Urban energy consumption patterns in Estonia - a mandate of master plans

Martin Gauk[1],*, Antti Roose[2]

[1]University of Tartu, Department of Geography, Tartu, Estonia

[2]University of Tartu, Department of Geography, Tartu, Estonia

*martingauk@gmail.com

Abstract This paper addresses changes in land and energy uses in the suburban zone in the context of liberal land policies and loose planning controls. Three aspects of residential energy use were evaluated by applying the life cycle assessment (LCA) methodology: the energy use for manufacturing of the building materials, energy needed for building's operational uses and energy use of private car transport. The results show, that the conflicts among diverse policies and regulations that focus on the planning rights of rural land have generated intense wave of master planning which has led to extensive 'overbooking' of suburban land parcels, creating considerable boundaries for implementing more sustainable development in the future.

1 Introduction

In recent years, an increased pressure has risen to study energy conservations of residential areas due to general concerns of climate mitigation and resource management. Today, urban areas account for approximately 60% of the European Union's (EU) primary energy consumption and about 70% of fossil fuel and direct greenhouse gas (GHG) emissions [1], and the trend is rising. The vastly expanding cities enable the development of vital socio-economic structures, but are also responsible for consuming huge amounts of natural resources and great proportion of energy, thus creating noticeable environmental impacts on local and global scale [2].

According to the European Environment Agency, cities, their planning strategies, and decision-making have a crucial role in implementing sustainable development and energy policies [3]. Cities are viewed as the key actors in this case due to their administrative coherence and their direct interests in issues concerning resources, environment and sufficient energy supply [4]. Yet in many aspects, local governments are still distancing themselves as active institutions in the making of energy and climate policies. As a result, the contemporary planning practice does not often involve an effective land use energy evaluation programmes in their development plans [5].

One of the main issues in urban agglomerations concerning energy use and environmental aspects is urban sprawl [4,6]. As more and more people move to suburbs, local governments are faced with the challenge of managing future growth in a manner that is environmentally and economically smart. Many activities associated with urban sprawl – new constructions, road building and expansion into former agricultural land – rely on enormous amounts of electricity and fuel. Although the new building stock is gradually more efficient in terms of intensity (kWh/m^2), the houses are bigger and more apart. Therefore the energy gains are consumed by the bigger houses and longer individual travel distances for commuting and commerce, since access to public transport is not always available.

The current wave of residential suburbanization in Estonia has been very expansive and urban land use has become a major driving force for land cover change since the late 1990s [7,8]. Since the turn of the millennium new residential estates, sporadic plots and infrastructure projects have occupied the cultivated fields at the city's perimeter, near suburban agro-villages, along major roads and at garden allotments and summer-house districts. The locations of new residential settlements are chosen according to the availability of land, mainly occupying valuable agricultural land as well as pressurizing green network, resulting in widespread impacts on environmental sustainability. The liberal planning practices have resulted in chaotic urban structures and statutory master planning has been unable to control urban growth. Ad hoc and case by case planning have been main approaches addressing land use change during rapid suburbanization without considering any strategical visions or environmental concerns.

This study examines the extent of suburbanization in the urban fringe of Tartu, the second largest city in Estonia, from the perspective of how urban sprawl contributes to the residential and transportation energy use in the light of liberal planning practices. These two metrics were chosen to indicate the overall energy intensiveness and climate change potential associated with different residential densities, which are highly relevant to urban planners given the current importance of energy supply issues and global climate mitigation. Energy use described in this study corresponds to the total fuel and electrical energy required for manufacturing building materials, operating buildings and private transportation, measured in megawatt hours (MWh).

2 Methods

2.1 Suburbanization

Tracking suburbanization processes provides information that could be applied in future land use planning. This paper uses Tartu city and its five surrounding municipalities - Haaslava, Luunja, Tartu rural, Tähtvere and Ülenurme with the total extent of 740km^2 as the study area. The focus lies on spatial dynamics, in particular on suburban land use and landscape change. The relevant aspects of suburbanization are assessed on the levels of administrative units, master plans and parcels. Master plans are treated as key tools in delivering land use planning in suburban areas. In addition, extensive surveys were carried out in 2008 to determine the actual deployment of planning and construction rights in the issued master plan areas.

