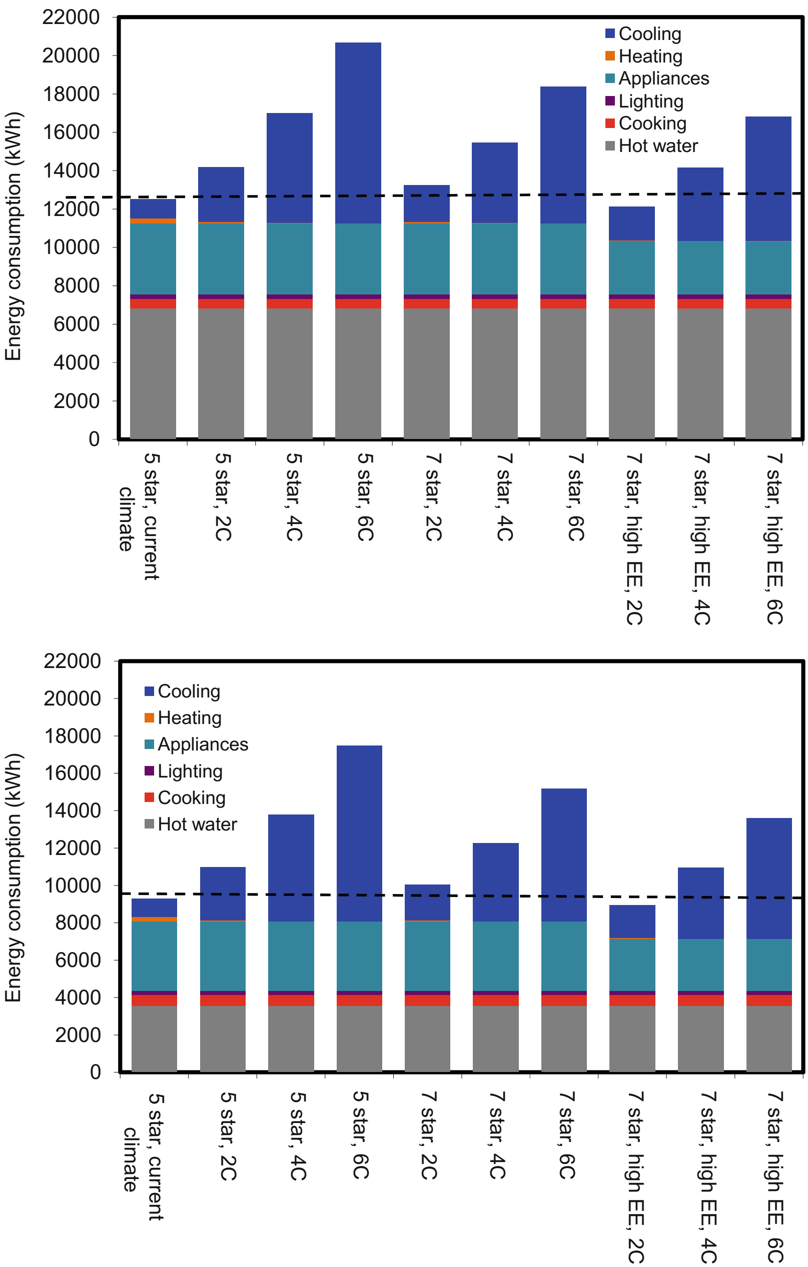


Fig. 6 continued

Table 4 The adaptation options to maintain housing energy consumption no more than current levels for years 2030, 2050 and 2070 under high carbon emission scenario A1FI

Emission scenario A1FI	House 1 (2 star)			House 2 (5 star)		
	Retrofitted to 5 stars	High energy efficient appliances	PVs (kW)	Upgrade to 7 star	High energy efficient appliances	PVs (kW)
2030	√	No	0	√	No	0
2050	√	√	0	√	√	0
2070	√	√	0	√	√	0.3

As shown in Figs. 4 and 5, even under high carbon emission scenario A1FI, the energy consumption of houses in 2100 is lower than the values when global temperature increases up to 6 °C.

4 Conclusions

This study investigated climate change impacts and potential pathways for climate change adaptation in terms of the total energy consumption and related carbon emissions of housing in Brisbane which represents the climate zone with balanced heating and cooling.

It was found that in Brisbane, slight global warming of 1.0 °C causes insignificant increase in the energy consumption of lower performing houses (such as 2 star 'House 1'). However, as global warming continues to rise, energy consumption will increase rapidly. In particular, as temperatures rise more than 4 °C, energy consumption will increase regardless of improving energy performance of building envelops and using higher energy efficient equipment and appliances. On the other hand, global warming causes immediate increase in the energy consumption of higher performing new houses (such as 5 star 'House 2'). As temperatures rise more than 2 °C, energy consumption will continue to increase regardless of the improved performance of their building envelops and installing higher energy efficient equipment and appliances.

Considering the uncertainties in future carbon emissions, the total energy consumption for the existing and new houses will increase apparently starting from 2030 given the high carbon emission scenario A1FI and medium emission scenario A1B, and increase linearly after 2050.

It was also demonstrated that in heating and cooling balanced regions such as Brisbane current mitigation techniques such as building envelop and appliances upgrade at current global temperatures may only maintain current levels of energy consumption and carbon emissions as temperatures increase, and therefore may no longer serve for carbon mitigation in the future. Other technologies may be required to boost the adaptive capacity. These may include the installation of on-site renewable energy such as solar PVs and solar hot water.

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European Citizens, Carbon Footprints and Their Determinants—Lifestyles and Urban Form

Vera Peters, Fritz Reusswig and Corinna Altenburg

Abstract In this study we explore the differences between carbon footprints of private households across three European countries. The assessment of CO_2 emissions for housing, mobility and food is based on a survey of 844 inhabitants of rural and urban areas in Scotland, Czech Republic and Germany. The relevance of urban form, household structure, socio-demographics and lifestyle characteristics is investigated in relation to area specific conditions that influence the energy demand but also determine its enviormental impact. We can see significant differences in the carbon footprint across the case studies, which can to a certain extend be related to varying income levels in Scotland, Czech Republic and Germany. But of course, there are other influencing factors on different levels: different structural factors, such as the respective energy mix of a country, the availability of district heating and eco-friendly products such as green electricity, the urban form and household structure. Without the support of the built environment and public institutions, it is mostly difficult for individual households to translate their pro-environmental preferences into real behavior, but the data also reveals that the actors' environmental values do have a direct influence on the level of CO_2 emissions in some areas like food and flight emissions.

Keywords Carbon footprints · Energy · Lifestyles · Urban form

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1 Introduction

Climate change is already underway and it will become more severe in the future. Although the really dangerous physical *impacts* of climate change will occur later in time, the economic *costs* of climate change have to be taken into account already now (Stern 2006; Ackerman et al. 2010; van den Bergh 2010). Extensive research on the impacts of climate change in Europe show that all regions will be affected, with Southern Europe most probably experiencing more severe and earlier damages (Ciscar et al. 2011).

The European Union as a major global emitter of greenhouse gases has taken over global responsibility by accepting a 8 % reduction targets (EU 15) under the Kyoto Protocol, and it has more ambitious targets of 20–30 % as part of the Europe 2020 Strategy (European Comission 2011a). The long-term perspective is to achieve a carbon-free economy until about 2050 (European Commission 2011b). Becoming a 'green economy' (Rifkin 2011) is a big challenge, as it will require different transformations:

- The European energy system will have to be restructured towards a 100 % renewable energy basis.
- The European building sector will have to adopt a zero emission or even carbon negative standard, which is a challenge especially with respect to the existing building stock.
- Mobility in Europe will have to become carbon neutral, relying on new engines and to a larger share on carbon neutral public transport.
- Production and consumption systems will have to reduce their carbon footprints significantly, e.g., by large efficiency gains, more recycling, or by developing completely renewable materials.
- European consumers will have to adopt greener lifestyles in order to purchase these new forms of energy and products.
- European cities will play a major role in this transformation process, as their metabolism and structure will by large determine the degree to which European citizens in- and outside cities can adopt greener lifestyles.

While there is a widespread consensus that the energy system needs a substantial 'greening', that energy efficiency gains will have to be achieved, and that all kinds of technological innovation is needed, many scholars and politicians hesitate to ask for lifestyle changes and the reflection of consumption patterns. However, we argue that without complementary and supporting changes in individual lifestyle and consumption Europe will not be able to meet its long-term climate policy targets (Reusswig 2010).

This raises various questions with respect to the capacity of European societies to achieve these goals, and to meet the associated challenges mentioned above. Of particular interest is the question whether European citizens are ready and able to reduce their individual carbon footprints, and if and how their willingness and ability to do so is influenced by some structural constraints, namely the 'urban form'.

In a wide sense ‘urban form’ comprises all structural features of the built environment (including infrastructures) that influence individual choices and behaviors. Whether or not individuals choose a bus or train to commute to their workplace for example is clearly dependent upon the availability and the costs of public transportation—among other things. Whether or not people decide to heat their homes with a district heating system obviously depends upon the availability of such an option. If green products are not on offer, or not at affordable prices, people will find it hard to change their consumption habits in an environmentally friendly way. The density of a city has an influence on both travel patterns and patterns of energy use, and so forth. While the general coupling of lifestyles and consumption patterns on the one hand and the urban form on the other is widely accepted, it is not clear how exactly these connections work.

2 Approach and Methods

2.1 General Approach

The main research interest of the European project GILDED (“Governance, Infrastructure, Lifestyle Dynamics and Energy Demand: European Post-Carbon Communities”) was to analyze variances of household energy use across Europe and to identify if European citizens felt the necessity to change their energy consumption habits and lifestyles due to the needs of climate change mitigation. For that reason, three dimensions of comparison—and thus of possible variance—were introduced:

- We were looking at case study regions in five *different countries* in the European Union (United Kingdom, The Netherlands, Germany, Czech Republic and Hungary), as country differences in availability of services, energy prices and income level, political boundary conditions, and cultural traditions influence the choices of individuals.
- In every country, our case study was sub-divided into an *urban* and a *rural* sub-sample in order to control for the contextual influence of the urban form. We have chosen European mid-size cities [Aberdeen (UK), Assen (NL), Potsdam (D), Czeske Budějovice (CZ), and Debrecen (H)] and their rural hinterlands, so we cannot draw conclusions with respect to larger cities (e.g. European metropolises).
- Across the whole sample, the households were studied according to a *lifestyle segmentation approach* in order to take different socio-economic and cultural conditions of individuals into account. The lifestyle segmentation approach was only applied in the German, Scottish and Czech case study, which is the reason why we exclude the Dutch and Hungarian dataset from the current analysis.

2.2 Sampling

The data derives from a survey conducted from February to May 2011. The households had already been questioned in 2010, because one goal of the project was to test a social psychological intervention and its potential to decrease emissions over one year. We omit this aspect of research for the purpose of this chapter.

Due to the large study areas the households were determined by cluster sampling and visited personally by a drop-and-collect method. The response rate was not as high as we hoped for (Table 1) which probably had a couple of reasons: the CO_2 calculator that was part of the questionnaire was long and detailed, it took quite an effort and amount of trust to reveal these details of the household. We were not able to send a pre-notification, which most probably would have improved the response rate.

There are also some important constraints regarding the representativeness of the data: in all three countries the data is biased towards older respondents. Also, in Germany the share of respondents with a high formal education and high income is considerably larger than it generally is in Potsdam and its corresponding rural area Potsdam-Mittelmark.

2.3 CO_2 Calculations

Carbon dioxide emissions are the main driver of anthropogenic climate change. Along with the current academic status quo, we hereby define a general carbon footprint as the direct and indirect greenhouse gas emissions measured in tons of CO_2-equivalents, which are required to satisfy a given consumption (Minx et al. 2009). For our CO_2-e calculations we used an extensive questionnaire that included

Table 1 Response rates per country for 2010 and 2011

		Czech Republic	Germany	Scotland	Total
2010	Total target sample	5,000	1,842	6,340	
	Number of questionnaires returned	500	543	1,099 (489*)	2,142 (1,532)
	Response rate	10 %	29 %	18 %	
2011	Number of questionnaires returned	309	320	279	908
	Drop-out rate between 2010 and 2011	38 %	41 %	43 %	
	Number of respondents a CO_2 footprint could be calculated for	292	300	252	844

* 489 respondents out of 1,099 were given the whole survey material, including the CO_2 calculator

information on the energy sectors housing (heating and electricity), mobility (car, air travel, train and coaches, public transport) and food. Calculations were based in part on electricity and heating bills, in part by an assessment through self reported behavior and information on the households' infrastructure (e.g., type of heating system, annual mileage, room temperature, preference for organic products).

Indirect emissions from modes of transportation other than personal motorized vehicles (e.g., flights see Jardine 2009) and food consumption were included. Regarding food emissions the lifecycle emissions that can be attributed to food items were estimated. We had to exclude indirect emissions embodied in other consumer goods as data is not as robust for all GILDED countries. The following criteria had to apply for the carbon calculator used by GILDED:

- It should be based on the data of each individual household as opposed to geo-consumptive data which represents meta-footprint data on a regional level. We thus have chosen a consumption based approach as opposed to a primary energy balance based approach (cf. Minx et al. 2009), which allows us to include emissions from product lifecycles, independent to where they have been generated. This is important given the high relevance of trade for the European economy.[1]
- The right balance between accurateness and length of the tool had to be found: there is a trade-off between the appropriate length of surveys still being accepted by households and the accurateness of the final carbon footprint.
- It had to be based on CO_2-equivalents as opposed to only CO_2 emission factors: CO_2-equivalents also take into account the impact of other GHGs such as methane, which is especially important in the domain of food production.

We adopted the methodology of the CO_2 calculator developed by Schächtele and Hertle (2007) and used by German Environmental Agency (UBA), but also made use of national CO_2 calculators in order to take the particularities of national energy systems into account, e.g., with respect to the CO_2 intensity of the national energy mix.[2]

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[1] It should be noted that experiences with lifecycle assessment based product carbon footprints that we have been involved with reveal that currently we can only operate with estimates or rather generic data that do not account for product specific differences. For example it makes a big difference whether orange juice comes from Spain or from dry concentrate from Brazil, however most calculators use a generic emission value for 'orange juice' (cf. the German Product Carbon Footprint Pilot Project, www.pcf-projekt.de).

[2] See: http://carboncalculator.direct.gov.uk, http://kalkulacka.zmenaklimatu.cz.

