# DIPLOMARBEIT

Titel der Diplomarbeit

**The Times They Are A-Changin'**

*The impact of technological innovation on the time-allocation of UK households in connection with energy intensities of household activities*


Verfasser

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# 1. INTRODUCTION

## 1.1 BACKGROUND

In industrial nations, continuously rising energy use due to economic growth and increasingly high provision of goods and services has been identified as the main driver behind greater impacts on the environment. According to different projections and scenarios energy consumption is expected to grow between 36% (IEA 2010: 4) and 49 % (EIA 2010: 1) until 2035, accounting for both OECD and non-OECD countries. While increasing consumption and economic activities is generally regarded as key to rising living standards and welfare in industrial as well as developing countries, this poses two types of environmental problems.

(1) As today's economic activity is closely connected to the use of fossil energy sources, world's energy consumption is causing a rise in anthropogenic greenhouse gas emissions. This – what has been coined *output* problem – is one of the main drivers behind the threat of climate change. (IPCC 2008)

(2) Additionally, rising levels of industrial activity accelerates the depletion of current energy resources. This *input* problem of resource scarcity is projected to hit us soon, if our societal consumption patterns are not altered. (Meadows et al. 2004)

To reach the goal of a 'sustainable society' where development "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1991) the United Nations agreed that it would be necessary to change unsustainable patterns of consumption and production. Therefore, frameworks for different regional and national programs on sustainable consumption were developed and implemented in order to satisfy the notion of sustainable development in the three main dimensions - ecological, economic and social. (UN 2002)

Following the first earth summit in 1992 held in Rio de Janeiro, the United Nations agreed upon and implemented the *Agenda 21* document, which stresses two objectives for sustainable consumption: (1) "To develop a better understanding of the role of consumption and how to bring about more sustainable consumption patterns" and (2) "to promote patterns of consumption and production that reduce environmental stress and will meet the basic needs of humanity." (UN 1992: § 4.7)

Reinforcing these goal statements at the second Earth summit in Johannesburg in 2002, they were since then taken up by several countries, developing initiatives and concepts for further work. The UK government stated in its publications of an UK Framework for Sustainable Consumption and Production entitled *Changing Patterns* and its follow-up *Securing the Future* (DEFRA 2003, 2005) to have sustainable production and consumption as one of their main priorities in order to "break the link between economic growth and environmental degradation." (DEFRA 2005: 17)

## 1.2 Promoting Technological Solutions

Increasing energy efficiency through technological innovation has often been regarded as the perfect tool for a sustainable development, promising the double dividend of reducing environmental impacts without harming prosperity and economic growth. This technological optimism has been especially strong in ecological modernization theory. The basic premise of this approach can be seen, for example, in the debate around the concept of *factor 4* which states and emphasizes the possibility to curb emissions by half while doubling economic prosperity. In line with neoclassical reasoning of environmental economics, this school argues that the development of a new organization of consumption activities has to revolve around the introduction of new and innovative technology and design, promoting a new green capitalism. In such a system a new ecological rationality triggered by new technologies emerges that leads to the internalization of environmental considerations; the key mechanism in such considerations being an increase in efficiency. (Hawken et al. 2000; Schmidt-Bleek 1997, 1998)

> *"Consequently, innovations are said to increase resource productivity and eco-efficiency both on a societal level and on the level of specific products and services, and to lead to a de-linking between economic growth and the use of natural resources."* (Jalas 2006: 7)

The general adoption of new information and communication technology (ICT) has been regarded as the latest and most promising wave of technological innovations, opening up the possibility for a transition from an industrial economy towards a dematerialized, information society.[1]

The focus on technological innovation has been adopted by most policies and research agendas, highlighting the possible progress attainable through eco-friendly novelties in

[1] However, there is an argument saying that the increased energy input for ICTs due to their widespread use is actually reducing this hope. For a discussion of the ambiguity of the use of ICTs cf. Hilty (2008).

the production processes. Thus, in order to decrease the environmental impact of societal consumption the various strategies and measures promoted concentrate on new and eco-efficient product design, and cleaner production. (e.g. DEFRA 2005: 44, UN 2002)

