Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale

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Resource consumption drivers and pathways to reduction: economy, policy and lifestyle impact on material flows at the national and urban scale

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A B S T R A C T

An analysis of material flows that also considers economic and social indicators has been performed at the national (Sweden) and urban scale (Stockholm and Gothenburg) to study the dynamics of resource use during the last two decades. A summary of policies related to resource consumption implemented at the EU, national and local scale is presented and their probable effects discussed based on empirical evidence. The resource consumption trends indicate that the implemented policies have failed to bring significant reductions in resource and energy throughput. Resource consumption has increased both in Sweden as a whole and in the studied cities. Moreover, the consumption of construction materials and electronics has grown exponentially, even when normalized by population. The few success stories are the absolute reduction in fossil fuel consumption achieved in Stockholm, building energy reduction by halve and complete abolishment of oil as the heating fuel in Sweden. The lifestyle characteristics that have an impact on resource consumption include high income, car ownership, large residential floor space, social movements and trends related to dietary choices. The consumption of electronics, textiles and cosmetic products was shown to have increased considerably. The same quantities of food are consumed, but the diet has changed. Waste generation by far outpaces improvements in recycling. In recycling, waste-to-energy is growing faster than material recycling, which impedes the development of a circular economy. The main limitation of the policies implemented to-date is that they only address efficiency of use, but do nothing to reduce the demand for resources. In addition, efforts have so far been restricted to energy consumption. The reality is that we must urgently reduce the consumption of all resources, not just fossil fuels. We call for greater concern and more action towards reducing nonfuel resource consumption.

1. Introduction

The unsustainable way in which we use resources has resulted in the challenges we face today – climate change, environmental pollution, ecosystem degradation and raw materials exhaustion. Not only do we need to address the effects on the environment immediately, but an even more critical challenge is to urgently change the way we use resources to avoid causing irreversible damage to our planet.

This paper has the following objectives: 1) investigate the cases where resource reduction seems to be happening; 2) suggest methods for measuring the reductions; 3) contribute to a discussion on the factors that drive resource use; 4) analyze potential approaches to reduction in material throughput and energy use and how these can be implemented.

The paper focuses on resource consumption in urban areas and considers both nonfuel resources and fossil fuels. The resource consumption for the period 1996–2011 is examined at two administrative scales – national (Sweden) and metropolitan areas (Stockholm and Gothenburg), and at three different levels of detail: 1) the national and urban economy; 2) components of the economy – throughput of main material types; and 3) household consumption at product group level. Thereafter, policies related to resource consumption implemented at the EU, national and local scale are summarized and their probable effects discussed, based on evidence of materials and energy throughput trends.

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2. Theory

Reductions in resource consumption are at the core of the concepts of resource productivity, decoupling[1] and eco-efficiency. Resource productivity relates to the natural resources used as inputs to the economy. Decoupling also includes the "unused" material flows that are side effects of economic activities (Adriaanse et al., 1997). Eco-efficiency refers both to the input of natural resources and the outputs of wastes and emissions. Eco-efficiency is discussed in Agenda 21 (United Nations, 1992).

The general recognition that all these aspects; decoupling, improvements in resource productivity and eco-efficiency have to be realized through a combination of technical and lifestyle changes comes from the IPAT theory (Ehrlich and Holdren, 1971), used to describe the factors driving environmental impact (I) and also resource consumption (I). I = (population) × (affluence [e.g., GDP per capita]) × (technology [e.g., energy or resources per GDP]). In this paper, resource consumption is investigated in relation to population, economy and lifestyle while the impacts of technology and industrial production are not studied.

The focus on urban resource consumption is imperative. Cities have been called the building blocks for sustainable development. Currently, cities contain more than half of the global population. They are responsible for 80% of the global economic growth and 75% of the resource consumption (UNEP, 2013). It is also known that most innovations are first developed in a city, after which they spread gradually (Bai et al., 2009). See UNEP 2013 for numerous examples of experimentation with sustainability innovations at the city level. With a growing list of organizations focusing on sharing best practices among cities (e.g. UN-Habitat, and ICLEI, the C40, The World Bank-Urban Development), this is a particularly important time to explore the current state of resource consumption in cities, along with the success stories and what characterizes them, and to distribute knowledge on possible urban sustainability interventions (UN-Habitat; ICLEI; C40; World Bank Urban Development).

Resources are the basis for an economy operating in quantitative terms. Therefore, a quantitative description of the resource flows, set targets and how these are assessed is necessary to promote and enable resource-use reductions. Material Flow Analysis (MFA) is an appropriate tool to describe flows and stocks of resources at the national and city level. The resource-intensity of the economy can then be measured by the relationship between the consumed physical resources and the produced value of GDP. In particular, MFA indicators such as Domestic Material Consumption (DMC) and Domestic Material Input (DMI) can be analyzed as functions of time and in relation to GDP in order to investigate economic growth decoupling from physical resources consumption. Previously Weisz et al. (2006) have analyzed DMC (year 2000) for the EU-15 countries in order to identify possible reasons for cross-country variations in the levels of material use. In particular, the overall and disaggregated DMC cross-country variability has been compared with the variability of the following indicators: percentage share of the tertiary sector in the overall GDP, population density, per capita GDP and final energy consumption. Across EU-15 countries per capita GDP showed only weak correlation (Pearson coefficient 0.37) with per capita DMC. The level of use of biomass, industrial minerals, ores, and fossil fuels was concluded to be determined largely by the structure of the economy rather than by national income or economic development. In contrast, the DMC of construction minerals was less determined by the economic structure and more by economic development.

Recently, an inter-temporal (years 1996–2011) analysis of resource consumption was conducted for Sweden and its largest metropolitan areas, in order to investigate whether decoupling of the economy is occurring, among other trends (Kalmykova et al., forthcoming). One of the motivations for the study was to reexamine the finding from a previous economy-wide MFA study (Eurostat, 2002): that Sweden was one of the economies in a state of absolute decoupling during the time period 1980–2000 (i.e. resource consumption was decreasing together with a growing GDP). However, no absolute decoupling was confirmed for the studied period, neither for Sweden as a whole nor for the metropolitan areas. In particular, the material consumption was increasing both in absolute and per capita terms, as was the waste generation, despite considerably improved recycling systems. However, relative decoupling was observed together with reductions in CO_2 and energy consumption, indicating that the studied areas may be moving towards sustainable resource consumption, although the results varied for different areas. A detailed study of resource consumption at a higher resolution, combined with lifestyle trends and policy implementation history is offered in this paper to identify characteristics of case studies leading to different resource consumption stories.

Until now, few quantitative inter-temporal analyses have been conducted at the urban scale, limiting the potential for studies of transitions to sustainable resource use. A comparative analysis of inter-city resource consumption over time was carried out by Kennedy et al. (2007), however the findings are difficult to generalize as a variety of methods were used and a number of researchers involved. Another quantitative analysis relating to urban sustainability transitions in Chinese cities was undertaken by Dhakal et al. (2009, 2011). This study looks at the energy intensity of different cities (per unit of GDP) in relation to per capita income, and investigates the transportation and industrial sectors' shares of urban emissions over time. The authors propose high, medium, and low-resource intensity development pathways.

