Eco efficiency of urban form and transportation

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Abstract

Urban planning and transportation system solutions and decisions have a large-scale significance for eco efficiency, the consumption of energy and other natural resources, the production of greenhouse gas and other emissions, and the costs caused by communities.

Planning solutions may impact on greenhouse gas emissions by 10 % at regional level, by 20 % at local community level and even by 200 % at local dwelling area level. Impact on emissions caused by transportation is even bigger: at least double compared to the impact on total emissions. Similarly large impacts can be seen concerning consumption of energy and other natural resources as well as costs.

The most important factors in sustainable urban and transportation planning are at dwelling area level: location, structure, building density, house types, space heating systems, at community and regional level: area density, energy consumption and production systems, location of and distances between dwellings, working places and services, transportation systems, possibilities of walking and cycling, availability of public transport, and necessity for use of private cars.

The presentation is based on the author's research and case studies from 1992 to 2006. The assessment method EcoBalance was developed to assess sustainability of communities and it has been applied at different planning levels: regional plans, local master plans and detailed plans. The EcoBalance model estimates the total consumption of energy and other natural resources, the production of emissions and wastes and the costs caused directly and indirectly by communities on a life-cycle basis.

Introduction

An ecologically sustainable area can be described as an area which requires the supply of as little energy and raw materials as possible, (especially non-renewable materials), and which produces the minimum of harmful emission and wastes from all the building and operating processes on a life-cycle basis. A sustainable area should also offer people a good living environment and be economically affordable. (Lahti and Harmaajärvi 1992)

In order to evaluate the ecological sustainability or eco efficiency of urban structures it is necessary to develop appropriate assessment methods. Methods for sustainability assessment are described for example in COST Action C8 "Best Practice in Sustainable Urban Infrastructure" (Towards Sustainable Urban Structure 2006).

Eco efficiency includes the consumption of energy and other natural resources, the production of greenhouse gas and other emissions, and the costs caused by communities. The EcoBalance model has been developed and used in several cases in Finland for evaluating the impacts of different solutions in urban planning and transportation at different planning levels: residential area, municipality and regional levels (e.g. Harmaajärvi 1992, Harmaajärvi 1998, Harmaajärvi and Lyytikkä 1999, Harmaajärvi 2002, Halme & Harmaajärvi 2003, Halme, Harmaajärvi & Koski 2003, Harmaajärvi, Halme & Kärkkäinen

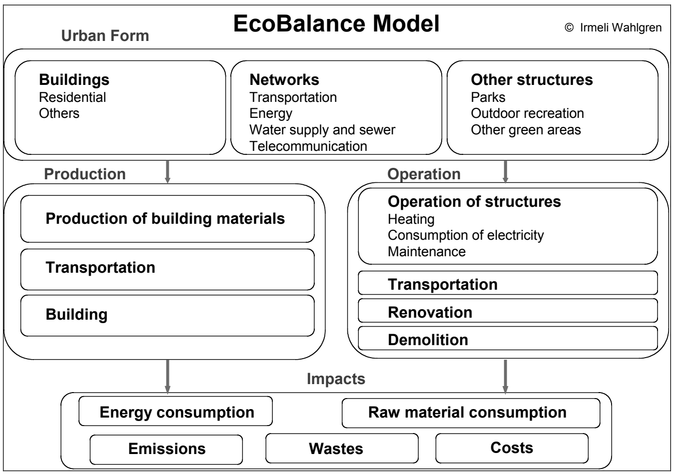

Figure 1. The structure of the EcoBalance model *(Harmaajärvi 1995, 2000).*

2005, Wahlgren & Halonen 2006, Wahlgren 2007). Results of the case studies show how ecologically sustainable different areas are, which impacts appear in different areas and urban form levels, which are the essential choices of urban planning and transportation and how to act to promote ecological sustainability in land use and transportation planning.

Figure 2. Case study areas. *Rural "eco-villages": 1 Ekolehtilä, 2 Pellesmäki, 3 Puutosmäki, 4 Vuonislahti. Urban residential areas: 5 Sodankylä (mixed area), 6 Kotka (mixed area), 7 a compact small house area, 8 a loose small house area, 9 a mixed area, 10 an area with blocks of flats. Municipal and regional level: 11 Sipoo (9 structure models), 12 Kuopio (2 structure models), 13 Kuopio Region (5 structure models). (Source of the map: Google Earth)*

The EcoBalance model

The EcoBalance model estimates the total consumption of energy (primary energy) and other natural resources, the production of emissions and wastes and the costs caused directly and indirectly by urban structures and transportation (e.g. Harmaajärvi 1995 and 2000). (Fig. 1)

The EcoBalance model is divided into three sub-models: production, operation and transportation models. The ecological balance sheet has the following dimensions: consumption of energy (primary energy), consumption of natural resources (building materials, fuels, water), emissions, wastes and costs. All effects are measured with their natural dimensions (tons, kWh, m^3, euros).

The EcoBalance model includes all urban structures: buildings, technical infrastructure and green areas. The model covers the whole life-cycle of urban structures starting from the production of building materials and fuels, and continuing through maintenance and the use of the structures as well as transportation in the urban structure and finally to the demolition of the structures.

The EcoBalance model calculates

1. total energy consumption (primary energy, kWh);
2. consumption of building materials (tons of wood, concrete, other stone materials, metals, glass, oil and plastic products);
3. consumption of fuels (tons of gasoline, diesel oil, fuel oil, coal, gas, peat, wood, etc.),
4. production of emissions (tons of CO_2, CO, SO_2, NO_X, CH and particles);
5. water consumption and waste-water production (m^3),
6. production of wastes (tons for recycling, compost, dump, etc.);
7. total costs of construction, operation as well as transportation (euros).

All these impacts of an area are evaluated in different phases of the life-cycle: production, operation and transportation. Continuous impacts (operation and transportation) are evaluated using, for instance, a period of 50 years. The output of the EcoBalance model consists of total and relative figures (for instance, tons of CO_2 per inhabitant) for each ecological dimension.

Eco Efficiency of Urban Form and Transportation – Examples of Case Studies

This paper introduces results of case studies in which the EcoBalance Model has been used to assess eco efficiency – ecological and economic impacts - of different urban planning and transportation solutions at different planning levels. The total number of different areas and structures in 7 case studies is 26 (Fig. 2).

