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Spatial aspects of the environmental load of consumption and mobility

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Department of Geography, Institute of Ecology and Earth Sciences, Faculty of Science and Technology, University of Tartu, Estonia

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CONTENTS

LIST OF PUBLICATIONS

This thesis is based on the following three publications that have been published in international peer-reviewed scientific journals.

I **Poom, A.**, Ahas, R., Orru, K. 2014. The impact of residential location and settlement hierarchy on ecological footprint. *Environment and Planning A* 46: 2369–2384, doi:10.1068/a140059p.

II **Poom, A.**, Ahas, R. 2016. How does the environmental load of household consumption depend on residential location? *Sustainability* 8: 799, doi: 10.3390/su8090799.

III **Poom, A.**, Orru, K., Ahas, R. 2017. The carbon footprint of business travel in the knowledge-intensive service sector. *Transportation Research Part D: Transport and Environment* 50: 292–304, doi:10.1016/j.trd.2016.11.014.

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Author's contribution to each paper:

	I	**II**	**III**
Original idea	50%	100%	100%
Study design	70%	100%	90%
Data collection	70%	5%	80%
Data processing and analysis	100%	100%	100%
Interpretation of the results	90%	95%	90%
Writing of the manuscript	75%	100%	90%

ABSTRACT

Location is one of the key drivers of the consumption and mobility behaviour of people. Agglomeration results in concentrated activity nodes, better provision of public transportation and superior environmental infrastructure, and smaller living spaces that may decrease the environmental load of mobility and energy use. On the other hand, urbanized areas are the nodes of growth and consumption that provide better accessibility to a wide spectre of commodities. This may in turn increase the environmental load of households living in more urbanized areas.

The thesis addresses the dilemma between the environmental benefits and disadvantages of urbanization across the settlement hierarchy of Estonia, aiming to receive new insights about the effect of location on the environmental load of final consumption. It explores the environmental load of the consumption and mobility behaviour of Estonian residents and analyses the carbon load of business travel along the travel needs and management in knowledge-intensive business service sector.

The thesis applies environmentally extended input-output methodology to analyse the ecological footprint or carbon load of final consumption based on the data collected from high school students (2009) or acquired from Household Budget Survey that was conducted by Statistics Estonia (2012). The carbon load of business travel is explored with the help of data gained from active mobile positioning and individual interviews with business travellers, and focus group interviews with organizations (2013). The concept of settlement hierarchy is used as a proxy for geographical location of residents and businesses.

The environmental load of the final consumption of households derives in majority from shelter-related consumption and is considerably lower in Estonia than in European countries of higher wealth. The differences in disposable income levels between the compared countries could lead to even higher differences in the environmental load. However, the high share of expenditure on domestic energy use among Estonian households due to the climatic conditions and poor insulation of dwellings as well as the carbon intensity of the energy sector in Estonia decrease the expectable environmental benefits deriving from lower overall expenditure volume. The size of the environmental load of Estonian residents could not be compared to other Eastern European countries due to the lack of conducted research available.

The findings of the thesis confirm the benefits of dense urban settlements over suburban or rural areas in terms of the environmental load from mobility. Higher level urban settlements, nevertheless, do not show advantages in front of smaller towns, although it could be expected on the basis of previous research. The benefits of higher level urban areas are evident only in case of business travel due to the economic agglomeration and concentration of businesses as professionals working in locations that are more distant need to put more efforts on reaching their business network in the main economic centres.

On the other hand, the thesis points out the lifestyle environmental impacts of additional consumption that occurs along higher degrees of urbanization both in dense urban cores and in their surrounding hinterland. Better availability and accessibility of various commodities, especially leisure-related goods and services, in higher hierarchy level settlements favour their consumption and the consequent environmental load also when differences in income levels and other socio-demographic aspects of households are considered.

The thesis reveals the exceptional position of the residents of regional industrial centres in Estonian settlement hierarchy considering their significantly low environmental load from final consumption. The very conservative consumption and mobility pattern of the households residing in the Eastern Estonian industrial cities is only partially explained by lower affluence level and different ethnical composition of the population when compared to the rest of the country. It may be assumed that the industrial character, founding and development peculiarities when compared to other cities in Estonia, environmental problems, remnants of Soviet period scarcity-determined consumption culture, lack of opportunities for self-expression, and low rate of social relations with the hinterland areas have hindered these regional centres to develop towards contemporary urban cores of active lifestyle.

The study on business travel showed that the need for business travel in knowledge-intensive service sector considerably depends on the phase of the business cycle at hand. While the success of marketing and sales especially depends on physical co-presence, then core business processes, where the need for travel and communication is the highest, provide opportunities for some travel substitution with virtual modes of communication. Established trust relationships in business partnership are one of the main prerequisites for such substitution and its environmental benefits.

1. INTRODUCTION

1.1. Background

The sustainable development agenda 2030 of the United Nations envisages '[a] world in which consumption and production patterns and use of all resources /…/ are sustainable' (UN 2015b: 4). The task is grandiose. Our daily lives are tightly interwoven with various consumption and consumption-based environmental impacts are considered to be among the most challenging in the world (Jorgenson, Burns 2007). It is argued that household consumption directly and indirectly accounts for 72% of the global greenhouse gas emissions (Hertwich, Peters 2009).

This thesis follows the tradition of household metabolism research (Biesiot, Noorman 1999; Di Donato *et al.* 2015; Turner 1998). This concept refers to the direct and indirect flows of resources either through the households or elsewhere to accomplish the household consumption (Moll *et al*. 2005). Household is the smallest social organizational unit that has a joint consumption pattern by consuming a complex and changing mix of commodities (Biesiot, Noorman 1999). Hultman (1994: 39) argues that household, being a physical and mental base for most individuals, is a suitable unit for capturing the conflict between society (needs and wants) and the environment (source and sink), as household can be seen as the main target for all anthropogenic activities in the process of 'societal metabolism'.

Research about the environmental implications of final consumption emerged in the scientific literature in the 1960s and escalated along with the global energy crisis during the next decade (Røpke, Reisch 2004: 2). The studies of that age particularly used to address the energy use and waste disposal behaviour of consumers (*ibid.*). The first cross-national survey exploring the relationship between lifestyle and energy use was published in *Science* by Mazur and Rosa in 1974. They showed that all life-style indicators correlated highly with energy consumption and raised the question whether decrease in energy use could also harm the social welfare of people. Soon Robert Herendeen and his colleagues conducted a series of household energy use surveys in the USA and Norway, applying input-output methodology (Herendeen 1978; Herendeen *et al.* 1981; Herendeen, Tanaka 1976). These studies were the first to capture the direct as well as indirect energy use of a full set of household expenditure and to link the results to socio-demographic variables of households. The authors also covered the spatial dimension of final consumption, presenting the environmental advantages of urban living in front of rural living due to smaller living spaces and decreased travel needs in cities (*ibid.*).

Also later, the research that explored the spatial aspects of the environmental costs of consumption have considered the type and urbanization level of settlements to be among the key factors that determine the environmental outcome of the consumption and mobility pattern of residents. It has been shown that residents from dense urban areas tend to use less energy for car fuel, heating, and electricity than residents of rural, suburban or nonmetropolitan areas (Ala-Mantila *et al.* 2014; Brown *et al.* 2009; Muñiz, Galindo 2005; Newman, Kenworthy 1989; Næss 2005). The spatial effect on the energy demand of mobility and housing is yet ambiguous due to the varying levels of dwelling insulation, technical spaces, or concentration of activity spaces across settlement types and levels of urbanization (Cervero, Murakami 2010; Jones, Kammen 2013; Ottelin *et al.* 2015). Furthermore, studies that involve the consumption of non-energy commodities have presented that the relative win from mobility and housing in dense urban areas may be offset by the increased consumption of consumer goods and services due to better accessibility and higher affluence (Ala-Mantila *et al.* 2014; O'Regan *et al.* 2009; Shammin *et al.* 2010). There is no universal understanding over the spatial effects on various consumption types when socio-demographic variables are considered.

This thesis is the first to cover the spatial effect on the environmental load of the whole set of final consumption across the differentiated settlement structure of a country. It explores the spatial variability of mobility, energy use, and final consumption of goods and services of Estonian residents and relates the consumption to the socio-economic factors of households. The analysis does not explore the individual-motivational factors related to consumption. Final consumption is amended in the thesis by business travel practices of knowledge workers. The thesis addresses Estonia, an Eastern European country, where the environmental effects of final consumption of the spatially distributed population groups have not been explored earlier.

1.2. The definition of consumption

By definition, the term *consumption* involves:

- the act or process of consuming – such as eating,
- being exposed to or used by a particular audience – such as consumption of public services,
- or the utilization of economic goods for the satisfaction of wants or in production processes in a way that results in their destruction or transformation – such as consumption of household goods (https://www.merriam-webster.com).

Consumption during the daily lives of people is thus related to either private or professional activities. While private activities drive household consumption and respective expenditure, professional activities are often related to the intermediate use of commodities during production processes or end use of commodities in governmental and non-profit sectors.

In international statistics, the term *final consumption* refers to the total expenditure on the end use phase of commodities incurred by households, non-profit organizations serving households, and general government units (OECD

2007). In the concept of *final use*, gross capital formation and exports supplement final consumption expenditure named above (Eurostat 2016b). The *use* tables of national accounts also cover the intermediate consumption of commodities as inputs during the process of production (Eurostat 2016b; Statistics Estonia 2016a). This intermediate consumption is later involved in the final consumption expenditure by end users, enabled by input-output tables of national accounts.

This thesis addresses consumption that derives both from private and professional activities of Estonian residents. The main emphasis is put on final consumption expenditure by households, which is extended by consumption related to business travel of organizations. Consumption is registered either through the act of purchases during the study period measured in currency or by the consumed amounts of resources or travelled distances assessed in physical quantities.

1.3. Geography of consumption

Everyday activities and the related consumption are driven by various motives such as survival, self-development and -expression, or pursuit of pleasure (Hultman 1994: 45; Mansvelt 2005) and are enabled by the material and energy resources extracted from nature and later returned to the ecosphere as waste (Rees 2000: 27). In a globalizing world, the repercussions of consumption reach out across the planet (Newman, Jennings 2008: 2) and each commodity-chain has a unique life-cycle considering the material and energy balance within their geographical and temporal settings, 'placed in a mental, geographical and infrastructural shadow world' (Hultman 1994: 54). Therefore, the capture of the particular environmental burden of a commodity is sophisticated for consumers.

While the environmental impacts related to consumption emerge mainly along the 'hidden' production spaces, the demand is aligned across various consumption spaces. The geography of consumption involves context-sensitivity, i.e. consumption spaces and places shape consumer behaviour by either enabling, predisposing, or hindering particular consumption (Goodman *et al.* 2010: 13; Smas 2005: 7). This is evident in the case of physical and material characteristics such as the presence of certain infrastructure or retail spaces (Cervero, Murakami 2010; Hickman, Banister 2007; Kshetri, Bebenroth 2012; Stead, Marshall 2001), but socio-cultural aspects also configure consumption decisions (Glennie, Thrift 1992; Hudson 2005; Hultman 1994; Smas 2008). According to Paterson (2006: 171), spatial context helps to structure the activities of people, and the design and planning of consumption spaces intentionally and unintentionally alter consumer behaviour.

Consumption in turn constructs spaces and places (Fleischer 2010; Goodman *et al.* 2010). The agglomeration of people, goods, and merchandise have created urban spaces (Lefebvre 2003 [1970]). Cities are the main arena where producer and consumer meet for commodity transaction (Smas 2008). In postindustrial societies, the substantive improvements in wealth have further developed urban consumerism (Chua 1998), together with retail, leisure and tourism as major engines of growth (Gregory *et al.* 2009: 18).

According to the variety of commodities that cities provide and the type of relationships with other settlements, settlement hierarchy orders cities by their centrality (Christaller 1933). Higher level urban areas contain more developed markets and better access to consumer goods, more resources and affluence (Berry 1958; Carol 1960; Christaller 1933; Preston 1971). Along with higher income levels, higher level urban areas also generate additional consumption among their residents (Heinonen *et al.* 2011; Pachauri 2004; Shammin *et al.* 2010; Wiedenhofer *et al.* 2013). Urbanization is particularly shown to increase the consumption of services, if the income levels are kept constant (Ala-Mantila *et al.* 2014; Heinonen *et al.* 2013).

Agglomeration produces economies of scale that have also positive environmental outcomes, e.g., by the means of superior environmental infrastructure such as waste management, waste water treatment, district heating, and access to cleaner energy (Cai, Jiang 2008; Capello, Camagni 2000; Dodman 2009; O'Regan *et al.* 2009; Slagstad, Brattebo 2012). Compactness of cities is seen as the key factor for minimizing the material and energy flows of settlements (EEA 2015). While the consumption of non-energy commodities may increase along urbanization as shown above, the consumption of commodities that use energy directly, i.e. travel by car, use of electrical appliances or domestic heating, tends to decrease in larger and denser settlements due to the concentration of activity nodes, better provision of public transportation, or smaller living spaces (Brown *et al.* 2009; Heinonen, Junnila 2011b; Herendeen, Tanaka 1976; Lenzen *et al.* 2006; Muñiz, Galindo 2005; Shammin *et al.* 2010; Stead, Marshall 2001). However, large centralized settlements may also increase the distances travelled due to better transport infrastructure and road-network (Cervero, Murakami 2010; Rodriguez *et al.* 2006) or the more separated activity destinations in large metropolitan areas (Jones, Kammen 2013; Stead, Marshall 2001). Especially the distance to destination has been shown to be a decisive characteristic of built environment in determining the amount of vehicle miles travelled (Ewing, Cervero 2010). On a more local scale, design and diversity of the neighbourhood affect the use of low-carbon travel modes (Ewing, Cervero 2010).

Spatial structure has ambiguous effects also on direct energy consumption. For example, supporting technical spaces such as elevators or underground parking may increase housing energy demand in high-rise buildings despite the smaller living spaces of inner-city living (Heinonen *et al.* 2013; Ottelin *et al.* 2015). Housing maintenance costs are also higher in urban areas (Heinonen, Junnila 2011a). In addition, better thermal insulation of new suburban dwellings together with larger resource-sharing families may offset the energy win from smaller living spaces in older multi-unit inner-city houses (Ala-Mantila *et al.* 2016; Glaeser, Kahn 2010; Ottelin *et al.* 2015). On the other hand, access to district heating has shown to have positive effects in achieving energy efficiency goals (Connolly *et al.* 2014; Holden, Norland 2005). Therefore, it has been argued that energy efficient infill housing (Glaeser, Kahn 2010; Kuzyk 2012; Wende *et al.* 2010) together with energy efficiency investments into the existent housing stock (MKM 2015) form a spatially optimised solution in achieving resource-efficient and low-carbon society (EEA 2015).

According to the concept of settlement hierarchy, urban cores are tightly connected to their surrounding hinterland that provides them workforce and client base, enabling thus the economic benefits of agglomeration (Berry, Garrisson 1958; Christaller 1933). When considering the urban, suburban, and rural parts of large functional regions as a whole, the benefits of higher density disappear, as stressed by Jones and Kammen (2013). They show how larger urban areas contain more districts with very low carbon load in the central areas, but at the same time more suburbs with high commuting needs that more than offset the resource-use win gained from living in the central districts.