3 Results on Differences Between the Case Studies' CO_2 Footprint

3.1 Overview of CO_2 Differences Between Cases Studies

Based on the above outlined GILDED methodology the carbon footprints per household and per capita were calculated. As can be seen in Fig. 1, the average per capita emissions differ considerably in the three countries. We see an average per capita consumption in our study regions of 6.1–8.0 tons of CO_2 per year, with Czech households at the lower and Scottish households at the top end.

It needs to be noted that these results vary from other national results as emission from consumption and public infrastructure are not taken into account. In the German case, one would roughly have to add 3.75 tons CO_2-e for consumption and 1.1 tons CO_2-e for public emissions in order to end up at the national average of about 11.0 tons per person (Klimaktiv n.d.).

Comparing the total distribution of CO_2 footprints (Fig. 2) especially the range in the Scottish sample is apparent.[3] The extreme values represent respondents that have exceptionally high emissions mostly due to frequent air travel or because of inefficient usage of coal for heating. They are partly responsible for the high mean value in the Scottish sample, but the Scottish median is also considerably higher than in the other two countries: 6.7 tons compared to 5.9 in the German and 5.4 in the Czech sample. There is also relatively little variance in the Czech data.

It is interesting to see that in Europe today we can already find households with individual carbon footprints in the range of 2–3 tons per capita and year—not only in the Czech Republic, but also in Germany and Scotland. If we accept the long-term goal of 2 tons per capita that we need to reach by 2050 in order to meet the 2 °C goal adopted by both the EU and the member states of the UNFCCC, these individuals are quite close to that target already today. It is clear that they only represent a minority, and that indirect emissions from consumption and public infrastructure have to be added to our results, but still the existence of relatively low-carbon lifestyles in Europe today is an encouraging sign and needs further research.

3.2 Factors Influencing Individual CO_2 Footprints

As mentioned in the introduction, various factors influence the consumption and lifestyle choices of individuals, thus leading to different private carbon footprints.

[3] Extreme values and outliers were generally not excluded from analysis, only when they resulted from apparently false information. For the most part however the large variance of CO_2 emissions represents reality. It was checked if differences between groups resulted from single extreme values. Such instances however did not emerge for the analysis of this chapter.

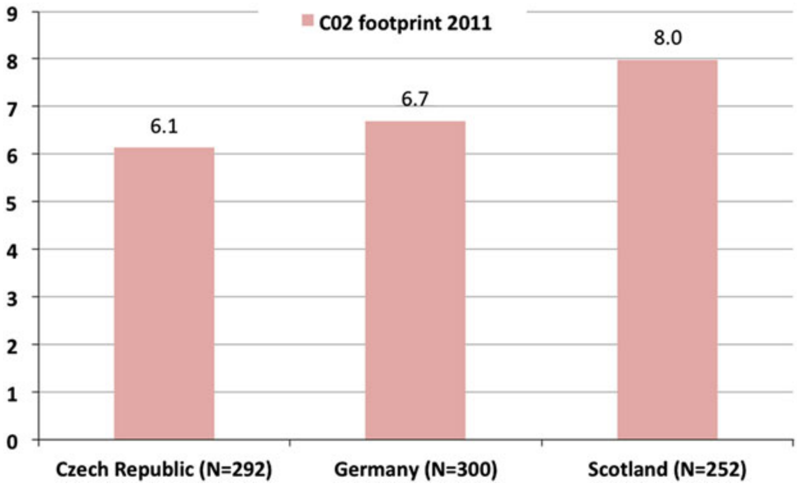

Fig. 1 CO_2 footprint (housing, mobility, food) average per country in tons CO_2-e per year per capita (2011)

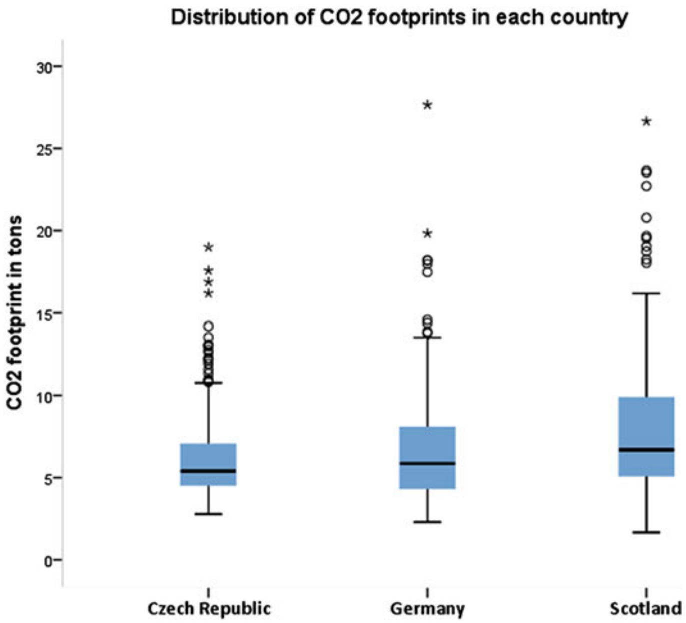

Fig. 2 Boxplots of the CO_2 footprints (in tons CO_2-e per year per capita), the *black band* represents the median, the colored *box* ranges from the 25th to 75th percentile and the *upper* and *lower* whisker show the 1.5 interquartile range, *circles* representing outliers, *stars* extreme values (2011)

Some of these factors are listed below, together with the average per capita emissions associated with that characteristic (Table 2).

We can see that indeed several of these characteristics are associated with the level of overall emissions. A first interesting result can be derived from our general indicator of the urban form, i.e., the residential *location* of households in either a city or its rural hinterland. Here we seem to find some confirmation for a global pattern described by Satterthwaite (2008): in more developed countries (in terms of economic performance), we find that city dwellers have lower per capita emissions than rural dwellers. This is a double effect of the higher densities and efficiencies in cities on the one hand, and of a rather high level of income and infrastructural development of suburbs and peri-urban regions in places like the US or Western Europe, on the other: here modernization and urbanization processes have also affected the 'hinterlands', but lower building densities and higher mobility demands have led to relatively high emissions.

We can also see that the *type of house* affects par capita emissions significantly. As one would expect, detached or terraced houses in all countries have higher emissions than appartement buildings. The largest difference can be found in the German case study region, with about 2 tons difference between house dwellers and inhabitants of flats. In the Czech Republic, we still find a difference of 0.7 tons.

Household size also affects the emissions. Across all countries there appears to be a negative linear relationship between the increasing number of people living in a household and their per capita emissions. This effect holds due to the economy of scale of private households. Given the trend towards smaller household sizes—an effect of both individualization processes and demographic changes in modern societies—we can thus predict *ceteris paribus* a growth trend of per capita emissions in Europe. This finding supports the idea of additional measures—either in terms of efficiency, or in terms of more renewable energy sources, or of more sufficient lifestyles—in the private household sector in order to meet Europe's reduction targets.

No clear trend can be observed with respect to formal education levels and per capita emissions. In Germany and Scotland a slight positive correlation exists, but in the Czech Republic we can see that highest educational levels show slightly smaller emissions. While age and gender also do not offer an unambiguous influence, income is confirmed also by this data to be a very important predictor for individual GHG emissions. This holds true at least for Germany and Scotland: while the lowest income quintile emits 5.6 (Germany) or 5.7 tons (Scotland) respectively, we find the top income quintile emitting 8.0 (Germany) or even 10.9 tons per year (Scotland). In the Czech Republic, the association is less marked.

3.3 Lifestyles and CO_2 Emissions

Up to now we have used the term 'lifestyle' in a rather vague sense, referring to the consumption patterns of private households. Nevertheless, the term does have a

Table 2 Average CO_2 footprints differentiated by contextual, household and socio-demographic characteristics (2011, in tons CO_2-e per year per capita)

	Czech Republic	Germany	Scotland
Contextual characteristics			
Urbanity	(Rural: 53 %)	(Rural: 46 %)	(Rural: 52 %)
Rural	6.5	7.1	8.6
Urban	5.7	6.3	7.2
Household characteristics			
People in Household	(M = 2.9)	(M = 2.6)	(M = 2.3)
1	8.8	7.5	10.0
2	6.6	7.4	8.3
3	5.8	6.2	6.7
4	5.3	5.2	5.5
5+	4.4	5.3	5.1
Type of house	(*House*: 63 %)	(*House*: 70 %)	(*House*: 85 %)
House detached	6.5	7.3	8.2 (not differentiated)
Semi detached house	6.1	6.8	
Terraced house	6.9	8.2	
Flat 2–3 stories	6.0	5.8	6.5
Flat multi story	5.4	4.9	
*Equivalent net income**	(M = 600 Euro)	(M = 1,500 Euro)	(M = 1,700 Euro)
Lowest income group	5.4	5.6	5.7
2nd lowest income group	7.0	6.0	6.9
Medium income group	5.4	6.6	8.1
2nd highest income group	6.9	7.0	8.3
Highest income group	6.5	8.0	10.9
Sociodemographic characteristics of respondent			
Gender	(Female: 52 %)	(Female: 46 %)	(Female: 46 %)
Male	6.2	6.4	8.1
Female	6.0	7.1	7.8
Age	(M = 46)	(M = 54)	(M = 58)
18–30	5.7	6.2	5.2
31–40	5.6	5.5	7.1
41–50	6.1	6.5	6.5
51–60	7.4	7.6	9.4
61–70	6.4	7.2	8.5
71+	5.3	6.6	8.2
Formal Education	(Tertiary: 16 %)	(Tertiary: 47 %)	(Tertiary: 16 %)
No or primary education	4.6	–	–
Secondary lower	6.3	6.7	7.2
Secondary higher	6.3	6.5	7.0
Tertiary	5.9	6.9	9.3
Employment status	(Retired: 24 %)	(Retired: 35 %)	(Retired: 43 %)
Employed (all also halftime)	6.3	6.4	8.0
Retired	6.2	6.9	8.3
Housewife/-man	4.5	9.6	3.9
In training/school/studying	5.5	5.4	7.0
Momentarily unemployed	7.4	6.9	4.7

* For the estimation of equivalent net income the households' income was weighted according to the new OECD scale, however in a simplified way since we lacked information on the age of each household member: the estimated monthly disposable income of a household is divided by people in the household: 1st person counts 1, each further person 0,5 (according to the new OCED Scale children under 14 years are only accounted as 0.3)

rather specific meaning which was mainly, developed during the 1970s and 1980s in consumer research and the social sciences (Earl 1986; Otte 2004). Here, the concept of lifestyle was meant to detect group specific ways of leading and interpreting one's individual way of life, thus including 'objective' and 'subjective' dimensions. Examples for the former would be income or consumption patterns, while value orientations and attitudes would be examples for the latter. In modern sociology, the concept of lifestyle aims at a modernized concept of social inequality that encompasses the mental dimension (attitudes and values) as relevant aspects of social differentiation (Müller 1992; Schulze 1992). French sociologist Pierre Bourdieu (1976) has made a famous attempt in that direction. While Bourdieu has provided us with an inspiring, both analytically stringent and very colorful picture of the French society of the late 1960s, contemporary sociology and some market research institutes inform us about recent changes in lifestyles. The social milieus approach by the Germany-based Sinus Institute[4] for example combines data on the social structure of individuals (such as income or educational level) with information about their values and life goals. As a result, Sinus obtains 10 different social milieus, i.e. 'like minded' social groups that show internal similarities with respect to their social situation and values (SINUS n.d.).

Regarding energy-related behavior the lifestyle approach was able to explain certain differences in behavior patterns, such as travel behavior, especially leisure mobility: e.g., analysis has shown group differences regarding the mode of transportations (Beckmann et al. 2006) and holiday destinations (Otte 2004). Lifestyle research also suggests significant group differences on factors influencing direct energy use at home, e.g., the requirements of accommodation (Schneider and Spellerberg 1999) and the amount and kind of electronic appliances (Bohunovsky et al. 2011). However, it has yet to be shown if different energy patterns result in different levels of overall consumption and emissions between the groups.

Based on this work we developed a comparable typology of lifestyle groups, combining information on the economic resources of our respondents (equivalent net income) with information about their values (traditionality, hedonism/materialism, self-fulfillment and environmental awareness) and consumption preferences (thriftyness, materialistic, hedonistic, sustainable). A two step cluster analysis was applied for each country in order to detect groups with similar lifestyles as defined here by the interaction of economic resources, general values and consumption preferences. As we were interested in the differences between the groups regarding their ecological orientation (Fig. 3), we created an index that ranges from high to low agreement to sustainability values and consumption practices (x-axis). Combined with the vertical resource axis (high-low equivalent income) we obtained a two-dimensional social space. The size of the 'bubbles' indicate the groups' share in the national sample, their color the case study region they belong to. The

[4] See: http://www.sinus-institut.de/en/.

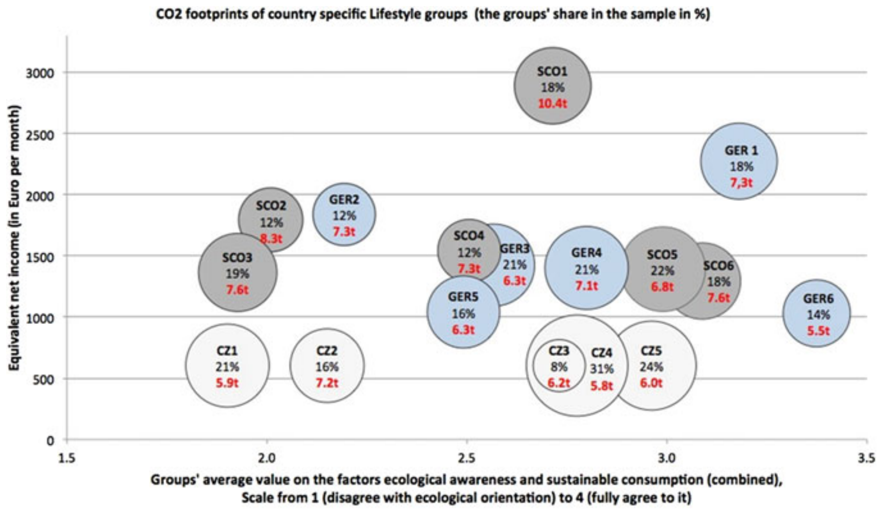

Fig. 3 Mean CO_2-e footprints (per capita per year) of country specific lifestyle groups in Germany (*blue*), Scotland (*grey*) and Czech Republic (*white*). Numbers represent the mean CO_2 emissions of the group. Percentages and size of the *bubbles* depict the share of the group in the sample (2011)

average per capita CO_2 emissions of the particular lifestyle group is indicated inside the bubble.