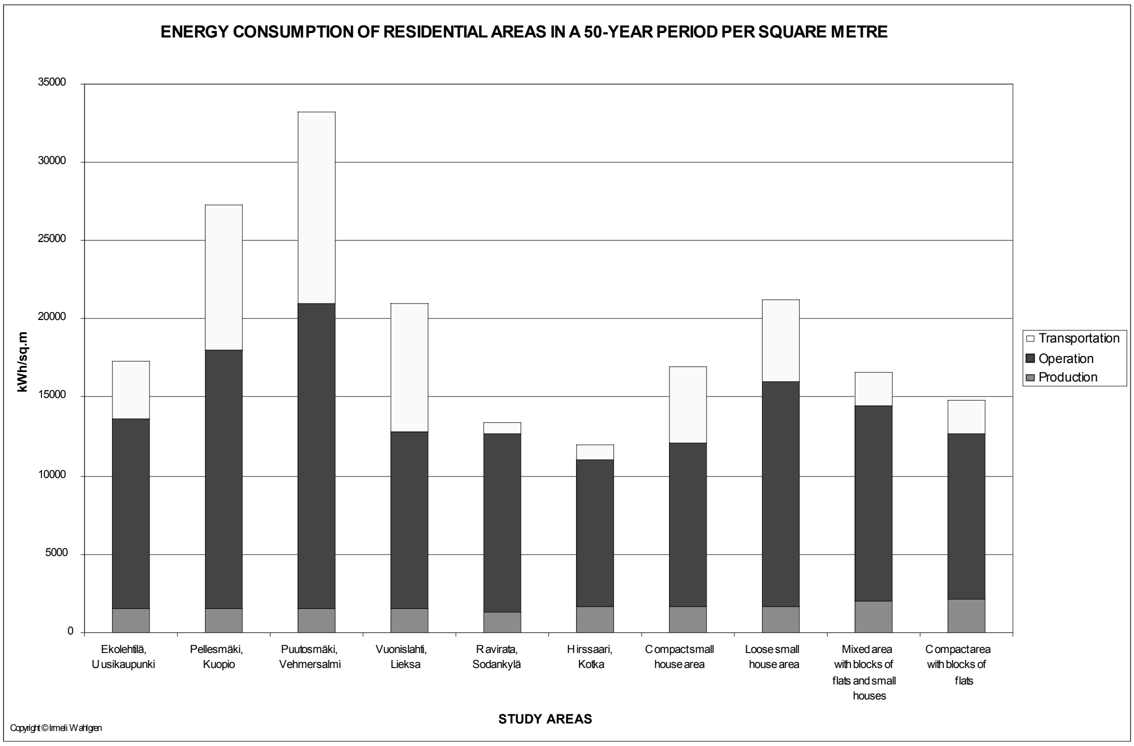

Figure 3. Energy consumption of residential areas in a 50-year period. *Most energy is required in rural areas for transportation.*

RESIDENTIAL AREA LEVEL

Eco efficiency of residential areas has been studied in 10 areas in different parts of Finland. Study areas have different solutions concerning location, structure, building efficiency, house types, heating systems etc. Two of the studies concern already built areas and two of them plans of the areas; studies have been made at the planning phase and assessment has been utilized in planning.

The study areas are:

1. Four typical Finnish residential areas: a compact small house area, a loose small house area, a mixed area with blocks of flats and small houses and a compact area with blocks of flats. (Harmaajärvi 1992)
2. Two relative new areas: Ravirata (former race track) in Sodankylä and Hirssaari in Kotka. They are mixed areas with a majority of small houses. (Harmaajärvi 1998)
3. Four "eco-villages" (rural areas that have been planned or are being developed with environmental interests as a priority): Ekolehtilä in Uusikaupunki, Pellesmäki in Kuopio, Puutosmäki in Vehmersalmi (nowadays a part of Kuopio) and Vuonislahti in Lieksa. The first two are relatively new areas with new technical or other solutions, which are intended to lead to environmental conservation. The others are old villages where sustainable solutions for their future development are sought. (Harmaajärvi & Lyytikkä 1999)

Energy consumption

In a 50-year period residential areas require energy 12 000 – 33 200 kWh per square metre (Fig. 3). The production phase makes only about 10 % of the total energy consumption. Most of energy consumption is due to heating and use of electricity. Transportation draws the greatest differences in energy consumption between areas. Energy is consumed most in rural "eco-villages" and small house areas because of long distances and wide use of private cars.

The least energy is consumed in areas which have district heating and efficient energy production system and which are located close to the city-centre and walking and bicycling as well as public transport are widely used.

Raw material consumption

Residential areas require 3.3 – 11.3 tons of raw materials per square metre in a 50-year period (Fig. 4). Of these, on average 60 % comprise building materials and 40 % fuels. Raw materials are required most in rural areas with scattered structure, which leads to a greater amount of infrastructure, as well as a relatively large amount of fuel used in heating and electricity consumption. Raw materials are required least in areas with compact structure and short distances.

Greenhouse gas emissions

Greenhouse gas emissions account for 3.5 – 6.7 tons of CO_2-eq. per square metre in a 50-year period (Fig. 5).

The majority of greenhouse gas emissions is caused by heating and electricity consumption of buildings. Greenhouse gas emissions caused in the operation phase are less in rural "eco-villages" than in other areas, due to the use of wood heating. Greenhouse gas emissions caused by transportation nevertheless eat away the savings obtained by wood heating. Transportation forms the greatest differences between areas.

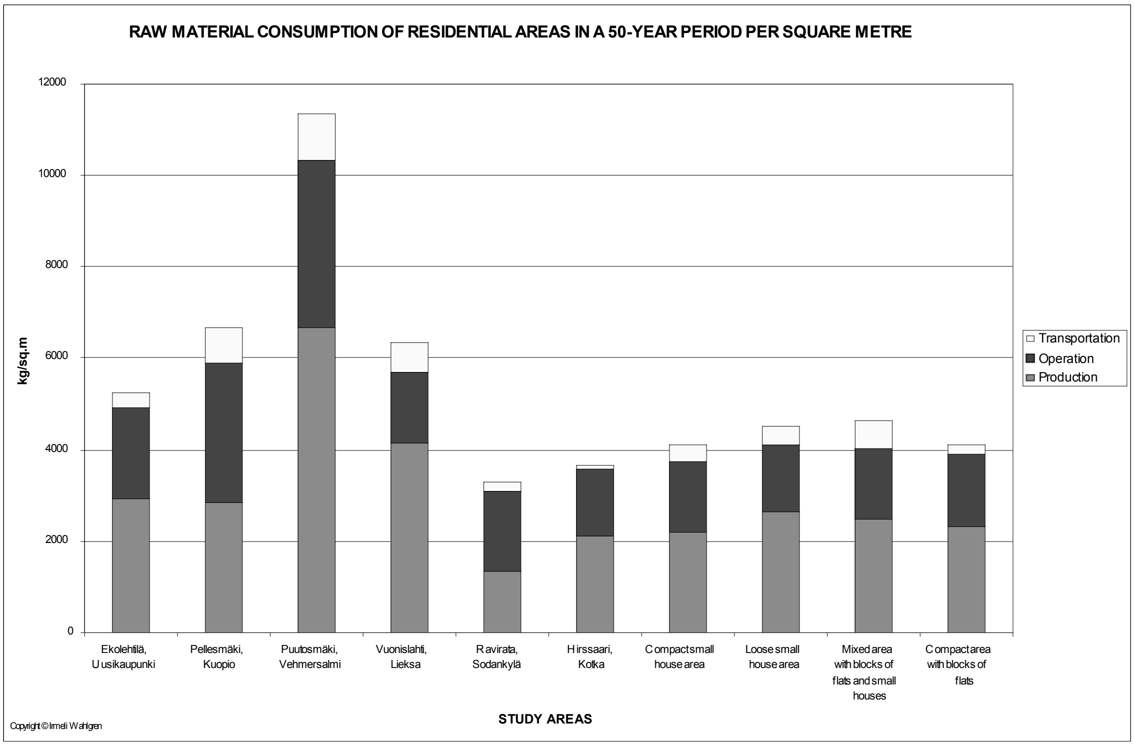

***Figure 4. Raw material consumption of residential areas in a 50-year period**. Raw materials are produced most in rural "eco-villages" in the production phase for infrastructure.*