Recently new research areas concentrate specifically on the impact emerging from the *consumption*-side of the production-consumption nexus and necessary structural changes in consumption patterns. An analysis of the household as the smallest economic unit is of special interest in this regard because of three aspects:

(1) While the environmental impact of a single household is negligible, the mere sum of millions of households in Europe adds up to the household sector being a major contributor to ecologically damaging impacts. (OECD 2002) According to statistics provided by the European Environmental Agency (EEA 2009) the household sector is one of the largest final energy users in the EU in 2006 accounting for approximately 26 % of total final energy consumption (Fig. 1).

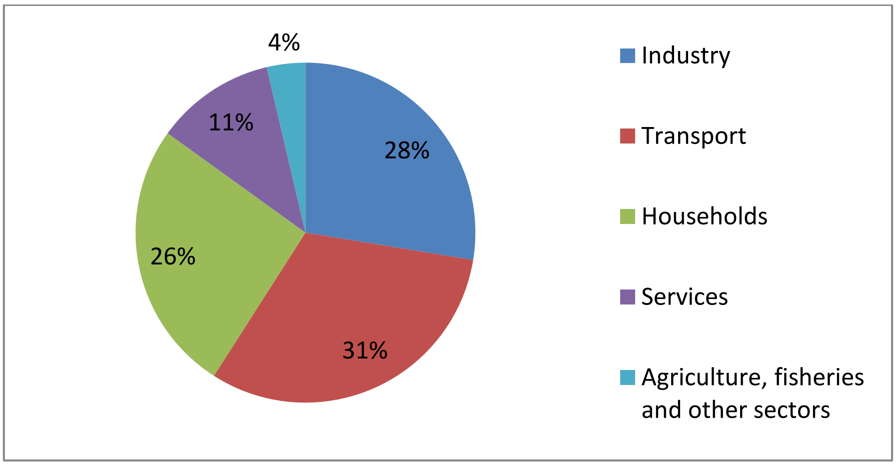


Figure 1: Final Energy Consumption by sector in 2006 (EEA 2009).

(2) Production will in the end always be about production of goods and services for final consumption in the household sector. As consumers are linked to the production process through their monetary expenditure on market goods, an analysis of all the direct and indirect energy coming into the household will allow investigating the total energy chains involved in production-consumption activities until the final use. (Noorman et al. 1998; Biesot and Noorman 1999)

(3) Non-market activities - people's daily life and consumption activities - revolve around and are shaped in the household. In order to understand the processes

of structural change in the economy as a whole, evidence about everyday life has to be considered. (Gershuny 1987) Because the consumer can to a certain degree guide and shape production processes through his/her consumption decisions, he/she is often regarded as the principle lever of change. (Sanne 2002) As different life-style choices and decisions about what types of goods and services are acquired are closely linked to environmental concerns, understanding consumer behavior and the response to technological change is relevant. In this vein Tim Jackson (2005) states that:

> *"behavioural change is fast becoming the 'holy grail' of sustainable development policy,"* as it is generally agreed that *"people's choices, behaviours and lifestyles will play a vital role in achieving sustainable development."* (Jackson 2005: 4/105)

Consequently the "black box of the household" (Wilk 1989) has to be opened in order to get a better understanding of the various factors shaping household activities and the structural changes happening on the household level.

## 1.3 Scope and focus of this study

These aspects suggest that a focus on household's consumption is promising for an analysis of rising energy consumption and has been the starting point for this study. Technological optimism is at the heart of most policies for sustainable development. When looking at environmental consequences however, the impact of technological advances and the integration of technologies into the household is ambiguous at best (see chapter 4). Behavioral responses and life-style choices often diminish or offset hoped for energy savings making an analysis of household behavior necessary.

Generally, most researchers focus on the monetary aspect of different life-styles, focusing on the types of products bought and the money spent by consumers. This research tries to adopt a different approach, modeling life-style choices as the respective differences and changes in time spent on various activities.