Bai et al. (2010) and Broto and Bulkeley (2013) have made valuable contributions towards a general understanding of urban sustainability transitions. Bai et al. analyzed 30 case studies in 11 Asian countries and used a five-tier framework to highlight important triggers, actors, links, barriers and pathways in urban sustainability experiments. They found that public policy and local governments are the most important factors to the success of individual experiments, although there are often multiple triggers. Broto and Bulkeley carried out an analysis of 627 urban climate change experiments in 100 cities around the world, with focus on the stakeholders and technologies involved. They concluded that urban infrastructure, the built environment and transportation are the most common sectors for experimentation. Again, local government was found to be a key actor, but the private sector has played a particularly strong role in Asia.

3. Methods

3.1. Study area

Sweden is a country of 9.5 million people in the north-west of Europe. Stockholm is the capital of Sweden and its largest metropolitan area, with a population of 2.1 million. Stockholm generates 27% of the Swedish GDP, and its GDP per capita grew by an average of 2.8% per year during 1996–2011 (adjusted to 2011 prices),

[1] Decoupling refers to the disconnection of economic growth – e.g., as measured by GDP growth – from material and energy throughput. Declining material consumption in parallel with a growing GDP is defined as an "absolute decoupling", while "relative decoupling" is the case where both material consumption and GDP are growing but GDP is growing at a higher rate and "no decoupling" or "rematerialization" refers to a faster increase in material consumption than in GDP (Eurostat, 2002).

placing it among the strongest-performing European metro-regions (OECD, 2013). In 2008, the service sector employed 85% of the working population in Stockholm, while the industrial and construction sectors employed 9% and 6% respectively. Gothenburg is Sweden's second largest metropolitan area with a population of 0.95 million. The GDP per capita grew by an average of 2.6% per year during 1996–2011 (adjusted to 2011 prices). In 2008, the service sector employed 77% of the working population in Gothenburg, while the industrial and construction sectors employed 16% and 7% respectively.

3.2. Material flow analysis

Material Flow Analysis (MFA) is a systematic assessment of materials, and their stocks and flows, over time and space, within a defined system (Brunner and Rechberger, 2004). The Urban Metabolism Analyst (UMAn) method has been used to account material flows and MFA indicators at both country and city scales (Niza et al., 2009; Rosado et al., 2014). See Fig. 1 for the scheme: to perform an urban MFA, all the Imports from the rest of the country (i.e. national) as well as from other countries (i.e. international), per means of transport (road, air, water and train) are accounted. The Imports, together with the DE within the studied territory (agriculture, fish, mining, etc.) compose material Inputs. The latter can either be final products, or raw materials and intermediate products that will be used by the economic activities to produce final or intermediate products for the local consumption or export. Materials that are imported being then exported, without being consumed or transformed are called crossing flows (crossing flows are not accounted in the standard MFA procedure). In this paper crossing flows were not considered. Domestic Material Consumption, DMC = Domestic Extraction + Imports − Exports; in absolute and per capita terms was used as an aggregated indicator of the resource consumption. The consumption of selected materials in metric tonnes per annum and of products in units or metric tonnes per annum was used for the detailed analysis. The method accounts only the direct (as opposite to the embodied materials) consumption for all the sectors in the economy.

3.3. Data sources

For data sources and uncertainty of the MFA results, see (Kalmykova et al., forthcoming; Patrício et al., forthcoming). The following statistical data is used, for the urban area scale, all in physical units (tonnes): International Trade by Combined Nomenclature (CN); domestic transport by station of origin and destination, means of transport (road, air, water and train) and cargo type (by Nomenclature uniforme des marchandises pour les statistiques des transports, NST code); Industrial Production and Domestic Extraction (DE) by establishment (Nomenclature statistique des activités économiques dans la Communauté européenne, NACE code); solid and liquid waste, including treatment type and gaseous emissions. The following data is often publicly available for the national scale, but must be ordered for the metropolitan scale: population, tertiary education, income, household size and residential floor area, car ownership and registration of new cars, volumes and types of construction (SCB, 2013). For electronics consumption, sales statistics (Branchkansliet, 2014) was used for the national scale, while the UMAn model was used for the metropolitan scale. National sales of fuels were acquired from the Swedish Petroleum and Biofuels Institute (SPBI, 2014) and the data on food consumption at a country level from the Swedish Board of Agriculture (Jordbruksverket, 2014). The statistics on private vehicles fleet by fuel type and mileage was collected from Transport Analysis (Trafikanalys, 2014). The development projects in the cities; their environmental agenda as well as past and current policies and norms were gathered through review of the annual reports from the city councils.

4. Results

The aggregated DMC and its fractions for the following materials were investigated: Fossil Fuels, Non-Metallic Minerals, Metals, Biomass, Chemicals and Fertilizers and Others (includes fibers, salts etc.). A comparison between recent consumption levels for Sweden and the cities with consumption levels in 1996 is presented in Table 1; see Supplementary Material for the complete data set for

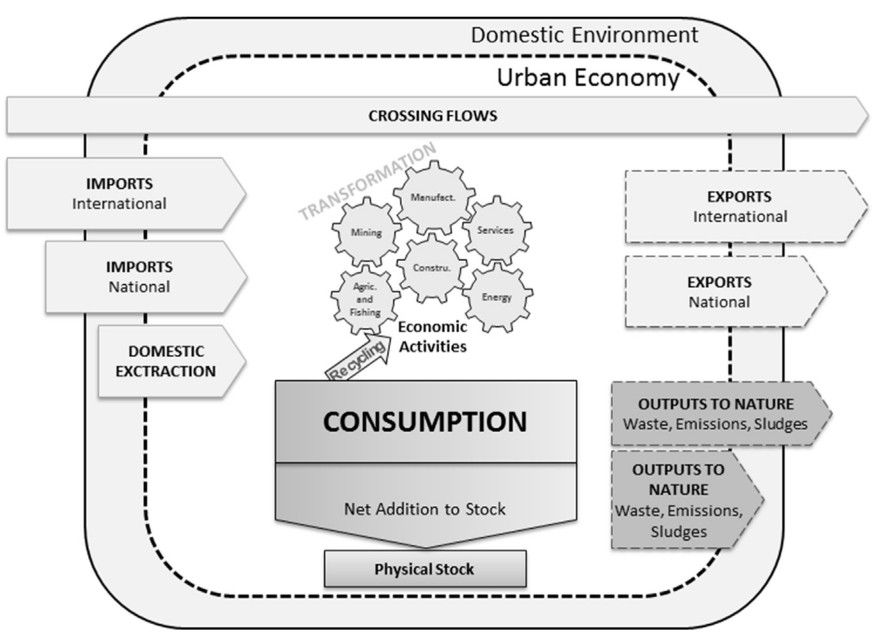

Fig. 1. Method.

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Table 1
Benchmarks for Sweden, Stockholm and Gothenburg. All per capita except for the area.

	Sweden	Stockholm	Gothenburg
Area (km^2)	450,295	6526	3695
Population density (km^2)	22.6	305	246
Disposable income (Million kronor)	0.23	0.26	0.24
Tertiary education	0.31	0.39	0.37
Number of personal cars	0.41	0.31	0.37
Residential floor area (m^2)	44.1	40.8	42.7
DMC/capita (tones)	18.5	10.3	10.9
	Sweden (2011/2000)	Stockholm (2011/1996)	Gothenburg (2011/1996)
Population	1.07	1.20	1.14
Resource consumption			
- Fossil Fuels	0.99	0.63	2.08
- Metals	1.00	1.29	1.80
- Non-Metallic Minerals	1.11	1.61	1.88
- Biomass	0.98	1.09	2.22
- Chemicals and Fertilizers	1.28	2.77	2.34
- Others	0.91	1.93	1.81
Total DMC	1.05	1.31	1.97

the time series. Gothenburg's DMC (per capita) has doubled since 1996, with nearly equal growth rate among the different material types. Stockholm's DMC, on the other hand, has increased by 30%. The national-wide DMC was stable during the last decade.