The centre of the case study area, Tartu, is the second biggest city in Estonia and it belongs to the group of medium-sized cities on the European scale with its population of 98,000 [9]. As the regional pole of Southern Estonia it fulfils a central role as Estonia's leading research, educational, health-care, and administrative centre. The latest wave of suburban development in the Tartu area has been ongoing since the late 1990s.

2.2 Life cycle assessment (LCA)

The energy consumption patterns in the new suburban settlements were estimated by applying the LCA methodology. LCA is a comparative analysis process that accounts for all material and energy inputs and evaluates the direct and indirect environmental burdens associated to a product or service in its life cycle [10]. The life cycle of a building includes several phases: the production of materials, on-site construction, operation, disassembly and waste management and considers the total energy use and environmental outputs [11].

This study focuses on the energy use of building material production and household's operational requirements (heating, appliances, lightning and water heating). In addition, the operational energy of personal transportation for each household is taken into account. Energy used for on-site construction, renovation, demolition and utilization is excluded from the study due lack of available data and to their relative insignificance to the overall life cycle energy [11,12]. Two functional units are analysed: energy use per person and energy use per square metre for a period of 50 years.

Building material energy considers the energy content of all the materials used in the building and energy that is needed during the manufacturing processes. Building material quantities were extracted from the data available on the Estonian Building Register and the embodied energy was calculated by applying the energy values of the building materials extracted from previous studies and databases [13,14]. Building material energy was calculated using the following formula:

$$BE = \sum m_i M_i / L_b$$

where BE = building material energy; m_i = quantity of building material (i); M_i = energy content of material per unit quantity $_{(i)}$; L_b = li life span of the building.

Operational energy use of the buildings was calculated by taking into account the standard climate conditions and by estimating building's energy demand at standard use. Data on heating systems were extracted from the Estonian Building Register, and data on consumption at standard use was extracted from a previous study [15]. Operational energy was calculated using the following formula:

$$OE = \sum E_{O(f)} A$$

where OE = annual building's operational energy; $E_{O(f)}$ = annual energy required for different operations $_{(o)}$ per square metre, considering the efficiency of different heating systems $_{(f)}$; A = size of dwelling's floor area.

Transportation operational energy resulting from everyday migration between fringe and core were estimated considering the number of new suburban dwellings, size of different households, distances from the city centre via road network, average fuel consumed by cars per km. The distances between the new settlements and the city centre were calculated using ArcInfo 9.2 Network Analyst tool. Data on the size of different households, average cars per household, average trips travelled per day, and fuel consumption were extracted from previous studies [16,17].

Operational energy for private transportation was calculated using the following formula:

$$OE_T = D T_y E_d C$$

where: OE_T = annual operational energy for transportation; D = distance from the city centre T_y = annual trips; E_d = energy used for travelling one kilometre; C = cars per household. The resulting annual vehicle operating energies were normalized to per person and per-unit living area basis for each case study.

3 Results and discussion

3.1 Suburbanization in Tartu

Tab.1: The number of issued master plans and building parcels within the master plan areas

Suburban municipality	Issued master plans	Parcels within master plans	Master plan area (ha)
Haaslava	22	329	92.0
Luunja	44	551	203.0
Tartu rural	57	813	267,7
Tähtvere	31	248	105.4
Ülenurme	85	1677	407.6
Total	239	3615	1075.8

The suburbanization processes in the *peri*-urban zone can be well tracked by master plans. In total, 239 master plans and 3615 parcels were analyzed in the five municipalities of the Tartu fringe (Tab. 1). The core city itself was excluded from the study. On average, 15.1 parcels were designed per master plan (293 parcels per km^2). There is a strong relationship between the distance from the city centre and the size of the master plan area: the average size of a master plan area close to the city is 5.2 ha and this decreases in distant areas to 2.5 ha. The area varies to great extent between municipalities, depending on the availability of attractive land for residential development and the connections to the city. The leading municipality was Ülenurme with 85 issued master plans with the size of 407.6 ha (Tab. 1).