Central for an understanding of technological change and consequent energy savings in the general economy as well as in households, has been the debate around rebound effects. Linking a temporal approach to life-styles and consumption with the concept of the rebound effect has been suggested by several authors, especially Mikko Jalas (2000, 2002, 2005, 2009), Mathias Binswanger (2001, 2002) and Patrick Hofstetter and Michael Madras (2003). These studies helped to illuminate the role of technology in changing consumption patterns of households and will be central to the methodological approach of this study.

This study is built around three major parts. First, in a theoretical part - after a brief summary of concepts related to ecological economics – different concepts of consumer behavior and decision making processes have been regarded. This will lay the groundwork for a temporal, activity-based approach adopted in this research.

Second, concepts, empirical findings and methods of rebound effects are discussed. Integrating a temporal approach based on activities with the concepts rebound effects, this study tries to adopt the notion of a very specific type of rebound - a rebound effect in respect to time. (Chapter 6)

An empirical research of UK households will be the last section considering two main questions. First, how is the introduction of a new household technology influencing the time allocation to various activities in the short term? As the data availability is rather precarious, the United Kingdom was taken as a case study as it has a longer tradition in data collection of time use in households than other countries.[2] Moreover a rather unique longitudinal research data-set (Gershuny 2002, cf. Hofstetter and Madjar 2003) stretching over three consecutive years is adopted and reused for the purpose of this study.

The second question is concerned with the way such changes impact on the environmental dimension of choices. The focus lies however not on the differences in specific lifestyle choices of individuals or groups due to socio-economic factors or different values. But, average time styles will be analyzed as the average time allocated to various activities in the household sector linking them to environmental impacts connected to these activities. Thus the analyzed changes happening due to the introduction of the new household technology – in this case study the personal computer – will be discussed considering their respective environmental burden.

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[2] Most time use studies are not available for free or are not adopted in the regularity necessary for calculating time rebound effects. See www.timeuse.org for a collection of data on time use.

# 2. Ecological economics

This diploma thesis is rooted in the scientific field of Ecological Economics, which tries to bridge the gap between economics as a social and ecology as a natural science.

> *"Environmental and resource economics, as it is currently practiced, covers only the application of neo-classical economics to environmental and resource problems. Ecology, as it is currently practiced, sometimes deals with human impacts on ecosystems, but the more common tendency is to stick to 'natural' systems. Ecological economics aims to extend these modest areas of overlap. It will include neo-classical environmental economics and ecological impact studies as subsets, but will also encourage new ways of thinking about the linkages between ecological and economic systems* (Costanza 1989: 1)

Combining environmental concerns with aspects of societal consumption has been a dynamic research area over the last decade in and outside ecological economics. As ecological economics promotes an interdisciplinary and problem-oriented approach, in order to research the topic of societal consumption it "taps into the knowledge provided by other fields dealing with consumption." (Røpke 2005)

This next chapter will first summarize the system-approach, an approach towards consumption, and other important concepts related to ecological economics that are relevant for this thesis. Special emphasis will lie on the different aspects influencing consumers' decision making processes and the temporal aspects of consumers' non-market activities, considering the important connection between technological innovation and behavioral adaptation.

## 2.1 System's approach

The most fundamental difference between ecological economics and traditional neoclassical economics is its understanding of the ecosystem and the economic system as two interrelated and interdependent systems. A system-approach common in the field of (human) ecology has been central to ecological economics as "with systems we can look at connections between elements, at new properties that emerge from these connections and feedbacks, and at the relationships between the whole and the part." (Voinov 2008: 25) The conceptual framework places the human/economic system inside the wider ecological system, viewing it as a subsystem of the biological and geological world. Economic processes and cultural or institutional settings are therefore not independent of, but imbedded and integrated into the biosphere.