Income level is one of the key determinants of the environmental load of consumption pattern as wealthier households can afford more consumption that may lead to carbon-intensive life-style (Baiocchi *et al.* 2010; Druckman, Jackson 2008; Duarte *et al.* 2010; Heinonen *et al.* 2011). With rising income, the share of the consumption of non-energy commodities, including pleasure-related goods and services, increases (Biesiot, Noorman 1999; Herendeen, Tanaka 1976; Kerkhof *et al.* 2009a; Weber, Matthews 2008). Residential location is often strongly linked to the disposable income level of households (Druckman, Jackson 2008; Tammaru *et al.* 2016) and spatial segregation also shapes the outcome of consumption-based impacts across settlement types. For example, while in the UK, the most carbon-intensive lifestyles are related to prospering suburbs and country side living (Druckman, Jackson 2009), then in Finland, the highest wealth accompanied by the highest carbon emissions is concentrated to the dense inner-city living of the capital region (Ala-Mantila *et al.* 2014; Heinonen *et al.* 2011). The share of renewable energy sources and the energy supply system of a particular country also shape the balance of carbon emissions between various consumption clusters (Kerkhof *et al.* 2009a) and hence between urban and rural living.

Cross-national surveys have given little evidence that the level of urbanization increases the size of the per capita consumption-based environmental impacts of nations (Jorgenson, Burns 2007; Jorgenson, Clark 2011). This limited effect apparently derives from the spatially ambivalent patterns of consumption described above that are related to the different socio-economic and infrastructural context of world cities (see, e.g., Lenzen *et al*. 2006; Wang *et al.* 2016).

1.4. Business travel

Next to private activities of people, spatial location also shapes the needs and choices and the consequent environmental load of organizations. This research direction has received much less scholarly attention than the spatial aspects of private consumption. However, especially in the sphere of mobility, the issue is important as location determines the level of accessibility of other sites that are important to businesses (Aguilera, Proulhac 2015). For example, Aguilera and Proulhac (2015) demonstrate how in France, the concentration of economic activities to metropolis decreases the need for long-distance business travel of the organizations located there when compared to business locations in less urbanized areas.

Business travel amounts have been considerably increased during the past decades along the globalization of economies and new business forms, expanded markets and business networks, increased importance of knowledge in business processes, and improved transport infrastructure (Castells 2010; Gustafson 2012; Harrington, Daniels 2006; Jones 2013). The motives for business travel are often related to the creation and maintenance of the geographically spread business network where the professionals from dispersedly located organizations need to interact and communicate with each other (Aguilera, Proulhac 2015; Gustafson 2012; Millar, Salt 2008). Interaction is the best mediated by face-to-face meetings as this type of communication enables to build the relationships of trust between network members (Castells 2010; Faulconbridge *et al.* 2009).

The existence of trust relationships and physical co-presence are particularly important in knowledge-intensive business processes where the ultimate goal is to provide the clients tailor-made solutions (Jones 2013; Larsen 2001). Organizations providing knowledge-intensive business services incorporate a business community where knowledge can be created, accumulated, and disseminated (Miles *et al.* 1995). Thus, in the knowledge economy, knowledge is either transferred through the business network and adapted to local conditions, or socially produced as new knowledge due to the synergistic effects of knowledge sharing and learning between the members of network (Faulconbridge 2006). Temporary geographic proximity by the means of business travel enables knowledge transfer and generation also in cases when business network members are distantly located (Torre 2008). Furthermore, Millar and Salt (2008) argue that different tasks related to knowledge transfer require different type and length of proximity and interaction, starting from long-term assignments to short business travel and even virtual communication.

Indeed, the new modes of communication enable business networking and spatial integration also between locations that are distant from metropolitan areas with high concentration of activities and well-developed transport infrastructure (Castells 2010). Virtual communication may be seen thus a promising substitute for business travel and its environmental consequences. However, the environmental advantages of information and communication technology (ICT) are disputable due to the energy and material use and short life-span of ICT facilities (Ong *et al.* 2014). Furthermore, the type of relationship between the use of ICT and physical travel is far more complex (Cohen-Blankshtain, Rotem-Mindali 2016; Denstadli *et al.* 2013) and there tend to be more evidence supporting the complementarity and travel generation effects in front of substitution effects (Aguiléra *et al.* 2012; Choo, Mokhtarian 2005). Virtual communication is shown to substitute some of the physical travel when working with existing, well-known contacts (Lo *et al.* 2013; Sau 2014), and is suitable for follow-up and information exchange purposes, or short or repetitive meetings (Arnfalk, Kogg 2003). Meetings at the beginning and end of a project require physical proximity (*ibid.*).

The type of interaction in each particular business communication episode is finally a result of the needs of the business task at hand, organizational policy and context, as well as personal needs, skills and preferences of employees (Arnfalk, Kogg 2003; Gustafson 2012; Lo *et al.* 2013).

Jones (2013) has raised the need to better understand whether and how particular mobility practice (including the choice of communication mode) is related to the economic success of the firm. He proposes an outcome-oriented methodology for business travel management, in the decision-making process over communication and travel mode, to address the function and significance of business travel for economic outcomes.

The current thesis adapts this approach by exploring the travel needs and practices of different phases in the cycle of knowledge-intensive business services, considering the economic, environmental, temporal, and personal aspects in the decision-making over business communication and travel mode.

1.5. Methods to assess the environmental load of consumption

The environmental load of final consumption including mobility appears in a wide variety of impacts like air and water quality degradation, soil degradation, noise, land use change, loss of habitats, depletion of biological resources, changes in ecosystem integrity, or climate change. Due to the wide spectre and diffuse location of particular environmental impacts as well as data limitations, the analysis of the environmental load of consumption is often delimited to aggregated studies of resource requirement or pollutants that are directly and indirectly embodied in commodities.

While the majority of research has explored the energy requirement and/or greenhouse gas emissions of consumption (e.g., Druckman, Jackson 2009; Herendeen, Tanaka 1976; Hertwich 2011; Lenzen *et al.* 2006; Moll *et al.* 2005; Shammin *et al.* 2010; Vringer, Blok 1995), other studies have addressed also other air and water pollutants (Kerkhof *et al.* 2009b; Sánchez-Chóliz *et al.* 2007) or use of resources (Steinberger *et al.* 2010; Wier *et al.* 2005). Next to particular pollutants and resource requirements, environmental effect and performance indices have been used to explore environmental impacts of consumption, e.g., ozone depletion potential index, air pollution index for hazardous substances, eco-efficiency (Wier *et al.* 2005), ecological footprint (Eaton *et al.* 2007; Wiedmann *et al.* 2008), or sustainable development index (O'Regan *et al.* 2009). Due to the variance of resource use and waste generation in production processes of different commodities, the size of the environmental effect of the same commodity may differ between the indicators applied (Wier *et al.* 2005). For example, while transportation accounts for high effects in the spheres of ozone depletion, photochemical oxidation, and global warming, it does not significantly contribute to water consumption (*ibid.*).

Aggregated studies of the environmental load of human activities use national statistical datasets and input-output computing (top-down approach), information gained from process and life-cycle assessment (bottom-up approach), or hybrid research approaches (Di Donato *et al.* 2015; Hertwich 2011; Kok *et al.* 2006; Tukker, Jansen 2006). Input-output analysis is a well-known economic tool that was originally developed by Wassily Leontief in the 1930s and 1940s in order to study the monetary relations among various economic sectors (Leontief 1941, 1986). On the basis of monetary relations, it also allows the allocation of resource use and waste generation of production processes to final demand (Bicknell *et al.* 1998). As a result, input-output computing is a typical research method in the studies of the environmental load of consumption, including the discourse of household metabolism (Ala-Mantila *et al.* 2014; Arvesen *et al.* 2010; Hertwich 2011; Lenzen *et al.* 2006; Minx *et al.* 2009). In these studies, consumption data in the form of expenditure or physical quantities are transferred into environmental costs meaning that various consumption categories are ascribed resource or pollutant intensities per monetary or physical units covering the whole life-cycle of the commodity (Alfredsson 2002). Household metabolism studies enable the comparison of environmental load of different consumption patterns and lifestyles as different commodities embody varying degrees of resources and emissions (Kerkhof *et al.* 2009b; Lenzen *et al.* 2006).

Ecological footprint analysis. This thesis incorporates ecological footprint and carbon accounting as indicators for environmental load. The concept of ecological footprint was developed by spatial planners William E. Rees and Mathis Wackernagel in the 1990s. Their definition for the concept is as follows:

'Ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area' (Wackernagel, Rees 1996: 9).

The concept enables the comparison of different types of consumption on a common ground with the help of the unit 'global hectares' that are standardized according to biomass productivity of particular land area (Kitzes *et al.* 2009; Wackernagel *et al.* 2002). Ecological footprint accounting incorporates six types of land areas that are either directly or indirectly needed to support human activities. These are cropland, pasture, forest, built-up land, productive sea area, and land for carbon uptake (Chambers *et al.* 2004). The latter land type accounts for the amount of forest land that is necessary to absorb the carbon dioxide emissions from combustible energy sources (Kitzes *et al.* 2009). Ecological footprint as a measure for demand can be compared with the available biocapacity, i.e. the biologically productive space on Earth that expresses the supply of ecological services in global hectares (Wackernagel *et al.* 2002).

Despite the wide coverage of land requirement, the ecological footprint analysis has limited ability to cover other environmental impacts of consumption. For example, it does not include the burden from other pollutants than carbon dioxide, local impacts of freshwater use, nor the disturbance and loss of biodiversity (Kitzes *et al.* 2009; Wackernagel *et al.* 2002). The criticism considering ecological footprint accounting addresses also the assumptions that underlie the calculation methodology of land requirement, limits to estimate the effects of land use intensification and degradation, missing relevance on local scale, or the general ambitions to consider ecological footprint as a measure of sustainability (Ayres 2000; Fiala 2008; McManus, Haughton 2006; van den Bergh, Grazi 2010; van den Bergh, Grazi 2014). At the same time, it has been acknowledged that developing an indicator for expressing the overall environmental pressure is difficult due to the complexity of environmental externalities and agglomeration advantages as well as aggregation and weighing challenges (van den Bergh, Grazi 2014).

Nevertheless, ecological footprint analysis has become increasingly popular and it has been found to be a relevant indicator to assess and compare the pressure of human activities on an aggregated level, assigning environmental costs to final consumers of commodities from the full supply chains (Weinzettel *et al.* 2014). In addition to aggregated national accounts, ecological footprint analysis has been applied in the research of household metabolism and spatially differentiated load of consumption and mobility (Caird, Roy 2006; Eaton *et al.* 2007; Holden 2004; Muñiz, Galindo 2005; O'Regan *et al.* 2009; Wood, Garnett 2009). It requires the use of land cover data that are combined with data gained from life-cycle analysis, environmentally extended input-output analysis, or hybrid approaches (Eaton *et al.* 2007; Hopton, White 2012; Kuzyk 2012; Patterson *et al.* 2007; Simmons *et al.* 2000). Global Footprint Network has developed standards for ecological footprint accounting on national, subnational, organizational, or product level (GFN 2009).

To cover the use of other resources and the emissions of other greenhouse gases, ecological footprint analysis has been increasingly complemented by water, energy, and carbon footprint indicators (Fang *et al.* 2013; Ridoutt, Pfister 2013; Rushforth *et al.* 2013). The 'footprint family' is also claimed to incorporate other environmental footprints such as biodiversity and nitrogen footprint, social and economic footprints, and combined footprints such as exergy and chemical footprint (Čuček *et al.* 2012).

Carbon accounting. During the past two decades, carbon accounting has been the most common method for studying the environmental costs of consumption

(Hertwich 2011). It has evolved from the earlier research focusing on the energy use. Carbon accounting framework incorporates the anthropogenic emissions of carbon dioxide and eventually also other greenhouse gases – methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride (Fuglestvedt *et al.* 2003; Hertwich, Peters 2009; IPCC 2006). Different greenhouse gas emissions are weighed together using their global warming potentials and expressed, as a result, in *aggregate anthropogenic carbon dioxide equivalent emissions* (CO_2e) (*ibid.*).

The different coverage of greenhouse gas emissions and related methods within carbon accounting framework has driven confusion around the concept and terminology (Fang *et al.* 2013; Wright *et al.* 2011). There is a set of indicators in use: carbon dioxide emissions, greenhouse gas emissions, carbon load, carbon footprint, climate footprint, or global warming potential (see, e.g., Brown *et al.* 2009; Fan *et al.* 2012; Heinonen *et al.* 2011; Hillman, Ramaswami 2010; Wright *et al.* 2011) that have to be defined in each study. Attention has to be paid also whether production- or consumption-based approach has been used (Mi *et al.* 2016; Peters 2008). The various methodological challenges in carbon management accounting are well-described by Schaltegger and Csutora (2012).

For the clarity of the methodology and the comparability of studies, a number of carbon accounting standards have been developed by different institutions. For example, International Organization for Standardization has developed greenhouse gas quantification and reporting standards for organizations and products (ISO 2006, 2013) while World Resources Institute together with its stakeholders has established the Greenhouse Gas Protocol that incorporates a series of standards for different entities engaged in carbon emissions accounting (WRI 2014; WRI *et al.* 2014; WRI, WBCSD 2004, 2011). Intergovernmental Panel for Climate Change has published guidelines for national greenhouse gas inventories (IPCC 2006). There are also several commercial and non-commercial LCA and carbon coefficient databases available for analyses conducted on sub-national level that require bottom-up or hybrid accounting approach. One of the most prominent set of conversion factors has been provided by the British Government (GOV.UK 2016; Hill *et al.* 2012), and the database is updated annually due to the changing mix of energy carriers and developing production technology.

Drawing from the above section, carbon accounting may occur on various spatial and organizational levels such as nations (Hertwich, Peters 2009), regions (Brown *et al.* 2009), cities (Hillman, Ramaswami 2010; Mi *et al.* 2016), households and individuals (Arvesen *et al.* 2010; Bin, Dowlatabadi 2005; Jones, Kammen 2013; Weber, Matthews 2008), economic sectors (Minx *et al.* 2009), organizations (Haslam *et al.* 2014; Larsen *et al.* 2013), processes or supply-chains (Recker *et al.* 2011; Rizet *et al.* 2010), or commodities (Ingwersen, Stevenson 2012; Weber 2012). In the current thesis, carbon accounting is used on the levels of household and individual as well as business travel as an organizational process.

1.6. Aim

The aim of the thesis is to get new insights about the effect of location on the environmental load of final consumption. The thesis explores how the type and level of urbanization of settlements in the Estonian settlement hierarchy drive various types of consumption and hence shape the environmental load of residents. Covering the whole consumption pattern of residents, the thesis addresses the possible trade-off between the environmental load from transport and domestic energy use and the consumption of non-energy commodities in various settlement hierarchy levels as the environmental load of spatially varying consumer behaviour regarding all final consumption has this far remained under-researched.

To refine the aim of the thesis, five research questions are posed:

1. How is the environmental load of final consumption in Estonia divided between various consumption clusters? *(Papers I and II)*
2. How is the environmental load related to the residential location in the settlement hierarchy? *(Papers I and II)*
3. To what extent does the environmental load depend on residential location, when socio-economic differences within population are taken into account? *(Papers I and II)*
4. What factors determine the choice of business communication and travel mode during the knowledge-intensive business cycle? *(Paper III)*
5. How is the carbon load of business travel related to the phase of knowledge-intensive business process at hand? *(Paper III)*

2. METHODOLOGY

2.1. Data and methods

The current thesis is based on original research data and data collected by Statistics Estonia in order to explore the spatial effects of the environmental load of various consumption types in Estonia. Data about the consumption of goods and services, energy use and/or mobility of Estonian households, high school students, or organizations are analysed in the thesis. The environmental load of various types of consumption is assessed either by ecological footprint or CO_2 emission. Table 1 gives an overview of the sample, data, environmental indicator, and methods used in Papers I, II, and III.