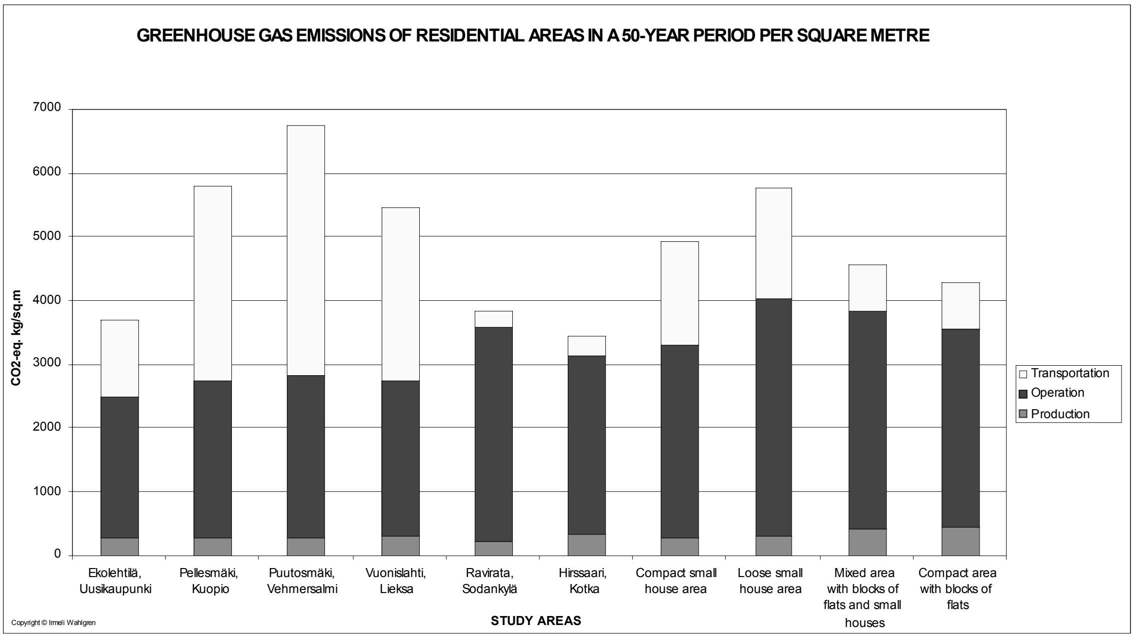

***Figure 5. Greenhouse gas emissions of residential areas in a 50-year period.** Emissions are produced most in rural areas by transportation.*

Other emissions

Other emissions (CO, SO_2, NO_x, CH and particles) account for 24-160 kg per square metre in a 50-year period (Fig. 6). These emissions are mainly caused by transportation and in rural areas also by wood heating.

Water consumption

Water consumption is 25-75 m^3 per square metre in a 50-year period. The use of compost toilets seems to halve water consumption.

Wastes

Wastes of 140-270 kg per square metre are produced in a 50-year period.

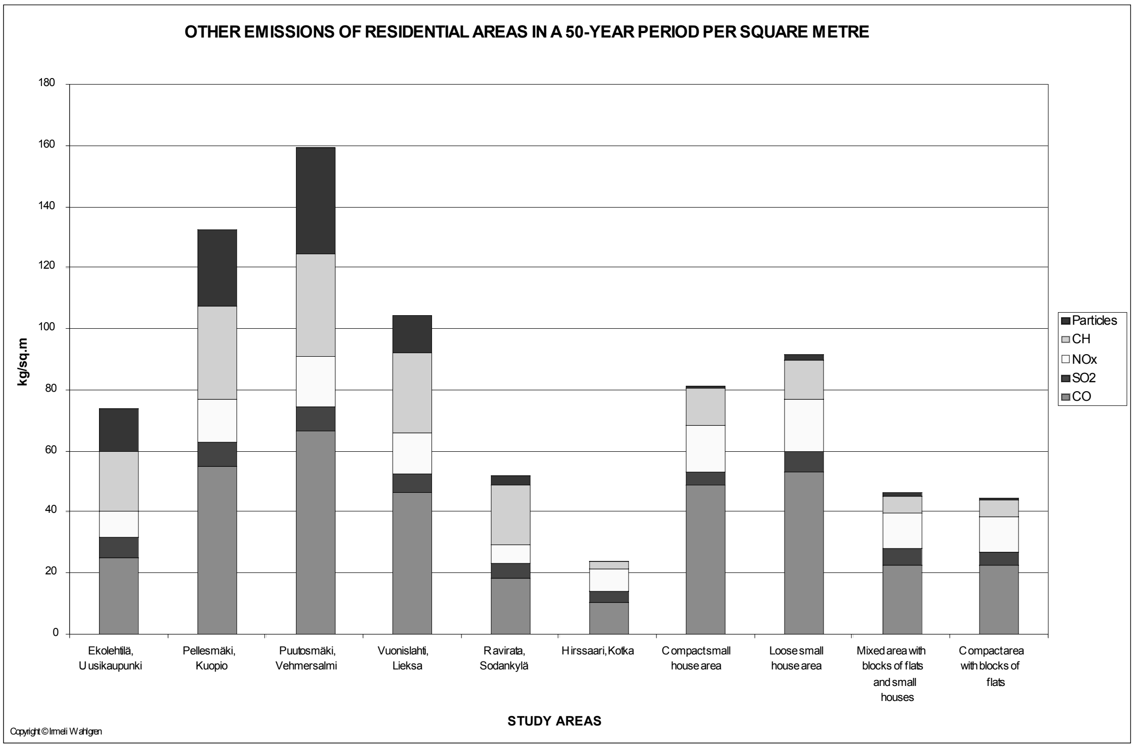

Figure 6. Other emissions of residential areas in a 50-year period. *Emissions are produced most by transportation.*