The biosphere as a closed system is materially closed and energetically open to and dependent on energy input from the sun. Every social system is dependent on certain services provided by the eco-system, namely life support services, amenities, resources and a sink function for waste products. Exchange between those systems is happening as materials and energy are entering the economic system as inputs and exiting the system as outputs. This material and energetic throughput is described as *flows* through and inside the respective system and enable (economic) activities of humans. Such flows can be piled up and integrated into the structure of the economic system (as human capital) or saved for a later use. Those piled up stocks can either be consumed in their utilization process, e.g. used up in a production process, or providing a service without deteriorating through its use, e.g. a statue which is nice to look at. (Common and Stagl 2009) Consequently, the stock-and-flow model makes it possible to represent systems as a collection of reservoirs. (Voinov 2008)

The concept of stocks and flows and material and energy throughput has been further conceptualized in the notion of a societal metabolism. A societal metabolism – the exchange of energy and materials with other systems and the internal processing of those flows - is necessary for the production, preservation and reproduction of the functionality of the societal stocks. Social and institutional arrangements regulate the throughput of energy and matter and influence parts of the environmental reproductive cycles. (Fischer-Kowalski et al. 1997)

The metabolism concept has been applied to the household subsystem as the smallest consumptive unit in the socio-economic system. Consumers organized into households are dependent on stocks and flows coming from the socio-economic system, but also influence or even determine which commodities (how much and in what way) are produced. (Noorman et al. 1998: 25)

Therefore households

> *"influence […] the throughput of energy flows and material cycles throughout the entire economy. By adopting the household metabolism metaphor, a picture is obtained that relates the use of natural resources to the very basis of economic activity: consumption in households." (*Biesot and Noorman 1999: 369 – 370)

## 2.2 Evolutionary Thinking

Furthermore, two concepts emanating from evolutionary theory are central to ecological economics' understanding of a joint ecologic-economic system and its subsystems: co-evolution and path dependency.

Both system and its subsystem are not only dependent on each other but sensitive to alterations in the respective other system. Such *co-evolving* systems react and adapt to changes happening in their environments and linked systems, which will influence the future development paths and dynamics of the system on different hierarchical levels. This adaptive capacity however can be insufficient to maintain basic systems characteristics, when sudden disturbances disrupt the reproductive and metabolic processes. Starting from an understanding of the household sector as a subsystem of the wider economic and social system, it is therefore adapting to and influenced by new technological innovations, developments of social norms and values and prevailing economic organizations and incentives. Equally, changes in consumption patterns are likely to be influential on developments of the economic system as a whole. The integration of new technological appliances will therefore influence the inner workings of households.

Past decisions and historic development paths determine (to a certain degree) possible future development options at a certain point in time. For example, the utilization of fossil fuels for combustion engines went hand in hand with the building of a specific infrastructure, construction of cars using those engines, etc., supporting the continuous use of this type of engine. The concept of *path dependency* describes how such a situation can limit the set of decisions open for future sustainable development paths, which includes *lock-in* situations where the prevailing practices are unlikely to change. The adoption of technologies can therefore equally result in breaking up path dependencies through opening up possible new development paths, while still causing the danger of creating new path dependencies and lock-in situations. (Nelson and Winter 1982)

## 2.3 Consumption in Ecological Economics

Due to the transdisciplinary approach of ecological economics, contributions covering consumption come from a variety of different scientific fields and can rarely be attributed to ecological economics alone. However, the journal *Ecological Economics* (e.g. 1999) and especially contributions by Inge Røpke (2005) as well as the co-edited book *The Ecological Economics of Consumption* (Røpke and Reisch 2004) provide good overviews from the historical development of the interest in consumption to recent discussions on the subject matter.

Neoclassical economics separates economic activity into supply and demand. Consumption is then solely included in and limited to the factor of final demand, where consumers seek to acquire the demanded goods and services over market transactions. In the end, every production process serves, albeit over various production and provision chains, the final consumption of goods and services in the final demand sector. (Princen 2002: 4) In contrast, ecological economics dissolves this distinction. Both production and consumption are understood as having productive and consumptive elements in them. Concentrating on the material aspect of consumption, it is not defined as the act of buying following economic demand, but is about the act of appropriating and transforming (natural) resources. (Røpke 2005) Herman Daly argues that production is better understood as the part of the material use of resources that serves to build stocks, while consumption is that part subtracting from existing stocks. The production sector of an economy uses natural resources to build (produce) human-made stock like commodities and infrastructure, while at the same time diminishing/consuming part of the natural stock. Equally the consumption sector uses flows from the production sector to build/produce household specific stocks, thereby diminishing stocks of previously produced items. (Daly and Farley 2004) The traditional conceptual allocation of consumption processes to households and production processes to firms is opposite to such a definition of consumption. Domestic activities are equally productive and consumptive as they transform, appropriate and dispose material goods, building infrastructure and getting a service out of the process. Still, it is sensible to distinguish between different sectors or subsystems in a socio-economic system, the household sector being one of them. The act of buying can then be thought of as a specific link between the household subsystem and the 'production' subsystem. (Røpke 2005)