Paper I is based on original research data about consumption and mobility of Estonian high school students. The sample consisted of 450 students from 30 randomly found high schools in Estonia with 15 first-year students from each school who were selected from class-lists by a fixed step. The response rate was 90%, which was achieved by active cooperation with the liaison teachers, the students, and their parents. Data were collected via a specially developed ecological footprint online calculator[1] that involved questions about nutrition, energy use and housing, mobility, consumption of various goods and services, and waste management of students or their households during last 12 months (covering in majority the year 2008). The analysis was conducted on per capita basis.

Ecological footprint involves direct and indirect land use and emitted CO_2 per consumption unit and is expressed with the indicator global hectares per capita and year. The computing methodology in Paper I used a hybrid approach that combined component-based (bottom-up) and compound (top-down) accounting methods of ecological footprint (Bicknell *et al.* 1998; Chambers *et al.* 2004; Ewing *et al.* 2008; Ferng 2001; GFN 2006, 2008; Simmons *et al.* 2000; Wackernagel, Rees 1997). Component-based computing involved life-cycle data from various sources while compound computing applied input-output analysis of energy use statistics, land use data from CORINE land-cover database and Estonian input-output tables from 2005 (see Table 1 and Section 3.4 in Paper I for a detailed description of the methodology and sources). Statistical data analysis in Paper I was based on descriptive statistics, analysis of variance, and linear regression models.

[1] The methodology of the calculator was developed by the author of this dissertation at the Department of Geography, Tartu University under the funding of Environmental Investment Centre of Estonia. Web application of the calculator was created by Positium LBS. The calculator can be launched at http://www.ut.ee/mobility/jalajalg/.

Table 1. The overview of sample, data, indicators, and methods used in Papers I, II, and III.

	Paper I	Paper II	Paper III
Unit of analysis	Individuals	Households, individuals	Organizations
Final sample	407 high school students	3,537 households with 9,080 household members	3 micro or small organizations with 30 employees
Consumption types			
Food & beverages	Involved	Involved	Not involved
Domestic energy use	Involved	Involved	Not involved
Construction	Partly involved	Not involved	Not involved
Waste management	Partly involved	Involved	Not involved
Other shelter-related consumption	Involved	Involved	Not involved
Transport	Involved	Involved	Involved
Consumer goods & services	Involved	Involved	Not involved
Leisure-related goods & services	Involved	Involved	Not involved
Education & healthcare	Not involved	Partly involved	Not involved
Governmental costs	Involved	Not involved	Not involved
Environmental indicator	Ecological footprint: direct and indirect CO_2 emissions and land use (gha/year cap)	Direct and indirect CO_2 emissions (CO_2/year cap)	Carbon footprint: direct and indirect greenhouse gas emissions (CO_2e/trip)

	Paper I	Paper II	Paper III
Data used for indicator coefficients	Input-output tables of Estonian economy from 2005, other statistics collected by Statistics Estonia (2011), Global Footprint Network's Estonian National Account (GFN 2008), GEMIS lifecycle database (GEMIS 2009), CORINE land-cover database (EEA 2006), other statistics, reports, scientific publications (Arro *et al.* 2006; Chambers *et al.* 2004; EIA 2007; EPA 2005; FAO 2008; Maanteeamet 2008, 2010; Nilsson 2004; TTÜ 2010; Wackernagel, Rees 1996)	Input-output tables of Estonian economy from 2010, energy use of economic sectors, inflation rates (Statistics Estonia 2015, 2016b), GHG inventory report (Ministry of the Environment 2014)	DECC and DEFRA guidelines (Hill *et al.* 2012)
Data collection methods	Ecological footprint online calculator	Data collected by Statistics Estonia: consumption diary and interview within Household Budget Survey (Statistics Estonia 2012a)	Active mobile positioning Focus groups Follow-up interviews
Data analysis methods	Input-output computing Descriptive statistics ANOVA, multiple linear regression	Input-output computing Descriptive statistics ANOVA, multiple linear regression	Descriptive statistics Content analysis Analytical hierarchy process

Paper II is based on Household Budget Survey 2012 that was conducted by Statistics Estonia. The methodology of the survey is described by Statistics Estonia (2012a). Data collection involved the documentation of expenditure such as gathering bills and checks or filling an expenditure diary, as well as interviews. The sample of round 2012 involved over 7000 households of which there were 3587 responding households including 9080 household members. The sampling procedure by Statistics Estonia aimed to achieve a geographically representative sample of various household types in Estonia (*ibid.*). The databases of Household Budget Survey cover household profile, income, and expenditure and have restricted access. Expenditure data are given on the detailed COICOP classification (UN 2015a) level, involving over 800 commodity types.

In the study presented in Paper II, 50 households were omitted from the sample as extreme cases (see Paper II for a more detailed explanation) and the final sample size was 3537 households. All commodity types were ascribed carbon emission intensity coefficient per spent euro that was found by using energy use statistics of various economic sectors (Statistics Estonia 2015, 2016b), CO_2 emission coefficients used in national reporting (Ministry of the Environment 2014), and input-output computing that used input-output tables of Estonian economic sectors of year 2010 (Statistics Estonia 2016b). Post-purchase emissions of energy carriers such as car fuels, firewood, or similar were added to the upper-tier sectorial intensities found by input-output computing. The final 35 sectorial emission intensities used in the study can be found in the Supplementary Materials of Paper II. The methodology, assumptions, and limitations of input-output computing are described in Section 2.3 in Paper II. Statistical data analysis involved the use of descriptive statistics, analysis of variance and linear regression models that covered total, direct, and indirect CO_2 emissions as well as emissions of different consumption clusters on per household and per capita level, as described in Section 2.4 in Paper II.

Paper III is based on original research data about the travel behaviour and business communication management of three micro or small organizations from knowledge-intensive service sector (see Table 1 in Section 3.1 in Paper III for the description of the organizations). The sample consisted of 30 employees that represented 45% of the total number of people in these organizations. A focus group interview about business meeting and travel management was conducted in each organization. Individual participants were engaged in a month-long survey of business travel that was conducted with the help of active mobile positioning and follow-up interviews. Active mobile positioning was enabled by the Estonian mobile operator Telia (former EMT) and the Positium Data Mediator (Positium 2014) and covered the location of business professionals by a 15-minute-step throughout May 2013. From this location database, (principal routes of) work-related trips out of the office town were extracted. In the case of five respondents, business travel data were gathered with the help of the business calendar of professionals due to the failed activation of positioning. Data about the semantics of each business trip (travel reason, travel mode, number of people travelling by car, etc.) were gained from the individual follow-up interviews. The latter also covered personal business travel considerations and prioritizations. Business travel data were used to calculate carbon footprint, i.e. greenhouse gas emissions in CO_2-equivalents per trip.

All business trips were allocated to a particular phase of the cycle of knowledge-intensive business services: internal management coordination, training, marketing and sales, core business processes, and the delivery of business outcomes. This classification was further used in the content-analysis of the transcriptions of focus group interviews, in the descriptive statistics of carbon footprint, and in business goal prioritization with the help of analytical hierarchy process (Saaty 1987, 2003). Content-analysis focused on business travel needs, management principles and practices, travel mode choices, and substitutability of physical travel with virtual communication. Analytical hierarchy process was used for prioritizing business travel goals, i.e. travel related to the phases of knowledge-intensive business cycle. The unique mixed methods approach in the study with a small sample size enabled an in-depth analysis of each trip and the considerations in business communication and travel management during the different phases of the knowledge-intensive business process. The methodology of the study is described in more detail in the Section 3 of Paper III.

2.2. Settlement hierarchy

The spatial aspects of the environmental load of consumption and mobility in Estonia are analysed in the current thesis, particularly in Papers I and II, with the help of the concept of settlement hierarchy. The concept originates from the central place theory by Walter Christaller from the early 1930s (Christaller 1933, 1934). Analysing the 'gravity' of urban places with the example of phone connections, Christaller was the first to give a theoretical framework in quantitative geography about the hierarchy of various urban structures and their hinterland that formed functional regions (Christaller 1933). Hence, settlement hierarchy characterizes the tiered system of functional regions within the whole country and is based on the size and type of settlements, their mutual relations and functions provided and used (Berry 1958; Berry, Garrisson 1958; Christaller 1933; Marksoo 1980, 1984; Tammaru 2001a). A functional region is formed on the basis of a central place, which provides services and often workplaces to the residents of the whole functional region, and its hinterland, which supplies the central place with physical resources, human labour, and client base. Central places in turn are subordinated to each other according to their size, profile, level and diversity of functions and services provided. Central places of higher level provide a wider variety and more specialised services to the residents of the respective functional region while lower level central places supply their residents with daily commodities and necessities only (Berry, Garrisson 1958; Christaller 1933). Functional regions are not static constructions, but in mutual development following the economic and population changes in the regions and surrounding areas.

Christaller's central place theory was adapted by Edgar Kant to the context of Estonia already in 1935 (Kant 1935) when he amended his unpublished dissertation (Kant 1934) about the structure, development, and mutual relations of settlements in Estonia (see Tammiksaar, Pae 2014; Tammiksaar *et al.* forthcoming). Already in the end of 1930s, the theory was applied in the administrative reform of Estonian municipalities (Pae, Tammiksaar 2015), making Estonia the first country in the longer row of states that used this concept in their spatial restructuring and planning (Tammiksaar *et al.* forthcoming). During the whole Soviet era since World War II, the central place theory by Christaller and Kant's legacy in economic geography could not be officially used in Estonia due to political reasons (Tammiksaar *et al.* 2013), but the ideas remained known and were further elaborated especially by Salme Nõmmik and Ann Marksoo (Marksoo 1980, 1984, 1990; Marksoo, Nõmmik 1977). This hierarchical and functional perception of Estonian territorial system has remained a norm also in the studies of economic, population, and urban geography that are compiled since Estonia regained independence in 1991 (see, e.g., Ahas *et al.* 2010a; Leetmaa *et al.* 2013; Novak *et al.* 2013; Raagmaa, Kroon 2005; Sjöberg, Tammaru 1999; Tammaru 2003, 2005; Tammaru *et al.* 2004; Tammaru *et al.* 2009).

In the current thesis, the functional regions are based on commuting statistics that are gained from the Population and Housing Censuses in 2000 and 2011 (Statistics Estonia 2000, 2012b) and prepared by the Centre for Migration and Urban Studies of Tartu University with some further specification by the author of the thesis. The structure and allocation of Estonian settlement hierarchy to local municipalities in Papers I and II as well as the respective sample structure are described in Table 2. According to the settlement hierarchy, Estonian settlement structure is divided into subordinated levels of urban cores with their respective hinterland areas or rural peripheral areas (Marksoo 1984; Tammaru 2001a; Tammaru *et al.* 2003). There are four levels of urban cores: the capital as the highest level, regional centres, county centres, and small towns as the lowest level. The hinterland of the capital, regional centre, or county centre has been defined as a municipality where from at least 15% (far-hinterland) or 30% (near-hinterland) of the working population commute to the urban core. The rest of the municipalities are classified as rural peripheral municipalities, lying outside any of the functional urban regions.

Due to the sample structure in Paper I, small towns are missing and regional and county centres have been merged, enabling the differentiation of five settlement hierarchy levels. In Paper II, nine settlement hierarchy levels have been differentiated as regional centres have been further divided into polyfunctional and industrial centres, as introduced already by Marksoo (1984). The spatial differentiation of study areas in Paper III is confined to the differentiation of Tallinn, the capital, and Tartu, the main regional centre in Estonia, while the rest of Estonia is handled unitedly.

Table 2. The description of Estonian settlement hierarchy and allocation of municipalities in Papers I and II together with respective sample structure.

Settlement hierarchy level	Municipalities	Allocation in Paper I (baseline Census 2000)	Allocation in Paper II (baseline Census 2011)	Population (Census 2011)	Share of population (Census 2011)	No of respondents, Paper I	Share in the sample, Paper I	No of respondents, Paper II	Share in the sample, Paper II
Capital	Tallinn	Tallinn	U1	393,222	30%	82	20%	707	20%
Hinterland of the capital	e.g., Anija, Harku, Keila, Kiili, Maardu, Rae, Saku, Viimsi	Hinterland of Tallinn	H1	154,341	12%	65	16%	292	8%
Regional poly-functional centres	Pärnu, Tartu	Central towns	U2pf	137,328	11%	102[a]	25%[a]	243	7%
Regional industrial centres	Jõhvi, Kohtla-Järve, Narva, Sillamäe	Central towns	U2i	120,891	9%	[a]	[a]	276	8%
Hinterland of regional centres	e.g., Audru, Kambja, Kohtla, Mäetaguse, Paikuse, Puhja, Sindi, Vaivara, Vara, Ülenurme	Hinterland of central towns	H2	71,357	6%	63[b]	15%[b]	179	5%

Settlement hierarchy level	Municipalities	Allocation in Paper I (baseline Census 2000)	Allocation in Paper II (baseline Census 2011)	Population (Census 2011)	Share of population (Census 2011)	No of respondents, Paper I	Share in the sample, Paper I	No of respondents, Paper II	Share in the sample, Paper II
County centres	Haapsalu, Jõgeva, Kuressaare, Paide, Põlva, Rakvere, Rapla, Valga, Viljandi, Võru	Central towns	U3	105,780	8%	[a]	[a]	457	13%
Hinterland of county centres	e.g., Halliste, Kaarma, Karula, Paide, Põlva, Raikküla, Sõmeru	Hinterland of central towns	H3	57,042	4%	[b]	[b]	241	7%
Small towns	e.g., Antsla, Elva, Kiviõli, Kunda, Mustvee, Otepää, Paldiski, Põltsamaa, Tõrva	n.i.	U4	67,071	5%	n.i.	n.i.	280	8%
Rural peripheral municipalities	e.g., Ahja, Kadrina, Käina, Mustjala, Noarootsi, Pala, Rõuge, Saarde, Sonda, Tarvastu	Rural municipal-lities	H4	181,566	14%	92	23%	862	24%
Estonia				1,294,455	100%	407	100%	3,537	100%

[a] All central towns are handled together.
[b] Hinterland municipalities of all central towns are handled together.

3. RESULTS

3.1. How is the environmental load of final consumption in Estonia divided between various consumption clusters?

The final consumption of Estonian high school students accounted for 3.04 gha/a as mean per capita ecological footprint while Estonian households caused on average 8.6 t CO_2 emissions per household and 3.9 t CO_2 emissions per capita and year. The division of environmental load across consumption clusters of both samples on per capita level is shown in Figure 1. The environmental load of the final consumption of Estonian residents derives mainly from shelter-related consumption where domestic energy use holds the largest share (44 and 56% of the total environmental load in Paper I and II respectively). Domestic energy use, belonging to shelter cluster, accounts for 34% of total per capita ecological footprint or 52% of total per capita carbon emission respective to the study.

The shares of the clusters of transport and food consumption are very similar in both studies: 12 and 16% of the ecological footprint and 13 and 14% of the carbon footprint respectively. Goods and services including governance costs held 28% of the total ecological footprint in the case of high school students, while in the household budget survey, the carbon footprint from the consumption of goods and services, leisure-related activities and education and healthcare accounted in total for 17% of the per capita footprint.