The results of the lifestyle analysis are interesting in various respects. First, we find that people with similar economic resources may have very different sustainability values and consumption orientations, and the other way around. For example in Germany there are two groups with high agreement to ecological values and preferences (GER1 and GER6), but they differ completely when it comes to their economic resources (Fig. 3, the two bubbles to the very right): this difference in living situation affects their value system—while the high income group GER1 combines ecological orientations with hedonistic interests and a focus on political correct consumption, the less affluent and older lifestyle group GER6 embeds ecological values in thriftiness and traditional values, like the focus on duties and orderliness. But the difference in economic resources apparently also affects these groups' energy consumption, seemingly regardless of their values: GER1 is also among the groups with the biggest CO_2 footprint in the German sample (7.3 t).

Similarly, the Scottish most affluent lifestyle group (SCO1) is the one with the-by far-highest ecological footprint. Another relatively high income group is the Scottish hedonic group SCO2: these respondents are fun and consumption oriented, without considering much environmental issues. SCO2 also has a larger average CO_2 footprint (8.3 tons), which might be connected to both, the comparatively high income or the values and consumption preferences (this will be further analyzed in the multivariate analysis).

The Czech lifestyle segmentation represents an exception: the two step cluster analysis did not identify like-minded groups with distinct income levels.[5] When looking at the Czech lifestyle groups there is no indication that environmental values and consumption preferences are connected to a lower CO_2 footprint; the two Czech groups that seem to have a rather low environmental awareness (CZ1 and CZ2, together 37 % of the sample) have a slightly larger CO_2 footprint, but it does not considerably differ from that of the other, more environmental aware groups.

Finally, comparing the 'overall' environmental awareness level between the countries does not help explaining their differences in CO_2 emissions. Even though differences across countries are significant (e.g. only 12% in Germany show very little interest in environmental matters, compared to 31% in the Scottish case), this variance does not help explaining the two country's differences in CO_2 emissions. For a large part of people lacking environmental orientation does not emit more than their eco-friendly counterparts. The environmental friendly groups do not stand out as emitting fewer emissions. Hence, different levels of environmental awareness in Scotland and Germany do not result in varying carbon footprint in our case studies.

On the other hand lifestyle analysis suggests that income can explain quite much of the level of CO_2 emitted—within and between countries. Considering the overall smaller CO_2 footprints of lower income groups, the low income level in the Czech sample might very well be connected to the Czechs generally lower footprint.

3.4 Multivariate Analysis of the Overall CO_2 Footprint

The influence of attitudinal and socio-demographic characteristics of the respondents, as well as household and context factors is tested by applying multivariate regressions for each country. For this purpose multivariate hierarchical regression analysis on CO_2 emissions was used. The influence of socio-demographic variables alone and combined with the lifestyle aspects were estimated in two different models (step 1 and step 2). The share of explained variance by each of the two models (R^2 and adjusted R^2) and the regression coefficient (β) of each explaining variable will be examined.

As it could be expected, in all of the three countries the overall CO_2 footprint can partly be explained by structural factors, but not by values and preferences (Table 3). Especially in Scotland socio-demographic characteristics of the respondents worked overall quite well as predictors of CO_2 emissions: 39 % of the personal CO_2 footprint could be predicted, foremost by the variables equivalent

[5] These results suggest that in the Czech case there is no connection between income and values as operationalized here. This most likely indicates a problem with transferring the lifestyle concept to the Czech cases study and needs further investigation. But for this particular purpose the use of the segmentation is still useful and seems legitimate, since the ecological values we are focusing on in this paper were tested as reliable for the groups.

Table 3 Summary of hierarchical regression analysis for socio-demographic and lifestyle variables predicting the CO_2 footprint per capita

Variables	Overall CO_2 footprint per capita								
	Czech Republic			Germany			Scotland		
	B	SE B	β	B	SE B	B	B	SE B	β
1st step	8.97	1.38		7.54	1.86		−0.59	1.44	
Equivalent income	0.00	0.00	0.07	0.00	0.00	0.27***	0.00	0.00	0.33***
Region (urban = 1; rural = 2)	0.37	0.46	0.06	0.23	0.40	0.04	0.75	0.33	0.14**
Type of house (house = 1–3; flat = 4–5)	−0.28	0.13	−0.17**	−0.61	0.13	−0.33***	0.30	0.14	0.14**
Gender (male = 1; female = 2)	−0.51	0.33	−0.09	0.22	0.32	0.04	0.00	0.32	0.00
Age	0.00	0.01	0.01	−0.01	0.01	−0.03	0.03	0.01	0.15**
Formal education	0.18	0.13	0.09	−0.14	0.26	−0.03	0.31	0.11	0.16***
Number of people in HH	−1.20	0.15	−0.50***	−0.76	0.16	−0.32***	−0.78	0.17	−0.30***
2nd step	8.98	1.42		7.50	2.01		−0.73	1.47	
Equivalent income	0.00	0.00	0.06	0.00	0.00	0.24***	0.00	0.00	0.31***
Region (urban = 1; rural = 2)	0.43	0.47	0.08	0.24	0.40	0.04	0.71	0.33	0.13**
Type of House (house = 1–3; flat = 4–5)	−0.28	0.13	−0.17**	−0.59	0.13	−0.32***	0.30	0.14	0.14**
Gender (male = 1; female = 2)	−0.58	0.35	−0.10	0.24	0.33	0.04	0.11	0.32	0.02
Age	0.00	0.01	0.02	0.00	0.01	−0.01	0.03	0.01	0.17**
Formal education	0.16	0.13	0.08	−0.18	0.27	−0.04	0.34	0.11	0.17**
Number of people in HH	−1.19	0.15	−0.50***	−0.76	0.16	−0.32***	−0.82	0.17	−0.31***
Values: Traditionality				0.10	0.18	0.04	0.30	0.16	0.10*
Values: Hedonism/Materialism	−0.16	0.18	−0.05	0.08	0.19	0.03	0.13	0.17	0.05
Values: Self-fulfillment	0.05	0.16	0.09	0.18	0.03	0.02			
Values: Environmental awareness	−0.35	0.21	−0.12	−0.15	0.19	−0.05	0.08	0.21	0.03
Consumption: Thriftiness				−0.23	0.19	−0.08	−0.15	0.16	−0.05
Materialistic consumption	−0.11	0.18	−0.04	−0.07	0.19	−0.03	−0.19	0.16	−0.07
Hedonistic consumption	0.21	0.18	0.07						
Sustainable consumption	0.11	0.20	0.04	−0.08	0.20	−0.03	−0.42	0.21	−0.15**
Explained variance by the models	Adjusted R^2 for step 1 = 0.241*** ΔR^2 for step 2 = −0.010			Adjusted. R^2 for step 1 = 0.255*** ΔR^2 for step 2 = 0.001			Adjusted R^2 for step 1 = 0.385*** ΔR^2 for step 2 = 0.008		

Note The dependent variable CO_2 p.c. was split in 10 categories of the same size so that the residues follow a normal distribution. Predictors were checked for multicollinearity: variance inflation factors (VIF) of all variables were < 2. *$p < 0.10$. **$p < 0.05$, ***$p < 0.01$. Pairwise deletion of missing data was used (this accounts also for all other regressions) income and household size, but also age and formal education on the one hand, region and type of house on the other. As for lifestyle effects, in the Scottish case it is indicated that sustainable consumption preferences have a small effect on the CO_2 footprint (−0.15**). In the Czech Republic and Germany the model is not at all improved if lifestyle aspects are included. Even though the variance in CO_2 footprints is overall considerably less well explained in Germany than in Scotland, income, type of house and household size also show rather strong effects, while the household size and type of household are apparently the only significant predictor in the Czech case.

Comparing these results to the descriptive, bivariate analysis it is interesting to see, that the weak association between the urban and rural region and the CO_2 footprint is diminished or weakened. Apparently the difference between the sites is explained by the other variables: income, size of household and type of house. One of the most interesting findings is the lack of connection between income and emissions within the Czech case study. For a better understanding of carbon footprints and their determinants we need a closer look at the different domains of household energy consumption. Figure 4 splits the overall carbon footprint of the three GILDED countries into separate domains: heating, electricity, car use, air travel and food. Questions on the use of public transport were only included in the German and Czech survey, so the results are shown separately.

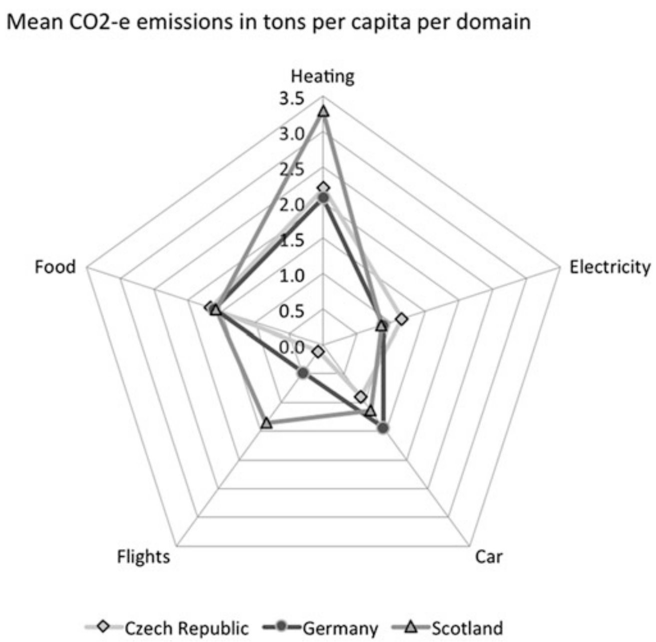

Fig. 4 Carbon emissions (in tons CO_2-e per year per capita) in different energy sectors (2011)

4 Sectoral Breakdown of Emissions

4.1 Heating

Emissions from space heating clearly dominate the total household emissions. Scottish emissions are on the top-end here, which can partly be explained by cold climate conditions in the Northern part of Scotland and partly by the high percentage of heating oil usage and heating with electricity (Fig. 5). Also, it reflects a high demand for refurbishment needs in the domestic sector—not only in Scotland, but also in the other countries.

The German and Czech results on heating emissions are fairly similar, even though the energy sources and therefore average emission factors are diverse. In the Czech Republic especially the large share of coal but also biomass and district heating is evident.

So, the emission factors hide the fact that Czech respondents actually consume less energy for heating. This has a lot to do with differences in household structure, with the Czech respondents more often living in larger households, resulting in less m^2 per person. The emissions of single households are disproportionally high, while in families emissions per capita are a lot lower.

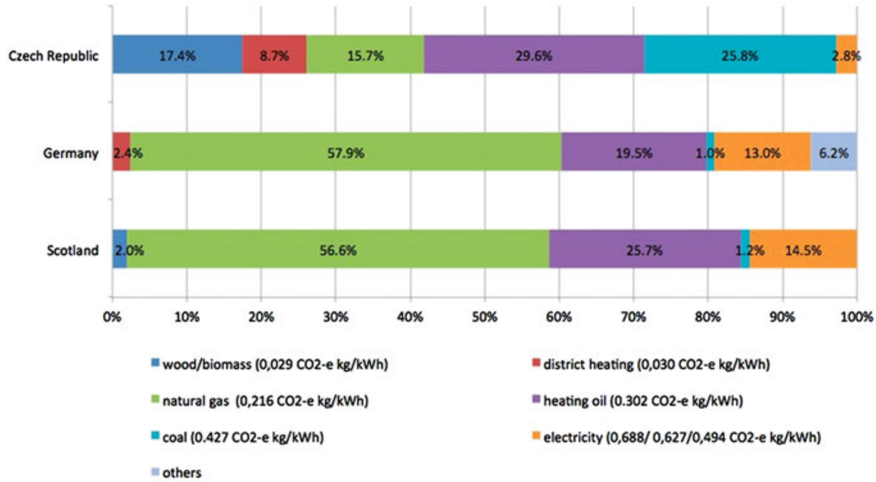

Fig. 5 Share of primary energy *sources* used for heating in the different countries (2011, in tons CO_2-e per year per capita), in *brackets* the emission factors of each heating source based on Klimaktiv 2.0 are presented (Klimaktiv n.d.). Coal emission factors depend on the use of coal or lignite. *Note* The emission factors of electricity depend on the country's electricity mix (see Table 4)

Table 4 Country's emission factors for electricity (2010), additionally the emission factor for green electricity based on Gemis 4.5 (Öko-Institut, n.d.)

German electricity mix	CO_2-e kg/kWh	0.627
Czech electricity mix	CO_2-e kg/kWh	0.688
UK electricity mix	CO_2-e kg/kWh	0.494
German green electricity	CO_2-e kg/kWh	0.04

4.2 Electricity

Electricity related emissions are highest in the Czech Republic, and nearly similar in the German and Scottish sample. This again not only reflects the quantity of electricity consumed (which in turn depends on the number and efficiency of appliances, as well as of consumer behavior), but also the energy mix of the respective countries (Table 4). The support for green energy would be a helpful measure to reduce household GHG emissions from electricity, as well as the spread of feed-in tariff systems. The German samples' mean electricity emissions are actually lowered quite substantially by the 19 % of the respondents that obtain electricity from green energy providers—compared to 8 % in the Scottish and only 0.3 % in the Czech case.

4.3 Car Use

By driving, the German and the Scottish respondents emit significantly more CO_2 than the Czech respondents. While in the more Western countries car related emissions exceed those of electricity, it is the other way around in Czech Republic. Looking into some of the direct determinants of the car related CO_2 emissions (Table 5) we can see some of the differences between the countries.

In Scotland there are few people without a car, but the car owners tend to drive a little less than their German counterparts. So overall the CO_2 emissions between these two case studies are quite the same. The Czech respondents on the other hand quite often do not own a car and if they have a car there is a rather high share of people who tend to drive it little (under 5,000 km annually), which is probably due to high gas prices. Interestingly, the Czech and German respondents use overall similar types of cars, very few consider their car an upper class car. In the Scottish sample the share of upper class cars is considerably higher.

4.4 Air Travel

Air travel is a very sensitive point in the household carbon footprint: one single long-distance flight may easily dominate the overall carbon footprint of an—

Table 5 Country differences in car owner ship and estimated number of km in the last 12 months (2011)

	Czech Republic	Germany	Scotland
Car ownership			
No car	18 %	9 %	8.6 %
Type of car			
Compact car	32 %	30 %	24 %
Medium sized car	64 %	66 %	61 %
Upper class car	4 %	4 %	15 %
Km in the last 12 months			
Mean km and standard deviation	11,328 (SD = 8,871)	13,854 (SD = 9,976)	12,900 (SD = 6,631)
5,000 km or less	29 %	15 %	12 %

Table 6 Country differences in the use of air transportation (2011)

	No flights (%)	Short flights (about 500 km) (%)	Medium distance flights (within Europe) (%)	Intercontinental flights (%)
Czech Republic	89	0	11	2
Germany	70	4	28	7
Scotland	54	21	30	20

Sums can be larger than 100 % due to multiple responses

otherwise—low-carbon household. In our case, the Scottish households have the largest footprint. As shown in Table 6 very few of the Czech respondents traveled by airplane in 2011. In Germany the number is also not very high, flights within Europe are most common. The Scottish respondents on the other hand use air travel fairly frequently, for short and long distances alike. This maybe due to the island position rather expensive train or ferry services in Scotland, combined with limited infrastructure in the Northern Scottish region.