Following the discussed concepts a representation of a joint ecological-economic system can be depicted as a metabolic system with different exchange modes, separate subsystems, and stocks and flows between different them (Fig. 2).

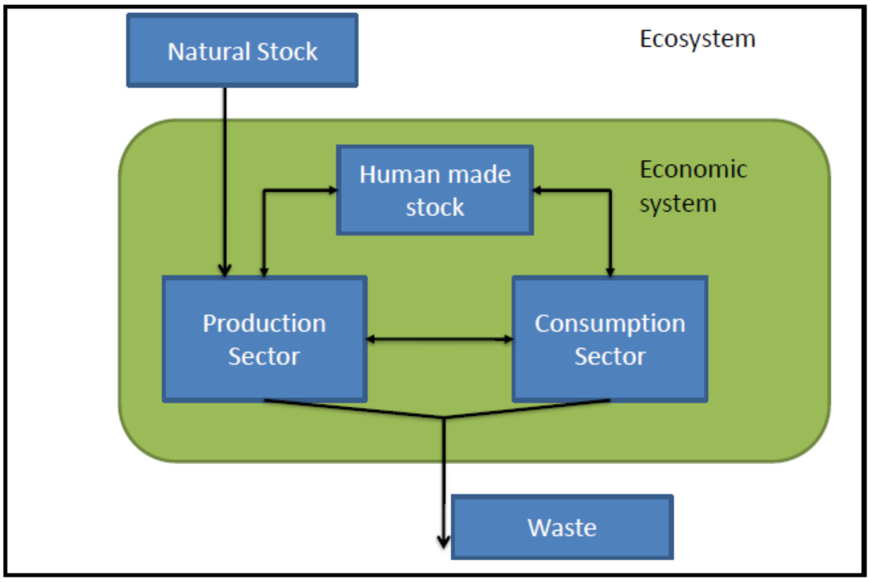


Figure 2: Scheme of a joint ecological-economic system and the stocks and flows between different sectors. (Own design)

The previous discussion of consumption is often connected to a discussion, which highlights the problem of scale and growth resulting from the material dimension of consumption. However, different consumption activities can be more or less environmental damaging. The decisive differences connected to specific consumption behavior should thus not be neglected. A closer look at how consumption is structured and formed is needed, as changing patterns towards sustainability could also mean increasing the consumption of certain goods and services. (Wilk 2004)

## 2.4 Sustainable Development

The previous considerations have implications for thinking about sustainable development. While neoclassical economics is mostly concerned with an efficient allocation of resources to economic activities and the role of final demand, an approach following ecological economics makes it necessary to think about the quantity of throughput and the scale of the economic, e.g. the rate of stock building and depletion. Equally the quality of the transformation and appropriation processes of resources comes into focus depending on internal structures, technological settings, and prevailing institutional arrangements. As the maintenance of both the ecological and the socio-economic system is necessary for future human societies to exist, it is required that both, the natural stock (or capital) and the human-made capital is utilized in a sustainable matter. Starting from this perception ecological economics leans towards a concept of a strong sustainability, which states that there is nearly no substitutability of natural and man-made capital. As the natural stock providing ecological services is irreplaceable by human stock, a sustainable society will have to seek to preserve both those stocks. While such a strong approach is rarely proposed in its strictest form, it still demands attention to the barriers of substitutability between ecological and social processes and certain absolute limits to growth. (Daly and Farley 2004, Common and Stagl 2009) Highlighting the problem of scale, an ecological economics approach to sustainable development is furthermore concerned with the social arrangements and qualitative aspects of sustainable consumption patterns. Drawing a more complex picture than the one which would be obtained by reducing the question of sustainable consumption to a quantitative measurement of throughput, Richard Wilk argues that:

> *"the issue of sustainability is not about simply consuming less (metaphorically putting ourselves on a diet), but of rates of flow, transport costs, length of curation, types of cycling, recycling, and reuse, alternative sources and trade-offs, all problems that are complex and cannot be reduced to the idea that 'consuming less Is better for the planet'"* (Wilk 2004: 19)

# 3. Approaching 'the consumer'

It has been shown that a path towards sustainability has to consider the question of scale as well as the way consumption activities are structured. Taking the household sector as the unit of analysis an understanding of its inhabitant, *the* consumer is necessary. Consumers make choices by selecting and deciding between various ways to consume and different alternative actions, impacting the environment differently as a result. Such decision-making processes are complex, shaped and influenced by a variety of factors. Depending on the school of thought and scientific field, different approaches are used to better understand and model consumption behavior. Following an interdisciplinary approach favored by ecological economics, the next paragraphs summarize a very broad discussion on the various drivers and influencing factors, specifically concentrating on the aspects of household consumption and the aspect of time as this is important for this study. This summary will however not do justice to discussing the complexity of the debate in the respective scientific schools and will eclectically pick and throw a spotlight on what seems important for this research.

## 3.1 Rational Actor

*Homo oeconomicus* or the *rational actor model* is functioning as the basic model for most (neoclassical) approaches to come to grips with human behavior. It underlies the calculation of demand curves in standard economic theory. The basic assumption is that an actor is rationally calculating the possible outcomes of his/her actions and decisions. Two prerequisites for such calculations are assumed to hold true. First, consumers are equipped with perfect knowledge about the different possibilities open to them and the respective consequences following their decisions. Consumers know what types of goods can be acquired and are aware of the costs and benefits connected to those actions. The act of buying certain goods is thus a deliberate decision, selecting between different courses of action.

The second assumption of neoclassical theory states that consumer preferences are exogenously given. The motive behind this decision making is not subject of rational actor models as actors are thought of as entering the market with already shaped and determined preferences. What shapes and influences evaluation processes is therefore reduced to the costs attributed to a specific decision. A consumer will choose the alternative that he subjectively expects to yield more benefits and to come with the least costs.

Following from such assumptions is a consumer that will make decisions that allow him/her to attain an optimal outcome. Meaning that by choosing from various commodities, products and services obtainable, he/she will get the maximum value or utility out of them. Bought commodities are the necessary source in the fulfillment of desires and preferences; the act of consuming specific products being directly connected to the consumers' well-being. Because there are always new desires and needs to be fulfilled, they are said to be infinite and insatiable, setting no limit to the drive towards more consumption.[3] The range of possible alternatives is constrained by available resources and costs. As in standard neoclassical theory the price signal is the most important guide for decision making processes (at least in market behavior), it's the monetary budget which is defined as the decisive limit. (Samuelson and Nordhaus 2005)

To account for non-market activities household economics extended the traditional rational actor model to apply to household behavior. (Becker 1965; Linder 1970; Gronau 1977) What happens in the household is seen parallel to normal production processes. Goods and services entering the household system are resources processed for further utilization. They are used *in addition to time inputs* as inputs for productive activities. Contrary to the standard model, goods and services are thus not seen as the source of the utility per se, but as means for further processing. The important point is that optimizing behavior is based on getting the optimal outcome from a combination of time inputs and commodities inputs.

Several studies have been conducted in this tradition. For example, Becker (1965) argues that consumers allocate their time between labor and leisure differently according to the expected value/costs (measured as the opportunity cost of forgone earnings) of time. Different time allocations in households are thus result of conscious decisions reflecting consumer preferences to substitute leisure for labor or vice versa.