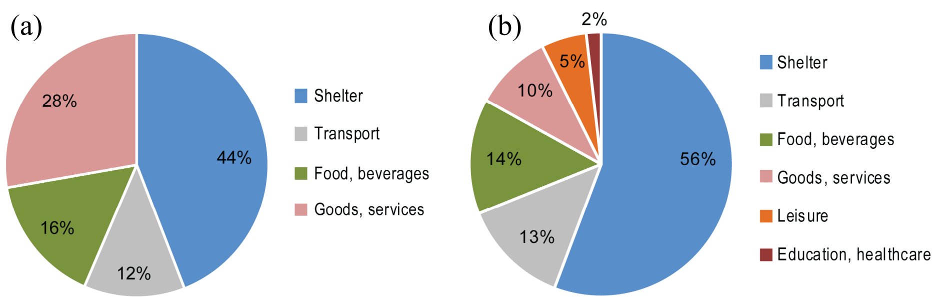

Figure 1. The division of per capita annual environmental load across consumption clusters: (a) ecological footprint of Estonian high school students according to Paper I, (b) CO_2 emissions of Estonian household members according to Paper II. *Source: Paper I (data), Paper II (figure).*

3.2. How is the environmental load related to the residential location in the settlement hierarchy?

High school students living in Tallinn metropolitan area, i.e. Tallinn together with its hinterland, have significantly higher ecological footprint than students living elsewhere in Estonia (Figure 2). Regarding all Estonian age groups, then in addition to Tallinn metropolitan area, the residents of Tartu and Pärnu together with their respective hinterland also tend to have higher per capita environmental load than can be related to the consumption and mobility pattern of people living in other settlement units of Estonia (Figure 3). However, the differences between settlement hierarchy levels are not so straightforward when all population groups are addressed than when considering high school students only.

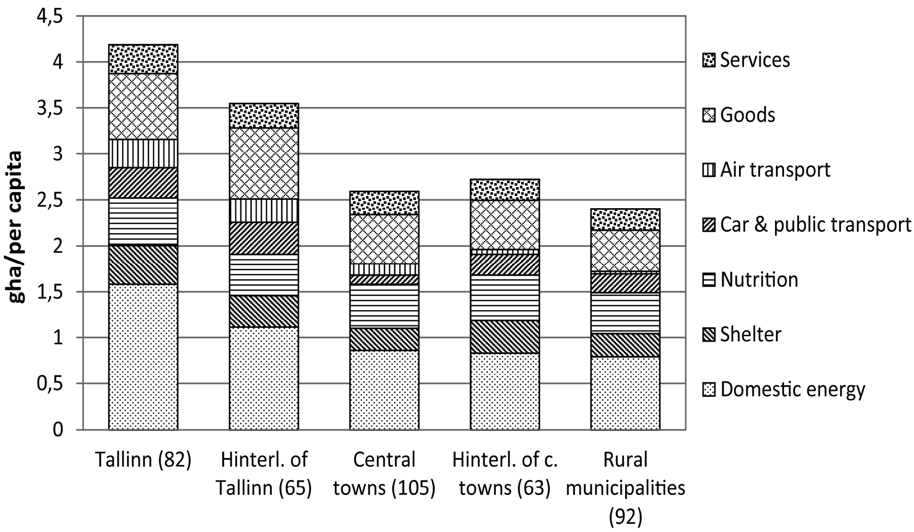

Figure 2. Pattern of average ecological footprint of Estonian high school students by settlement hierarchy class. *Source: Paper I (figure).*

By far the lowest carbon load among all Estonian residents derives from the consumption and mobility pattern of people living in regional industrial centres. This shows that treating different types of central towns – regional polyfunctional centres, regional industrial centres, and county centres – as one hierarchy level as is done in Paper I due to the sample structure is a problematic generalisation that hides the significant differences between these urban cores.

While studying the carbon load on per household level, then the highest load is imposed by the households residing in the hinterland of both the capital and regional centres and the lowest carbon load is again caused by the households living in regional industrial centres. This result is related to the size of the households as families with children form the highest share of the residents in the hinterland of the main central cities (see Table 2 in Section 2.2 in Paper II).

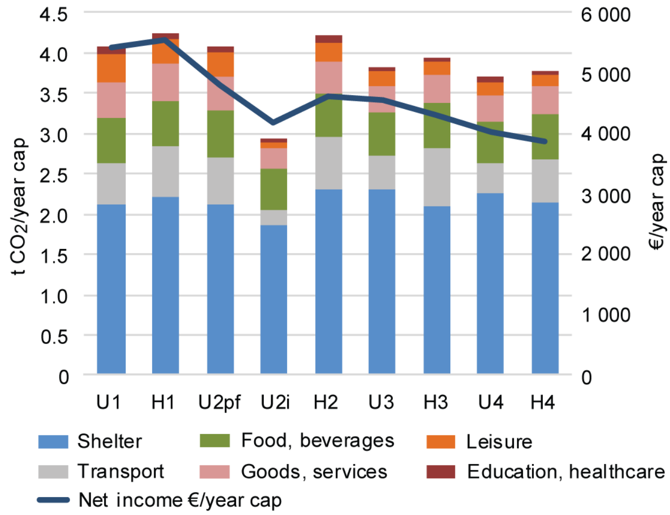

Figure 3. Annual per capita carbon load of household consumption across settlement hierarchy divided into consumption categories with average per capita net income. Hierarchy levels: U1 – capital; H1 – hinterland of capital; U2pf – regional poly-functional centres; U2i – regional industrial centres; H2 – hinterland of all regional centres; U3 – county centres; H3 – hinterland of county centres; U4 – small towns; H4 – rural peripheral municipalities. *Source: Paper II (modified figure).*

Shelter-related consumption. To understand the differences between settlement hierarchy levels better, the composition of the environmental load has to be studied. Significant variations in the per capita environmental load between hierarchy levels occur in almost all consumption clusters except food and beverages (Papers I and II) and domestic energy use (Paper II only). When considering only high school students, a significant difference in the ecological footprint of domestic energy use appears across the settlement hierarchy. This is partly explained by the share of carbon-intensive electricity used for heating purposes, being higher among the students living in Tallinn.

Carbon emissions from other shelter-related consumption than from domestic energy use, i.e. water and waste water management, waste management, maintenance, or rent, decrease from the capital towards lower hierarchy level urban areas, being typically higher in urban core than in the respective level of hinterland or rural area, with the exception of regional industrial centres. These differences are explained by the presence and the level of use of commercial housing maintenance, water supply, and waste water treatment possibilities in urban or urbanised areas.

Transport. Environmental load from mobility stems from daily travelling by car or public transport, air travelling, and other transport-related costs, such as purchase and maintenance of vehicles or travel by water. Transport-related environmental load is the highest among the households living in various levels of hinterland of urban cores or among the students residing in the Tallinn metropolitan area. The carbon emissions from transport are overwhelmingly the lowest in regional industrial cities, followed by small towns and county centres.

Travelling by car holds the largest share of the environmental load from mobility: 43% in the case of high school students and 64% among all the Estonian residents in the sample. While the emissions from car fuel are more or less similar among the residents of all urban cores in Paper II, then there is a clear tendency shown by both studies that people living in the hinterland or rural peripheral municipalities impose higher load from car travel than people residing in the respective level of urban core, indicating the car-dependency and longer commuting distances in the case of suburban or rural living. Also the share of households that own a car is higher in the hinterland and rural municipalities than in urban cores (see Table 2 in Section 2.2 in Paper II).

The capital region and regional polyfunctional centres provide, in turn, better possibilities for public transportation use; that is reflected also in the higher carbon load from that consumption type of those residents. Higher settlement level urban centres demand more carbon-intensive mobility from their residents and commuters than smaller towns and regional industrial centres. This may stem from the larger physical size of the higher level cities together with the scattered activity locations of the residents across the urban area. This higher demand of carbon-intensive travelling is somewhat mitigated by the provision of public transportation opportunities that decrease the carbon load from daily travel of the residents of urban centres. Living in smaller towns enables better access to everyday destinations by walking and cycling.

Emissions imposed by costs from transport other than travelling by car or public transport also show regional disparities. Air travelling causes higher environmental load among the residents of the capital region and eventually also among the residents of regional polyfunctional and county centres than among residents of other settlement hierarchy levels. Some of the costs for flights are hidden in the leisure cluster within the expenditure on package trips that include travelling with different travel modes, accommodation, some of the food expenses, and guided tours. Therefore, regional disparities in private air travelling cannot be conclusively drawn in Paper II. Altogether, emissions from other transportation costs than from car and public transport show higher rates in the Tallinn metropolitan area, regional polyfunctional centres together with their hinterland, and in the hinterland of county centres.

Consumption of various goods and services. The largest regional disparities occur within the environmental load derived from the consumption of non-energy commodities. This broad consumption type involves the consumption of various consumer goods and services (e.g., clothing and footwear, household equipment, alcohol and tobacco, communication), leisure-related goods and services (e.g., recreation, culture, accommodation, restaurants), education and healthcare costs as well as other governmental costs.

The students from the capital region cause the highest ecological footprint due to the intensive consumption of various goods and services. In the case of the whole households, the regional disparities of consumption-related carbon emissions are most distinctly present among leisure-related consumption, as illustrated on Figure 4. These emissions decrease from the capital region and regional polyfunctional centres towards small towns and rural peripheries, being exceptionally low among the residents of regional industrial centres. The emissions from the consumption of consumer goods and services show similar regional trend with smaller differences in absolute terms than in the case of leisure-related consumption. Carbon emissions from education and healthcare also show regional disparities between the capital and some lower level settlements together with regional industrial centres. However, the latter consumption types are underestimated in the study as these costs are often covered by taxpayers through the state or local budget.

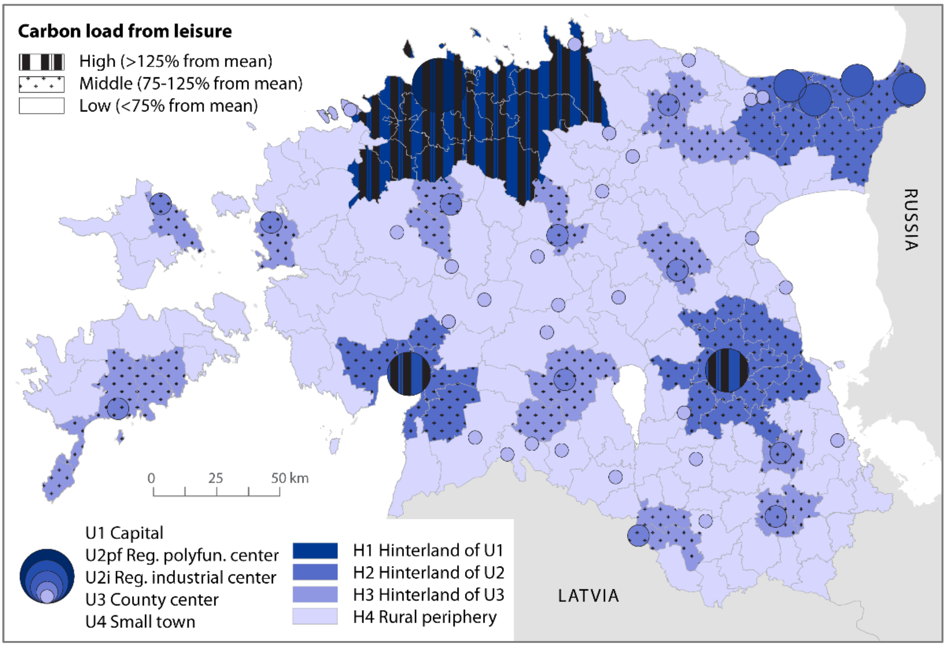

Figure 4. The spatial patterns of relative per capita carbon load from leisure-related goods and services. *Source: Paper II (figure).*

3.3. To what extend does the environmental load depend on residential location, when socio-economic differences within population are taken into account?

The majority of the regional variances presented in the above sections is explained by spatially different division of income (people from higher settlement hierarchy levels tend to have higher income), household composition (households with children reside more often in the hinterland of the higher level urban cores and there are more single person households in urban areas), or size of living space (there are more detached houses in all levels of rural areas). Owning a car, having higher education and speaking Estonian as the first language also explain some of the differences shown above.

Settlement hierarchy keeps its statistically significant position in explaining the variance of ecological footprint of students even when controlling for the effect of net per capita income, household size, living space, and housing age group. The ecological footprint of the students from the capital region, i.e. Tallinn with its hinterland, is significantly higher than the footprint of students living elsewhere in Estonia (see Table 3). The multiple regression model explains 25% of the total ecological footprint of students.

More dynamic results in total carbon load and in carbon emissions across various consumption clusters are presented in Paper II. The results show that if other socio-economic variables are considered, then households from the capital emit more carbon in statistically significant level only in comparison with the households from rural peripheral municipalities. More important variables than settlement hierarchy are the differences in net per capita income, household type, and the size of living space, complemented by car ownership, heating option, ethnicity, and education level. The multiple regression model of those significantly explanative variables describes 42% of the variance in total carbon load per household (see Model 1 in Table 4).

Settlement hierarchy level has no straight effect on the carbon load from domestic energy use and the consumption of food and beverages. However, the regression models show that the presence of district heating diminishes carbon emission both in the case of direct energy use and shelter-related consumption, along the decrease in living space and some other explanative variables (Models 2 and 5 in Table 4). The presence of district heating is weakly, yet negatively correlated with the carbon emissions from domestic energy use ($r=-0.21$, $p<0.001$).

The effect of settlement hierarchy along the other variables is weak also in the case of the regression model of transport-related carbon emissions (Model 6 in Table 4). Households living in the hinterland of regional centres have the highest carbon load from transport. Car ownership has the strongest positive effect on the environmental load. Attention has to be paid to the fact that only households that had declared any transport-related costs (55% of the sample) are covered by the model.

Table 3. Results of multiple regression analysis of the ecological footprint of Estonian high school students. *Source: Paper I (table).*

Explanatory variable	Observed power according to ANOVA	Base	β	B
Living space (m^2)	0.993***	continuous	0.208	0.000***
Settlement hierarchy	0.987***	Tallinn (82)		
		parameter		
		hinterland of Tallinn (65)	–0.090	–0.075
		central towns (105)	–0.246	–0.170***
		hinterland of central towns (63)	–0.167	–0.140**
		rural municipalities (92)	–0.260	–0.188***
Income class	0.963***	high (109)		
		parameter		
		middle (189)	–0.075	–0.065*
		low (83)	–0.240	–0.180***
		unspecified (26)	–0.065	–0.081
Household size	0.752*	up to 3 persons (121)		
		parameter		
		4 persons (154)	–0.081	–0.050
		5 and more persons (132)	–0.159	–0.103**
Housing age group	0.602*	new (96)		
		parameter		
		old (311)	–0.104	–0.074*
Constant / intercept				0.532***
R^2/adjusted R^2			0.252/0.232	

* Significant at 5% level, ** significant at 1% level, *** significant at 0.1% level.

More evident effect of settlement hierarchy on the carbon load of consumption is seen from the consumption clusters that emit carbon indirectly (i.e. consumption types other than domestic energy use and fuel purchases). Households from the capital tend to emit significantly more carbon indirectly than households from county centres, small towns, rural peripheral municipalities, and regional industrial centres (Model 3 in Table 4). Net per capita income together with household type is the main socio-economic variable that explains the differences in indirect carbon emissions. The model describes 45% of all the indirect emissions.

Looking more specifically into the consumption of consumer goods and services, then the households from Tallinn tend to have significantly higher emission than households from regional industrial centres and county centres (Model 7 in Table 4). In the case of leisure-related emissions, households from the hinterland of Tallinn even surpass the carbon load of the households from Tallinn, causing the highest carbon load among Estonian households (Model 8 in Table 4). Rural peripheral municipalities, small towns, county centres, and regional industrial centres are regions that provide residence to households with the lowest carbon load from leisure-related consumption. Leisure-related carbon emissions form the consumption cluster where regional disparities among Estonian households are the strongest.