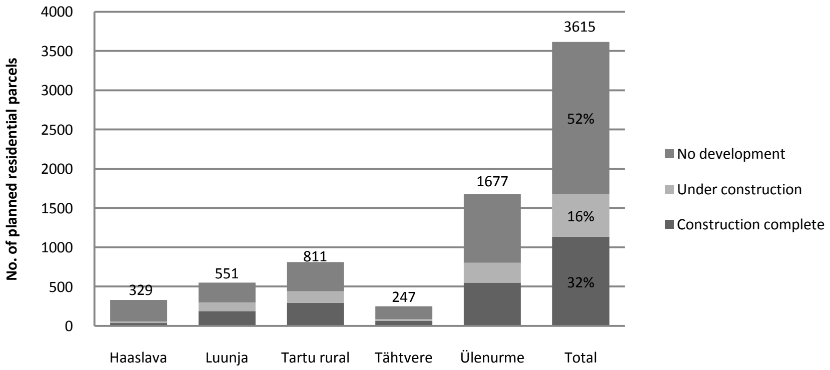

Fig. 1: Deployment of planning and construction rights by parcels in the Tartu suburbs by 2008

Analysis shows, that there is a big gap between issued master plans and actual development (Fig. 1). Only 48% of the planned development has been carried out (32% of the planned development completed and 16% under construction). But there has been no deployment of the construction rights on the 52% of the planned parcels (Fig. 1), which clearly indicates to planning above real demand with the aim of preserving planning and construction rights for the future.

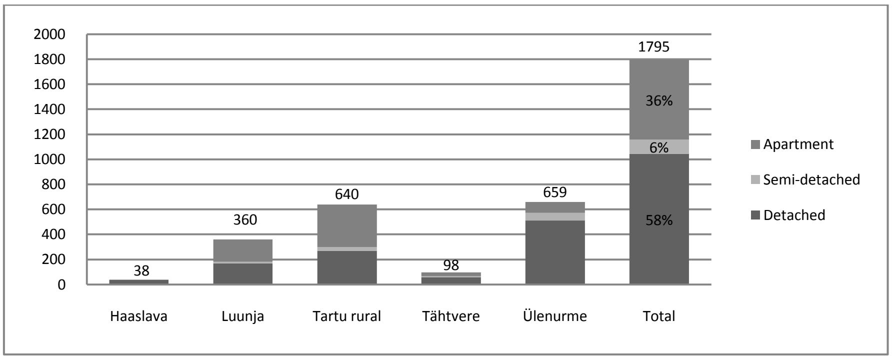

Fig. 2: Distribution of new dwellings in suburban areas by 2008

Distribution of the new developments between municipalities has been mainly influenced by land prices, accessibility to different infrastructures and local council's ability to modify planning codes to lure real estate developers. Too much emphasis was given to the delivery of quantity, namely land supply rather than the benefits of quality and allocation choices during the growth phase in many municipalities.

Figure 2 shows that 58% of the new residential stock is formed by detached single-family dwellings, but the share of apartments is also high - 36%. As the development of detached single-family dwellings were dominant in the 1990's and early 2000's, more compact housing types became popular in the second half of the 2000's, due to the growing land and construction prices.

3.2 Energy use in the new suburban settlements

3.2.1 Building material energy use

The results of the first part of the LCA analysis show that embodied energy resulting from material production is approximately 1.7 times higher in the case of average detached single-family dwelling than in average semi-detached dwelling, and 2,2 times higher than in average apartment dwelling on per capita basis (Fig. 3).

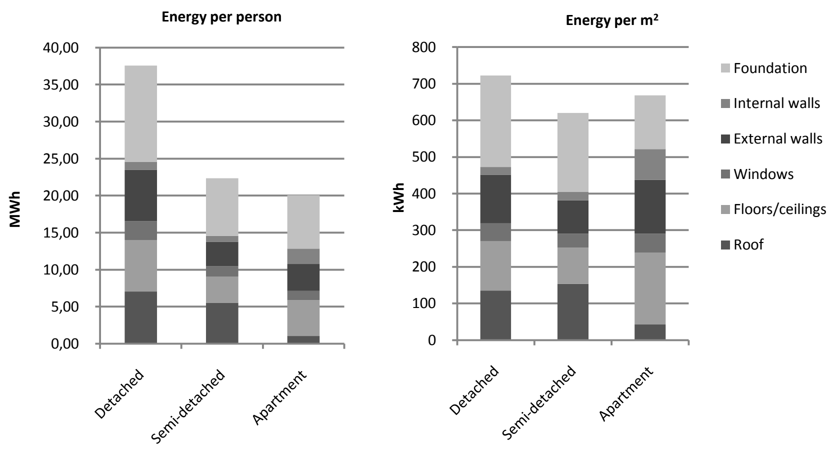

Fig. 3: Average energy use related to production of building materials for different types of dwellings