In conclusion the rational actor approach to decision making processes stresses the inherent rationality and functionality of consumer choices to satisfy their needs and concentrates on the aspect of costs and benefits. Although this approach has been used for mathematical model building and as the basis for the majority of rebound effect analyses (see chapter 5), challenges to both assumptions stem from economic, biological, and sociological scientific fields.

[3] One critique of this assumption of insatiability argues that it is important to distinguish between needs and wants. (Jackson et al. 2004) The former are basic for human well-being, while the latter are seen as luxury goods and not necessary. Jackson (2005) elaborates that there are finite needs, which have to be fulfilled, but infinite satisfiers, which can fulfill those needs.

## 3.2 Conspicuous Consumption

In sociological and cultural theories some consumption theories emphasize the communicative and cultural aspects of consumption activities (Gram-Hanssen 2008), thereby (implicitly) criticizing the narrow functionalistic approach of consumption concepts in the rational actor model.[4]

In 1899, Thorstein Veblen in his Book *Theories of the leisure class* introduced the term *conspicuous consumption* to describe the extensive consumption activities the emerging new rich 'leisure class' of the late 19th century was engaged in, trying to display a higher status in society through luxurious consumption. This approach has been generalized to describe consumption behavior, which - far from deliberately choosing the best utility - will be inclined towards wastefully spending on different brands and status symbols. (Jackson 2005) Similar, Fred Hirsch (1977) describes the existence of positional goods in economics. Like the Veblenesque consumption theory, positional goods are acquired to display one's status mainly through material consumption, e.g. having a luxurious car or house. Because status can be seen as relative to the living standards in society, the set of goods which is necessary to present one's status is subject to social change. Consumers are therefore driven to further consumption to uphold their higher status in an irrational race to the top. Thus, there are social and ecological limits to the power of growth to increase people's quality of life. A related concept has been derived from biological theories. An extension of the Red Queen hypothesis[5] to societal processes (Ridley 1998, 2003) tries to explain and understand status and display-oriented consumption as a race between competitive individuals in society.

Going beyond the concept of consumption as a means to display status, the cultural anthropologists Mary Douglas and Baron Isherwood consider the purpose of consumptive goods not in their functional use to satisfy needs, but in helping to achieve "an individual's main objective in consumption [...] to help create the social world and to find a credible place in it." (Jackson 2005) Material consumption carries with it and symbolizes different cultural and social meanings beyond their functional importance for individual consumption. Equally, the process of consuming goods and the cultural meanings attached to them are necessary to form and maintain social groups. Douglas and Isherwood (1996) stress the importance of marking services, where social rituals

[4] A very good overview is given by Jackson (2005).

[5] The Red Queen Hypothesis was originally conducted to describe the co-evolution between host and parasite.

(diner parties, festive celebration) are a means to position oneself in society. Social consumption activities function as upholding a group's cohesiveness.

> *"In other words, the symbolic function of consumer goods fits them perfectly to play a key role in 'social conversations' – the continuing social and cultural dialogues and narratives that keep societies together and help them function."* (Jackson 2005: 15)

The focus of consumption as a meaningful cultural phenomenon highlights two important insights. On the one hand it stresses that incentives for further consumption derive from the fact that consumers live as social beings in a social context laden with cultural and social meanings. On the other hand the element of conspicuous consumption is important for setting the stage for introducing new technologies by connecting them to emotions and cultural meanings. (Gram-Hanssen 2008)

## 3.3 Inconspicuous consumption

However, daily activities happening in the household like buying food, washing clothes, the use of domestic appliances and the disposal of waste are rarely attributable to such acts of conspicuous consumption. Those activities are undertaken through unconscious decisions and routinized actions. Contrasting Veblen's conspicuous consumption this has been included in the notion of *in*conspicuous consumption or ordinary consumption. (Watson and Shove 2008) Unconscious decision making is defining daily life actions a great deal more than the rational actor's rationality suggests, where "individuals [are] robot-like optimizers who instantly react to price signals." (Söderbaum 1999: 165) Instead, criticizing both rationality and functionality in decision-making processes several disciplines point to the importance of habits and routines. (Söderbaum 1999) Two approaches, which try to focus on that aspect of consumption behavior, are described in the following section – a different view on rationality from biology and economy, and concepts drawing from social practice theory.