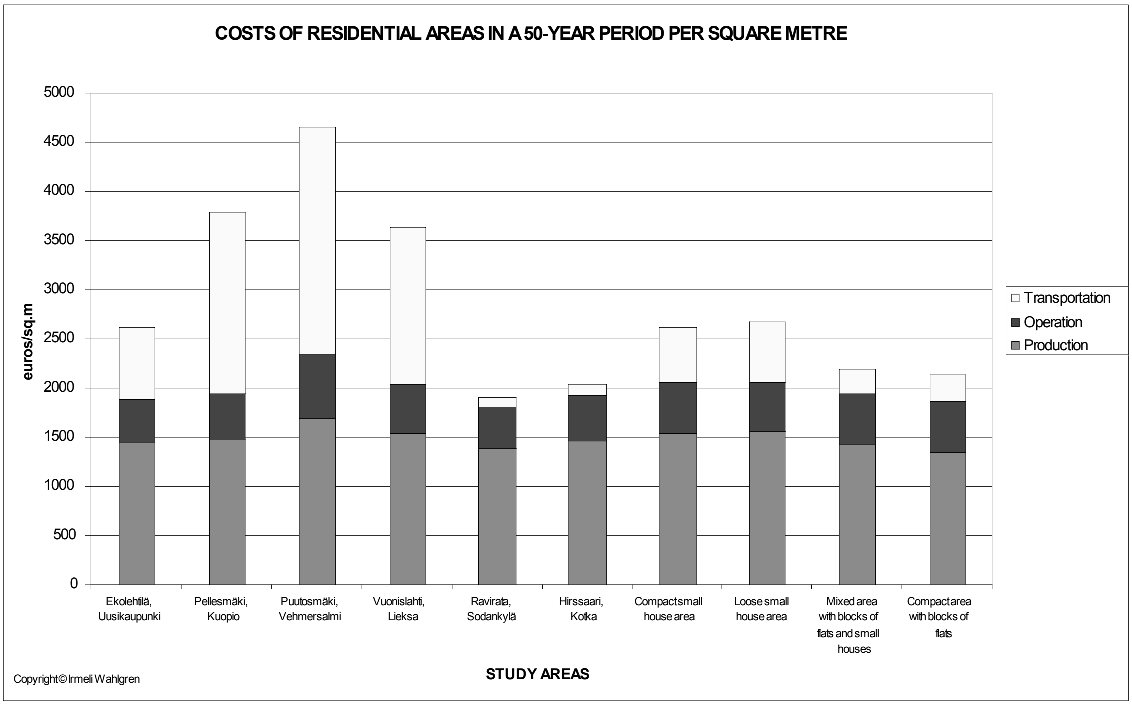

Figure 7. Costs of residential areas in a 50-year period. *The greatest differences between areas are due to transportation.*

Costs

Building and operational costs, including transportation, in a 50-year period amount to 1 900-4 700 euros per square metre (Fig. 7). Most of the costs are incurred by the production of structures and especially in the rural areas by transportation, as well. The greatest differences between the costs of study areas are due to transportation.

The results of the case studies show that there are big differences in the ecological impact of different areas. Eco-villages are not necessarily very sound from an ecological point of view. On average, eco-villages require more energy and raw materials, they produce more emissions and they cost more than urban areas. One of the most important explanations for the differences is transportation, especially in the use of private

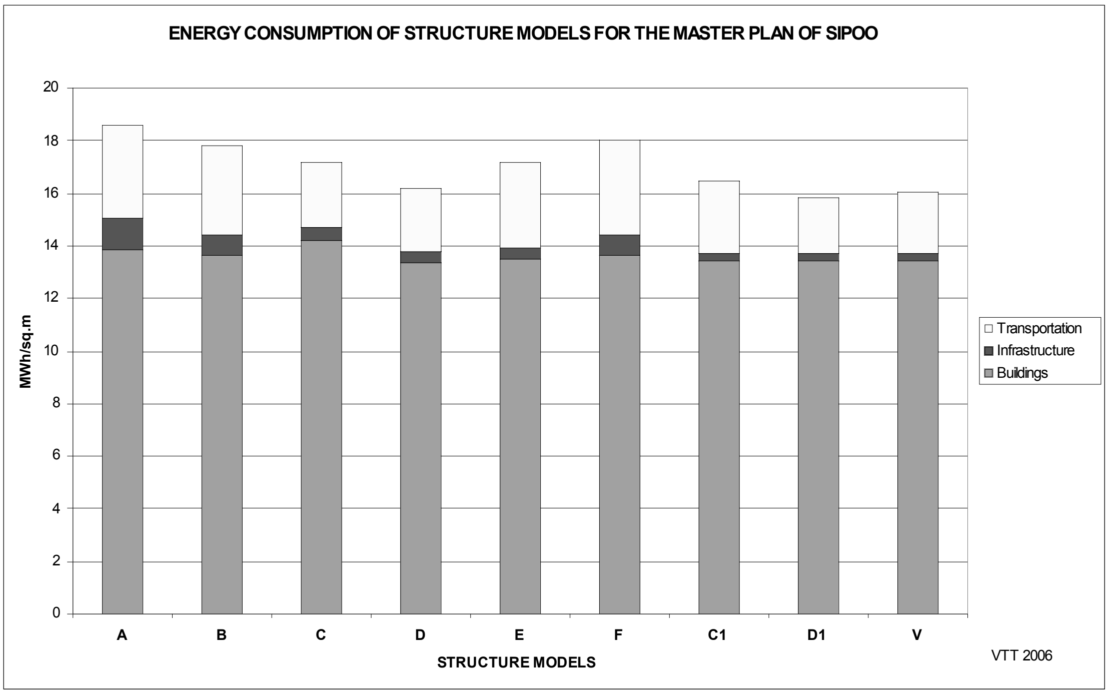

Figure 8. Energy consumption of the structure models of the Sipoo Master plan 2025. (Wahlgren & Halonen 2006, Wahlgren 2007)

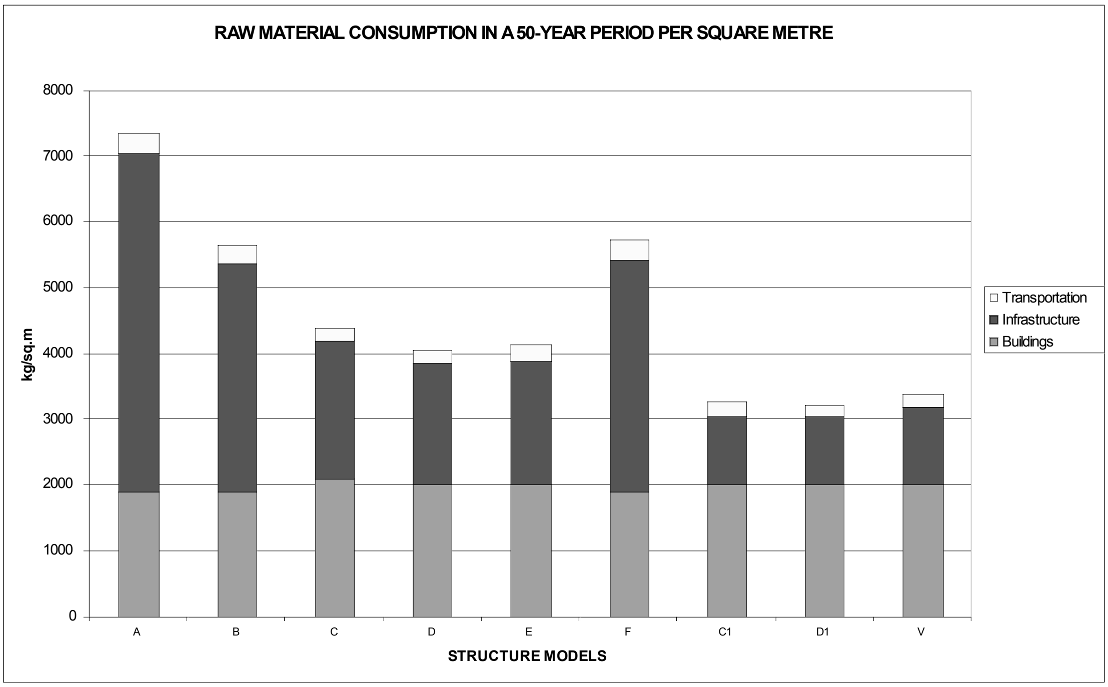

Figure 9. Raw material consumption of the structure models of the Sipoo Master plan 2025. (Wahlgren & Halonen 2006, Wahlgren 2007)

cars. This is strongly affected by the location of the area, the availability of public transport and individual preferences. Another important explanation for the differences lies in the consumption of heating energy and especially electricity. It would be most desirable to minimize electricity consumption.