4.5 Food

The countries' samples do not differ much regarding their mean food emissions, with Czech respondents at an average of 1.67 tons of CO_2, Scottish 1.58 tons and Germans 1.62 tons. Meat consumption as well as "alternative", lower emission products are consumed to a similar extent.

Table 7 Comparison of mean per capita CO_2-e emissions (in tons per year per capita) resulting from public transport and car usage in the German and Czech sample (2011)

	Czech Republic	Germany
Car emissions	0.9	1.4
Public transport emissions	0.1	0.04

4.6 Public Transport

The public transport domain is one where an increase of emissions would be seen as a positive shift, as this in large parts would reflect a modal shift away from the car. Interestingly, emissions from public transport are higher in Czech Republic, while in German the share of public transport emissions is minimal compared to the amount of car emissions. See Table 7.

5 Urbanity and CO_2 Emissions

5.1 Descriptive Results

Urbanity has been shown to be an important factor for the size of a household‘s CO_2 emissions. Looking into the urban and rural data separately should explain more of the variation in CO_2 emissions, especially regarding the different energy sources for heating, but also differences in car emissions, supposedly. Figure 6 shows the different emissions in urban and rural settlements.

In the German and Czech case study the rural areas have a larger footprint of about 0.8 tons, in the Scottish case the difference is bigger (1.2 tons). Evidently, in Germany and Scotland this difference mostly reflects higher heating emissions in rural areas and to a lesser extend also higher car emissions. When differentiating between rural and urban respondents it can be seen that especially the Scottish rural respondents tend to have very large CO_2 footprints. But also the urban Scottish respondents have a higher CO_2 footprint than their German counterparts, mainly because their more frequent use of flights.

The amount of air travel also distinguishes the German rural and urban households: in the rural area 83 % of the respondents did not fly while in the urban part it is much more common, almost every second respondent used a plane in the year preceding the survey (46 %).

In contrast the Czech rural and urban respondents only differ noticeably regarding their electricity emissions. This difference has to do with rural households heating water very often with electric boilers: 64 versus 32 % in the city. Another, smaller share of rural households also uses electricity and wood to heat up water (16 %). Contrary to that, the urban households’ warm water is often provided by the central heating station (i.e., district heating: 54 versus 1 % rural

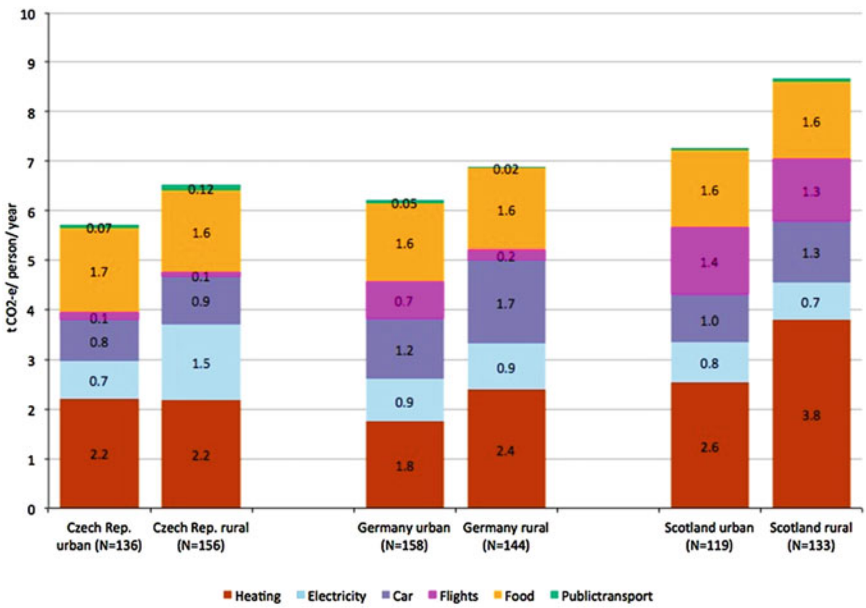

Fig. 6 Comparison of mean urban/rural CO_2-e emissions (per capita per year) for each country in the different energy domains (2011)

households). Their warm water emissions are thus included in the heating category, by that raising the urban heating emissions. Surprisingly car emissions are almost equal across the Czech rural and urban sites. The emissions from public transport suggest, that the Czech rural households are apparently not as dependent on the car as the rural households in the other countries. So the higher emissions from public transport compared to Germany mostly result from the frequent usage of public transportation of the Czech rural respondents.

5.2 Multivariate Analysis on Sectoral Emissions

In the German and Czech case, again, only structural factors turn out to be significant predictors for sector specific CO_2 emissions, with the exception of food emissions in Germany: food emissions in Germany and Scotland are barely explained by the first model—taking into account only structural factors—it improves significantly when horizontal lifestyle aspects are added. Sustainable consumption preferences (SCO: −0.29***; GER: −0.13*) and ecological awareness (GER: −0.20**) play a moderate role to explain food emissions, especially in Scotland. In the Scottish case lifestyle aspects also have a significant influence on flight and electricity emissions: flight emissions are negatively influenced by thriftiness ($\beta = -0.15$**) and sustainable consumption (−0.17**), and positively by hedonistic values (0.18**). CO_2 emissions by electricity are also negatively influenced by sustainable consumption preferences, albeit weakly (−0.10*).

Interestingly the results on Czech food emissions are very different from the Scottish and German ones: seemingly regardless of values and preferences Czech men tend to have higher food emissions (−0.19**), while older respondents (−0.20**) and respondents that live in households with more people (−0.24***) emit less by their nutrition. Gender also plays a role with regards to car emissions: Czech and German men tend to have a higher fuel consumption than women (CZ: −0.26**; GER: −0.15**); in the Czech case gender is actually the only variable that shows a significant effect on car emissions.

In Scotland on the other hand, car emissions are influenced by living in the rural area (0.21**) and by household size (−0.36***), but also by equivalent income (0.19**). Again, only in Scotland and Germany a relationship between income and emissions—in this case car emissions—is apparent (SCO: 0.19**; GER: 0.20***). It is quite astonishing that income has seemingly little influence on fuel consumption in a country with high fuel prices like the Czech Republic. The same pattern arises regarding flight emissions: while income does not explain flight emissions in the Czech case, in Scotland and Germany it explains flights moderately to very well (GER: 0.27**; SCO: 0.36***).

The respondent's age plays a rather different role in the three samples. In Germany older people use more heating energy (0.28***) and have considerably lower car emissions (−0.41**). This kind of "trade off" adds up to an average CO_2 footprint for older people (cf. Table 3). In Scotland, however, older respondents by trend have a higher CO_2 footprint, because they use noticeably more heating energy (0.31***) and electricity (0.14*).

The factor 'type of house' has an decisive influence on heating in Germany (−0.30***), less so on electricity (−0.16**), but also on car mobility (−0.14*). In Scotland it is not a significant factor—maybe an effect of the undifferentiated response categories "flat" and "house". In Czech Republic it has a strong effect on electricity (−0.41***), but—astonishingly—not on heating.

Summing up, equivalent income, household size and the urban or rural region are overall the strongest predictors: they have moderate effects on overall and sector-specific emissions, especially in Scotland. This also holds true for Germany, but here the type of house is more decisive for the CO_2 emissions than the rural location. In Scotland also education and age are important predictors for housing emissions. In the Czech case, on the other hand, equivalent income and education do not represent significant influences, while gender differences are quite important when it comes to food and car transportation. Lifestyle aspects in most cases do not help to explain the level of emissions. However, in Germany and Scotland they serve better to explain food choices than socio-demographic variables, and in Scotland they also help to understand flight emissions, electricity consumption and even the overall CO_2 footprint.

6 Conclusions

In this paper we focused on household emissions and managed to include direct, indirect, and even some embodied emissions (food). However, we had to set aside business travel, indirect emissions from the public sector, and emissions embodied in other consumer goods. Also regarding the little variance in food emissions, further research on product carbon footprints and more precise proxies on food consumption are necessary.

While the differences in carbon footprint across the case studies reveal an income gradient, the proximity of Czech emissions (6.1 t) to those of Germany (6.7 t) is surprising regarding the wide income gap. Conversely, the Scottish and German case study shows only slight differences in average income, but their mean carbon footprint diverges considerably. As shown there are other influencing factors on different levels—different contextual factors, such as the respective energy mix of a country, the availability of public transport, the urban form, household structure and socio-demographic characteristics and potentially also individual attitudes. Hence, in this paper we shed some light on on the overall relations between structural factors and private carbon footprints in different EU countries.

Using the lifestyle concept does in some instances increase the explanatory power of social science models analyzing energy use and carbon footprints of societies. However, we find the lifestyle concept even more important when it comes to explaining behavioral and wider social change. Change as an intentional project requires the involvement of the actors' values and social interactions. It thus is very helpful to choose a segmentation strategy that includes values. As a rule, people with higher incomes tend to have higher carbon footprints, pointing to the need of a de-coupling of growth and GHG emissions. Nevertheless, there are 'rich' households in Europe living on a carbon footprint of 3–5 tons. It is not a lack of income that shapes their behavior, but a range of factors, apparently some form of voluntary simplicity when it comes to energy use and climate protection.

These people might eventually serve as examples and multipliers of a low carbon lifestyle. They bear the potential for being positive role models for a wider social transformation to a low-carbon society, as they combine social status with relatively low carbon footprints. And it is not the need for de-coupling growth from emissions, but a deliberate stance or lifestyle that they actually exemplify.

Lifestyles include choices, but also contextual constraints. Energy systems, infrastructures, the urban form influence lifestyles, and lifestyles shape their built and technological environment. Our findings support the view that there is no choice between 'lifestyle politics' and 'infrastructure politics'. In fact, the two are closely interrelated. If Europe should become a green Economy, it will only be possible if we re-direct public and private investments in a way that carbon–neutral will emerge, but also by propagating and supporting greener lifestyles of these cities' dwellers. Without the support of the built environment and public institutions, individual households will find it hard to translate their pro-environmental preferences into real behavior, and without supporting attitudes and behaviors green cities will neither come about nor function.

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Corinna Altenburg is a social scientist with a background in European Studies and Environmental Management. In her dissertation project at the University of Potsdam she compares two urban regions in the United States and in Germany and focuses on the inter-linkages between climate mitigation and adaptation, multi-level governance and civil society participation. She currently works as a research fellow at the newly-founded chair of "Management of Regional Energy Systems" at the University of Applied Sciences Lausitz, Germany

Assessment of Urban Heat Island and Mitigation by Urban Green Coverage

Dong Chen, Xiaoming Wang, Yong Bing Khoo, Marcus Thatcher, Brenda B. Lin, Zhengen Ren, Chi-Hsiang Wang and Guy Barnett

Abstract Urban heat island (UHI) is a growing threat to human well-being and poses increasing pressure on urban utility infrastructure, especially during summer months. This study examined the UHI in Melbourne using remote sensing imagery from MODIS to derive land surface temperature (LST) for the summer of 2009. Then, the potential of urban green coverage in reducing extreme summer temperatures in Melbourne was investigated using an urban climate model for 2009 and for projected 2050 and 2090 future climates. Modeling results showed that the average summer daily maximum (ASDM) temperature differences between Melbourne CBD, suburbs and rural areas were in the range of 0.5–2.0 °C. It was also found that despite the projected climate warming in 2050 and 2090, the cooling benefit in terms of the reduction in the average summer daily maximum temperature due to various urban forms and vegetation schemes remains similar to that estimated for 2009. Thus, the cooling benefit due to various urban forms and green schemes in future climates can be reasonably projected based on the benefits identified with the present-day climate.

Keywords Urban heat island · Green coverage · Climate change · Urban climate model · Remote sensing · Land surface temperature

1 Introduction

The Australian landscape is becoming increasingly urbanized with around 85 % of Australians living in urban areas and 64 % in the eight capital cities (DSEW-PaC 2011). Although the percentage of the urban population has only increased slightly from several decades ago, the total Australian population has doubled in the

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past 50 years. This rapid population growth has led to extensive urban and suburban development and an increase in the density of housing and other urban infrastructure.

The transformation from native landscape to engineered infrastructure leads to increased heat generation from anthropogenic activities and heat accumulation due to massive heat absorption and storage of radiative heat by roads, buildings and other urban infrastructure. This results in higher temperatures in urban areas in comparison with rural areas, a phenomenon known as the urban heat island (UHI) effect. High ambient temperatures and humidity affect the livability and sustainability of our cities, especially during the summer. The most recent heat wave event in Melbourne in January 2009 may have resulted in an estimated 374 excess deaths over what would normally be expected: a 62 % increase in total all-cause mortality and 8 fold increase in heat-related presentations to the emergency departments (DHS 2009).

Melbourne has a temperate climate with warm to hot summers, mild and sometimes balmy springs and autumns, and cool winters. In 2009, it had one of the hottest summers since the commencement of records from mid-1800. In January 2009, Melbourne experienced a record heat wave with three consecutive days over 43 °C. On 7th February 2009, it recorded the hottest day with its maximum temperature reaching 46.4 °C in CBD.

Urban summer heat accumulation is likely to be further exacerbated with global warming. Climate change projections for Australia suggest an increase in the number of warm nights and heat waves which can pose significant threats to human health (Alexander and Arbalster 2009). The dual pressures from the increasing UHI effect and climate change present enormous environmental challenges which require urgent collaborative efforts and measures from governments, industries and communities.

One strategy to mitigate the UHI effect is the "cool cities" concept (Luber and McGeehin 2008). The "cool cities" strategy reduces the urban heat island effect by promoting tree planting to shade buildings, to cool the ambient temperature through evapotranspiration of vegetation and using reflective roofs and paving surfaces to reduce the heat accumulation due to solar radiation. These "cool cities" strategies, at the same time, reduce the cooling energy consumption of residential and commercial buildings and thus reduce green house gas (GHG) emissions. In this study, the potential of urban vegetation in mitigating UHI in Melbourne was investigated by analyzing remote sensing imagery for the summer of 2009 and by using an urban climate model to predict urban temperature changes under various urban vegetation schemes for the 2009 climate and projected future climates in 2050 and 2090.