In absolute values, the distribution of the resource consumption by material type is similar for the country and city scales, with 50–60% represented by Non-Metallic Minerals, 20% by Biomass and 15–20% by Fossil Fuels. However, the per capita consumption differs. In particular, Gothenburg (a more industrial city) consumes about 50% more Fossil Fuels per capita than the national average, whilst Stockholm (service economy) consumes 50% less. The country-scale biomass consumption is significantly higher than the urban levels. Forest and paper industry are among the largest industries in Sweden that induces large biomass DE. The latter includes even the industrial sectors waste, i.e. unused extraction. In contrast, on the urban level, the biomass consumption is to a larger extent represented by final products and therefore the unused extraction for their production is not accounted for. The described phenomenon is a known as the DMC asymmetry and is currently being addressed by developing the Raw Material Consumption (RMC) indicator, which converts final products consumption into their raw material equivalents (RME), i.e. into equivalents of domestic extractions that have been induced in the rest of the world to produce the respective good (ifeu, 2012). To date available RME are for aggregated categories and the EU-27 economy. No RMC was accounted in this paper. The likely impact of the RME is that the urban-level RMC would be higher than DMC.

Fossil fuels and construction materials are (often) the largest flows in cities (Fig. 2). Normalized by population, Stockholm's consumption of fossil fuels has been decreasing continuously to reach 63%of the 1996 fuel consumption while fossil fuels consumptions in Gothenburg has doubled in 2011 compared to 1996. The consumption of construction materials (Non-Metallic Minerals) is constantly increasing (Table 1 and Fig. 2). Moreover, in cities the increase is exponential in absolute values ($R^2 = 0.70$) and even per capita values ($R^2 = 0.60$). In order to investigate the drivers behind the construction materials trends, the development of infrastructure and housing has been investigated. In particular, the

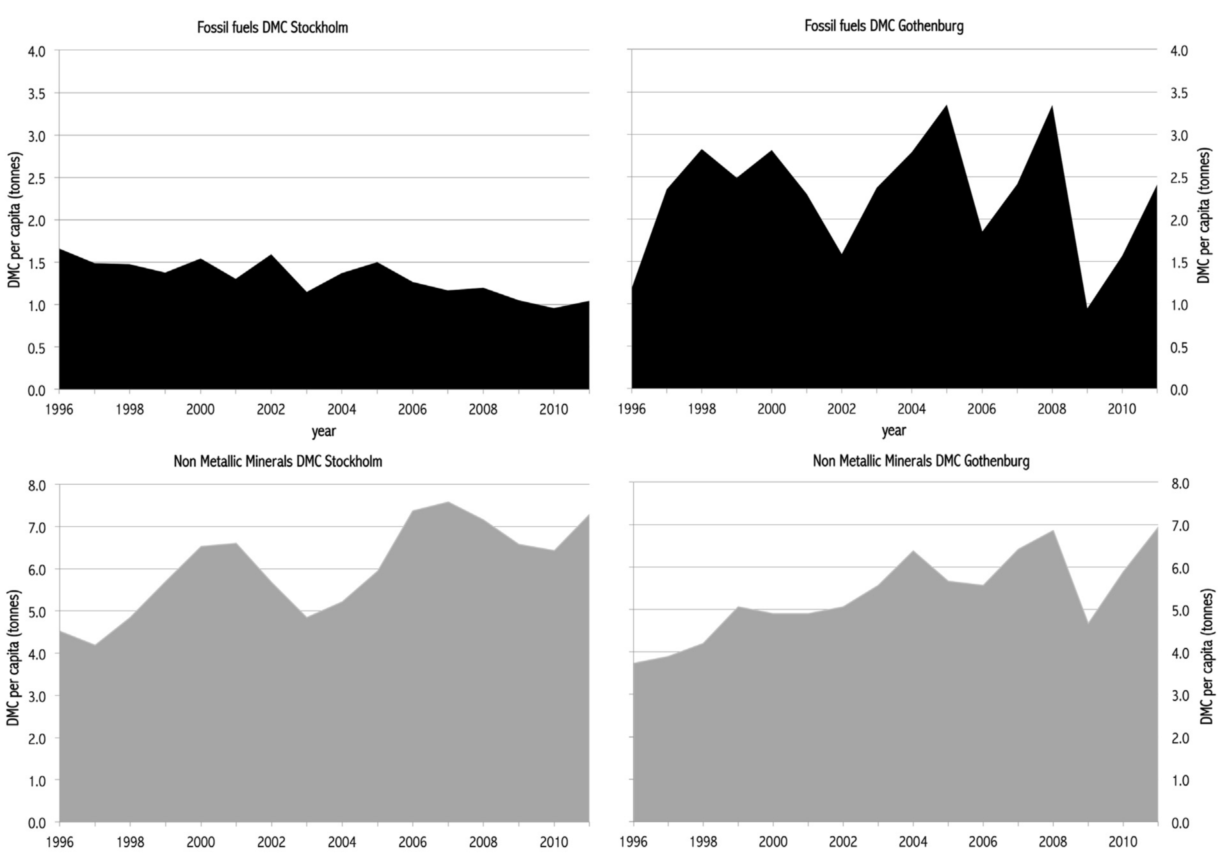

Fig. 2. Trends in urban consumption of selected materials: fossil fuels and non-metallic minerals.

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timelines of large construction projects in Stockholm and Gothenburg during the time period 1996–2011 were reconstructed (Fig. 3). Because residential construction is usually performed by small volumes in a large number of projects, only the few biggest developments were included in the timelines. The rest of the studied projects are large infrastructural (tunnels, road and railway), commercial (sport arenas, hotels, amusement parks etc.) and public developments (hospitals and museums).

For more details on urban material flows, see Rosado et al. (forthcoming) where an analysis of the full set of MFA indicators is conducted for three metropolitan areas and 28 material types, and different resource use profiles of urban areas are investigated.

The consumption of electronics, food and textile products was investigated in detail, in accordance with the priorities defined by the Swedish Waste Minimization Program for 2014–2020. The consumption of small household appliances and media and communication grew exponentially and doubled in per capita terms during the period 1996–2011 (see Fig. 6 for Stockholm as an example). During the same time period, the consumption of large household appliances increased by 80%. The consumption has been consistently higher than the average since 2007, but in general shows little variation year on year. Stockholm's clothes consumption, on the other hand, has doubled in 15 years - from about 6 kg/capita in the 1990s to about 12 kg/capita since 2007 (Fig. 6). The consumption of other textiles and footwear also doubled, both in Stockholm and in Gothenburg. The substantial increase in the per capita consumption of cosmetic products was observed for Sweden, and especially in the cities (not shown). As an example, the consumption of hair products in Stockholm increased sixfold, and the consumption of skin products, dental products and perfumes increased fourfold.