MUNICIPALITY LEVEL

Two research studies have been made at municipality (master plan) level: Municipality of Sipoo (Wahlgren & Halonen 2006, Wahlgren 2007) and Southern City of Kuopio (Halme & Harmaajärvi 2003).

Structure models of the Master plan 2025 of Sipoo

The structure models of the Master plan 2025 of Sipoo differ from each other by the share of rural housing, by transportation system, by location of new areas and by building efficiency.

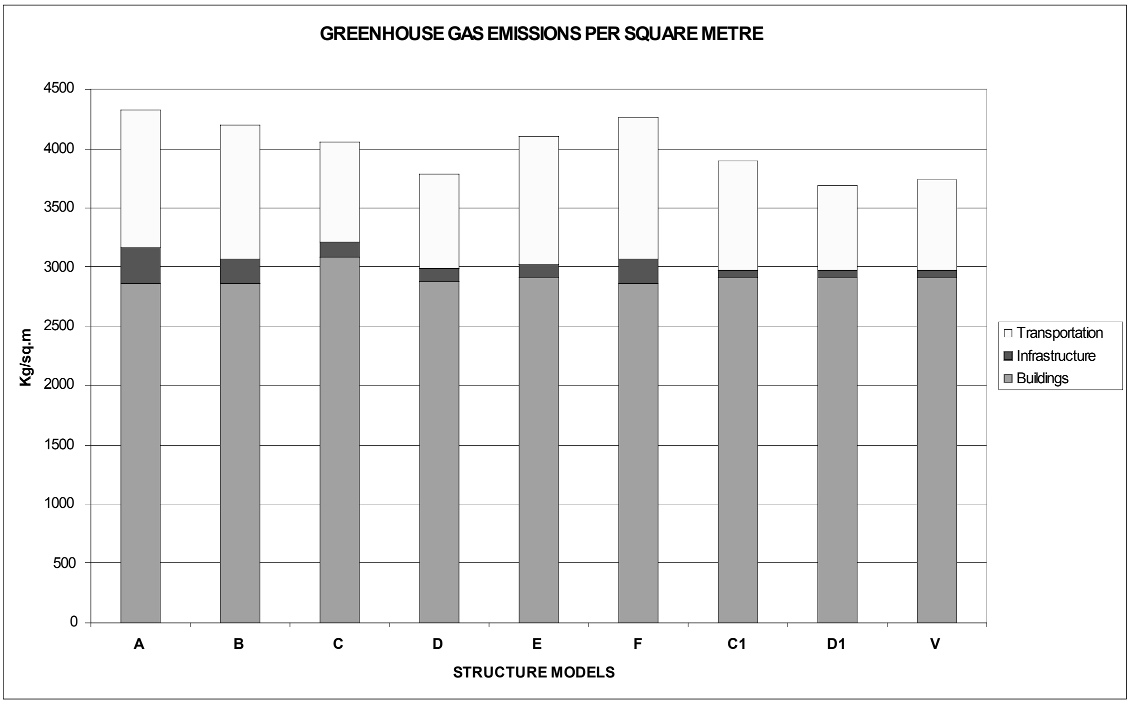

Figure 10. Greenhouse gas emissions of the structure models of the Sipoo Master plan 2025. *(Wahlgren & Halonen 2006, Wahlgren 2007)*

Structure model A has the most scattered structure and low density and it is strongly based on use of private cars. Structure models B and F have almost the same features than model A, but they have less housing in rural areas and slightly higher area density than model A. Structure models C, D and E are based on public rail transport and new areas are more compact. Structure models C1 and D1 have the same structure than models C and D, with significantly more new inhabitants and a little higher area density.

Structure model V is a combination of models C1 and D1, and it is by decision of the municipality the basis for the Master plan. Distances between dwellings, work places and services are shortest. Public transport is based on rail transport connections. Housing is located in urban areas and villages.

In a 50-year period structure models require energy 16-19 MWh per square metre (Fig. 8). Most of the energy consumption is due to heating and use of electricity of buildings but the greatest differences between models come from transportation.

Structure models require 3.2-7.4 tons of raw materials per square metre in a 50-year period (Fig. 9). The greatest differences are due to structure and building efficiency: scattered structure with low density requires more infrastructure than compact structure.

Greenhouse gas emissions account for 3.7-4.3 tons of CO^2-eq. per square metre in a 50-year period (Fig. 10). Differences between models are due to transportation. Effective public rail transportation causes clearly less emissions than transportation system which is based on private cars. The differences between models are even bigger when examining emissions per inhabitant.

Other emissions (CO, SO_2, NO_x, CH and particles) account for 38 – 57 kg per square metre in a 50-year period (Fig. 11). Most of other emissions are due to transportation.

Building and operational costs, including transportation, in a 50-year period amount to 3 600 – 4 400 euros per square metre (Fig. 12).

Southern City of Kuopio

Kuopio is planning and implementing a district (District of Islands), which consists of a chain of new neighbourhoods. A new special street (Street of Islands) will connect the new district directly to the city centre. It promotes cycling and bus transit and integrates the southern parts of the existing urban area with the Inner City. The street will cross a lake and pass several small islands. Because of the beautiful landscape the street has been designed for slow driving. It includes a good path for cyclists and pedestrians. The street will shorten the distances remarkably. (Fig. 13)

The study shows that the greenhouse gas emissions of the new District of Islands will be substantially lower compared with the alternative urban structure without the Street of Islands (Fig. 14). The same result concerns also other impacts: energy and raw material consumption, other emissions as well as costs.

REGIONAL LEVEL

Five structure models of the Regional Plan of Kuopio Region were studied with the EcoBalance Model (Harmaajärvi, Halme & Kärkkäinen 2005, Halme, Harmaajärvi & Koski 2003). The study showed that the best structure model has the shortest distances between functions, share of complementary building and infill development is relatively large, share of rural housing is relatively small, area density is relatively high and district heating possibilities are exploited. Greenhouse gas emissions are lowest and other impacts most advantageous in the Kuopio model (Fig. 15).