2 Assessment of UHI During the 2009 Summer in Melbourne

The assessment of UHI during the summer of 2009 in Melbourne used the MYD11A2 data product from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua satellite, which captures images once every eight days at 1 km spatial resolution. The images were converted to rasters using U.S. Geological Survey (USGS's) MODIS Reprojection Tool.

Figures 1 and 2 show the estimated daytime and night time land surface temperatures (LSTs) in Melbourne during the summer of 2009 derived using the averages of 12 daytime and 12 nighttime MYD11A2 images from December 2008 to February 2009. Day and night LSTs extracted from MYD11A2 images (2002–2011) at six locations in Victoria (Melbourne Airport, Werribee, Carrum Downs, Brighton, Aspendale, and Queenscliff) were compared with the average of eight days of measured maximum and minimum temperatures provided as part of the SILO climate data (Jeffrey et al. 2001). The results showed high levels of correlation ($R^2 > 0.70$) between the measured temperatures and those derived through remote sensing. In general, Melbourne and the surrounding urbanized areas experienced higher average LSTs compared with rural areas (about 20 °C and 10 °C for daytime and nighttime LSTs respectively) during this period. Figure 2 depicts the extent of higher nighttime LSTs to be clearly overlap with urbanized areas of Melbourne metropolitan areas as well as more densely populated town centers such as Geelong (to the south–west of Melbourne). Furthermore, areas near the coast had lower LSTs during the day but higher LSTs during the night as a result of evaporation, higher specific heat capacity and low solar absorptance of water relative to land-based areas. High nighttime LSTs were observed at the forest regions to the east, south west and west of Melbourne. Similar findings were reported by van Leeuwen et al. (2011) when they analysed LSTs in forest areas in Mato Grosso, Brazil. The high nighttime LSTs were believed to be due to nocturnal drainage of air from upper canopy layers and pooling of cold air at the forest floor keeps upper levels of the canopy relatively warm. On the other hand, high daytime LSTs to the west of Melbourne (Fig. 1) may be due to bare agricultural land and low soil moisture (as a result of

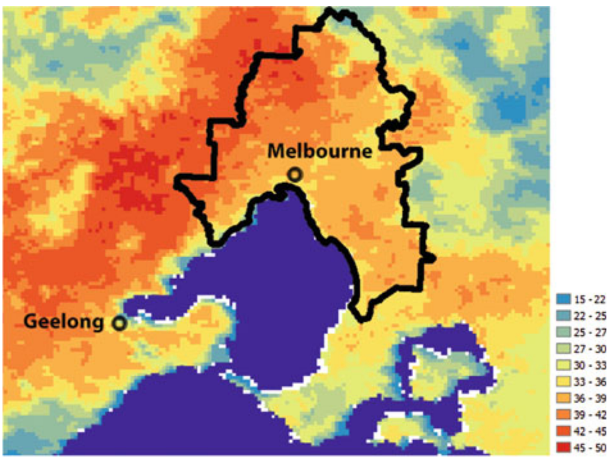

Fig. 1 Average daytime LST in degree celsius during the summer of 2009 at about 1600 h

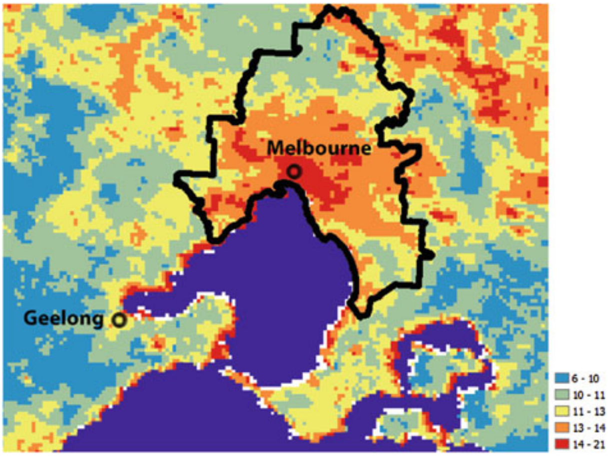

Fig. 2 Average night time LST in degree Celsius during the summer of 2009 at about 0300 h

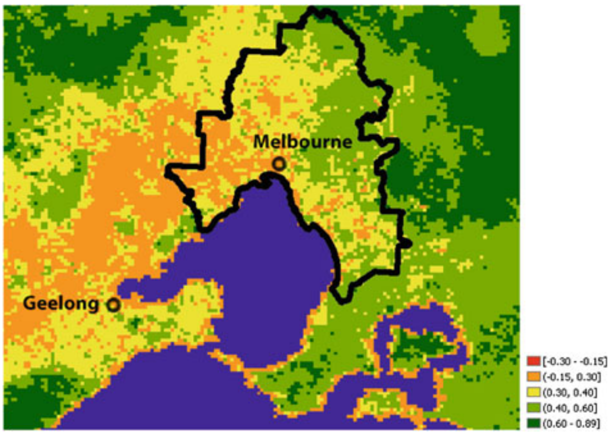

Fig. 3 Average NDVI during the summer of 2009

evapotranspiration) after a long drought period during the summer of 2009, indicated by low Normalized Difference Vegetation Index (NDVI) values in Fig. 3. NDVI is an estimate of the photosynthetically absorbed radiation over the land surfaces. High NDVI is an indication of abundance of live vegetation in the target area.

To further investigate the relationships between LSTs and the land use, information of NDVI and the distance to the nearest water body from 1,000 randomly selected grid cells (1 km × 1 km each) within the study region were extracted from the MYD11A2 data product. The percentage of urban infrastructure for each cell was also derived based on the Landsat TM 5 image taken on 6 November 2009 via Principal Component Analysis (Lillesand et al. 2008) and refined using Maximum Likelihood Classification (Lillesand et al. 2008).

Figure 4a and b show the relationships of average daytime and nighttime LSTs against NDVI. As shown in Fig. 4a, the average daytime LSTs can be significantly lower in areas where healthy vegetation is more abundant. On the other hand, vegetation appears to have relatively low impact on the average nighttime LSTs as shown in Fig. 4b. The trend is similar to what has been identified in other studies (Sun and Kafatos 2007). It can be considered as less evapotranspiration during the nighttime that would have cooled the land surface. Figure 4c and d show the relationships of average daytime and nighttime LSTs against the distance to the nearest water body. In general, average daytime LSTs are higher in areas that are further away from the nearest water body while there is no clear trend in average

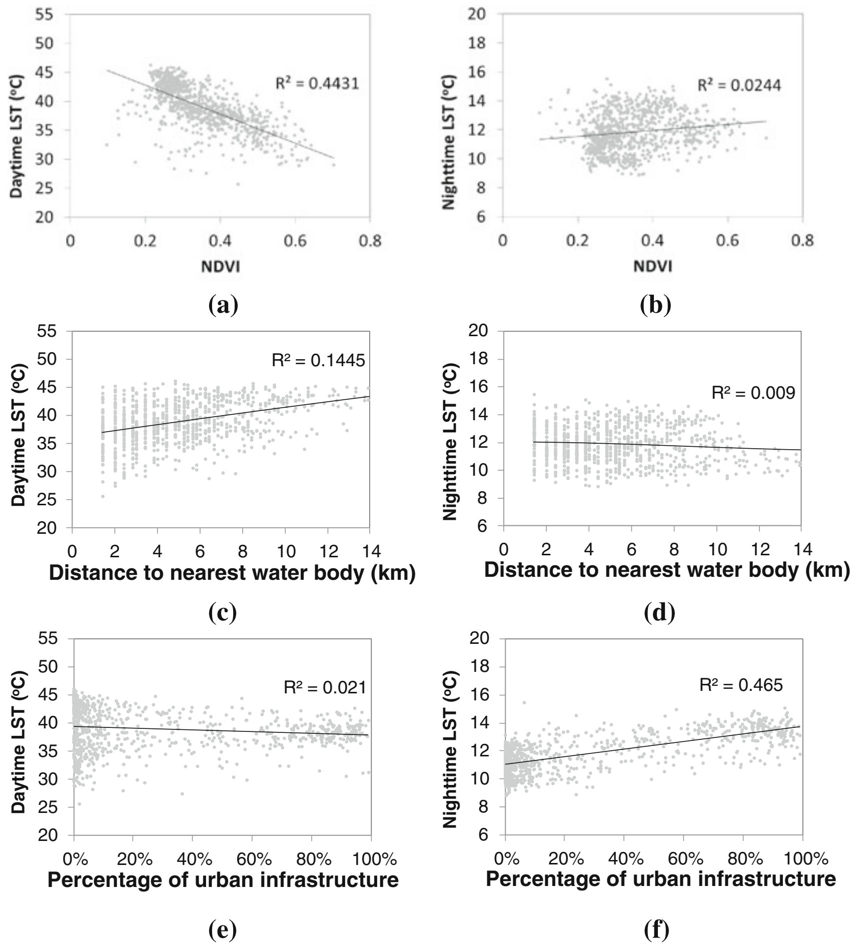

Fig. 4 Relationship between LSTs and land surfaces

nighttime LSTs. Figure 4e and f show the relationships of average daytime and nighttime LSTs against the percentage of urban infrastructure. Increase in the percentage of urban infrastructure appears to be correlated with higher average nighttime LSTs. It is due to the significant thermal mass factor of the built environment. However, there is no clear trend in the average daytime LSTs.

The assessment for the summer of 2009 in Melbourne shows that healthy vegetation coverage can be an effective measure for reducing UHI. Therefore, the following investigation will specifically focus on the improvement of urban climate via vegetation by proper urban planning.

3 Mitigating UHI by Urban Green Coverage

As shown above, healthy vegetation coverage can significantly reduce daytime LSTs, which can in turn result in lower maximum local ambient air temperature, though it could also be affected by urban forms and other environment parameters. Maximum local ambient air temperature is the major index for summer heat stress and is closely related to the peak electricity usage due to the requirement of air conditioning. To further quantify the potential of urban vegetation in mitigating UHI, a recently developed urban climate model (UCM-TAPM) (Thatcher and Hurley 2012) was used to investigate the impact of urban vegetation on ambient air temperature. The UCM-TAPM is a PC-based prognostic meteorological model which couples an urban canopy model based on the Town Energy Budget (TEB) model with a meso-scale climate model TAPM (Hurley et al. 2005) developed in CSIRO.

The UCM-TAPM uses fundamental prognostic equations for the conservation and continuity of momentum, turbulence, heat and moisture to simulate winds, potential temperature and specific humidity. It includes physical parameterisations for cloud microphysics (water vapour, cloud water, cloud ice, rain and snow) and radiation. The UCM includes an efficient big-leaf model to represent in-canyon vegetation in the predominately suburban component of Australian cities. The meteorological component of the model is nested within synoptic-scale analyses/forecasts that drive the model at the boundaries of the outer grid. The model employs a multiple one-way nesting procedure to dynamically downscale meteorological reanalyses, typically in steps of 30, 10, 3 and 1 km. In the UCM-TAPM, a 1 × 1 km grid tile of the land surface, for example, can be assigned one of 39 surface types that include a wide range of natural and built surface types (e.g. snow, water body, forest, shrub land, grassland, pasture, littoral, CBD, urban, and industrial). The characteristics of the surface types such as the average building height, building height to street canopy width ratio, vegetation coverage, leave area index, surface Albedos etc. can be adjusted for specific urban conditions. The UCM-TAPM model has demonstrated good capability in urban scale climate modelling for Australian cities (Thatcher and Hurley 2012).

Simulations were carried out for 2009 using UCM-TAPM with reanalysis climate data downscaled from National Centre for Environmental Prediction (NCEP) by replacing the Melbourne CBD areas with various urban and vegetation schemes as listed in Table 1. The vegetation and building coverage ratios of the generic urban type in Table 1 were based on measurements by Coutts et al. (2007). In Table 1, the summer maximum temperature is the predicted average summer daily maximum temperature (ASDM temperature) over December, January and February. In calculating the ASDM temperature reduction, the existing CBD is taken as the reference urban form.

Considering the ASDM temperature, the following can be found in Table 1:

1. Suburban areas are around 0.5 °C cooler than the CBD;
2. Leafy suburban areas may be around 0.7 °C cooler than the CBD;
3. Parkland (such as grassland, shrub-land and sparse forest) or rural areas are around 1.5–2 °C cooler than the CBD;
4. Doubling the CBD vegetation coverage may reduce the ASDM temperature by 0.3 °C;
5. 50 % green roof coverage of the CBD area may result in 0.4 °C ASDM temperature reduction;
6. ASDM temperature reduction of around 0.7 °C may be achievable by doubling the CBD vegetation coverage and 50 % green roof coverage in the CBD area.

Morris et al. (2001) reported an average UHI effect of around 1.3 °C for Melbourne summers between 1972 and 1991. Simulation studies by Coutts et al. (2008) also showed that the daytime UHI is between 1 and 2 °C. By

Table 1 Predicted ASDM temperature in 2009 with various vegetation schemes

Urban type	Vegetation coverage (%)	Green roof (%)	Building coverage (%)	Irrigation	ASDM temp (°C)	ASDM temp reduction (°C)
Forest (low sparse)	100	0	0	No	25.7	−2.1
Shrub-land	100	0	0	No	25.8	−1.9
Grassland	100	0	0	No	26.1	−1.7
Urban (leafy)	49	0	40	Yes	27.1	−0.7
Urban (generic)	38	0	45	Yes	27.3	−0.5
CBD (reference)	15	0	65	Yes	27.8	0
CBD (with 1/3 vegetation)	5	0	65	Yes	27.9	0.2
CBD (Double vegetation)	33	0	58	Yes	27.5	−0.3
CBD (50 % green roof)	15	50	65	Yes	27.4	−0.4
CBD (double vegetation +50 % green roof)	33	50	62	Yes	27.1	−0.7

reviewing a number of observation studies, Bowler et al. (2010) summarised that, on average, an urban park would be around 1 °C cooler than a surrounding non-green site, while 2.3 °C cooler was reported when compared with a town or city further away. Therefore, a difference of 0.5–2 °C in the ASDM temperatures between Melbourne CBD, suburbs, and rural areas is reasonable.

In modeling the benefit of vegetation under future Melbourne climate scenarios, the current Melbourne metropolitan boundary was assumed to be maintained in the next several decades. Future Melbourne climate was projected based on the A2 scenario using a coupled atmosphere–ocean general circulation model (AOGCM), GFDL2.1 (IPCC 2000). The IPCC suggested that due to the varying sets of strengths and weaknesses of various AOGCMs, no single model can be considered the best. Therefore, it is necessary to use multiple models to take into account the uncertainties of models in impact assessment. At the time of this study, the only climate model available for UCM-TAPM was GFDL2.1. Considering that the current study focuses on the relative impact of vegetation on local climate, the selection of a particular climate model may not significantly affect the modeling results.