Table 4. Results from multiple regression models of the carbon load of households. *Source: Paper II (modified table).*

Dependent variable: log(kg CO_2/year) of the respective consumption cluster		**M1 Total**	**M2 Direct**	**M3 Indirect**	**M4 Food and beverages**	**M5 Shelter**	**M6 Transport**	**M7 Consumer goods and services**	**M8 Leisure**
Explanatory variable: Reference	Parameter	Beta	Beta	Beta	Beta	Beta	Beta	Beta	Beta
Household type: With children	Single	–0.222***	–0.131***	–0.285***	–0.345***	–0.157***	n.i.	–0.294***	–0.132***
	Couple	–0.072***	–0.031	–0.111***	–0.068***	–0.042*		–0.173***	–0.113***
	Other without children	–0.036*	0.000	–0.065***	–0.048**	0.008		–0.103***	–0.099***
Education: Higher	Basic	–0.073***	–0.007	–0.136***	–0.050**	n.i.	n.i.	–0.106***	–0.140***
	Secondary	–0.071***	–0.043*	–0.080***	–0.042*			–0.021	–0.104***
First language: Estonian	Other	–0.079***	n.i.	–0.122***	n.i.	n.i.	–0.102***	–0.093***	–0.177***
Income (continuous)		0.256***	0.119***	0.316***	0.181***	0.096***	0.176***	0.258***	0.268***
Settlement hierarchy: U1 Capital	H1 Hinterland of capital	0.032	n.i.	0.073***	n.i.	0.009	0.008	0.020	0.068**
	U2pf Regional polyfunctional centres	0.003		0.018		0.000	0.014	–0.005	0.014

Dependent variable: log(kg CO_2/year) of the respective consumption cluster		**M1 Total**	**M2 Direct**	**M3 Indirect**	**M4 Food and beverages**	**M5 Shelter**	**M6 Transport**	**M7 Consumer goods and services**	**M8 Leisure**
	U2i Regional industrial centres	–0.018		–0.038*		–0.004	–0.046	–0.067***	–0.071**
	H2 Hinterland of regional centres	0.005		0.000		–0.013	0.053*	–0.013	0.014
	U3 County centres	–0.021		–0.068***		0.032	–0.018	–0.050*	–0.061**
	H3 Hinterland of county centres	–0.027		–0.016		–0.059**	0.011	–0.021	–0.033
	U4 Small towns	–0.017		–0.041*		0.016	–0.011	–0.017	–0.068***
	H4 Rural peripheral municipalities	–0.051*		–0.044*		–0.072**	0.054	–0.016	–0.101***
Living space, m^2 (continuous)		0.156***	0.167***	0.074***	0.054**	0.232***	n.i.	0.047**	0.035*
Dwelling type: Semi-detached, detached	Row house, small apartment building	n.i.	n.i.	0.034*	–0.008	0.038*	0.017	0.033*	n.i.

Dependent variable: log(kg CO_2/year) of the respective consumption cluster		**M1 Total**	**M2 Direct**	**M3 Indirect**	**M4 Food and beverages**	**M5 Shelter**	**M6 Transport**	**M7 Consumer goods and services**	**M8 Leisure**
	Large apartment building			0.075^{***}	-0.059^{**}	0.049	0.087^{**}	0.045^{*}	
Dwelling owner: From household	Other	n.i.	-0.044^{**}	0.034^{**}	-0.045^{**}	n.i.	n.i.	n.i.	n.i.
Heating option: Other	District	-0.088^{***}	-0.128^{***}	n.i.	n.i.	-0.098^{***}	-0.101^{**}	n.i.	n.i.
Private car: Yes	No	-0.173^{***}	-0.155^{***}	-0.148^{***}	-0.098^{***}	n.i.	-0.276^{***}	-0.152^{***}	-0.116^{***}
Constant		3.841^{***}	3.556^{***}	3.412^{***}	3.048^{***}	3.432^{***}	2.952^{***}	2.782^{***}	2.450^{***}
Adj R^2		0.42	0.23	0.45	0.29	0.14	0.18	0.36	0.31
N		3537	3537	3537	3530	3537	1946	3519	3168

3.4. What factors determine the choice of business communication and travel mode during the knowledge-intensive business cycle?

The most significant factors that influence the choice of communication mode of the professionals providing knowledge-intensive business services – either physical co-presence enabled by travelling or virtual communication enabled by the means of information and communication technology – are (1) the previous acquaintance and the presence of trust relations between the business partners, (2) the potential of the use of the communication mode to achieve strategic interests of the organization through the particular business task, and (3) the time considerations of the particular traveller. These considerations are well characterized by the following quotes from the interviewees:

> *'Earlier, we tried to decrease the amount of travelling to Tallinn, but what we realized was that we dropped out of the picture of decision-makers. So now we have internally set a target to be physically present as much as possible. [. . .] We are now searching for partners for a project and if we really want to see someone as a partner, actually I want to see before whom I'm going to sign the contract with, can't really do that just over the internet, albeit it is technically possible. It's more about building trust and investing in partner relations.'*
>
> [Member of board, Org 3]

> *'With marketing goals, I rather take these three days of travelling in order to reach the contract, because there have been a few negative experiences with sales over Skype; however, during some ongoing project, Skype provides satisfactory opportunities for discussion.'*
>
> [Member of board, Org 1]

The availability and high quality of virtual communication modes as well as the individual readiness of business partners to use those means are the prerequisites for using virtual communication channels in business communication in order to substitute business travel. This may lead to a substantial win, hence being dependent on the particular choice of business traveller:

> *'Earlier we used to have office meetings in Tartu on Mondays and in Tallinn on Tuesdays, discussing more or less the same issues. That repetition disappeared after installing these video-conference facilities in both meeting halls.'*
>
> [Member of board, Org 2]

> *'It depends on the preferences of the client. Some clients want to meet us in person, especially the first time, and some of the clients really do not*

use Skype, Facebook, or similar. But more active and innovative clients are eagerly using internet and video-conferencing for communication.'

[Member of board, Org 2]

In case when the particular traveller has chosen co-presence to undertake the business meeting, the choice of travel mode has to be made. The most important factors when choosing over the travel mode are (1) the time demand of the travel mode to reach business destination, (2) working opportunities during travelling, (3) the cost of the use of the travel mode, and (4) the possibility offered by the travel mode to combine business tasks with private needs. While car use often enables quicker and more flexible access to business and private destinations, then travel time working need often favours the choice of train or bus that provide Wi-Fi. The choice of public transportation is enabled only in the case of frequent connections between destinations, i.e. between Tartu and Tallinn in the case of the participating organizations:

'In the case of field trips and work in regions such as public hearings, then we use car. But in order to meet clients, our project managers often go to Tallinn as Tallinn inevitably is the place in Estonia where people tend to gather. Then taking bus or train is rather favoured. [. . .] And I think this is also the preference of the traveller because if you take bus or train, you can use the time for work and less time is wasted due to travelling.'

[Member of board, Org 2]

'The destination within Tallinn determines whether I take a car or a bus. When the destination is in the city centre, then it's more appropriate to take a bus. But if I go to our partner's office in the more distant city district of Tallinn, then I now always take a car. Once I tried to make it with public transportation and I don't want to waste that time again.'

[Member of board, Org 3]

Contextual factors also shape the choice of travel mode of particular travellers. Conscious choice of inner-city office location gives better starting position to use public transportation between the cities:

'Deciding the location of the offices both in Tartu and Tallinn were clearly decisions that favoured the use of public transportation and not travelling by car.'

[Member of board, Org 2]

3.5. How is the carbon load of business travel related to the phase of knowledge-intensive business process at hand?

Domestic business trips accounted for 1.6 higher carbon load (2.4 t CO_2e, 57 trips) and all business trips accounted for more than three times higher carbon footprint (4.9 t CO_2e, 66 trips) than commuting (1.5 t CO_2e) during the same period, i.e. May 2013, showing the considerable importance of business trips outside the office town in comparison to daily commuting of the same professionals.

Business travel needs and the consequent carbon load were unevenly divided between various business service phases, as seen from Table 5. Core business processes, i.e. meeting clients, business partners, and public authorities, or undergoing field works, caused the majority of the carbon load of domestic business travel. This phase in the knowledge-intensive business service also served the most prioritized business travel goal among the professionals (see Figure 3 in the Section 4.4 in Paper III). Marketing and sales, on the other hand, were the least prioritized business travel goal among business professionals and accounted for a modest carbon footprint in domestic context. Similar carbon load was emitted from business trips that were related to internal management and delivering business outcomes. Training-related trips occurred seldom during the study period and accounted only for a marginal carbon footprint.

Table 5. The number and carbon footprint (CF, t CO_2e) of trips made during May 2013 by travel goal and professional status. *Source: Paper III (table).*

Travel goal	All trips		Domestic trips			International trips		
	No	CF	No	CF	CF/trip	No	CF	CF/trip
Internal management, establishing team relationships	5.5	0.34	5.5	0.34	0.062	0	0	–
Training, obtaining knowledge	3	1.55	1	0.04	0.037	2	1.52	0.759
Marketing, sales	14.5	1.23	7.5	0.24	0.032	7	0.99	0.141
Executing core business processes	34.5	1.39	34.5	1.39	0.040	0	0	–
Delivering business outcomes	8.5	0.37	8.5	0.37	0.044	0	0	–
Members of board	34	3.36	28	1.10	0.039	6	2.26	0.377
Other staff	32	1.52	29	1.28	0.044	3	0.24	0.081
Total	66	4.88	57	2.38	0.042	9	2.51	0.279

The international trips undertaken during the study period were related to the potential partner network of the participating organizations and to the need to increase know-how of the professionals. Thus, only marketing and training related international trips occurred. Communication with the existing international partners was mediated by virtual modes during the study period, although the focus groups and follow-up interviews revealed that international trips related to core business processes also occur frequently. The small number of international trips during the study period does not allow further exploration of the needs for business travel and corresponding carbon load in international context.

4. DISCUSSION

The results of the thesis have shown that the geographical location of individuals, households, or organizations affects the behavioural choices – the consumption and mobility pattern – of residents in diverse directions. While income restrictions often determine the volume of consumption, location in settlement hierarchy shapes the needs, choices, and expenditure division together with the consequent environmental load the expenditure involves. This derives from the immanent property of settlement hierarchy to incorporate varying levels of availability of and accessibility to various activities, goods, and services that people need in their everyday or business life. The results to the research questions are discussed in the next subsections.

The size of the environmental load and the dominant role of domestic energy use therein. Several cross-national studies have shown that the per capita ecological footprint of nations is strongly dependent on the level of economic development of the country (Jorgenson, Burns 2007; Jorgenson, Clark 2011). The figures of carbon emissions found in Paper II are 1.2–2.7 times lower than has been previously shown by studies (Büchs, Schnepf 2013; Girod, De Haan 2010; Kerkhof *et al.* 2009a; Ottelin *et al.* 2015; Wier *et al.* 2001) conducted in other European countries (Denmark, Finland, Netherlands, Norway, Sweden, Switzerland, United Kingdom). Lower emissions are largely the result of the lower affluence level of Estonian society in comparison to the aforementioned Western European countries as the mean expenditure volume of Estonian households is approximately three times lower than mean of the member states of the European Union (Eurostat 2016a). There are no comparable studies available about the energy use, carbon load or ecological footprint of household consumption in other Eastern or Central European countries with whom Estonian households have more similar expenditure volume according to the Eurostat (2016a) data.

On the other hand, the share of domestic energy expenditure of all household purchases in 2010 was double as high in Estonia (18.5%) than in the EU countries on average (9.5%; Eurostat 2016a). In cross-national studies, it has been shown that the share of energy use depends on population density, geographical conditions, energy carriers and technology, typical dwelling insulation, and consumer lifestyles of the particular country (Kerkhof *et al.* 2009a; Lenzen *et al.* 2006; Moll *et al.* 2005; Pachauri, Jiang 2008; Reinders *et al.* 2003; Wier *et al.* 2001). Climate and the poor insulation of Estonian housing stock (Kurnitski *et al.* 2014; MKM 2015) explain the dominant position of carbon load from domestic energy use in Estonia that is higher than could be expected from the differences in mean expenditure level between countries. Namely, emission intensities of combustible energy sources surpass manifold the emission intensities of non-energy commodities (Kerkhof *et al.* 2009b; Sánchez-Chóliz *et al.* 2007). The outstandingly high share of carbon-intensive oil shale electricity in the energy mix used in Estonia (EEA 2014; Statistics Estonia 2016b) further increases the carbon emissions of energy use expenditure of

Estonian households, as seen from the emission intensities in Table S1 in the Supplementary Materials of Paper II.

Regional variations in domestic energy use occur only in the ecological footprint of high school students (Paper I) and are missing in the sample over the whole Estonian population (Paper II). Nevertheless, the presence of district heating tends to decrease carbon emissions from direct energy use. This may indicate the advantages of compact urban areas with district heating supply on the total energy use of households as is also suggested by Connolly *et al.* 2014, and Holden and Norland 2005, however, focused studies have to be conducted together with the use of localised process-level data as district heating networks in Estonia differ in energy sources, production processes, efficiency ratios, and prices per MWh (MKM 2015).

The results of the thesis indicate the need to improve the state of local energy infrastructure, the mix of energy carriers towards renewable energy sources, and energy efficiency of housing stock and to better regard energy implications in spatial planning in order to comply with the United Nations climate goals according to the agenda for sustainable development (UN 2015b). The Estonian National Energy Roadmap ENMAK 2030+ (MKM 2015) has indeed foreseen measures for a radical reduction in heating energy demand and carbon emissions from energy use by 2050.

Spatial aspects of the environmental load of consumption. Better provision of a wider variety of functions – services, consumer goods, leisure-time spending opportunities – is characteristic to higher hierarchy level settlements (Berry 1958; Carol 1960; Christaller 1933). The results of the thesis show that higher diversity and easier access to consumption and leisure-time opportunities, i.e. commercial non-energy commodities, increase the use of those opportunities together with the environmental load it involves. Residents of larger cities or their hinterlands tend to cause higher carbon load from spending on various goods and services than people from smaller or industrial type of settlements even when other socio-economic differences between households are considered. This confirms the notion by Goodman *et al.* (2010) and Smas (2005) that the presence or absence of consumption opportunities in the daily environment influences the actions and choices of people, either supporting or hindering respective consumption. Especially the abundance of goods in the surrounding environment helps people to express their freedom of choice (Keller 2004).

Previous research from Finland has stressed that if the differences in income levels are taken into account, then urbanization increases the consumption of services, but not necessarily tangible goods (Ala-Mantila *et al.* 2014; Heinonen *et al.* 2013). The spatially varying results of the analysis presented in this thesis regarding the use of all non-energy commodities may be driven by the polarization of Estonian society into fast-developing centres and shrinking peripheries (Tiit, Servinski 2015) indicating that in the latter regions, the limited spatial access to some goods may also decrease the quality of life not only due to income differences.

Spatial aspects of the environmental load of travel. The differences in urban and suburban/rural travel needs in the results of thesis follows the general understanding of many previous mobility studies that have shown the advantages of living in dense urban areas as opposed to the disadvantages of residing in the functional hinterland or rural areas as the latter derive higher load from travel, mainly due to longer commuting distances and higher share of car use (see, e.g., Brown *et al.* 2009; Cervero, Murakami 2010; Glaeser, Kahn 2010; Jones, Kammen 2013; Mattingly, Morrissey 2014; Muñiz, Galindo 2005; Stead, Marshall 2001).

Urban areas of higher density are often shown to result in more sustainable travel of their residents than cities with lower population density (Cervero, Murakami 2010; Muñiz, Galindo 2005; Newman, Kenworthy 1989). It may be thus expected that Tallinn, the largest and densest city and the main economic centre in Estonia, could provide its residents the most sustainable transport solutions among other Estonian urban cores. The results of Paper I show the opposite as high school students residing in Tallinn have significantly higher ecological footprint from car and public transportation use than students living in other central cities. Interestingly, Paper II does show neither advantages nor disadvantages of Tallinn in comparison with other central cities (except regional industrial centres) as different levels of urban cores impose similar carbon load of their residents due to daily travelling. On the opposite, lower carbon load from the expenditure on car and public transport is shown by the residents of small towns, if not to mention again the exceptionally low load of the residents of regional industrial centres. Only when considering all transport related costs (i.e. including the costs on vehicle purchase and maintenance or air travelling), then those living in Tallinn or regional polyfunctional centres cause considerably higher carbon load from transport than the residents of other central cities or small towns.