Food consumption was studied for 1959–2012, but only at the country level. The amount of food consumed per capita has not changed, but the diet has (Fig. 6). For the period of 1996–2012, a drastic threefold increase in the consumption of cooking oils was observed, in particular for coconut oils and oils for deep-frying. Meat and vegetables consumption have increased by 25% and 40% respectively. The fish consumption decreased by 65% and the

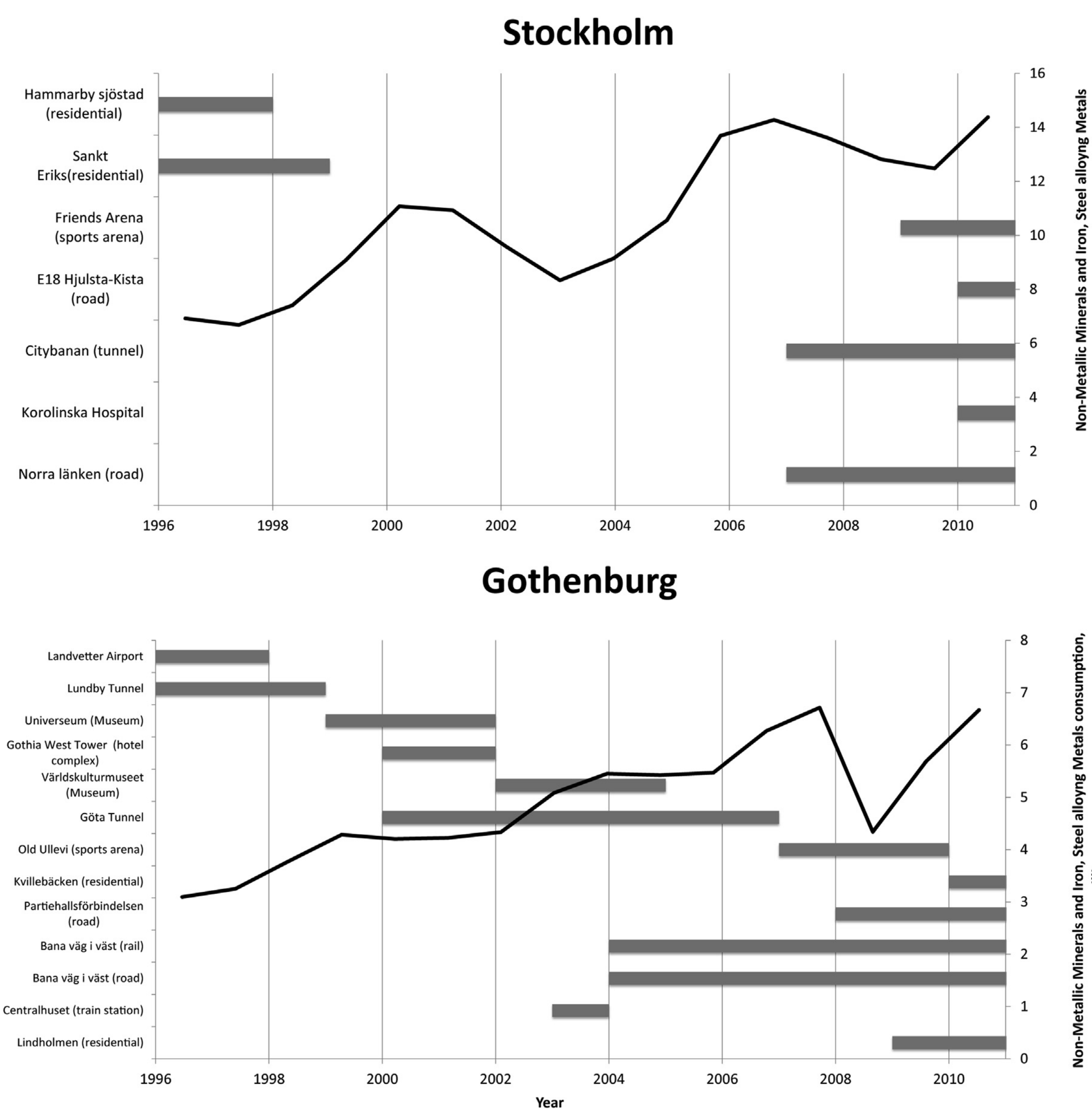

Fig. 3. Timeline of large development project versus construction materials consumption.

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flour and grain, and milk consumption both decreased by about 10%.

5. Discussion

5.1. Economy as driver of resource consumption at different scales

National and urban economies require consumption of physical resources (here, DMC). The impact of the economy (using the national GDP and sectors' GDP as indicators) on the DMC and the consumption of major material groups has been studied (see Supplementary Table 1 for the analysis). The DMC correlated strongly ($R^2 = 0.63–0.85$) with the GDP and its fractions for all the three case studies, confirming overall economy dependency on the materials. However, all the three economies are de-coupled from the fossil fuels consumption: from the negative to GDP development in Stockholm ($R^2 = -0.53, -0.69$) to the week relationship in Gothenburg ($R^2 < 0.3$) and no relationship in Sweden ($R^2 < 0.15$). Other materials correlating strongly with the GDP are the chemicals and ores. Metals consumption correlated with the cities industrial GDP. Construction materials consumption has been increasing continuously at the country level and exponentially in metropolitan areas during the study period, these materials consumption is driven by the GDP growth ($R^2 = 0.82–0.90$), which is in line with the conclusion by Weisz et al. (2006) made for the EU-15. In Gothenburg the total Non-Metallic Minerals and iron and steel consumption could be related to various infrastructural projects, including a tunnel (Göta tunnel) and a major rail and road construction (Bana väg i väst) (Fig. 3). In Stockholm, one of the peaks (2000–2001) in material consumption could not be related to any infrastructural projects, but correlated instead to volumes of started residential constructions (SCB, 2014). The other peak coincided with the building of a tunnel (Citybanan), a road (Norra länken) and a sports arena (Friends arena). In general, the consumption of construction materials also correlated with the quantity of residential area being produced in both cities (SCB, 2014).

The material flows normalized by population were constant in Sweden (Table 1), therefore the observed relative decoupling was achieved mostly due to the GDP growth and especially in the service sector, which is less resource-intensive than the industrial sector. Stockholm's relative decoupling was achieved by 40% lower per capita fossil fuels consumption despite growing GDP. Gothenburg's economy dependence on materials have increased during the study period with doubling of per capita DMC.