However, when comparing the embodied energy use of building materials per m^2, the results alter significantly. An average apartment dwelling becomes almost as energy intensive in terms of material production as an average single-family dwelling. Only an average semi-detached dwelling is slightly more energy efficient (Fig. 3). This is a result of using similar building materials in high and low residential development in the fringe of Tartu. Although the use of building materials can vary substantially between each case, the average building material consumption is quite similar. Therefore, in this case, the energy efficiency depends largely on the size of the dwelling, and thus the volumes of used building materials.

3.2.2 Dwelling's operational energy use

The household operational energy consumption patterns are largely determined by the climate conditions. As Estonia is situated in the northern part of the temperate climate zone and in the transition zone between maritime and continental climate, the average annual temperature is 5.2 °C [18]. Therefore, greater proportion of operational energy is consumed by space heating which absorbs almost 61 per cent of total household energy demand, with appliances accounting for 10 per cent, lightning for 4 per cent, pumps and ventilators for 5 per cent, and water heating for 20 per cent (Fig. 4). The energy efficiency of space heating varies significantly on account of the type of heating systems and on the characteristics of applied building materials [19].

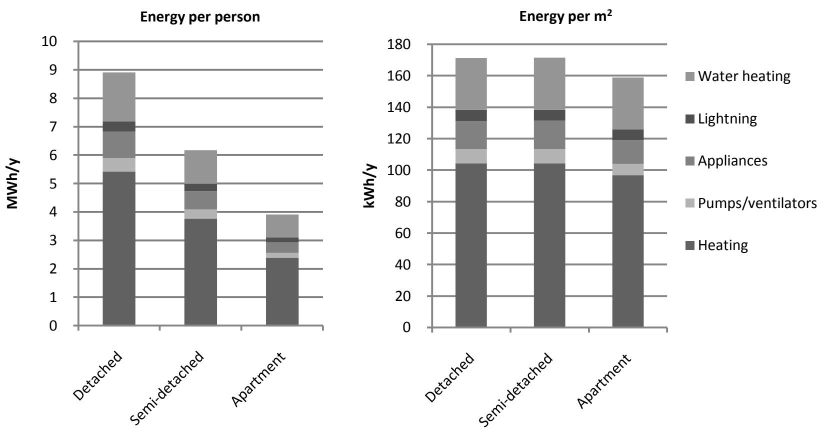

Fig. 4: Annual operational energy use for different types of dwellings

As can be seen on figure 4, the building's operational energy use per capita is in an average detached single-family dwelling 1.4-fold higher than in a semi-detached dwelling, and 2.3-fold higher than in an apartment dwelling. When changing the functional unit to floor area, it becomes evident that there are no big differences between various types of dwellings. Energy demand for each type of dwelling is around 150 - 170kWh/m^2. This is a result of the applying similar types of heating sources and as the houses are built in the same decade, the quality of construction, e.g. insulation, is quite similar. The apartment dwellings are slightly more efficient in terms of energy intensity due to the bigger share of internal walls, as the heat losses are smaller. The main energy gains in this case are associated with compact housing and related to smaller living areas per capita basis.

3.2.3 Relative contributions of building material production, dwelling's operational use and private transportation

Based on the results presented in the previous sections, an overall assessment of the relative contributions to energy use by the three urban development factors considered in this study has been conducted by summing the energy uses of material production, building operations and private transportation.

As can be seen on figure 5, energy uses in detached single-family dwellings are roughly 1.4 times as energy intensive as in semi-detached dwellings, and nearly 2 times as energy intensive as in apartment dwellings. The main differences lie in the buildings operational energy use due to the disparities in the size of living areas (Fig. 5) and on the account of the energy savings obtained by shared external walls.