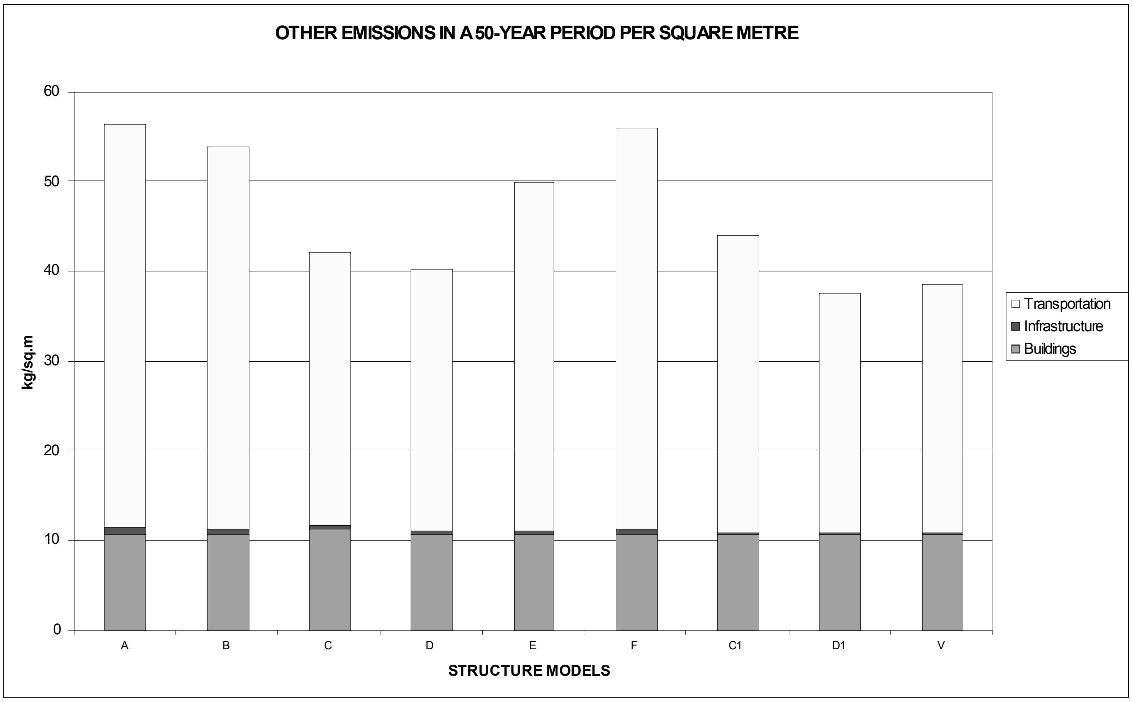

Figure 11. Other emissions of the structure models of the Sipoo Master plan 2025. *(Wahlgren & Halonen 2006, Wahlgren 2007)*

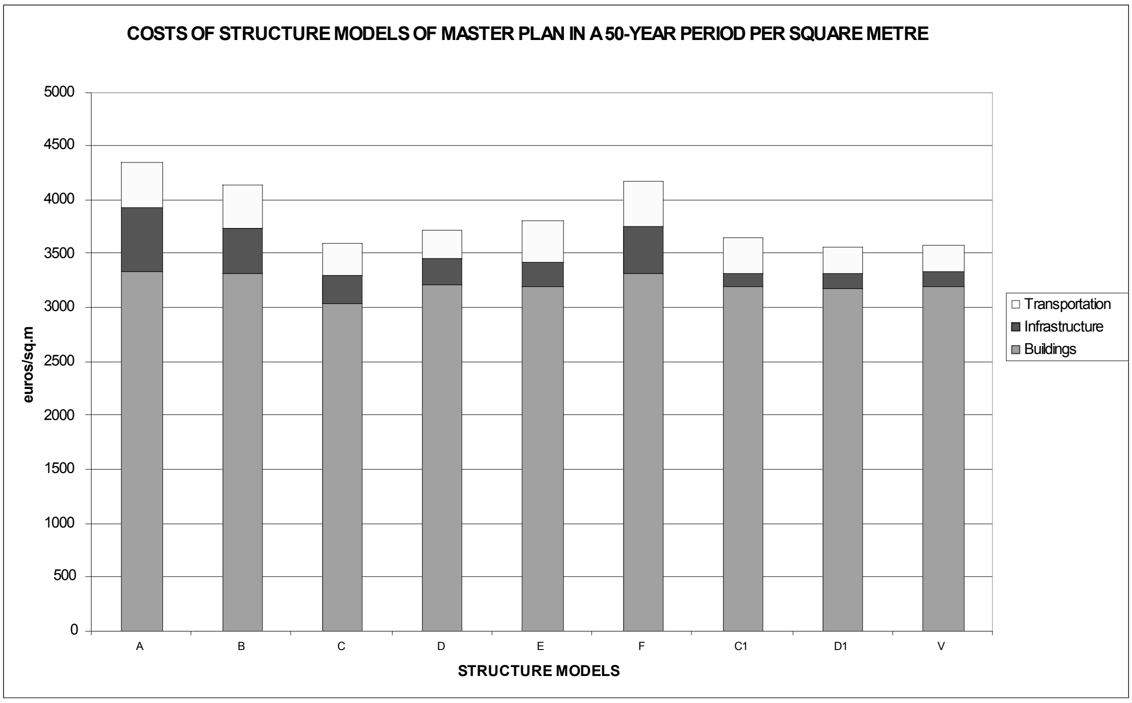

Figure 12. Costs of the structure models of the Sipoo Master plan 2025. *(Wahlgren & Halonen 2006, Wahlgren 2007)*

The structure models of the Helsinki Metropolitan Area

Greenhouse gas emissions of urban form alternatives have been studied at regional level also in the Helsinki Metropolitan Area (Harmaajärvi & Huhdanmäki 1999). The study showed that urban sprawl increases emissions even 50 % and more infilling decreases emissions 20 % in comparison to the basic model.

NATIONAL LEVEL

Greenhouse gas emissions at the national level were studied when preparing the National Climate Programme of Finland (Harmaajärvi, Huhdanmäki & Lahti 2001, 2002). The study showed that it is possible to reduce greenhouse gas emissions by 2.3 million tonnes in 2010 by developing urban form in a target oriented way. This amounts to 15 % of Finland's target in accordance with the Kyoto protocol for greenhouse gas emissions reductions.