The results of both papers considering the environmental load from car and public transportation of various levels of urban settlements may be explained by the following double-sided effect. While higher density with mixed land-use of larger cities decrease the travel load of their residents due to potentially close activity locations and low-carbon travel opportunities within the city (see Cervero, Murakami 2010; Muñiz, Galindo 2005; Newman, Kenworthy 1989), the larger physical size and hierarchical structure of cities with their more diverse provision of time use opportunities, on the opposite, increase the travel load of the residents. In latter cities, there may be more activity locations, these may get more scattered around the city, the distances between the destinations increase, and the destinations are hence less accessible by light travel modes (see also Stead, Marshall 2001). The difference in the travel-related environmental load between Papers I and II may stem from the different nature of the sample in both studies, as Paper II covers a significantly wider and more representative set of population (age) groups of Estonia.

As the urban cores function together with their hinterland, Jones and Kammen (2013) have stressed the need to consider functional regions as a whole: the denser the city, the larger its hinterland, so that the benefits of density are outweighed by the larger spatial outreach of commuting areas. Indeed, the hinterland of Tallinn has overwhelmingly the largest and increasing spatial outreach among the functional regions of Estonia when comparing the censuses of 1989, 2000, and 2011 (see also Leetmaa, Tammaru 2007; Tammaru *et al.* 2009). Nevertheless, the residents of the hinterland of Tallinn do not show the largest environmental load from daily travel among the residents of other hinterlands, as seen from Paper II, only the high school students residing there cause the highest ecological footprint from travelling when compared to other students. People from peripheral rural areas that do not function as hinterlands to any urban cores presumably cause somewhat lower carbon load from travel than the residents of functional hinterlands of central cities. The relatively similar outcome in travel-related environmental load for all functional regions in Paper II might be a result of the importance of Tallinn as an urban destination also to the population of other areas outside the capital region, both in relation to jobs and private life. This is related to the importance and influence of Tallinn metropolitan area in Estonian context as other areas, except Tartu region, are suffering from shrinking and aging population (Tiit, Servinski 2015) due to the constraints in employment and opportunities for self-realization (Anniste *et al.* 2012; Nugin 2014).

Exceptional position of regional industrial centres. The very low carbon load from transport of the residents of regional industrial centres in comparison to people living elsewhere in Estonia (Paper II) derives from the different historical and ethnical background of these cities. The cities, being industrial from their economic profile and development, incorporate large compact areas of housing estates as a typical outcome of Soviet era settlement planning (Leetmaa, Tammaru 2007; Tammaru 2001b). The aggregated location in Eastern Estonia and historic development and functions of those cities are different from the other larger centres of Estonia. The ethnic background of these cities is strongly related to Soviet era migrant labour, resulting in significantly different population division that is typical to the majority of the cities in Estonia. The residents of regional industrial centres have also less social relations with their surrounding municipalities than other urban cores in Estonia, with the exception of Jõhvi as a historical county centre (Ahas *et al.* 2010b; Novak *et al.* 2013; Silm, Ahas 2014). Historically, there have been a few large industrial employers and the region is still characterized by some dominant companies (Siseministeerium 2009). Large employers provide organized transport to workplaces that may be located in the surrounding industrial areas, e.g., oil-shale mines, energy power plants, or chemical companies. Thus, it may be expected that the workforce spends less on work-related travel than people on average elsewhere in Estonia. Lower carbon load from transport in the results of Paper II may thus be a combination of (1) compact settlement structure that enables low-carbon travel modes, (2) low rate of social relationships outside the urban areas, (3) low general income level of the population to afford the use of private car, and (4) underestimated travel costs due to organized work-related travel.

The results of the thesis also reveal the significant differences in consumer behaviour of the residents of regional industrial centres in comparison to other settlement levels, even when modelling has taken into account income and other social variables. The industrial character of those cities and workplaces and historic and ethnic background of the population of those cities may also explain the low expenditure level and only modest environmental load from the consumption on non-energy commodities. While younger Russian-speaking generation is more open to market-based consumer culture that 'is the most neutral, non-discriminating and accessible area where Estonian Russians' feeling of exclusion is alleviated' (Kalmus *et al.* 2009: 68), then the older generation tends to keep the practices of Soviet-era conservative consumer culture (Kalmus *et al.* 2009; Keller, Vihalemm 2005). In conclusion, although lower average income levels predispose lower consumption volume of the household of regional industrial centres in comparison to many other settlement hierarchy levels in Estonia (see Figure 3), then the founding and development peculiarities together with the 'Soviet-era legacies in the mentality and consumption culture have probably hindered these centres from developing into postmodern hubs of consumption and leisure, even though their size and regional importance could enable more economic activities and opportunities for consumer culture,' as is argued in Paper II (p. 12).

Business travel in the knowledge-intensive service sector. Each phase in the provision of knowledge-intensive business services has a particular need for business travel and face-to-face contacts with business partners. The travelling need depends on the potential of the trip to contribute to the achievement of business goals and the economic sustainability of the organization as well as the presence of trust relationships within the business network. The importance of physical proximity in the development of trust relations, the maintenance of business networks, and the provision of knowledge-intensive business services has been highlighted to be the main driver of increasing rates of business travel (Larsen 2001; Urry 2003).

Core business processes are the business phase that, on the one hand, drive the highest need for business travel, and, on the other hand, provide the best potential for substituting business travel with virtual communication modes. The achievement of business goals in knowledge-intensive businesses depends the most on the core business processes as these, according to Faulconbridge (2006), enable the joint co-production of new knowledge and provision of tailor-made solutions for clients. The already established trust relations during that phase, on the other hand, help to substitute frequent travel with virtual modes of communication and thus partially prevent the environmental load of business communication (see also Arnfalk, Kogg 2003; Lo *et al.* 2013; Sau 2014).

The substitution effect occurs also during internal management while other types of business communication in the cycle of knowledge-intensive business service – training, marketing and sales, and delivering business outcomes – are more successful if they are mediated by face-to-face contacts. Especially marketing and sales are the most fragile business phase where virtual communication is a risky choice. This is explained by the notion that business negotiations and financial deals demand a high degree of physical proximity in order to build trust relations (Arnfalk, Kogg 2003; Castells 2010).

The distance from vivid economic centres increases business travel demand of organizations (Aguiléra, Proulhac 2015) as these organizations in lower hierarchy level settlements have to make additional efforts to reach the more dominant business centres in order to keep their respective business network. This tendency is well visible in the results of Paper III as the interviewees, with the office location in Tartu, stressed the need to travel to Tallinn, to the main economic centre of Estonia, in order to stay in the picture of decision-makers, gain new contracts, and work with clients or civil servants. Similar tendency concerning international business travel may be related to Estonian distant location from European economic and administrative centres. Virtual communication helps to partially overcome this additional economic and environmental burden in the management of business network from more distant locations.

Methodological issues. The structure of Papers I and II is similar covering the wide spectrum of final consumption of residents; however, some variations in the results are related to the different sample structure, data acquisition methods, and the distinction of settlement hierarchy levels between the two studies. Paper I addresses a young subsample of Estonian population (N=407), while Paper II covers all types of households with a sound number of participants (3,537 households with 9,080 household members). The latter allows taking into consideration the effect of additional sociodemographic variables, such as educational level or car ownership. Although the whole household shares everyday practicalities and the practices of younger members are largely explained by their older family members' attitudes and behaviour (Grønhøj, Thøgersen 2012), the age cohort affects travelling amounts, including travelling by car (Grazi *et al.* 2008; Stead, Marshall 2001; Van Acker *et al.* 2010). In addition, private expenditure on transport made by households may underestimate the private demand for travelling as some of the expenditure related to car use may be done by employers as a part of their compensation package for employees (De Borger, Wyuyts 2011; Macharis, De Witte 2012).

The analysis of Paper II based on Household Budget Survey where data collection involved the collection of expenditure documentation that was classified according to the detailed COICOP classification scheme (UN 2015a). In Paper I, the level of distinguishing expenditure during data collection covered significantly less consumption types especially in the case of consumption of goods and services where the students were asked to assess the annual expenditure volume with the help of their parents. This evaluation may have resulted in some undercoverage of data in the related consumption clusters.

While Papers I and II both covered the whole Estonian territory, the allocation of municipalities to settlement hierarchy was more profound in Paper II than in Paper I (9 levels versus 5 levels respectively) due to the differences in sample sizes. This brought out major variation in the results of the two studies. The strong differences in consumption and mobility pattern between the residents of industrial and polyfunctional regional centres that are evident in the results of Paper II are veiled if both types of cities are aggregated into one hierarchy class as is done in Paper I. During the recent decades, all regional centres have been treated commonly in the studies that are conducted in the Department of Geography, Tartu University (see, e.g., Novak *et al.* 2013; Sjöberg, Tammaru 1999; Tammaru *et al.* 2003). Paper II showed that it is essential to differentiate regional industrial centres from regional polyfunctional centres in the settlement hierarchy classification due to their different economic, functional, and social background, as already depicted by Marksoo (1984).

The residential location on the one hand and real consumption and mobility practices on the other hand have mutual effects due to the phenomenon of residential self-selection. This may involve neighbourhood and mobility preferences (De Vos, Witlox 2016; Kährik *et al.* 2012; Mokhtarian, Cao 2008) or considering the opportunities for active life-style (Frenkel *et al.* 2013; Pavelka, Draper 2015; Tu *et al.* 2016). Residential self-selection hypothesis was not tested in the thesis and the size of the potential residential self-selection bias in the total effect of location on the environmental load of consumption and mobility requires further research.

Papers I and II aimed to cover the whole annual cycle of consumption and mobility of residents. The limited number of participating organizations and a short study period in the pilot study presented in Paper III limit the level of generalization of the results of business travel to all knowledge-intensive business service providers and to the whole year due to the seasonal effect on travel needs that the respondents brought out. Furthermore, in order to draw conclusions on the impact of location on business travel demand during various business phases, the spatial reach of the study area has to be extended so that the whole hierarchy of economic centres and peripheries is covered. The balance between the preferences for physical travel or virtual communication in the cycle of knowledge-intensive business services that drives from the level of trust relationships between business partners is considered to be a more universal finding of Paper III.

The thesis involves a wide combination of data acquisition and research methods. The original research data have been gathered by a variety of bottom-up approaches – online questionnaire, focus group and individual interviews, active mobile positioning, or using original data collected by Statistics Estonia – that are combined with the use of aggregated databases and research methods such as national statistical databases, ecological footprint or carbon emission coefficients, and input-output computing. This multitude of methods has enabled a detailed assessment of the direct and indirect environmental load of consumption and mobility behaviour of residents and organizations.

Further studies should address the above-named sample-related extensions in business travel research, the travel needs of Estonian population by combining the results of Household Budget Survey (Paper II) with the activity space of Estonian residents that is acquired by passive mobile positioning methods, the effect of consumption spaces on consumption pattern on a more detailed spatial level, accompanied by the meanings of consumption, and the residential self-selection effect in consumption and mobility choices. The difference in the consumption and mobility pattern of the residents of regional industrial centres have to verified by the next wave of Household Budget Survey and the reasons behind the exceptionally low environmental load need to be studied by additional qualitative research methods, e.g., by comparatively interviewing the same ethnical groups from the industrial centres and the capital region.

5. CONCLUSIONS

The location of individuals, households, or organizations in the settlement hierarchy significantly shapes their consumption and mobility behaviour and the consequent environmental load. This derives from the immanent property of settlement hierarchy to incorporate varying levels of availability of and accessibility to various activities, goods, and services that people need in their everyday or business life. Availability and accessibility create a structural context to the consumption and mobility choices of people, either providing opportunities (e.g., cafeterias or commercial leisure services) or even predisposing certain consumption (e.g., travel by car or connection to district heating) and hence stimulating additional consumption of commodities, or hindering consumption in the absence of provision (e.g., poor public transport or deficit in commercial leisure services).

This stimulating effect of urbanization results in higher environmental load from active lifestyle. The residents of the main urban centres of Estonia – Tallinn, Tartu and Pärnu – and from the hinterland of capital cause higher environmental load from the consumption of non-energy commodities than residents from smaller or more rural settlements. Better availability and accessibility of various commodities, especially leisure-related goods and services, increase their consumption and the consequent environmental load also when differences in income levels and other socio-demographic aspects of households are considered.

Urban settlements provide benefits in front of suburban and rural areas only in the sphere of daily mobility due to the concentrated activity locations and better opportunity to use low-carbon travel modes. Residents from lower level hinterlands and peripheral rural areas are clearly more dependent on car use than people living in urban cores or in the hinterland of Tallinn. However, the expected additional advantage from higher urbanization level in decreased travel load when comparing different types of urban cores did not find confirmation in the results concerning Estonian high school students or households. The benefits of the agglomeration and concentration are evident only in case the of business travel as professionals working in more distant locations need to put more efforts on reaching their business network in the main economic centres.

Regional industrial cities that have a different developmental, economic, environmental, functional, and social background are characterized by a conservative consumption and mobility pattern of their residents. These households show the overwhelmingly lowest per capita environmental load among Estonian population that is only partially explained by their lower income level or different ethnical background. It may be assumed that the developmental peculiarities, industrial dominance, poorer access to opportunities for life-style oriented consumption, remnants of Soviet period scarcity-determined consumption culture, and low rate of social relations with the hinterland areas have hindered these regional centres to develop towards contemporary urban cores of active lifestyle.

The environmental load of the final consumption of households derives in majority from shelter-related expenditure and is considerably lower in Estonia than in European countries of higher wealth. The difference in environmental load is proportionally smaller than could be expected from the differences in disposable income levels. The high share of expenditure on domestic energy use among Estonian households due to the climatic conditions and poor insulation of dwellings as well as the carbon intensity of the energy sector in Estonia decrease the expectable environmental benefits deriving from lower overall expenditure volume.

The need for business travel in knowledge-intensive service sector considerably depends on the phase of the business cycle at hand. While the success of marketing and sales especially depends on physical co-presence, then core business processes, where the need for travel and communication is the highest, provide opportunities for some travel substitution with virtual modes of communication. Established trust relationships in business partnership are one of the main prerequisites for such substitution and the realization of its environmental benefits. Apart from outcome-oriented motivations and human relationships, time considerations of business professionals are one of the key factors that determine the communication and travel mode in business life.

Knowledge about the spatially varying levels of environmental load from mobility and consumption behaviour is of importance in Estonian spatial policy, planning, and development. Wise consideration of urban and suburban land use to avoid sprawling and highly hierarchical settlements, putting special attention to supporting the development of life and access to essential services in locations that are more distant from the main central cities, and well-developed public transportation and good connectivity in the whole country are needed in Estonian local, regional, and national planning in order to achieve a socio-environmentally balanced society.