5.2. Lifestyle impact on resource consumption

The influence of lifestyle was investigated with reference to a range of indicators (Table 1). The DMC increased with an increasing income ($R^2 = 0.3$), suggesting a role of income (proxy for affluence) in the increasing resource consumption (Fig. 4). The fraction of

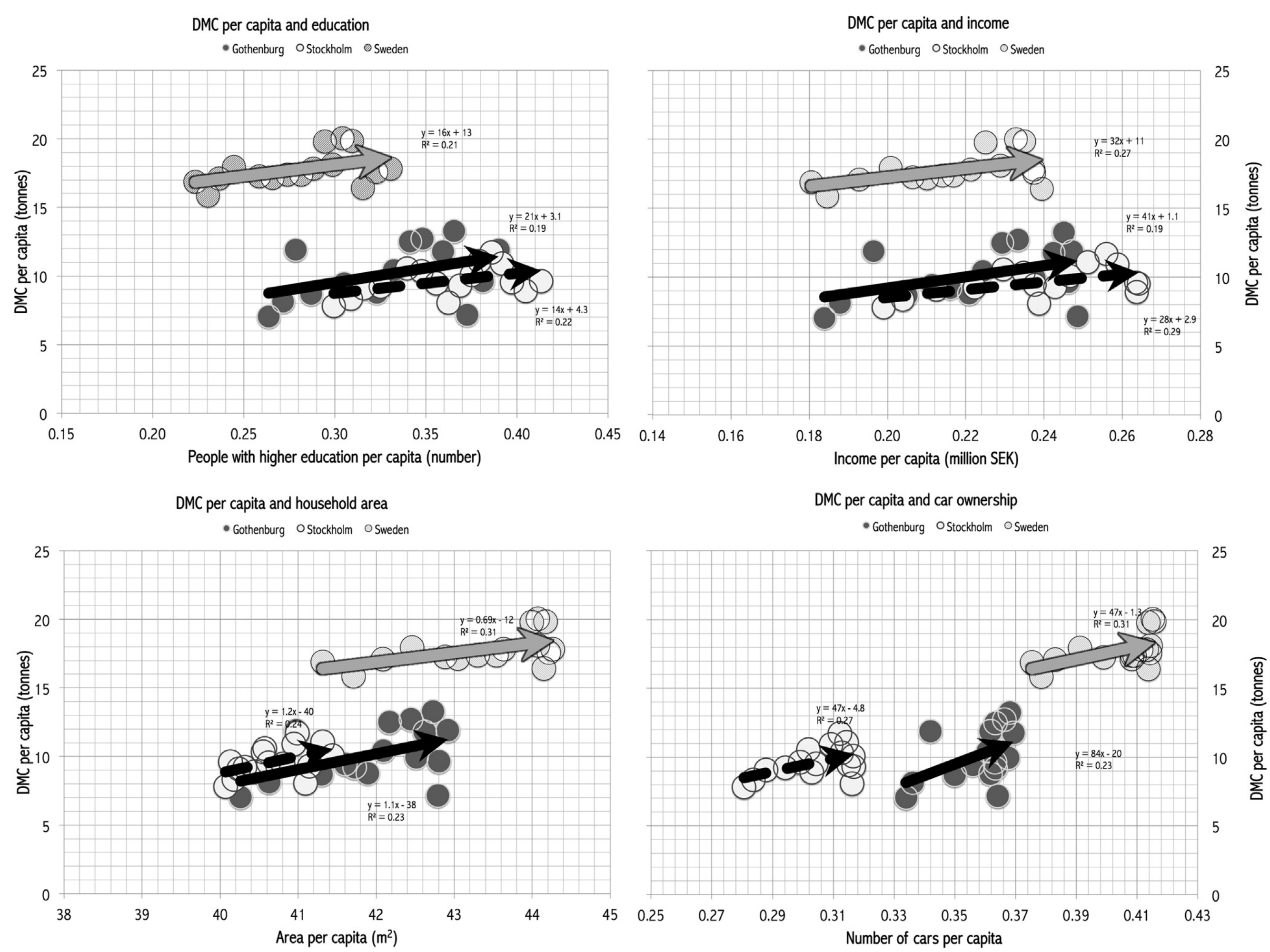

Fig. 4. Consumption drivers: income, education, car ownership and residential floor area.

population with higher education shows similar to the income versus DMC trends, probably because higher income is a function of the higher education. Higher car ownership and average residential floor area per capita have a weak correlation with the DMC increase ($R^2 = 0.2–0.3$). It is possible that the domination of the bulk materials (i.e. Non-Metallic Minerals) over the DMC measure may mask the trends for other resources. Trends for car ownership, residential area and consumer products consumption along with the consumption of the associated resources are analyzed in detail below.

The average residential floor area in Sweden and in the cities (Table 1), is higher than the EU median of 33 m^2/capita (ENTRANZE, 2014). Nationally, the average floor area has increased by about 7% since 1996, in addition to a population increase of about 7%. Moreover, the average household size (number of people, around 2) has been decreasing during the study period, whilst the proportion of single households has increased from 47% to 50%. Stockholm's residential area per capita remained constant during 1996–2011, while the population increased by 20%. As mentioned in the Results section, infrastructure projects impact could readily be observed on the construction materials consumption, which suggests residential construction demand for materials is less important in comparison. Yet, construction materials consumption correlated with the quantity of residential area being produced in both cities (SCB, 2014). Reduction in consumption of the construction materials in the next decade is unlikely due to both: large ongoing infrastructural projects and the shortage of housing in the both cities. For the residential construction the following current trends may reduce materials consumption: apartments are becoming a common form of accommodation even in the areas outside the big cities and the smaller apartments caused by high property prices and restrictions on the mortgage market. Currently, houses are 15% more common than apartments outside the three largest metropolitan areas, but this difference is diminishing due to the fact that more apartments than houses have been built since 2008. In metropolitan areas, apartments have been more common than detached houses since the 1990s, by a factor 3 in Stockholm and a factor 1.5–1.6 in Gothenburg and Malmo (third largest city) respectively.

Car ownership at the countrywide level has remained stable since 2001 (0.4 cars per capita) and decreasing in Stockholm since 2005 (currently 0.3 cars/capita) and since 2008 in Gothenburg (0.35 cars/capita), the level is almost twice as high in the countryside (Fig. 5). The number of registrations of new cars in Sweden dropped dramatically in 2007–2009, before evening out at a long-term constant level. Only a small number of electric cars are registered each year, whereas flexible fuel cars have made up 15% of the new registrations since 2006.