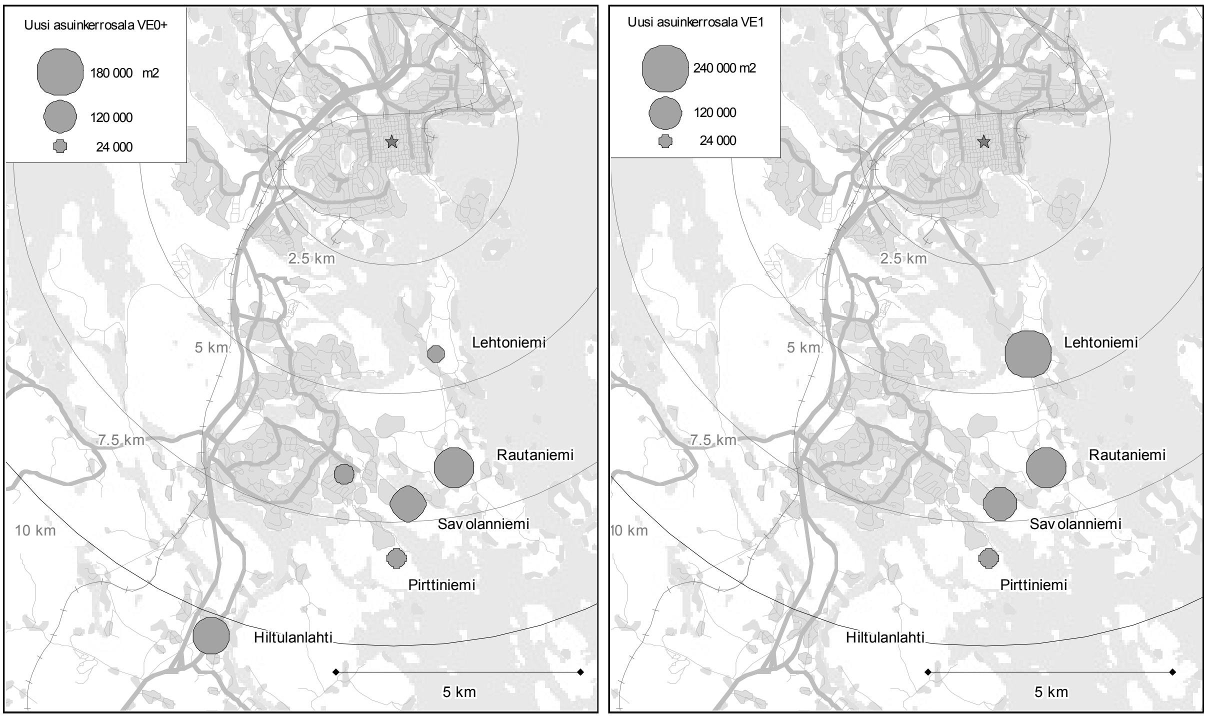

Figure 13. Town structure alternatives in Southern City of Kuopio. *Location of new residential areas and amount of new residential floor area. Alternative 1 on the right includes the Street of Islands. (Halme & Harmaajärvi 2003)*

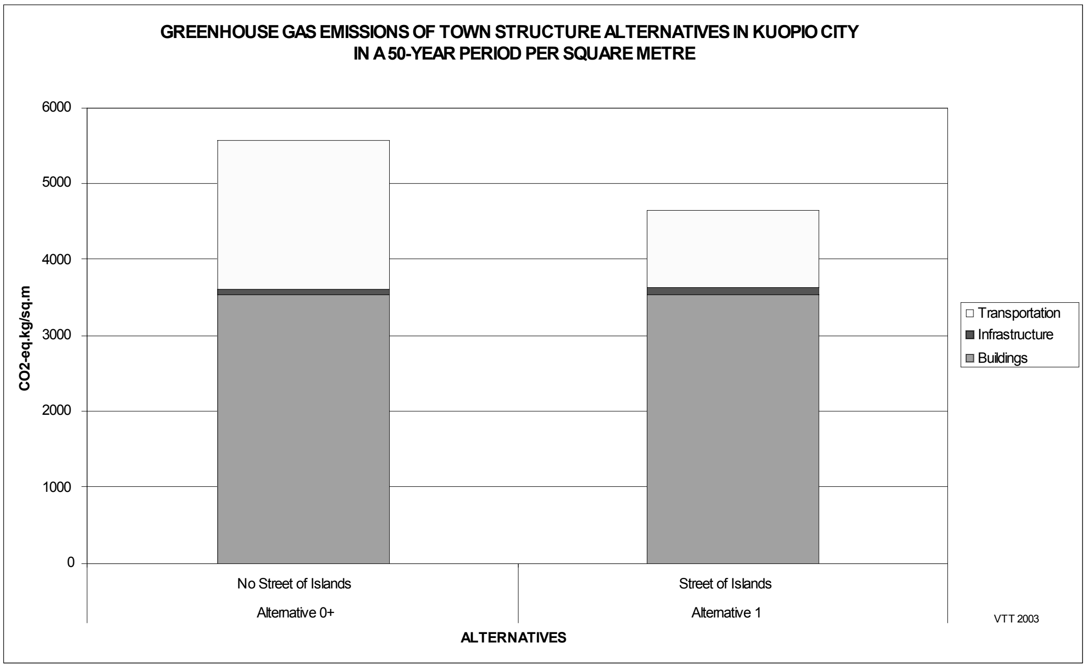

Figure 14. Greenhouse gas emissions of the structure alternatives of Kuopio*. Street of Islands halves emissions from transportation. (Halme & Harmaajärvi 2003)*

CONCLUSIONS

The most important factors in sustainable urban and transportation planning are at residential area level: location, which forms the transportation basis, structure, building density, house types and space heating systems, and at municipality and regional level: area density, energy consumption and production systems, location of and distances between dwellings, working places and services, transportation systems, possibilities of walking and cycling, availability of public transport, and necessity for use of private cars.

Effectiveness of urban planning

Effectiveness of urban planning to eco efficiency of urban areas at different planning levels is assessed by considering relative differences of urban form choices (Fig. 16) and reduction potential of greenhouse gas emissions of urban form choices

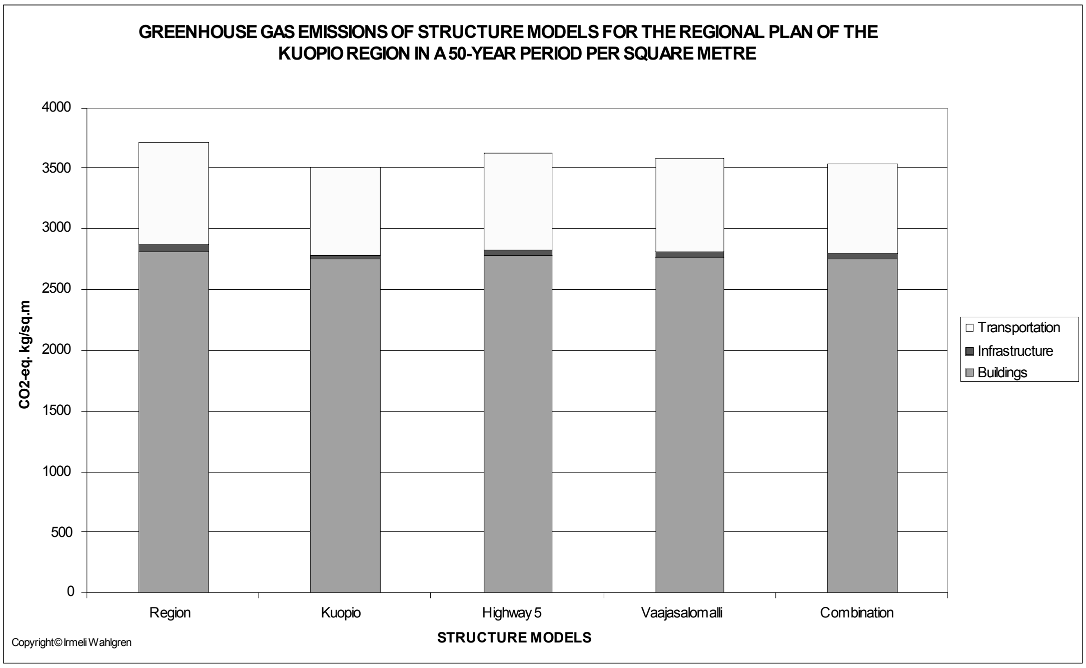

__Figure 15. Greenhouse gas emissions of the structure models of the regional plan of Kuopio Region.__ Biggest differences are caused by transportation. (Harmaajärvi, Halme & Kärkkäinen 2005)