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Tartu 2017

SUMMARY IN ESTONIAN

Tarbimisest ja mobiilsusest tuleneva keskkonnakoormuse ruumilised aspektid

Doktoritöös uuritakse, kuidas asukoht Eestis asustussüsteemi hierarhias mõjutab siinsete elanike liikumis- ja tarbimiskäitumisest tulenevat keskkonnakoormust. Seejuures vaadeldakse linnastumise kui tarbimiskäitumise kujundajaga kaasnevat soodsat ja ebasoodsat mõju keskkonnakoormuse kujunemisele. Töö pakub uudseid teadmisi, sest senises teaduskirjanduses ei ole ammendatavalt käsitletud kaupade ja teenuste kättesaadavuse ning tarbimismahu ja keskkonnakoormuse omavahelisi seoseid ega ka kogu lõpptarbimise keskkonnakoormuse jaotumist detailsel hierarhilisel tasandil, iseäranis arvestades leibkondade sotsiaalmajanduslike tunnustega. Töös argumenteeritakse, et suuremate keskuslinnadega kaasnev kaupade ja teenuste parem kättesaadavus väljendub ka sealse piirkonna elanike tarbimiskäitumises ja keskkonnakoormuses. Eraldi tähelepanu pööratakse liikumiskäitumise seostele asukohatunnustega, sh tööalaste reiside võtmes. Eesmärgi täitmiseks püstitati järgmised uurimisküsimused.

1. Kuidas jaguneb Eesti elanike keskkonnakoormus tarbimiskategooriate kaupa?
2. Mil moel jaguneb elanike keskkonnakoormus asustussüsteemi hierarhias?
3. Kuidas sõltub elanike keskkonnakoormus elukoha asukohast, kui võtta arvesse ka leibkondade teisi sotsiaalmajanduslikke tunnuseid?
4. Millised tegurid määravad ärisuhtluse ja tööalaste reiside viisi teadmismahuka teenuse pakkumise protsessi jooksul?
5. Kuidas sõltub tööalaste reiside süsinikukoormus teadmismahuka teenuse pakkumise protsessi faasist?

Tarbimise keskkonnakoormust kujundava asukoha mõju analüüsimiseks kasutatakse siinses doktoritöös asustussüsteemi hierarhia kontseptsiooni. See tugineb Walter Christalleri keskuskohtade teooriale (Christaller 1933), mille järgi on erinevad linnalised ja maalised asumid üksteisega hierarhiliselt ja funktsionaalselt seotud. Eesti kontekstis rakendas Edgar Kant keskuskohtade teooriat juba 1930. aastate keskpaigas (Kant 1935). Selle mõjul on asustussüsteemi hierarhia siiani sageli kasutatav ruumiline käsitlusviis Eesti ala puudutavates uuringutes (Marksoo 1984; Novak *et al.* 2013; Pae, Tammiksaar 2015; Tammaru *et al.* 2003).

Asustussüsteemi hierarhia järgi on Eesti linnad omavahel hierarhiliselt seotud. Keskuslinnade hierarhia tipus on pealinn Tallinn, millele järgnevad regiooni- ja maakonnakeskused ning väikelinnad. Keskuslinnadega on tihedates funktsionaalsetes sidemetes tagamaa omavalitsused. Maaomavalitsusi, mis ei kuulu ühegi keskuslinna tagamaa hulka, nimetatakse perifeerseteks maavaldadeks. Eesti asustussüsteemi hierarhia klassifikatsioon tugineb tänapäeval rahva- ja eluruumide loenduse käigus kogutud pendelrände infole (Tammaru 2001a).

Lõpptarbimise ruumilised eripärad. Tarbimine ja liikumine on igapäevaelu tavapärased osad. Meid ümbritsev keskkond ja ruum kujundavad meie tarbimisvajadusi, -võimalusi ja -otsuseid (Goodman *et al.* 2010: 13; Smas 2005: 7). Tarbimise ja liikumise ruumilisi eripärasid kajastav teaduskirjandus on näidanud, kuidas tarbimiskoormus on seotud inimeste asukoha tunnustega: näiteks suuremates ja tihedamates linnades elavad inimesed kulutavad vähem kodusele energiakasutusele ja autotranspordile (Brown *et al.* 2009; Heinonen, Junnila 2011b; Lenzen *et al.* 2006; Shammin *et al.* 2010; Stead, Marshall 2001), samas kui mitmesuguste kaupade ja teenuste tarbimiskulutused võivad linlastel olla kõrgemad kui maa-asumis elavatel inimestel (Heinonen *et al.* 2011; Shammin *et al.* 2010; Wiedenhofer *et al.* 2013). Võrreldes erinevaid linnastuid kaob suuremate ja tihedamate linnade eelis transpordikoormuse kujundajana, kui käsitleda keskuslinna ja tema tagamaad ühise funktsionaalse asustusüksusena (Jones, Kammen 2013). Lisaks on ka näidatud, et suurtes hierarhilise struktuuriga linnades võib elanike transpordikoormus tõusta, sest tegevuskohtade vaheline vahemaa kasvab (Stead, Marshall 2001).

Koduse energiakasutuse puhul on seosed ümbruskonna ruumiparameetritega mõnevõrra ebaselgemad. Üldiselt peetakse tiheasumis elamist koduse energiakasutuse seisukohalt keskkonda vähem koormavaks kui maal elamist, sest korruselamutes on eluruumid väiksemad ja kaugküte pakub efektiivset energiakasutuslahendust (Ewing, Rong 2008; Connolly *et al.* 2014; Holden, Norland 2005; Kaza 2010). Samas on näidatud, et tihedates keskustes toovad suurema energiakulu kaasa (kõrg)hoonete tehnoruumid ja maa-alused parklad ning hoone haldusega seotud kulud (Heinonen, Junnila 2011a; Heinonen *et al.* 2013; Ottelin *et al.* 2015). Uuselamurajoonide kasuks võib rääkida ka parem soojustus kui vanemates linnamajades (Glaeser, Kahn 2010; Ottelin *et al.* 2015) ning kodukulude jagamine enamate leibkonnaliikmetega (Ala-Mantila *et al.* 2016). Kokkuvõtvalt on leitud, et linnade läbimõeldud tihendamine uute hoonetega on säästliku linnastu kujundamiseks siiski parim lahendus, eriti kui võtta arvesse ka liikumisest tulenevat keskkonnakoormust (Glaeser, Kahn 2010; Kuzyk 2012; Wende *et al.* 2010).

Eelpool nimetatud tarbimiskategooriatest on teaduskirjanduses kõige vähem käsitletud (tarbe)kaupade ja teenuste tarbimise mahu ja keskkonnakoormuse seoseid elukoha asukohaga ning enamasti on piirdutud linnade ja maa-asumite omavahelise võrdlusega (nt Herendeen, Tanaka 1976; Liu *et al.* 2011). Kuivõrd kaupade ja teenuste tarbimine on igapäevase transpordikulu või eluaseme energiakuluga võrreldes selgemini seotud elanike sissetuleku suurusega (Girod, De Haan 2010; Weber, Matthews 2008), siis ka tarbimiskoormuse ruumiline jaotus kajastab sageli majanduslikel põhjustel tekkinud ruumilise segregatsiooni joont. Nii näiteks elavad kõige suurema keskkonnakoormusega Suurbritannia leibkonnad maa-asumites ja madaltihedates eeslinnades (Druckman, Jackson 2009), samas kui Soome kõige suurema tarbimiskoormusega elanike rühm on Helsingi südalinnaelanikud (Ala-Mantila *et al.* 2014; Heinonen *et al.* 2011). Seega on asukoha enda kujundava mõju mõistmiseks oluline arvestada elanikkonna sissetulekute ja teiste sotsiaalmajanduslike tunnuste jaotusega. Üksikud uuringud on nimetatud seoseid ruumiliselt analüüsinud, näidates, et suurema asustustihedusega kaasneb suurem teenuste tarbimise maht ja keskkonnakoormus (Ala-Mantila *et al.* 2014) ning et kaupade-teenuste suurenenud tarbimise tõttu linnades võib väheneda transpordi- ja energiakuludelt saadud võit (Shammin *et al.* 2010; Wiedenhofer *et al.* 2013).

Tööalased reisid. Lisaks eraelusfäärile on tarbimine seotud ka tööalaste tegevustega. Asukoha mõju tööprotsesside keskkonnakoormusele võib välja tuua just tööalaste reiside näitel, sest asukoht määrab ettevõttele oluliste sihtkohtade kättesaadavuse. Nii on leitud, et suurtes majanduskeskustes paiknevate ettevõtete töötajad peavad ärivõrgustiku hoidmiseks ja klientidega suhtlemiseks vähem reisima kui väiksemates keskustes või asukohtades paiknevate ettevõtete töötajad (Aguilera, Proulhac 2015).

Nii kogu transpordi kui ka tööalaste reiside maht ja keskkonnakoormus on maailmas tõusuteel. Selle taga on globaliseeruvad ärivõrgustikud, teadmismahukate tööprotsesside ja teenusmajanduse osatähtsuse tõus ning paranenud transpordi infrastruktuur (Castells 2010; Gustafson 2012; Harrington, Daniels 2006; Jones 2013). Ärivõrgustike kasvu on soodustanud info- ja kommunikatsioonitehnoloogia (IKT) areng, mis võimaldab ärisuhtlust ka kaugemate vahemaade tagant (Castells 2010). Kuigi IKT ja virtuaalsete suhtluskanalite abil on võimalik ärireise seega osaliselt asendada ja kaasuvat keskkonnakoormust ära hoida, on leitud, et IKT kasutus toob kokkuvõtvalt kaasa siiski reisikäitumise muutumise ja ärireiside vajaduse kasvu (Aguiléra *et al.* 2012; Choo, Mokhtarian 2005; Denstadli *et al.* 2013).

Kõige olulisemaks ärireiside toimumise ja silmast-silma suhtlemise põhjuseks peetakse usaldussuhete loomist äripartnerite vahel (Castells 2010; Faulconbridge *et al.* 2009). Usaldussuhted on ärisuhtluses eriti olulised otsuste langetamisel ja finantsküsimuste lahendamisel, aga ka innovatsiooni ja teadmiste siirdel (Arnfalk, Kogg 2003; Castells 2010). Just silmast-silma suhtlus võimaldab teadmisi ärivõrgustikus koguda, kohandada, luua ja levitada, nii et tulemuseks on kliendile sobiv unikaalne lahendus (Faulconbridge 2006; Jones 2013; Larsen 2001; Miles *et al.* 1995).

Teaduskirjanduses on leitud, et erinevate teadmismahukate äriülesannete korral on silmast-silma suhtluse vajadus ja reiside asendamise võimalus virtuaalsete suhtluskanalitega erinev (Gustafson 2012; Millar, Salt 2008). Videokonverentsid jms virtuaalne suhtlus sobib regulaarseks suhtlemiseks ja infovahetuseks olemasoleva kontaktvõrgustikuga (Arnfalk, Kogg 2003; Lo *et al.* 2013; Sau 2014). Seevastu teadmismahuka projekti alg- ja lõppfaas vajavad silmast-silma suhtlust (Arnfalk, Kogg 2003). Kuidas aitab suhtluskanali valik kaasa konkreetse äriülesande edukusele ja ettevõtte majanduslikule heaolule, vajab tööreiside vajalikkuse üle otsustamisel paremat hindamist (Jones 2013).

Tarbimise keskkonnakoormuse hindamise meetodid. Lõpptarbimisega kaasnevat keskkonnakoormust käsitleb uurimisvaldkond, mida rahvusvahelises teaduskirjanduses tuntakse *leibkondade ainevahetuse (household metabolism)* nime all (vt Biesiot, Noorman 1999; Di Donato *et al.* 2015; Turner 1998). Vastavad uuringud tuginevad lõpptarbimiskulutuste rahalisele suurusele, tarbitud kaupade ja teenuste kogustele või transpordivahendiga läbitud vahemaadele.

Mitmesugust tarbimist võimaldav ressursi- ja energiavoog on iga tarbitud toote või teenuse puhul erinev nii sisult, ajaliselt kui ka ruumiliselt ning toote elutsükli jooksul tekkinud keskkonnamõju on raskesti piiritletav (Hultman 1994). Seetõttu hinnatakse tarbimise keskkonnakoormust reeglina agregeeritud näitajate abil, mis peegeldavad kas tarbitud ressursi- ja energiavoo kogust, tekkinud jäätmete ja heitmete mahtu või kaasuva keskkonnamõju tekke potentsiaali (vt nt Kerkhof *et al.* 2009b; Lenzen *et al.* 2006; Sánchez-Chóliz *et al.* 2007; Wier *et al.* 2005). Kasutusel on ka erinevad keskkonnakoormuse indeksid, nt ökoloogilise jalajälje indikaator (Eaton *et al.* 2007; Wiedmann *et al.* 2008) või jätkusuutliku arengu indeks (O'Regan *et al.* 2009). Seejuures on indikaatoritena kõige enam kasutatud energiakasutuse või sellest tulenenud kasvuhoonegaaside kogust (Hertwich 2011).

Käesolevas doktoritöös kasutatakse tarbimisega seotud keskkonnakoormuse hindamiseks ökoloogilise jalajälje meetodit ja süsiniku heitmete arvestust. Ökoloogilise jalajälje meetod hindab bioloogiliselt tootliku maa- ja merepinna suurust, mida läheb vaja inimtegevust toetavaks ressursikasutuseks ja jäätmete sidumiseks, ning kõrvutab seda tegelikult olemasoleva bioloogiliselt tootliku maa-alaga (Wackernagel, Rees 1996). Meetod käsitleb just neid ökosüsteemi teenuseid, mis on seotud elusaine kasvatamisega, nt toidu ja tooraine tootmise või süsihappegaasi eemaldamisega õhust, aga ka ehitusaluse maa-ala võimaldamisega (Poom 2010). Jalajälje arvestuse metoodilise toe on loonud Californias paiknev *Global Footprint Network* (GFN 2009).

Süsinikuheitmete arvestuses hinnatakse inimtegevuse tulemusena emiteeritud süsinikdioksiidi ja ka teiste kasvuhoonegaaside kogust, mida väljendatakse erinevate gaaside globaalse soojenemise potentsiaali alusel süsinikdioksiidi ekvivalentides (IPCC 2006). Tähelepanu tuleb pöörata kaasatavate kasvuhoonegaaside nimistule ja kasutatavale metoodikale, mis võib oluliselt varieeruda (Fang *et al.* 2013; Schaltegger, Csutora 2012; Wright *et al.* 2011). Erinevatel uurimistasanditel teostatava süsinikuheitmete arvestuse jaoks pakuvad abi mitmed metoodilised juhised (nt IPCC 2006; ISO 2006; WRI *et al.* 2014).

Leibkondade lõpptarbimine moodustab globaalselt 72% kogu kasvuhoonegaaside tekkest (Hertwich, Peters 2009). See sisaldab ka tarbitud toodete ja teenuste tootmisprotsessi emissioone. Lõpptarbimisega aitab vahetarbimise keskkonnakoormust siduda kas keskkonnaparameetritega täiendatud rahvamajanduse sisend-väljundmetoodika, toote olelusringi analüüs või nende kahe lähenemise kombineeritud meetod (Di Donato *et al.* 2015; Hertwich 2011; Kok *et al.* 2006; Tukker, Jansen 2006). Viimast kasutatakse ka käesolevas doktoritöös.

Metoodika. Doktoritöö tugineb kolmele teadusartiklile, mille valimi moodustavad Eesti gümnaasiumiõpilased (407 õpilast, 1. artikkel), Eesti leibkonnad (3537 leibkonda, 2. artikkel) ning peamiselt Tartus paiknevad teadmismahuka teenussektori väikeettevõtted (kolm organisatsiooni ja nende 30 töötajat, 3. artikkel). Gümnaasiumiõpilaste ja leibkondade lõpptarbimise keskkonnakoormuse uurimisel hõlmatakse analüüsi kogu teadaolev ja arvuliselt määratletav tarbimisspekter (sh liikumismahud); organisatsioonide puhul käsitletakse vaid tööalaste reiside mahtu ja teket. Tarbimis- ja liikumiskäitumise keskkonnakoormuse väljendamiseks kasutatakse ökoloogilise jalajälje ja süsinikuheitmete koguse indikaatoreid. Tarbimiskategooriate keskkonnakoormuse koefitsiendid on leitud keskkonnaalaselt laiendatud sisend-väljundmetoodika rakendamise, olelusringianalüüsi andmete ja ostujärgsete emissioonide andmete kombineerimise teel (täpsem info rakendatud meetodite ja kasutatud allikate kohta on toodud peatükis 2.1).