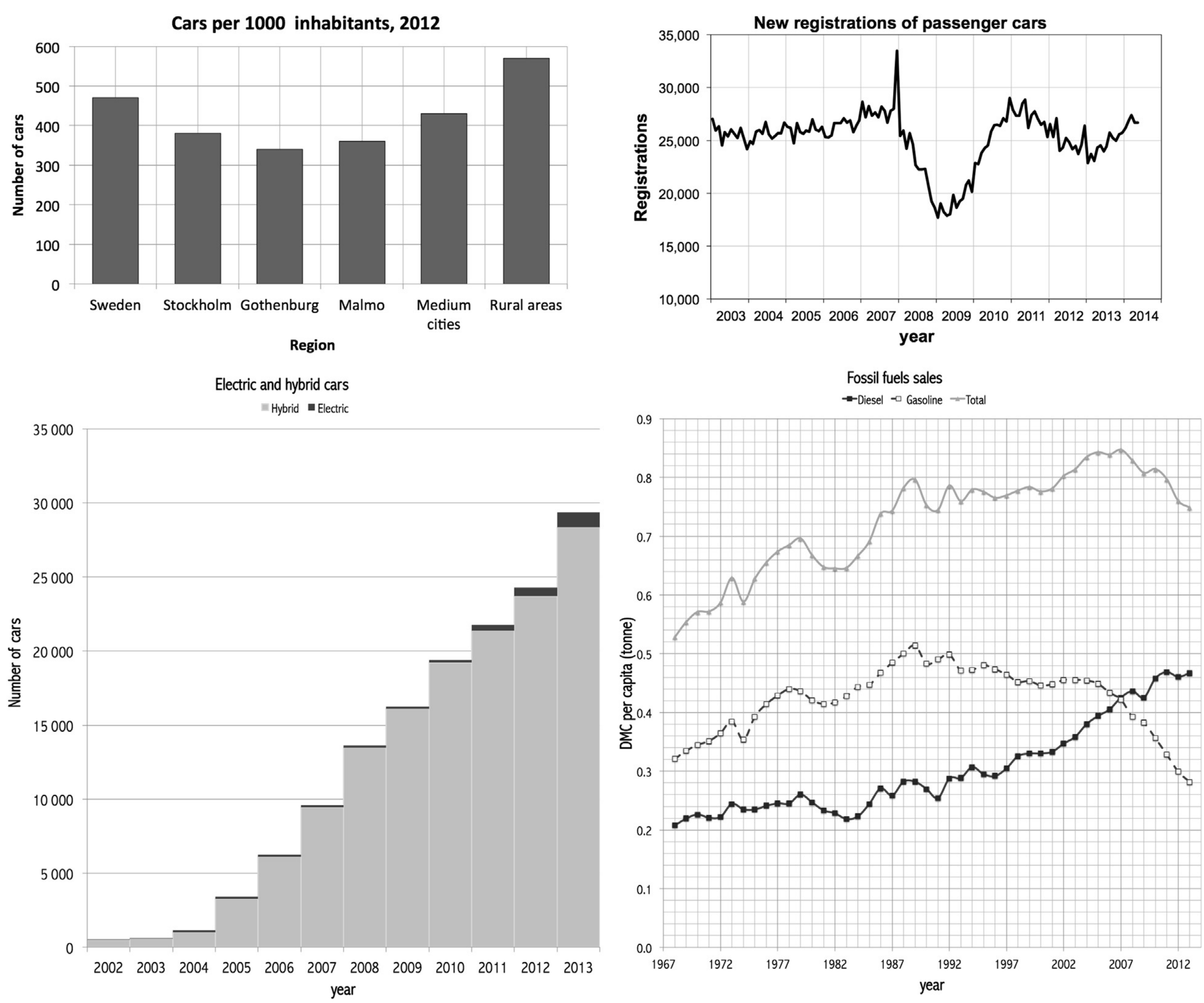

Fig. 5. Trends in car sales and ownership and fuel consumption.

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No reductions in fossil fuel consumption have been observed, despite the improved fuel efficiency of cars due to the constantly growing car fleet with an annual population increase of about 0.5–1.0%. The greater car fleet is probably the only reason for the increasing fossil fuel consumption, because the re-bound effect in fuel consumption as a result of the improved fuel efficiency is implausible due to the high and constantly rising fuel prices. Since the 1980s, the gasoline price has increased fivefold and the diesel price tenfold to reach the equal current price at $2.2 per liter. Since 2007 more diesel than gasoline is being sold in Sweden due to an increase in the proportion of diesel-fueled vehicles (DFV), from 5% in 2004 to 25% in 2013 (Trafikanalys, 2014). In 2012 the share of DFV among new sold cars was the highest ever at 70%. The same trend has been observed in the EU, where 30% of the fleet is composed by DFVs and sales of new diesel cars increased from 20% in the 1990s to 60% in 2012. See possible explanations for this trend in Section 5.3 Policy. It is possible, that fossil fuels consumption will decrease due to the switching to the DFV, which are 35% more fuel-efficient than their gasoline equivalents.

While car ownership, the fuel consumption and the residential area per capita have stabilized, several types of consumer products experience constant, and sometimes exponential growth. As was showed in the Result section, the electronic devices growth has been exponential and continues for all the studied case-studies. Textiles (including footwear) are another constantly growing consumption category with the average annual increase rate during the study period of 2.4%, 3.0% and 15.3% for Sweden, Stockholm and Gothenburg respectively. Stockholm had the highest textiles consumption in 2011 with 19.2 kg/capita, followed by Sweden with 16.3 kg/capita and Gothenburg with 15.9 kg/capita. Another product group with constantly increasing consumption is the cosmetic products. The consumption of cosmetic products is important in the context of environmental pollution and its effects on human health and the environment. Hundreds of thousands of synthesized compounds are used in cosmetics, for most of these the effects on human health and the environment are not known, while some are suspected to have negative effects (Eriksson et al., 2003). Moreover, it has been shown that current sewage treatment technologies fall

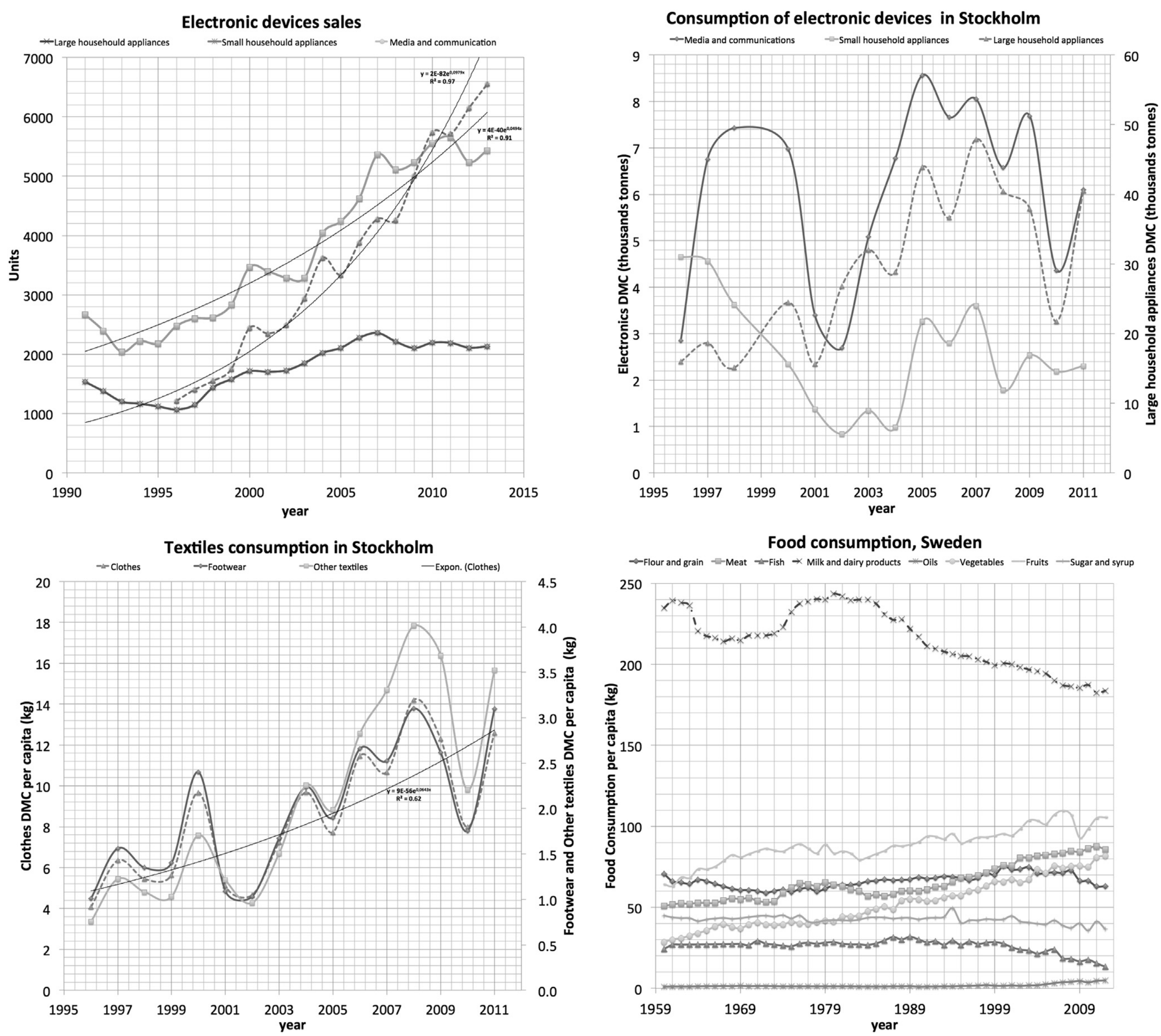

Fig. 6. Consumption of selected products: electronics, food and textile.

short of removing these synthesized compounds (Donner et al., 2008). For this reason, an increase in the consumption of cosmetic products leads to higher loads of potentially harmful substances in the water bodies.