The most energy demanding is dwelling's operational phase, which consumes 67-74% of the overall annual energy use, followed by private car transport with 20 - 27%. The building material energy use plays the lesser role in the overall life cycle (in this case 50 years), consuming only 5 - 6% of the energy annually.

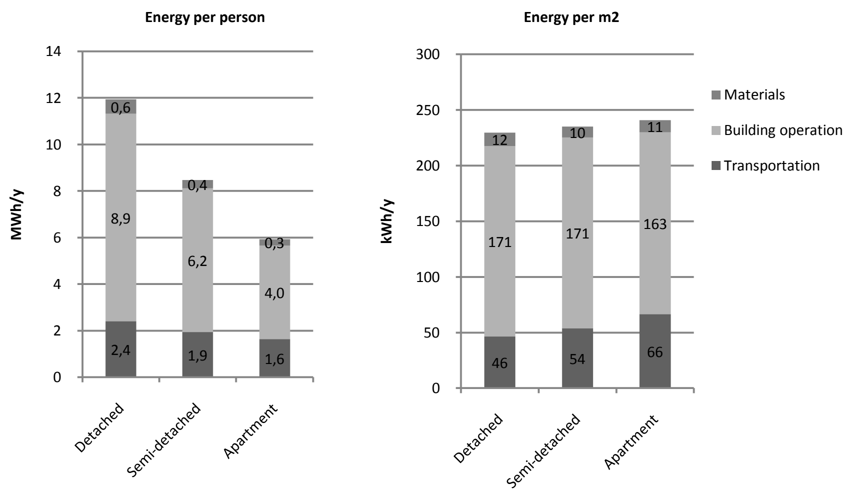

Fig. 5: Overall energy use for different types of dwellings

The current annual energy use in the new suburban settlements in the fringe of Tartu is estimated to be around 41.5 terawatt hours (Fig. 6). As not nearly even half of the planned developments are carried out, two future scenarios were created in order to predict the future energy use in the suburban areas. Scenario 1 refers to the buildings that are currently under construction and entering soon to the market and put in use and Scenario 2 refers to all the planned parcels that are yet to be developed. In case of Scenario 1, the energy demand will rise about 16% (Fig. 6) in the near future. But as Estonian economy turned into recession in 2007, the construction volumes have decreased significantly and it is likely that only a small amount of the planned empty parcels are built out in the next five to ten years. Therefore, as Scenario 2 shows, over 50% of the energy use in suburban settlements is booked for unknown time, putting the implementations of future sustainable development strategies at risk (Fig. 6).

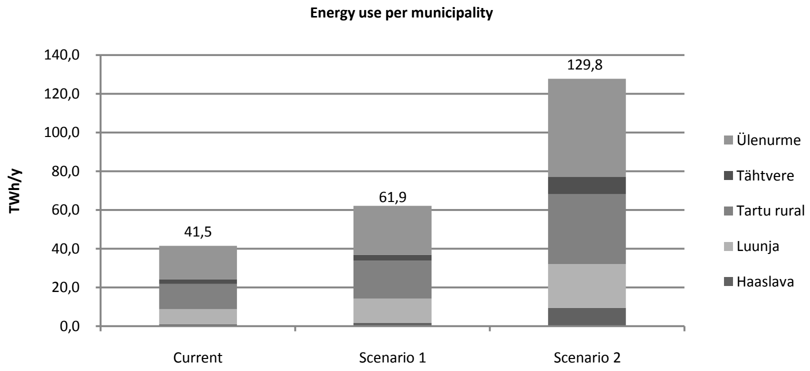

Fig. 6: Current and planned energy use in new suburban settlements

4 Conclusions

This study summarizes land use change, land management and planning practices in the urban fringe and adopts the life cycle assessment approach with the aim of introducing life cycle management strategies in developing sustainable land use policies in a highly fragmented suburban land.

The first part of the analysis shows that there has been a big gap between issued master plans and establishment of suburban settlements, which clearly indicates to planning above real demand. 239 master plans were issued between January 1997 and May 2008, but only 48 per cent of planned suburban settlements were actually built. The conflicts among diverse policies and regulations that focus on the planning rights of rural land generated an opportunity for real estate developers to preserve planning and construction rights for the future and thus resulted in intense 'overbooking' in suburban land parcels.