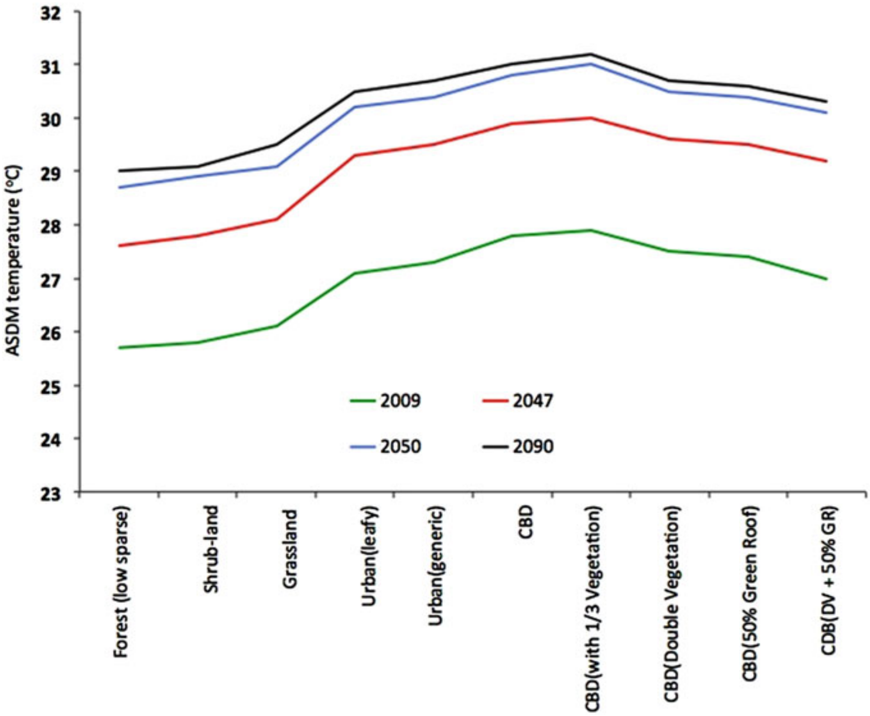

Fig. 5 Predicted ASDM temperatures in 2009, 2047, 2050 and 2090 for different urban forms and vegetation schemes in Melbourne

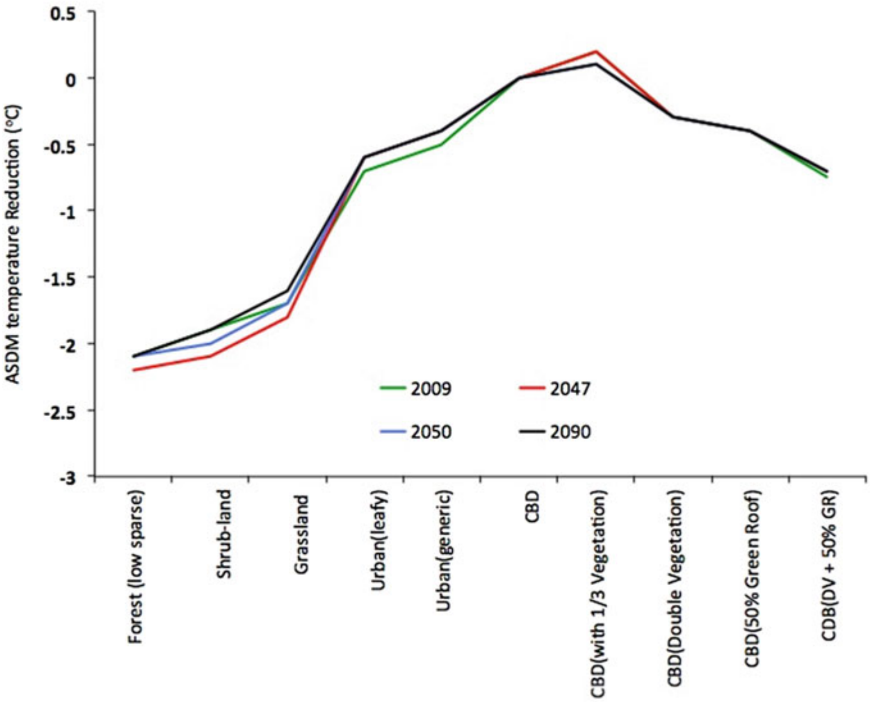

Fig. 6 Predicted reductions in the ASDM temperature in 2009, 2047, 2050 and 2090 for different urban forms and vegetation schemes in Melbourne

Simulations were carried out for years 2047, 2050 and 2090 by replacing Melbourne CBD areas with the urban and vegetation schemes detailed in Table 1. The predicted ASDM temperatures and the reductions in the ASDM temperatures relative to the CBD urban form in Table 1 for the year of 2009, 2047, 2050 and 2090 are compared in Figs. 5 and 6, respectively. Usually ten year simulations would be performed to estimate the climatology and the vegetation impact centered on 2050 and 2090. In this study, single simulation years such as 2047, 2050 and 2090 were used as random samples of the predicted future climates to demonstrate the cooling potentials by various vegetation schemes under global warming.

From Figs. 5 and 6, it was found that although Melbourne is projected to be warmer in 2050 and 2090, the relative impacts on the ASDM temperature due to various urban forms and vegetation schemes in any particular future year are projected to be similar to those in 2009. This is reasonable considering that the relative cooling effect of vegetation is mainly determined by vegetation types, shading and evapotranspiration. Since the current study assumes that the vegetation does not dry out with irrigation, the variation in rainfall, humidity, solar radiation and wind speed etc. for different years in the future may have some, but not significant, effect on the evapotranspiration rate and thus the cooling effect from vegetation. During this study, reanalysis and GFDL2.1 projected climate data were used for 2009 and future Melbourne climate respectively. The similar relative impact on the ASDM temperature due to various urban forms and vegetation schemes suggests that the selection of a particular climate model may not significantly affect the modeling results. Further modeling study is required to confirm this finding.

4 Conclusions

Analysis of remote sensing imagery in Melbourne in the summer of 2009 showed that healthy vegetation can significantly reduce daytime land surface temperatures, which can in turn result in lower maximum local ambient air temperature. The potentials of urban green coverage in reducing extreme summer temperatures in Melbourne were further investigated using an urban climate model for 2009 and for projected 2050 and 2090 future climates. Modeling results showed that the cooling benefit of various urban forms and vegetation schemes may be in the range from 0.3 °C by doubling the CBD vegetation coverage to around 2 °C with large parklands. It was also found that although Melbourne is projected to be warmer in 2050 and 2090, the relative cooling benefit of urban vegetation will not change significantly. Thus, the cooling benefit due to various urban forms and green schemes in future climates can be reasonably projected based on the benefits identified with the present-day climate.

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Urban Climate Change Mitigation in Mexico City: Innovative Solutions in Municipal Wastewater Treatment Plants

K. Peña Muñoz

Abstract Mexico City's Metropolitan Area (ZMCM) is the third largest mega city in the world (INEGI 2010). Mexico City is also a signatory of the Global Cities Covenant on Climate and the Carbon Cities Climate Registry, suggesting that Mexico City and its ZMCM must consider national mitigation and adaptation strategies (SMADF 2008). A good opportunity is located in Wastewater Treatment Plants (WWTPs). Until 2009, only 9 % of the Wastewater produced at ZMCM was treated at (WWTPs) while the rest was discharged into surface waters (SEMARNAT 2009). A WWTP is an essential public service that simultaneously consumes a large amount of energy and produces a significant amount of by-product such as sewage sludge. In ZMCM, sludge is disposed in landfill, contributing to the green house gas emission of the area. However, there is an excellent conservation potential in WWTP which includes anaerobic digestion of sludge for biogas production as a renewable source of green energy. Additional optimization of different processes and services at WWTPs could be reached by implementing a pre-treatment of sludge and a two-stage anaerobic digestion, which could increase the total yield of bio-methane-hydrogen. Moreover, hydrogen has the highest energy content per unit weight of any known fuel (Das 2009). This is particularly interesting, as there are additional socio-economic benefits of using bio-hydrogen as a source of green energy. This chapter explores the benefits of implementing pretreatments and anaerobic digestion of sewage sludge in WWTP in ZMCM and highlights the environmental framework for wastewater treatment and green energy production.

Keywords Anaerobic digestion · Climate change · Green energy · Mega-city · WWTP

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1 Introduction

Mexico City has 8,851,080 habitants, but Mexico City's Metropolitan Area (ZMCM) has a population of over 20 million, making it the third largest Megacity in the world, just behind Tokyo and Seoul (INEGI 2010). This Megacity includes the 16 boroughs (*delegaciones*) of Mexico City, 40 municipalities of the State of Mexico and one conurbation municipality of the State of Hidalgo (INEGI 2010). Moreover, the ZMCM is located in a geographical sensitive area where earthquakes, floods and thermal inversion are significant natural conditions that increase the vulnerability of its population. This Megacity provides shelter to approximately 22 % of the Mexican population (INEGI 2010). Therefore, it is important that the scientific community, investors, relevant stakeholders, urban planners and policy makers are brought together in a way that the interaction between them improves the understanding of the environmental problems that this megacity faces.

Indeed, Mexico has been favoured with the North American Free Trade Agreement (NAFTA) through several USAID's environmental programs. These programs focus on improving the management of natural resources for a better understanding and implementation of key environmental commitments towards Climate Change mitigation.

Mexico City itself is a signatory of the Global Cities Covenant on Climate (Mexico City Pact), a voluntary initiative of mayors and local authority representatives that aims to advance climate actions. By signing the Pact, signatories commit to 10 action points, including the reduction of emissions, adaptation to the impacts of climate change and fostering city-to-city cooperation (WMCCC 2010). In response to these initiatives, in 2007, the Green Plan was launched in order to address several environmental challenges and to ensure that Mexico City's government promotes environmental policies. It has seven pillars: soil conservation, housing and public space, water supply, mobility, air pollution, climate change and energy, and waste management (SMADF 2008).

Further, the Environmental Ministry of Mexico City has established the Climate Change Effect Action Plan (2008–2012), which considers five main topics: Transport, Water & Waste, Adaptation-Communication, Energy and Environmental Education (SMADF 2008). Parallel to these actions, the government of the State of Mexico has given high priority to municipalities that belong to the ZMCM. To this affect, the Environmental Ministry of the State of Mexico has implemented the Climate Change Program, Air Quality Control Program and Waste Management (SMADF 2008).

In sum, these are only a few examples reflecting that any type of action becomes significantly more effective when the federal, state government, municipalities and different sectors participate in a transversal policy strategy.

The ZMCM is also ready to face the "green energy revolution." A good opportunity has been pinpointed at Municipal Wastewater Treatment Plants (WWTPs) located in ZMCM. In general, a WWTP is an essential public service that consumes a large amount of energy. It is mandatory that each Municipality in Mexico has several WWTPs to guarantee the protection of surface water. Nevertheless, the cost involved in the operation and maintenance of any WWTP is very high. The main operation costs include: (a) the "electricity" for the operation of the site; and (b) the "disposal of by-products" (e.g. Sludge). This situation directly impacts the annual budget of many Municipalities, causing the stoppage of the WWTP operations, with a difficult decision of when to restart it. However, WWTPs offer an excellent conservation potential through the use of biogas in situ for generating heat and electricity. This electricity could potentially be introduced into existing operations or into the electrical network. On one hand, each cubic meter of biogas contains a calorific value equivalent to 5–7.5 kWh, if the biogas produced has a composition of methane between 50 and 75 % (BELV 2010). Biogas refers exclusively to the use of methane as sole source of fuel. Additionally, methane is related to Green House Gases (GHG) emission when it is incinerated rather than used in cogeneration systems. On the other hand, bio-hydrogen has been gaining more importance, since it has the highest energy content per unit weight of any known fuel, which corresponds to 120.21 MJ/kg; while the energy content of methane is only 50.2 MJ/kg (Das 2009). This is of particular interest since there are additional technical, socio-economic and environmental benefits to using bio-hydrogen. For example, it is easily transported for domestic/industrial consumption through conventional means, it is safer to handle than domestic natural gas, it is universally accepted as an environmentally safe and renewable energy resource, it is an ideal substitute for fossil fuels, and it does not contribute to the GHG emissions (Das 2009).

Some up-to-date applications of hydrogen are in the use of hydrogen fuel cells in combination with internal combustion engines, or in stationary back-up systems when operated with reformers for on-board conversion of other fuels. These can save energy and reduce air pollution, especially in congested urban traffic (European Commission 2003). In addition, fuel cells provide efficient and clean electricity generation from a range of fuels. Some benefits of hydrogen in fuel-cell systems are very low to zero carbon emissions and no emissions of harmful ambient air substances like nitrogen oxides, sulphur dioxide or carbon monoxide (European Commission 2003).

It is a reality that alternative fuels have to take over the market and new technologies need to be developed. However, developing a standard for the sustainability of bio-fuels has become a hindering factor for world free trade (WEC 2010). In addition, an incorrect or incomplete technology transfer could impact the social acceptance of technology and process that could contribute to the reduction of climate change impacts such as the Clean Development Mechanism. Therefore, any technology transfer must consider the socio-economic and political background of the city and the country.

This chapter gives the status quo in Mexico City and its ZMCM, including:

1. An overview of the environmental framework in Mexico;

2. Innovative ideas for the production and use of biogas and bio-hydrogen as a green energy source in situ in WWTPs;
3. Suggestions on how to improve the interaction between the scientific community (scientists researching on biogas/bio-hydrogen), the urban planners, policy makers and other relevant stakeholders for integrating hydrogen and methane in the national renewable energy market.

2 Mexico: Environmental Status Quo

Environmental protection is playing a very important role in the Mexican economy of the 21st Century. The beginning of this trend could already be observed in the early 1970s. At that time, the first environmental law, focusing on restoration of the environmental equilibrium in the Mexican territory, was adopted. Moreover, during this last 40 years, several institutions and a strong Ministry structure have been created with a special focus on environmental protection in Mexico City (Torres Landa Rulfo and Yañez Vega 2011). In comparison to other Latin–American countries, Mexico has some of the most developed environmental legislation. The following sections show the environmental background of this country and the status quos of two areas: wastewater and energy.