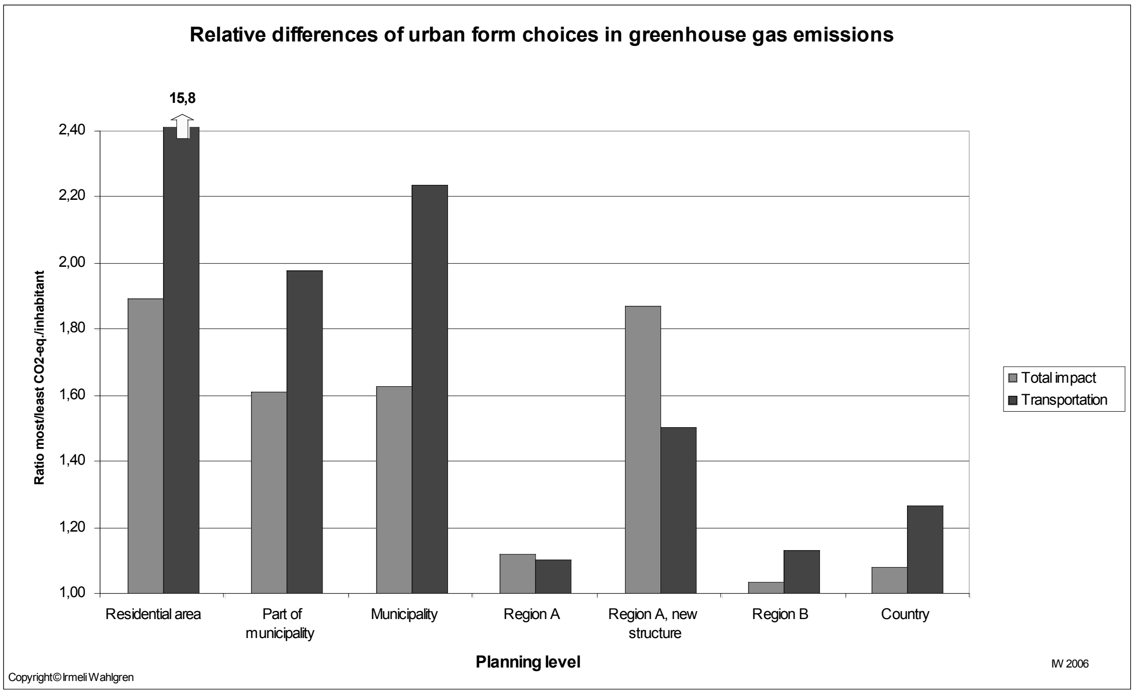

__Figure 16. Relative differences of urban form choices in greenhouse gas emissions.__ Ratio between the best and the worst solution at different planning levels.

(Fig. 17). Same kind of assessment can also be made concerning other impacts of urban development. This consideration concerns greenhouse gas emissions calculated per inhabitant.

This consideration shows that there are big differences between impacts of different urban form and transportation solutions. The differences are biggest at residential area or local levels: the worst solution causes about twice as much total greenhouse gas emissions per inhabitant as the best solution, emissions from transportation even 16-fold compared to the best solution. At regional level it is, however, important to consider also those parts of future structure which have differences (the new part of the whole future structure). The study shows that it is possible to influence future impacts of urban form by urban planning and transportation decisions.

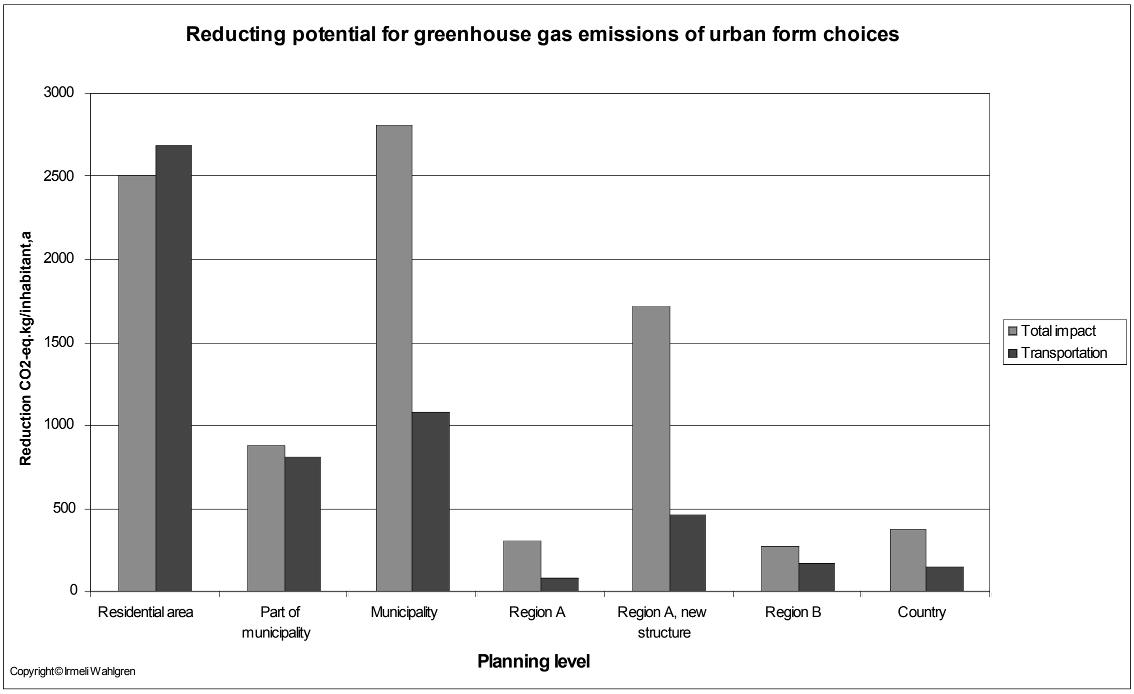

Figure 17. Reduction potential for greenhouse gas emissions of urban form choices. *Reduction of greenhouse gas emissions (CO_2-eq kg/inhabitant, a) from the worst solution to the best solution at different planning levels.*

Important choices

Important choices in urban planning and transportation concern: location of areas, distances, share of urban and rural development, complementary building, building density, structure – amount of networks, consumption of heating energy and electricity, heating system, energy production system, building systems and materials, living space, transportation system, possibilities to walk and bicycle, availability of public transport, especially rail traffic and the need for use of cars.

Existing buildings should be utilized, when necessary with change of purpose. Existing infrastructure should be utilized, when necessary with change of purposes, with complementary building, New areas should be implemented not before utilizing complementary building and infill possibilities. New areas should be located favourably in the urban structure. Possibilities for walking, bicycling and use of public transport, especially rail transport, should be created. Areas should have a good structure and a decent density.

Urban planning and transportation system solutions and decisions have a large-scale significance for eco efficiency, the consumption of energy and other natural resources, the production of greenhouse gas and other emissions, and the costs caused by communities.

Planning solutions may impact on greenhouse gas emissions by 10 % at regional level, by 20 % at local community level and even by 200 % at local dwelling area level. Impact on emissions caused by transportation is even bigger: at least double compared to the impact on total emissions. Similarly large impacts can be seen concerning consumption of energy and other natural resources as well as costs.

Most of the good urban planning and transportation solutions have also positive impacts e.g. on the quality of the environment.

Planning alone cannot stop the urban sprawl. When considering and assessing different measures on national level, legislative and fiscal issues, citizen participation and other background forces should be taken under serious consideration. Better cooperation between researchers, politicians, civil servants and citizens is needed to find deeper understanding about economic, social and environmental long-term effects of decisions concerning urban development.

Co-operation, interaction and dissemination of information are essential to contribute to sustainable urban form and transportation.

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