Massive overplanning and the preservation of building rights determines the future energy landscape as well. The majority of the new suburban dwellings are detached single-family houses, and it is evident that the future growth will continue the same pattern. However, the analysis shows, that the new detached single-family dwellings are approximately 2 times as energy intensive as apartments and 1,4 times as intensive as semi-detached dwellings in per capita basis. Although the new housing stock is more efficient in terms of intensity (kWh/m^2), the dwellings are bigger and more apart. Therefore, urban density and spatial organization are the key factors that influence energy consumption, especially in operational phases and transportation sectors.

In order to shift the policy focuses of local master plans and to better cope with the issues related to suburbanization, a policy response on a variable geographical scale is required, integrating local development initiatives and cooperation between different levels of administration. It is also vital to interlink planning practices with social, economic, energy-related and environmental studies to better predict the various impacts of the planned developments and to achieve a more sustainable future.

5 References

[1] International Energy Agency, *World energy outlook 2008. Technical Report*, International Energy Agency/OECD, 2008.

[2] Keirstead, J., Shulz, B. N., London and beyond: Taking a closer look at urban energy policy, *Energy Policy*, Vol. 38, No. 9, 2010, pp. 4870 - 4879.

[3] European Environment Agency, *Urban Sprawl in Europe. The Ignored Challange*, EEA, 2006.

[4] Nijkamp, P., Pepping, G., A meta-analytical evaluation of sustainable city initiatives. *Urban Studies* Vol. 35, No. 9, 1998, pp 1481–1500.

[5] Duvarcı, Y., Kutluca, A. K., Appraisal of Energy Efficiency of Urban Development Plans: The Fidelity Concept on Izmir-Balcova Case, *World Academy of Science, Engineering and Technology*, Vol. 1, No. 48, 2008, pp. 359 - 376.

[6] Newman, P., Kenworthy, J, *Sustainability and cities: Overcoming automobile dependence*, Island, Washington, D.C, 1999.

[7] Kulu, H., Billari, F., Migration to urban and rural destinations in post-Soviet Estonia: A multilevel event-history analysis. *Environment and Planning,* Vol. 38, No. 4, 2006, pp. 749–764.

[8] Tammaru, T., Leetmaa, K., Silm, S., Ahas, R., Temporal and Spatial Dynamics of the New Residential Areas around Tallinn, *European Planning Studies,* Vol. 17, No. 3, 2009, pp. 423–439.

[9] *Statistical Yearbook of Estonia,* Statistics Estonia, 2008.

[10] Ramesh, T., Prakash, R., Shukla, K. K., Life cycle energy analysis of buildings: An overview, Energy and Buildings, Vol. 42, No. 10, 2010, pp. 1592 - 1600.

[11] Gustavsson, L., Joelsson, A., Life cycle primary energy analysis of residential buildings, *Energy and Buildings*, Vol. 42, No. 2, 2010, pp. 210 - 220.
[12] Norman, J., MacLean, L. H., Kennedy, A. C., Comparing high and low residential density: Life-cycle analysis of energy use and greenhouse gas emissions, *Journal of Urban Planning and Development*, Vol. 132, No. 1, 2006, pp. 10 - 21.
[13] Esperk, T., *Life cycle analysis of envelope types of single-family houses in Estonia*, University of Tartu, 2007.
[14] Hammond, G., Jones, C., *Inventory of carbon & energy(ICE) Version 2.0*, Bath, 2011.
[15] Loigu, E., Kõiv, TA., *Additional analysis for the Government's regulation "Minimum requirements for energy efficency"*, Tallinn University of Technology, 2010.
[16] Ahas, R., Silm, S., *New suburban settlements of the hinterland of Tallinn. A time-space behavior analysi,*. University of Tartu, 2006.
[17] Lepplaan, T., *Automobile emissions of suburbanites and urbanites. Daily movements in Tallinn metropolitan region*, University of Tartu, 2009.
[18] <http://www.emhi.ee/?ide=6>, (Accessed 01.04.2011).
[19] Dzioubinski, O., Chipman, R., *Trends in consumption and production: household energy consumption, Discussion Paper of the United Nations. Department of Economic and Social Affairs*, United Nations, 1999.