2.1 Institutional Framework

In Mexico the environmental policy is determined every 6 years by the National Development Plan (NDP) where the environmental sustainability is one of the main points (Galindo 2010). The Ministry of Environment and Natural Resources of Mexico (SEMARNAT) is the Federal Government's agency in charge of impelling the protection, restoration and conservation of the ecosystems, natural resources and environmental services of Mexico, with the purpose of propitiating their use and sustainable development. It coordinates the environmental policy under the federal level with its federal delegations and local coordination offices. To fulfill this command, SEMARNAT has three secretariats and diverse agencies that are part of the Environmental Federal Sector. Their work is based on four high-priority aspects (SEMARNAT 2010):

- Conservation and sustainable use of the ecosystems and their biodiversity
- Prevention and control of pollution
- Integral management of the water resources
- Climate change mitigation.

SEMARNAT is divided into three secretariats: Planning and Environmental Policy, Management for Environmental Protection and Environmental Regulation. The secretariats support the following decentralized bodies: Federal Delegations, National Water Commission (CONAGUA), National Ecology Institute (INE), Federal Environmental Protection Agency (PROFEPA) and the Natural Protected Areas National Commission (CONANP). Additionally, there are two decentralized bodies: the Mexican Institute of Water Technology (IMTA) and the National Forestry Commission (SEMARNAT 2010).

2.2 Environmental Framework

The first environmental legislation in Mexico appeared in 1971. This legislation was the base for the Federal Law on Environmental Protection of 1982. Furthermore, two important amendments on the Mexican Federal Constitution were done: (a) article 27 which now includes the preservation and restoration of the ecological equilibrium; and (b) article 73 section XXIX-G which gives the Federal Congress the power for creating and applying federal, state and local environmental laws (SEMARNAT 2010).

In January 1988 the General Law for the Ecological Equilibrium and Environmental Protection (LGEEPA) was approved. The LGEEPA addresses ecological policy at a federal, state and municipal level. The three main areas under federal level are: air quality control, hazardous waste, water and wastewater (SEMARNAT 2010). This law marked the first step forward for Mexico and Latin America on environmental legislation and inclusion into international negotiations.

Finally, the states and municipalities were given jurisdiction over their respective territories to handle and implement environmental decisions that fall within their scope of authority and are not otherwise reserved for the federal agencies and branches of government (Torres Landa Rulfo and Yañez Vega 2011).

2.3 Climate Change

A megacity is a metropolitan area with specific characteristics: it is the seat of government power, it has a strong economic activity, the population size is larger than planned and therefore the environmental issues are complex. This is exactly the case of ZMCM, which is the major contributor to the environmental problems of Mexico. In addition, the city's vulnerability to the effects of climate change has become a national security issue. As a result, whatever this megacity does to reduce GHG emissions and to decrease the vulnerability through actions that mitigate climate change impacts is highly significant for Mexico City's inhabitants and the country. For instance, around 88 % of all GHG emissions in the ZMCM are attributed to energy consumption in the form of fossil fuels and electricity used in transportation, industry, trade, housing, or services (SMADF 2008). Nevertheless, it is possible for citizens to live and for the economy to function with a lower output of GHGs if the following steps are taken: grow and improve the public transportation; transform vehicle technology; increase the efficient use of energy in buildings, industrial facilities, public lighting systems, water pumping systems, and homes; exploit new renewable energy sources, like bio-hydrogen; optimize the use of water; reduce waste generation; and promote adequate wastewater and waste management.

Likewise, the outcomes of the Climate Change Conference (COP16) in Cancún include an agreement adopted by the states' parties that called for a large "Green Climate Fund" and a "Climate Technology Centre" towards a second commitment period for the Kyoto Protocol. The conference established the Cancun Adaptation Framework and the Adaptation Committee. It invited Parties to strengthen and, where necessary, establish regional adaptation centers and networks. Concerning mitigation, developed countries should submit annual GHG inventories and biennial reports on their progress, as well as take nationally appropriate mitigation actions in the context of sustainable development, supported and enabled by technology, financing and capacity-building, aimed at achieving a deviation in emissions relative to "business as usual" emissions in 2020 (UNEP 2010).

The Climate Change Effect Action Plan for Mexico City (2008–2012) has set in place public policies and programs designed to improve the quality of life for city residents with the aim to mitigate the GHG emissions and to attain the target for Mexico under the international climate change framework. One of the specific targets on climate change defined for Mexico includes the adoption of renewable energy as well as improving energy efficiency. Both topics are indirectly related to wastewater management as it can reduce the amount of sewage sludge disposed at landfills and also reduce the operating cost of WWTPs through cogeneration of heat and power. This program also proposes new initiatives and actions that are viable for citizens, communities, businesses and government (SMADF 2008). Additionally, a total of 26 GHG mitigation actions have been proposed in the Climate Change Effect Action Plan. If implemented, these will reduce the carbon dioxide equivalent emissions by 4.4 million tons a year, which represents 12 % of the annual GHG emissions in Mexico City. The budget for the implementation of these actions during that term was $56,152 million pesos (SMADF 2008).

2.4 Wastewater

The National Water Commission (CONAGUA) manages the national waters and wastewater through the National Water Law (LNA). This law sets the discharge limits, the conditions for obtaining a discharge permit and develops the infrastructure for the water protection. In addition, the LNA classifies the surface and ground waters in three main groups depending on the water use (SEMARNAT 2010). Furthermore, there are four Mexican norms, which regulate the wastewater discharge and final disposal of bio-solids. Likewise, the Renewable Energy Law was approved in 2008, opening a new chapter on producing green energy in WWTPs, like bio-methane and bio-hydrogen (SEMARNAT 2010; SENER 2010).

The Ministry of Environment and Natural Resources of Mexico (SEMARNAT) reported in 2008 a total of 1833 WWTPs with an installed capacity of 113,024 liters per second (lps). This figure represents 40.2 % of the total volume wastewater generated in Mexico. By the year 2009, this volume increased to 43.5 % (SEMARNAT 2009). In addition, the annual production of bio-solids in 2009 was reported as 640 millions of tons; 64 % of it was sent to landfills and open pits, contributing with GHG emissions (SEMARNAT 2009). One can clearly see two good opportunities for innovative ideas on waste and wastewater management.

One of the most important actions on these topics is reflected in the Sustainable Water Program for Mexico City (PROAGUA) which presents different programs and policies for improving the wastewater management of the city. For instance, the latest report (2007) states that there are 28 active WWTPs; 90 % of these have biological wastewater treatment (conventional) with a maximum installed capacity of 6.65 m^3/s; of which, only 3.65 m^3/s is in use. Few of the WWTPs have tertiary treatment, which represent an extra opportunity for other projects (SMADF 2007). Furthermore, the Municipalities from the State of Mexico, which belong to the ZMCM, have 70 WWTPs with an installed capacity of 1.38 m^3/s; of which, only 1.24 m^3/s is in use. To sum up, there are the 98 WWTP located in ZMCM which treat a total volume of 4.36 m^3/s wastewater. Nonetheless, considering the average water consumption in the ZMCM, which is 150 liters per inhabitant per day (SMADF 2007) the total amount of wastewater is 40 m^3/s (SEMARNAT 2009).

One can clearly see that less than 11 % of the wastewater generated in the ZMCM is treated and the rest of the volume is sent to the Valley of Tula, located 60 km North from ZMCM. This situation had brought a positive mass balance and excess water for its aquifer. The Valley of Tula has been receiving a steady flow of wastewater (WW) from the ZMCM, carrying a considerable amount of suspended inorganic and organic matter, including phosphorus and nitrogen. This has brought some benefit for the Valley of Tula, like becoming a highly productive agricultural district. However, on the other hand, this practice has impacted the water quality of the local aquifer (CONAGUA 2008). Therefore, in 2008 the Mayors of Mexico City, the State of Hidalgo and the State of Mexico signed an agreement on wastewater management which included the construction of the first Mega-WWTP of the country. The Mega WWTP is located in Atotonilco (Hidalgo). The Atotonilco Mega WWTP will start operation at the end of 2012 and will treat 23 m^3/s of wastewater, which represents 57.5 % of the total amount of wastewater produced in ZMCM.

The next challenge for the National Water Commission (CONAGUA) is to find a suitable solution for the 31.6 % (or 12.58 m^3/s) of wastewater that needs treatment. This situation is without considering the fluctuating population and population growth at the city (CONAGUA 2008).

2.5 Energy and Renewable Energy

There are two federal agencies in charge of developing strategies for renewable energy resources—the Ministry of Environment and Natural Resources of Mexico (SEMARNAT) which is responsible for the Environmental Policy and the preservation of renewable and non-renewable resources in Mexico and the Ministry of Energy (SENER), which defines the National Energy Policy and strategies. Some other institutions are the National Commission for Energy Savings (CONAE), which is responsible for promoting energy savings and energy efficiency, and the National Secretariat for Social Development (SEDESOL), which promotes the use of renewable energy in different sectors. These four Institutions are under the federal umbrella of the central government (SENER 2010).

The total energy consumption in Mexico is clearly dominated by an oil based economy (58 %), while less than 5 % of the produced energy is by means of renewable sources (EIA 2012). According to SENER, by the end of 2008, Mexico had an installed electricity capacity of 58 GW distributed as: 75.3 % thermal; 19 % hydro; 2.4 % nuclear (only one nuclear power plant: 1,400 MW); and 3.3 % renewable, other than hydro. In addition, the general trend in thermal generation is declining from a petroleum-based fuel and moving to natural gas and coal.

SENER needs to launch the National Strategy for Energy Transition and Sustainable Energy in order to increase the renewable energy production from 3 to 6 MW by 2012 (SENER 2010). At the moment the program does not give specific targets for the implementation of renewable energies as part of the main grid, but rather promotes the developing of networks, and invests in these technologies.

An example of local level solution is Mexico City's Green Plan which includes the Climate Change Effect Action Plan. In both cases, the Programs deal with a set of local actions that have global repercussions and a set of joint public policies that will be a reference point in both the national and international spheres. Some of the direct actions are energy saving and efficiency measures, the promotion of the use of solar energy, and the promotion of renewable energy sources. For this purpose, the Renewable Energy Law was approved in 2008, establishing a specific and more favourable framework for renewable energy sources and regulating the use of renewable energy sources and clean technologies to generate electricity. It includes the national strategy and instruments for financing the energy transition.

2.6 Summary of Programs for Mitigation and Adaptation in Mexico City's Metropolitan Area

The analysis of climate data gathered in recent decades shows that the Mexico City's Metropolitan Area (ZMCM) is vulnerable to extreme conditions, whether they involve a rise in environmental temperatures, heavy rains, or droughts. If correct measures are not taken the regional economy will suffer significant economic costs as a consequence of climate change (UNEP 2010). Thus, it is urgent to design, refine, and implement strategies to strength the ability to adapt to the effects of climate change, thereby reducing vulnerability to the most probable scenarios of adverse impacts on the population.

The "Climate Action Program 2008–2012" for Mexico City intends to contribute to the reduction of GHG, reduce the vulnerability of the city to the effects of global warming, and heighten adaptation. This program needs coordinated efforts, commitment, consciousness raising, cooperation, participation, and verification (SMADF 2008). Mexico City government has already instituted different programs related to control the waste management, transportation, water, etc. and that some of the planned actions have a high impact on the reduction of GHG and adaptation to climate change. After 5-years of operation, the main outcomes could be summarized as follows:

> … of the projected 4.4 million tons annual carbon dioxide equivalent reduction, 12 % was reduced in the water sector through the seven actions; 10 % was reduced in the energy sector through five integrated actions; 35 % in the waste sector through four specific actions; and 42 % in the transportation sector through ten actions contemplated in the Program (SMADF 2008, pp 14).

Additionally, the Program of Climate Change Adaptation consists of setting of both short and long-range actions to reduce potential climate change risks on the Mexico City population and economy. Likewise, the program promotes the development of adaptation abilities aimed at reducing vulnerability and moderating, reducing possible damages, forecasting risks, and taking advantage of opportunities derived from the climate change in Mexico City and its outlying areas. The main adaptation actions are:

> …. the implementation of a Metropolitan Hydro-meteorological Monitoring and Forecasting System for the Valley of Mexico (Early Warning System) geared towards identifying risks and threats to the Mexico City population and taking immediate, medium term, and long term action; Micro-basin management of urban ravines in order to deal with the threat of heavy rains and to help reduce risks to the population inhabiting these areas; assistance to people who are vulnerable to extreme climate events conditions such as heavy rains, or intense cold waves or heat waves; epidemiological monitoring or identification of vectors presented as a result of climate change … (SMADF 2008, pp 18).

Consequently, the Ministry of Environment and Natural Resources of Mexico (SEMARNAT) together with the government of Mexico City and State of Mexico have launched the Air Quality Monitoring Program (PROAIRE) with the purpose of reducing emissions and improve the air quality in ZMCM. Moreover, SEMARNAT has a National Environmental and Natural Resources Information System that contains national environmental information and databases (SEMARNAT 2010).

Concerning wastewater management, the Environmental Agency of the State of Mexico developed an "Inventory of domestic and industrial wastewater discharges" (SMA-Edomex 2012). Additionally, this agency has implemented the Sustainable Savings Program Resources. It is an education policy that promotes the principles and practices of conservation and rational use of natural resources. This program is carried out as an environmental management system and it is designed to prevent, minimize and reduce waste generation, energy and water, and to encourage their rational use.

Some other examples of actions are those published in the Gazette No. 1 (2011) which defines the “Water and Sanitation Program (PAS), as an Action Program orientated exclusively to WWTPs”. The PAS gives the opportunity to rehabilitate, build up, start up and operate WWTPs in Mexican territory. A second example is the program U031-Incentives for Operating Plants Wastewater Treatment. The objective is to incent WWTPs that are discharging with higher standards than the discharge limits set on the Mexican norms (SEMARNAT 2010).

3 Energy Saving and Green Energy Production in Municipal WWTPs

3.1 Background

Anaerobic digestion is the oldest process used for the stabilization of solids and bio-solids (sludge) for final disposal and thus green energy production. This process involves the decomposition of organic and inorganic matter (mainly sulphate) in the absence of molecular oxygen. It is a microbial process where organic material is biodegraded through a complex microbiological process leading to the production of a more suitable organic material and biogas (Tchobanoglous et al. 2003). Some important physic-chemical factors that define the process are type of inoculums, substrate, reactor type, hydraulic and solid retention time, bioavailability of nutrients, presence of inhibitory substance (toxic substances and heavy metals), temperature, alkalinity and pH (Tchobanoglous et al. 2003).