The changed diet in Sweden during the last 50 years could have negative implications for the greenhouse gas and other emissions and for health. In particular, consumption of meat and fish has increased with about 32% while the fraction of fish decreased threefold from 1/3 of the animal protein in 1960 to barely 16% in 2011. The simultaneous threefold increase in cooking oils consumption suggest meat-consumption trend may be due to the increasing popularity of the deep-fried fast food and the emergence of the carbohydrate-poor, but protein-rich diets. Notably, this change was also reported to have caused considerable increase of nitrogen concentration in the sewage that demands construction of additional nitrogen-removal units in Swedish sewage treatment plants (Matsson, 2014).

Currently, there is no basis to believe that the consumer goods consumption will reduce in Sweden and its cities. Consumption levels reestablish quickly and grow after the recession periods in the economy, while no political instruments are currently being implemented or planned to reduce the materials consumption, apart from the fossil fuels, see the 5.3.3. for the details.

5.3. Policy

5.3.1. Building energy

The targets of Swedish energy policies are non-fossil energy mix and improved energy efficiency. Regarding the energy mix target, 65% of the energy used in Sweden in 2011 was of other than fossil origin, with only transportation fuels and coal/gas for the steel industry being of fossil origin (Energimyndigheten, 2014). As a result of the energy sector reforms, 50% of the energy supply has shifted from fossil fuels to hydro- and nuclear power, and biofuels since 1970. In particular, oil was completely phased out as the heating fuel for buildings (was the main heating fuel in 1970). This become possible with help of the government grants, loans and similar offers; see Kes McCormick (2009) for the details on the policies mentioned below and others implemented in 1977–2010. Subsidized measures included the conversion of fossil fuel-based and electric heating to district heating, heat pumps and biofuels, as well as better insulation. Also efficiency of the building-related energy consumption has been improved substantially. Building energy consumption has halved in absolute terms since 1970 when it was 44% of the total energy consumption and equal to the industrial energy consumption. The necessary policies were triggered by the oil crisis in 1973 and began with the Swedish Building Norm of 1975, which defined maximum U-values (heat loss in watts per square meter) of 0.2 W/m^2K for roofs and 2.0 W/m^2K for windows. Currently, the maximum U-value has been set to 0.4 W/m^2K, the energy consumption requirement is 90 kW h/m^2 and energy use certification is compulsory for all buildings. The National Board of Housing, Building and Planning is responsible for implementing these policies. In cities, the agenda is more ambitious than for the national level with for example stricter energy use requirements (60 kW h/m^2). Gothenburg also set the goal that 75% of all heating should come from renewable sources (reached in 2011). This underscores the potential of cities for bold policy development and implementation.

Other policies aimed at reducing the energy consumption of buildings relate to lighting and electric appliances. Lighting accounted for approximately 20% of all household electricity used in the EU before the sale of incandescent light bulbs was banned in September 2009. Once all the bulbs are gone, the electricity consumption in the EU is expected to decrease by 39 billion kilowatt hours and in Sweden by 2 billion kilowatt hours per year (Energimyndigheten, 2014). In 2010, the EU adopted the Directive 2010/30/EU on energy labels. Energy labels help consumers to choose products that save energy and provide an incentive for the industry to develop and invest in energy-efficient product design.

5.3.2. Transportation energy

The transportation energy sector also has policies intended to improve energy efficiency and promoting fuel switching, but which are also aimed at reducing the demand for personal transport. The *White Paper - European transport policy for 2010*: *Time to decide* argued that internalization of external (environmental) costs through budget and fiscal policies is needed to decrease the transport related energy consumption that was responsible for 28% of CO_2 emissions in 1998 (European Commission, 2001). The current EU policy framework establishes specific targets to be achieved by the transport sector by 2020: 10% of renewable energy and 6% decarbonization of transport fuels (European Commission, 2013). The Renewable Energy Directive requires 10% of Europe's fossil fuel in transport to be replaced with liquid biofuels by 2020. The share of renewable energy in this sector reached 4.7% in 2010, up from 1.2% in 2005. The target for the transport sector is to achieve a 20% reduction in emissions, compared to the 2008 level, by 2030 (European Commission, 2011).

Sweden proclaimed a national goal of becoming a completely oil-free economy by 2020. However, the total travel by road, rail and sea, measured in passenger kilometers, has increased sixfold since 1950, while the share of public transport has declined from 49% in 1950 to 18% in 2009 (Trafikanalys, 2014). Nonetheless, some success has been achieved in reducing car transports in cities, partly as a result of the implemented agenda on denser living, short distance to services, restricted parking facilities and better public transport. Below are some of the rules adopted by the City Council of Gothenburg:

- Brownfields (often found in central locations but may require soil remediation investments) have priority for development, greenfield development projects are difficult to pass;
- parking lots and parking garages are being replaced by residential and commercial buildings;
- parking space quotas are less than one per apartment (0.5) in new multi-storey buildings;
- a public transport stop is required within 300 m of any residential development with the frequency of transport at least every 15 min; and
- access to bicycle lane and bicycle parking must be provided for each residential development.

The greatest effect was however achieved by the introduction of the congestion fee system in Stockholm in 2007 and in Gothenburg in 2013. A 20% decrease in the number of car passages into the city center and 5% increase in the number of journeys undertaken by public transport were reported in both cases (Swedish Transport Agency, 2013).

Of the EU member states, Sweden has the highest renewable energy use within transportation, at 12,6% in 2012 (Eurostat, 2014). The increasing number of flex-fuel cars can be attributed to the National climate policy in global cooperation bill passed in 2005 (Ministry of Sustainable Development (2005)). In 2006, the government passed a law obliging fuel stations (with annual sales of more than 1000 cubic meters of gas or diesel) to provide an alternative fuel option (Ministry of Sustainable Development (2007a)). The environmental vehicles bill (Ministry of Sustainable Development (2007b)) promote use of alternative fuels, including a tax exemption for ethanol and other biofuels, which resulted in a

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30% price reduction for ethanol over gasoline; a 10,000 SEK bonus to buyers of flex-fuel and energy-efficient cars (implemented in 2007, replaced by a 5-year exemption from the vehicle tax in 2009); a 20% discount on car insurance; free parking; and a tax reduction for flex-fuel company cars. By 2012, this incentive package resulted in flex-fuel cars sales representing 15% of new car sales (Fig. 5). However, the most remarkable fuel-switch has been in favor of diesel-fueled vehicles (DFV), which were claimed to decrease CO_2 emissions to some extent. This trend can be explained by private-economic but also policy factors. Diesel cars are 35% more fuel-efficient than their gasoline equivalents. In Europe, the price of diesel has historically been lower than the price of gasoline. Moreover, in Sweden newer diesel cars meet the “environmentally friendly vehicle” rules due to their lower than 120 g CO_2/km emission and therefore qualify for a tax reduction, or even a 5-year exemption from vehicle tax. Local policies in several Swedish cities, including Gothenburg, allow free parking for “environmentally friendly vehicles”. Fuel-switching to diesel is a sub-optimization, as fossil fuel sales and CO_2 from transportation continue to increase. The diesel-popularization trend is likely to die down from 2015, due to both price increases that will take the price of diesel to the gasoline price level and the new “environmentally friendly vehicle” rules, which include strict norms on NOx emissions, which few diesel cars will meet.