Gümnaasiumiõpilaste ökoloogilise jalajälje uuringusse kaasati 30 juhuvalimiga leitud kooli üle Eesti. Ökoloogilise jalajälje hindamiseks koostati Eesti taustaandmetele tuginev algoritm ja veebipõhine kalkulaator, mille abil koguti infot õpilaste tarbimis- ja liikumismahtude kohta nii rahalises vääringus kui tarbitud koguste ja läbitud vahemaade registreerimise abil. Ökoloogilise jalajälje koefitsiendid leiti maakasutuse ja heiteandmetega laiendatud sisend-väljundmetoodika abil, lähtudes kombineeritud jalajäljearvutuse metoodikast (Bicknell *et al.* 1998; Chambers *et al.* 2004; Ferng 2001; GFN 2006; Simmons *et al.* 2000). Uurimisperioodina käsitleti ühte aastat kuni küsimustiku täitmiseni 2009. aasta kevadtalvel. Tulemusi analüüsiti dispersioon- ja mitmese regressioonanalüüsi abil. Eestikeelse kirjelduse uuringu metoodika kohta leiab autori magistritööst (Poom 2010).

Leibkondade keskkonnakoormuse hindamiseks kasutati Eesti Statistikaameti läbiviidud leibkonna eelarve uuringu 2012. aasta andmestikku. Statistikaamet oli valimi koostamisel lähtunud muuhulgas geograafiliselt esindusliku valimi saavutamise eesmärgist. Keskkonnakoormust hinnati uuringus individuaaltarbimise klassifikaatori (UN 2015a) abil jaotatud lõpptarbimiskulutuste info alusel, millele omistati toodete ja teenuste olelusringis tekkiva süsinikdioksiidi heitmete hulga koefitsient (koefitsiendid on toodud 2. artikli täiendavas materjalis). Süsinikdioksiidi koefitsiendi leidmiseks kasutati taas heitenäitajatega laiendatud sisend-väljundmetoodikat. Tulemuste analüüsil kasutati dispersioon- ja mitmest regressioonanalüüsi.

Teadmismahukas teenussektoris toimuvate tööreiside vajaduse ja süsinikuheitmete hindamiseks kasutati kombineeritud uurimismeetodit. Kolmes väikeses organisatsioonis viidi 2013. aastal läbi fookusgrupi intervjuu, aktiivse mobiilpositsioneerimise meetodil registreeriti ühe kuu vältel sealsete tööülesannetes reisivate töötajate asukohad ning sellele järgnes individuaalne intervjuu töötajatega, mille käigus käsitleti positsioneerimisandmete põhjal leitud tööalaste reiside põhjuseid ja liikumisvahendeid ning töötaja harjumusi ja eelistusi tööreiside ja virtuaalsete suhtlusvahendite kasutamise korral teadmismahuka tööprotsessi jooksul. Aktiivset mobiilpositsioneerimist aitasid korraldada Telia sideettevõte (endine EMT) ja Positium LBS. Liikumisandmete teisendamiseks süsinikdioksiidi ekvivalentidesse kasutati organisatsioonide emissiooniarvutusteks koostatud andmebaasi (Hill *et al.* 2012). Tööreisidega seotud eelistuste ja prioriteetide analüüsimisel rakendati analüütilise hierarhia protsessi (Saaty 1987, 2003). Tulemuste interpreteerimisel kasutati lisaks ka kirjeldavat statistikat ja kontentanalüüsi.

Tulemused ja järeldused. Eesti elanike keskkonnakoormus hinnatuna ökoloogilise jalajälje indikaatori (3 gha/in a) või süsinikdioksiidi emissiooni (3,9 t CO_2/in a) kaudu on väiksem kui rikkamate Euroopa Liidu liikmesriikide elanike lõpptarbimisest tulenev keskkonnakoormus (Büchs, Schnepf 2013; Girod, De Haan 2010; Kerkhof *et al.* 2009a; Ottelin *et al.* 2015; Wier *et al.* 2001), kuid vahe on väiksem, kui võiks eeldada sissetulekute erinevuse põhjal. Väiksema vahe põhjustab eestlaste suur otsene energiakasutus kodudes, mis tuleneb küll kliimast ja kütmisvajadusest, kuid ka hoonete kehvast soojustusest ja Eestis toodetud elektri suurest süsinikuheitmete hulgast. Eluasemega seotud keskkonnakoormus põhjustab umbes poole kogu keskkonnakoormusest.

Keskkonnakoormuse ruumilist jaotust analüüsides ilmneb, et kõrgemates asustussüsteemi hierarhia klassides ehk Tallinnas, Tartus, Pärnus ja nende linnade tagamaal elavatel inimestel on mõnevõrra suurema keskkonnakoormusega tarbimismuster kui madalamatesse asustussüsteemi hierarhia tasanditesse kuuluvate asustusüksuste elanikel. Erinevus tuleneb peamiselt suurematest kaupade ja teenuste tarbimisest nimetatud kõrgema tasandi asustusüksustes. Ruumilised erinevused, iseäranis vaba aja kaupade ja teenuste (sh majutus, väljas söömine, kultuuri tarbimine jm) tarbimise puhul, jäävad alles ka juhul, kui sissetulekute ja teiste sotsiaal-demograafiliste tunnuste mõju kontrollida. Vaba aja kaupade puhul on Tallinna tagamaa elanikud kõige suurema keskkonnakoormust põhjustava tarbimismustriga rahvastiku rühm Eestis.

Väga erandliku tulemusega paistavad silma Ida-Viru regionaalsete tööstuslinnade elanikud, kelle konservatiivne tarbimis- ja liikumiskäitumine põhjustab konkurentsitult kõige madalama keskkonnakoormuse Eesti elanike hulgas. See on olulisel määral seotud madalamate sissetulekute ja teistsuguse etnilise koosseisuga, nagu näitab analüüs, kuid ükski arvestatud tunnustest ei selgita täielikult erinevate kaupade ja teenuste tarbimisest tulenevat väiksemat keskkonnakoormust. Võib arvata, et Ida-Viru tööstuslinnade majanduslik eripära, Eesti kontekstis eripärane tekke-, paiknemis- ja arengulugu, keskkonnaproblemaatika, nõukogude ajastust pärinev tarbimismentaliteet ning vähesed sotsiaalsed sidemed ümbritseva asustusega on pärssinud nende keskuste arenemist tänapäevasteks aktiivse eluviisiga linnadeks, kuigi nende suurus ja regionaalne tähtsus võiksid seda võimaldada.

Transpordikasutuses on näha selge jaotus, mille järgi linnaelanikud põhjustavad igapäevaliikumistega madalama keskkonnakoormuse kui tagamaa- või maavaldade elanikud. Sarnane muster joonistub välja iga funktsionaalse tasandi keskuslinna ja tema tagamaa puhul, viidates tiheasumist väljaspool elavate elanike suurele autosõltuvusele. Tallinna, selle tagamaa ja Tartu-Pärnu elanikud kasutavad aga enam ühistransporti kui muudes asustusüksustes elavad inimesed. Kuigi kirjandusülevaatest tulenevalt oleks võinud eeldada väiksemat liikumisega seotud keskkonnakoormust suuremate ja tihedamate linnade elanike puhul võrreldes väiksemate linnade elanikega, siis tulemused seda ei kinnita ja viitavad pigem vastupidisele tendentsile. See on selgitatav Tallinna hierarhilise ülesehituse ja suurusega, kus linnasisesed tegevuskohad võivad paikneda üksteisest kaugel ja linnasisene liikumine nõuab enam mootortranspordi kasutust kui väiksemates linnades. Suuremates keskustes ja pealinna tagamaal tuleneb suurem keskkonnakoormus lisaks ka auto soetamise ja hooldusega seotud kuludest ning lennureisidest.

Suurema linna eelis reisivajaduse kujundajana tuleb esile vaid tööalaste reiside puhul: Tartus kui väiksemas linnas paiknevad ettevõtted peavad tegema täiendavaid pingutusi, et jõuda oma ärivõrgustikuni. Üks intervjueeritavatest sõnastas selle erinevuse järgnevalt: „Klientidega kohtumiseks peavad meie projektijuhid sõitma sageli Tallinnasse, kuna Tallinn on paratamatult koht, kuhu inimesed koonduvad.“

Teadmismahuka teenussektori ettevõtete reisivajadus ja reisi asendamise võimalus virtuaalsete suhtluskanalitega sõltub otseselt käesolevast äriülesandest. Kui turunduse ja müügi tulemuslikkust silmas pidades on reisimine ja silmast-silma kohtumine hädavajalikud, siis teadmismahuka teenuse pakkumise põhiprotsessi käigus on ärireiside asendamise võimalus teatud määral olemas. Just selles faasis reisitakse siiski kõige enam, sest nende arutelude käigus toimub kliendile või äripartnerile sobiliku lahenduse leidmine. Asendamist võimaldavad aga selleks ajaks juba tekkinud head inimsuhted ning tehniliselt on vajalik kindlasti kõrge kvaliteediga virtuaalset suhtlust võimaldava aparatuuri ja ruumi olemasolu. Tööreisi asendamisele aitab olulisel määral kaasa ka virtuaalse suhtlemisega kaasnev ajavõit.

Kokkuvõtvalt võib tõdeda, et asukoht asustussüsteemi hierarhias mõjutab indiviidide, leibkondade ja organisatsioonide tarbimis- ja liikumismustrit ning sellega kaasuvat keskkonnamõju. See on seotud asustussüsteemi hierarhia aluspõhimõttega, et kõrgemal hierarhiatasemel paiknevad linnad koondavad endasse laiema spektri erinevaid tegevusi ja võimalusi, pakutavaid kaupu ja teenuseid, mis muudab need elanikele kättesaadavamaks kui madalama hierarhiatasandi asustusüksustes. Parem kättesaadavus omakorda suurendab nende tarbimise võimalikkust ja nagu näeme iseäranis vaba aja teenuste ja kaupade, aga ka tarbekaupade puhul, päädib see nende võimaluste aktiivsema kasutamisega. Eesti kontekstis näeme, et tulemuseks on pealinna ja suurte regioonikeskuste (Tartu, Pärnu) piirkonna elanike kõrgem keskkonnakoormus, mida ei tasanda võrreldes madalama tasandi asustusüksustega ka linnaelanike väiksem transpordivajadus.

Töö tulemused viitavad teadliku ja läbimõeldud ruumipoliitika, regionaalarengu kujundamise ja planeerimislahenduste väljatöötamise vajadusele, et saavutada sotsiaalselt ja keskkonnaalaselt tasakaalustatud ühiskonnakorraldus.

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1999–2000	Tallinn Technical University, Technology of Chemistry and Environmental Protection
1996–1997	Nils Ericson Gymnasium, Trollhättan, Sweden, exchange student
1995–1999	Tallinn Mustamäe Secondary School, golden medal
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Work experience:

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2007–2015	Short-term jobs: Interact Projektid ja Koolitus, Ecoprint, Ökomeedia, Ministry of the Environment, Tartu County Government, Tartu Environmental Education Centre
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Research interests:

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Publications:

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Poom, A., Ahas, R. 2016. How Does the Environmental Load of Household Consumption Depend on Residential Location? *Sustainability*, 8 (9): 1−18.

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Poom, A. 2006. Tallinna tagamaa uusasumi elaniku ökoloogiline jalajälg [The ecological footprint of the residents of new suburbs around Tallinn]. Roose, A. (Toim.). *Keskkonnasäästlik planeerimine ja ehitus 2. Publicationes Instituti Geographici Universitatis Tartuensis 100*. Tartu: Tartu Ülikool, lk 46−47.

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Supervised master's theses:

Liina Kuisma, 2016, (sup) Age Poom, Kati Orru. Liiklussaaste leevendamise meetmete toetamine Eesti elanike hulgas [The support for air pollution mitigation measures among Estonian residents], University of Tartu.

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Cris-Tiina Türkson, 2014, (sup) Age Poom, Janika Laht. Tallinna ühistranspordiliikide olelusringi võrdlusanalüüs [Comparative life cycle analysis of public transport modes in Tallinn], University of Tartu.

Jane Adler, 2014, (sup) Age Poom. KMH osapoolte huvide kaitse alternatiivide võrdlemisel tegevusloa keskkonnamõju hindamises AHP näitel [Multi-criteria methods in the comparison of alternatives in EIA by the perspective of stakeholders' interests: case of AHP], University of Tartu.

Johanna-Maria Siilak, 2014, (sup) Age Poom. Kumulatiivsete mõjude käsitlemine tegevusloa tasandi keskkonnamõju hindamises [Cumulative effects in Estonian EIA practice], University of Tartu.

Kadi Sau, 2014, (sup) Age Poom. Välislähetuste keskkonnakoormuse vähendamise võimalused Tartu Linnavalitsuse näitel [Environmental performance of international business travel: the case of Tartu City Government], University of Tartu.

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2008–2014	Tartu Ülikool, õppetöö läbiviija
2008–2009	Tartu Ülikool, spetsialist
2007–2015	Lepingulised tööd: Interact Projektid ja Koolitus, Ecoprint, Ökomeedia, Keskkonnaministeerium, Tartu Maavalitsus, Tartu Keskkonnahariduse Keskus
2002–2006	E.O.Map, Eesti põhikaardi välitööde teostamine

Uurimisvaldkonnad:
Leibkondade keskkonnakasutus, tarbimiskäitumine, keskkonnamõju hindamine, keskkonnakorraldus, tööreisid, GPS tegevusruumi uuringud, linnageograafia.

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Poom, A., Orru, K., Ahas, R. 2017. The carbon footprint of business travel in the knowledge-intensive service sector. *Transportation Research Part D: Transport and Environment*, 50: 292−304.

Poom, A., Ahas, R. 2016. How Does the Environmental Load of Household Consumption Depend on Residential Location? *Sustainability*, 8 (9): 1−18.

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Ühiskondlik tegevus:

2015–…	Keskkonnamõju hindamise litsentsikomisjoni liige
2015–…	Karlova Seltsi liige
2012–…	Eesti Keskkonnamõju Hindajate Ühingu liige
2011–…	Eesti Keskkonnajuhtimise Assotsiatsiooni liige

Juhendatud magistritööd:

Liina Kuisma, 2016, (juh) Age Poom, Kati Orru. Liiklussaaste leevendamise meetmete toetamine Eesti elanike hulgas, Tartu Ülikool.

Hedi Mikiver, 2015, (juh) Age Poom, Riina Raasuke. Keskkonnamõju hindamise leevendavate meetmete rakendamine veevaldkonna näitel, Tartu Ülikool.

Cris-Tiina Türkson, 2014, (juh) Age Poom, Janika Laht. Tallinna ühistranspordiliikide olelusringi võrdlusanalüüs, Tartu Ülikool.

Jane Adler, 2014, (juh) Age Poom. KMH osapoolte huvide kaitse alternatiivide võrdlemisel tegevusloa keskkonnamõju hindamises AHP näitel, Tartu Ülikool.

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Kadi Sau, 2014, (juh) Age Poom. Välislähetuste keskkonnakoormuse vähendamise võimalused Tartu Linnavalitsuse näitel, Tartu Ülikool.

Liisi Liivlaid, 2014, (juh) Age Poom. Tallinna kesklinna ja lähitagamaa leibkondade keskkonnakoormuse võrdlus, Tartu Ülikool.

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