It is well know that anaerobic digestion of sludge can produce sufficient biogas to meet most of the energy needs of any Municipal WWTP. In a conventional anaerobic digestion process, methane formation takes away a significant portion of the reactants acetate and hydrogen, which is produced by “hydrogen-producing bacteria” (e.g. Clostridium, Enterobacter) and at the same time consumed by “hydrogen-consumed bacteria” (e.g. methanogens, homoacetogens) for the methanogenesis. In contrast, a two-stage anaerobic digestion process produces hydrogen in the first stage (acido/acetogenesis), and methane in the second stage (methanogenesis) (Peña Muñoz and Steinmetz 2012).

Recent works suggest the combination of two processes for enhancing the biomethane-hydrogen production: a two-stage anaerobic digestion and a pre-treatment of the sludge (Peña Muñoz and Steinmetz 2012). According to Hallenbeck and Ghosh (2010) the inoculum (sludge seed) needs a specific pre-treatment in order to theoretically enhance the yield of 4 mol H2/mol substrate. Therefore a pre-treatment should selectively inhibit methanogenesis to increase the efficiency of acetate reduction by mixed cultures and thus increase the production of bio-hydrogen. Several researchers have identified three main pre-treatment groups, divided as follows: chemical addition or specific methanogen inhibitors; heat-shock such as thermal hydrolysis; and a combination of the two previous methods. In general, a simple heat shock applied to the inoculum removes any hydrogen consuming non-spore forming bacteria presented in the sludge (Li and Fang 2007).

According to Das and Veziroglu (2001) there are 4 main sources from which to produce hydrogen: from fossil fuels; from biomass; from water; and from microorganism, which includes fermentative bacteria and anaerobic digestion. In addition, bio-hydrogen production has been put forward as one of the cleanest hydrogen production technologies. The relevance of this process lays in the fact that bio-hydrogen and fuel cells together represent one of the most promising ways to produce green energy (European Commission 2003; Reed and Gutman 2011). In addition, the combination of a pre-treatment with a two-stage process reduces the amount of sludge for final disposal. One of the major bottlenecks in commercialization of the bio-hydrogen production processes is the use of efficient microbial strains which can use different carbonaceous organic materials as feedstock and the low rate of hydrogen production after the complete process (Das and Veziroglu 2001).

3.2 Feasible Solution for Municipal WWTPs

As previously mentioned, the operation and maintenance costs of Municipal WWTPs are high, and among other reasons, the main issue that hinders their operation. According to SEMARNAT (2009), many Municipal WWTPs located in ZMCM need to:

- reduce energy consumption,
- reduce the amount of sludge for final disposal,
- increase the quality of effluent, and
- become auto-sustainable.

These four concerns could be addressed by optimizing the process in WWTPs and integrating specific technologies, such as pre-treatment of sludge for enhancing bio-methane-hydrogen production in anaerobic digesters and producing green energy. Some studies have shown that pre-treatment can enhance the Bio-methane production of an anaerobic digester up to 80 %, while reducing the amount of bio-solids to final disposal up to 50 %. Furthermore, the size of the reactor can be significantly reduced or the efficiency of the existed digester could be increased 2–3 times its capacity (CAMBI 2011).

According to the Norwegian company CAMBI, some advantages of a thermal hydrolysis (pre-treatment) of sludge includes:

- the increasing of sludge bio-degradability and therefore increase in biogas production;
- significant sludge cake volume reduction;
- higher digestion rate;
- two to three times digestion capacity increase;
- stable and reliable digester operations;
- highly energy-efficient process;
- elimination of foaming problems caused by filamentous bacteria; and
- sludge dewaterability improves up to 40 % dry solids.

In terms of accomplishing Mexican norms, this pre-treatment guarantees pathogen kill and production of bio-product/bio-solids class A with no re-growth or reactivation of bacteria, 30–100 % more biogas production than conventional technology, 50 % mass reduction after dewatering, 2–3 times enhancing digester capacity and all steam produced is recycled (CAMBI 2011). Figure 1 shows the suggested treatment flow. In short, the energy produced by means of anaerobic digestion and pre-treatment is enough to cover the energy requirement of the WWTP, the pre-treatment of sludge and the anaerobic digestion itself, if a correct operation is planned.

One concrete action from the government of Mexico City, the State of Mexico and the State of Hidalgo is the sanitation of at least 50 % of the WW produced in the ZMCM. This has been nearly accomplished through the Atotonilco Mega-WWTP. This plant is design to treat a domestic wastewater flow of 23 m^3/s

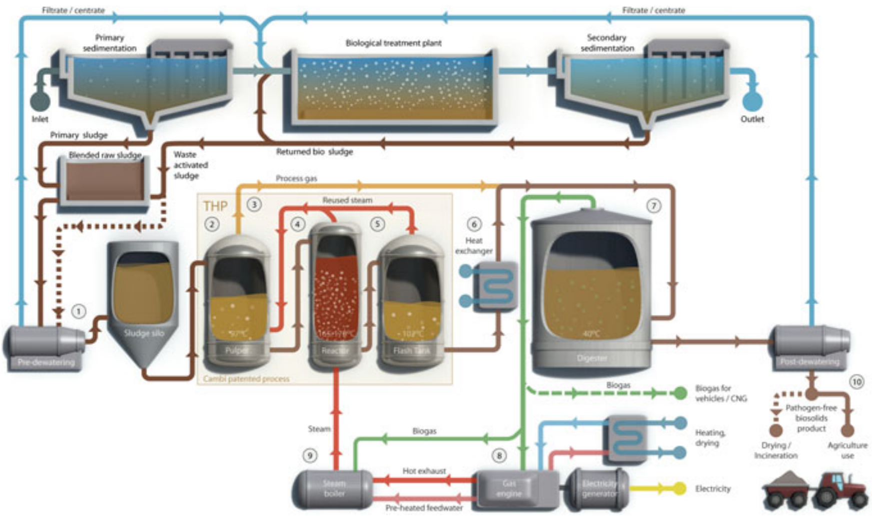

Fig. 1 WWTP with a thermal hydrolysis pre-treatment (CAMBI 2011)

(BOD5: 250 mg/L and TSS: 250 mg/L). The Mega WWTP was design to accomplish the Mexican Norm NOM-003 SEMARNAT-1997 (BOD5:30 mg/L and TSS: 40 mg/L). The treatment consists of a primary treatment for removal of solids, then a secondary treatment (activated sludge), tertiary treatment (coloration) and anaerobic digestion of sludge. The Mega-WWTP is expected to produce 1,134 ton DS/d of sludge. In addition, through a cogeneration 9,729 m^3 biogas/h will be produced, with a content of 70 % of methane. The usable energy has been calculated as 0.49 MW-h/d, which will reduce 507,276 tons of carbon dioxide emissions per year (CONAGUA 2008). Figure 2 shows the flow diagram of the Mega WWTP.

The operation and maintenance cost of the Mega-WWTP are calculated as MXN$632 million pesos per year, while the benefit from the green energy sold will be MXN$75 million pesos per year and the benefit from the carbon credits will be MXN$137 million pesos per year (CONAGUA 2008). The cost of treated water at the Atotonilco WWTP is calculated as MXN$2.06 pesos/$m^3$ without considering the benefits out of carbon credits, otherwise the cost of treated water could be reduced up to MXN$0.49 pesos/$m^3$ (CONAGUA 2008).

One existing opportunity at the Atotonilco WWTP is the integration of pre-treatment for sewage sludge for enhancing bio-methane-hydrogen production and increase the energy production at the site.

Other wastewater management opportunities in ZMCM are available, for example: select and implement the best available technologies; private companies could collaborate with Municipalities for technology transfer and apply to Clean

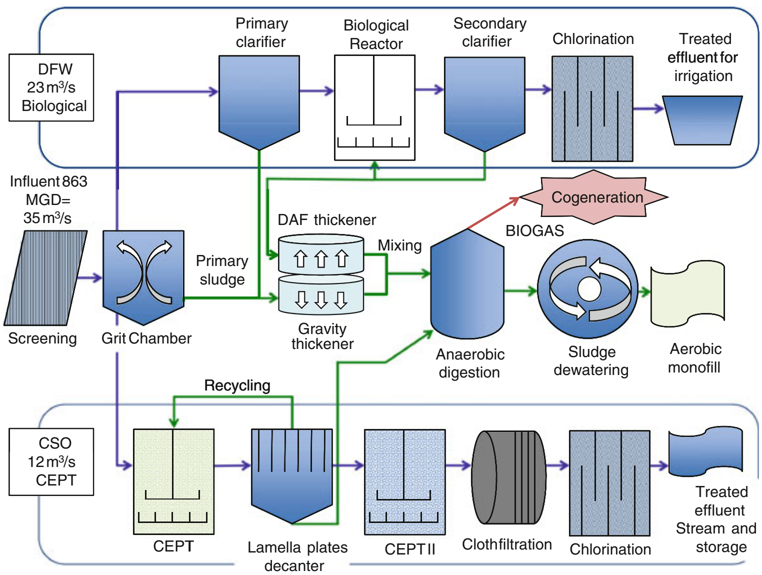

Fig. 2 Flow diagram of Atotonilco Mega-WWTP (CONAGUA 2008)

Development Mechanism (CDM). Although CDM projects do not have an explicit technology transfer mandate, it may contribute to technology transfer by financing emission reduction projects using technologies currently not available in the host countries. For instance, Mexico has been referring to American wastewater standards and environmental legal frameworks for over 30 years. Some advantages of this position is an easy way to transfer technology from U.S.A. to Mexico and a faster integration of the process into Mexican WWTPs. Nevertheless, a technology transfer from Europe into Mexico needs to take into consideration the environmental framework and background of each partner.

It is important to clarify that, by technology transfer one should understand "a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions" (Seres and Haites 2008). Indeed, the policy makers, federal institutions and private companies working on wastewater management need to come closer for building together the technology transfer, which will allow a "green energy revolution" in Mexico.

An example of this type of interaction is the company Ingeniería y Equipos Ambientales, S.A. de C.V. (IEASA), which has approached some Municipalities in ZMCM and Mexico. IEASA has proposed some innovative technologies for enhancing the biogas production in WWTP. It has optimized the actual process at the site. This company has suggested the construction of some WWTPs which include specific pre-treatments. The first studies have shown that "energy neutrality" at the WWTP is possible, when implementing a pre-treatment, integrated with anaerobic digestion in two-steps. Optimizing the actual treatment has to be done parallel to the integration of these units for accomplishing energy neutrality. This term basically refers to the matter that the energy required for operating the new units will be covered my means of the energy produced by the anaerobic digestion. In addition, there will be a "left over of energy" for operating the rest of the units at the site and possibly, for incorporating into the electrical network. As a consequence, the operation costs of the WWTP will be considerably reduced.

4 Conclusions and Recommendations

A careful review of the environmental framework is suggested, in order to identify weaknesses and "black holes" that have been the main reasons for the misconception of regulations, especially in the energy and wastewater sector. Additionally, policymakers need a better advisement team, so it will be easier to implement and generate new laws that manage the transition to a low-carbon growth path, the markets for low-carbon and high-efficiency goods and services. Mexico needs to actively participate in an effective international agreement that considers the economic costs of adaptation. In fact, the cost of taking actions to reduce the impacts of climate change is less, than the cost of inaction.

Certainly, a WWTP is a high energy demanding public service, but selecting the best available technology for the conditions of operations facilitates the treatment and guarantees the protection of the environment. Therefore, enterprises that design and construct WWTPs should be given an opportunity to approach policy makers, stakeholders and federal government spheres, to suggest, present and develop projects related with technology transfer to Mexico. More incentives should be proposed for companies, private holders and municipalities that produce green energy. Once WWTPs are looked at as sites where three goods are produced (treated WW, sanitized bio-solid and green energy), municipalities will be more willing to invest in these sites. The production of bio-methane-hydrogen in WWTPs offers many opportunities for reducing GHG by directly reducing the amount of sludge sent to landfills and using these green fuels for cogenerating heat and power. These actions will show that climate change issues have an important position in the Municipality's agenda and will contribute to the adaptation and mitigation targets under international agreements such as the Kyoto Protocol.

Just like the main challenges for the use of hydrogen and fuel cells, bio-hydrogen production must also consider the infrastructure that is required for hydrogen production, storage and distribution.

The selection of pre-treatment for enhancing bio-methane-hydrogen production in a two-stage anaerobic digester has to consider the type of wastewater that produces the sludge, the geographical location of the site, the options for technology transfer and the available technology in the country. The technology transfer must consider the Mexican and partner's context for a successful implementation.

The governments from Mexico City, the State of Mexico and the State of Hidalgo, should keep working together with private companies to suggest the most suitable and feasible solution to treat the remaining 31.6 % of wastewater in ZMCM. Optimization of WWTPs located in ZMCM, together with the implementation of the suggested pre-treatment for enhancing the bio-methane-hydrogen production, is required. This megacity could be an example for other cities in the country towards improving their wastewater management.

Indeed, Mexico is ready for facing the "green energy revolution."

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Glossary of Terms

AD Anaerobic digestion

GHG Green house gases

mg/l Milligrams per liter

m^3/s Cubic meters per second

WWTPs Waste water treatment plants

ZMCM Mexico City's metropolitan area

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Author Biography

Kristy Peña Muñoz is a PhD student in the Wastewater Technology Department (AWT) at ISWA, University of Stuttgart. Her current research focuses on *enhancing bio-hydrogen production in a two-stage anaerobic digestion as renewable energy source in WWTPs*. This project has been funded by the Alexander von Humboldt Foundation (AvH), the Instituto de Ciencia y Tecnología of Mexico City (ICYT-DF) and the company Ingeniería y Equipos Ambientales S.A. de C.V. (IEASA). At the moment Kristy is collaborating with IEASA to build a Benchmark WWTP in Mexico which includes a pre-treatment for enhancing bio-methane-hydrogen production. Prior to arriving at ISWA, she worked as an Environmental Engineer for an automotive company in Germany and Mexico. In 2008 this company built a benchmark plant in Mexico, where Kristy implemented an environmental system, based on guidelines that apply to any of its production sites. She has a M.Sc., in Air Quality Control, Solid Waste and Wastewater Process Engineering from the University of Stuttgart (Germany) and a Bachelor of Environmental Engineering from UPIBI-IPN (Mexico). Kristy's background includes several years of industrial experience in occupational health, risk assessment, wastewater management and wastewater technology. More specifically she is interested in technology transfer for reducing climate change, the impact of climate change/environmental regulation/policies on technology transfer/implementation, strategic development from climate change regulation and initiatives, corporate social responsibility and renewable energy technologies for developing countries.

Editors Biography

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Anshuman is a sitting member and Vice-Chair of the St. Albert Economic Development Advisory Committee (SAEDAC) and a Board Member of the Northern Alberta Business Incubator (NABI).

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