5.3.3. *Material flows*

Current policies on material flows management consider the control of dangerous substances and waste minimization. As a result of the EU landfill Directive 1999/31/EC, a landfill tax was introduced in Sweden in 2000, with the aim to promote recycling of materials. However, no visible effect on the quantities of landfilled materials was observed for the next two years. Instead, the ban on combustible waste landfilling in 2002 had a noticeable effect. In addition, the ban on organic waste landfilling (all waste with >5% organic content) in 2005 redirected almost all waste towards material and energy (incineration) recycling (Fig. 7). The ban is an implementation of the EU policy set out in Directive 99/31/EC, which demands that all EU Member States introduce national strategies in order to progressively reduce the quantities of landfilled biodegradable waste. Waste-to-energy “recycling” is currently the prevailing waste management method in Sweden: more than half of all waste is incinerated and the use of incineration is increasing faster than recycling. During 2006–2010 an Incineration Tax on Household Waste was implemented. This raised the proportion of material recycling above the share of waste incineration; however this tax was later abolished. It has been argued that investment in incineration plants hinders further development of material recycling, an issue summarized by Seltenrich (2013). In fact, Sweden's incineration capacity exceeds its need and waste is routinely imported from Norway and Great Britain. On the other hand, waste incineration reduces the need for fossil fuels, thereby reducing the resource consumption of the energy production sector.

Sweden is a pioneer in producer responsibility policies, with the first such instrument implemented as early as in 1975 in the shape of a deposit-refund program for cars, followed by the end-of-life vehicle producer responsibility in 1998. A tax on packaging materials was introduced in 1994, followed by the extended producer responsibility in 1997 (updated in 2006) (SFS, 1997). The first producer responsibility EU-policy relates to Waste Electric and Electronic Equipment (European Commission, 2002). The result of producer responsibility policies in Sweden is a high level of material recycling with over 75% of glass, 90% of paper, 86% of cardboard, 68% of metal and 60% of batteries being recycled. Plastic and organic waste recycling is still a challenge, with 26% and 20% being recycled respectively. Nonetheless, higher recycling rates have not reduced the resource consumption in Sweden. Moreover, waste generation is constantly increasing as a result of consumption growing ever faster than recycling. As of today, no policies focusing on reducing the demand and final consumption of goods have been implemented.

Greater success was achieved with the industrial waste in Sweden, which is a six times larger flow than the household waste. The waste volumes are more or less constant, despite growing levels of production, and materials are recycled to a much higher degree than for the household waste (Fig. 7).

6. Conclusions

Since 1996, Stockholm has achieved an absolute reduction in its Fossil Fuels consumption by 25%. No absolute reductions were achieved on the country scale or in Gothenburg. On the other hand,

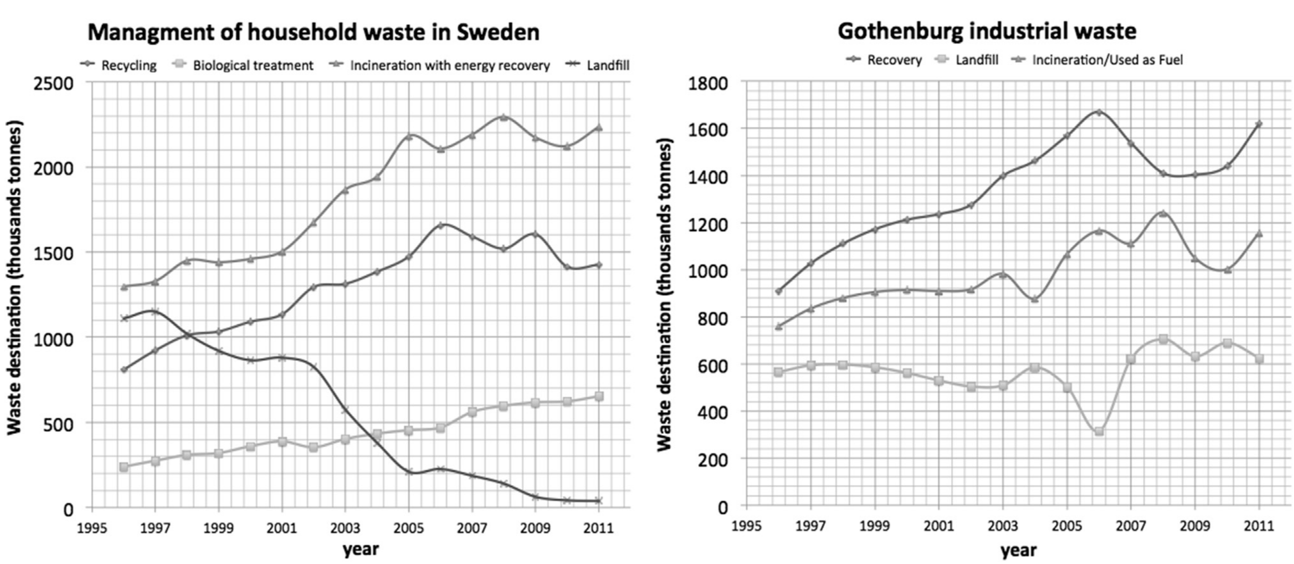

Fig. 7. Waste management.

the consumption of construction materials (in cities), electronics and textiles (in Stockholm) is growing exponentially, even when normalized by population. This is a consequence of a number of lifestyle factors, such as continual increases in income, residential floor area and technology development in consumer electronics. The only policies related to nonfuel resource consumption deal with waste management and have no influence on consumption. Moreover, waste management is not sufficient, as recycling rates improve at a much slower pace than the increase in consumption. It is obvious that we cannot recycle ourselves out of the exponential rise in consumption, and instruments that limit consumer demand must therefore be implemented urgently. Our 30-year experience of restricting fossil fuel consumption and CO_2 emissions needs to be applied to nonfuel materials. The instruments that appear to have been successful so far have been based on subsidies for energy-efficient renovations and for non-fossil and fuel-efficient vehicles, environmental taxes and, in cities, changes to the infrastructure and urban structure (for example densification and close access to services). To achieve similar success, instruments to curb nonfuel resource consumption should include those promoting smaller dwellings, renovation of products, including electronics, instead of new purchases, and a sharing economy. Environmental taxation may only have a limited effect in high-income countries such as Sweden and ways to change social norms and values relating to consumption must be found.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2015.02.027.

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