### *3.3.1 Rules of thumb and automatication*

One critique against the assumption of a *rational* actor stems from economic and evolutionary sciences and doubts that human being are capable of running the cognitive processes necessary for the alleged rational decisions. In this vein, Jager (2000) proposes to distinguish between reasoned and automated processes. The former describes all such processes, where as much calculations as possible about potential future outcomes flow into decisions in order to come close to an optimal state. These processes could be approximated by a rational actor model. Automatic processes in contrast are involved in those situations, where human beings use simple heuristics, a set of rules-of-thumb to deal with most of their daily life events. Without such shortcuts simple tasks would occupy too much processing power, because of the huge variety of possible decisions. For example, going to the supermarket and buying basic ingredients or groceries would demand too much in the face of the sheer number of products. Even the choice between going up the stairs on the left or the right side, would cost a lot of time. Such limited cognitive abilities were incorporated in the concept of *bounded* or *procedural* rationality in economics. In this model uncertainty about future outcomes, high transaction costs for information gathering and limited access to information run opposite the notion of perfect knowledge in the rational actor model.

> *Bounded rationality is simply the idea that the choices people make are determined not only by some consistent overall goal and the properties of the external world, but also by the knowledge that decision makers do and don't have of the world, their ability or inability to evoke that knowledge when it is relevant, to work out the consequences of their actions, to conjure up possible courses of action, to cope with uncertainty (including uncertainty deriving from the possible responses of other actors), and to adjudicate among their many competing wants. Rationality is bounded because these abilities are severely limited.* (Simon 2000: 25)

To cope with these limitations actors are content with 'satisficing' not optimizing their outcome in order to simplify their decision making process. (Simon 2000)

Rules of thumb and heuristics in decision making processes are reinforced by different aspects and influences. On the one hand they are frequently connected to emotional markers and emotions. (Damasio 2007) This fact has been frequently used by advertisement and marketing firms for creating an affective relationship with their brands. On the other hand, solutions featuring a satisfying, 'good enough' outcome are selected as workable solutions and repeated regularly, making individual biographies of actors and social influences important in shaping the decision processes.

Because such satisfying solutions and shortcuts get us through daily life, they are permanently developed into routines and habits, which do not have to be rational and don't have to be in accord with social norms and standards – in short, they can be far from an 'optimal' state. Although Tversky (1972) argues that the higher the stakes of the pending decision the more effort is put into the decision process, most of what is considered daily household activities falls in the sphere of automatic processing – in the sphere of unconscious routines.

### 3.3.2 *Social practices and Habits*

In sociology the concept of habits and routines has been developed and approached from a different viewpoint. Taking the works by Anthony Giddens on social practices and by Pierre Bourdieu on habits as starting points, practice theories have been further developed by Theodore Schatzki and Andreas Reckwitz. Recently a practice theory approach has been explicitly set into the context of the material dimension of societal consumption patterns. (Warde 2005, Gram-Hanssen 2008, Røpke 2009) In an attempt to mediate between action and structure Giddens introduced the concept of social practices, where social structures are seen to be continuously produced and reproduced by the actions performed by agents. Those agents rely on practical consciousness, which does not depend on a conscious reflection to carry out day-to-day actions. Through the implementation of routinely performed activities the problem of uncertainty over future outcomes and consequences can be reduced. (Gram-Hanssen 2008, Røpke 2009) The notion of practical consciousness strongly resembles the limits to cognitive ability discussed in the previous section. Additionally, the 'habitus' concept by Bourdieu stresses how the "world is unconsciously embedded in our bodily actions." (Gram-Hanssen 2008: 1182)

Building on those approaches, recent practice theories distinguish themselves both from models based on self-contained individuals such as homo oeconomicus as well as from models based on over socialized individuals, focusing on unconscious types of behavior. According to Schatzki, a practice represents "an organized constellation of activities", meaning routinized types of behavior which are not isolated but part of a set or block of interconnected and interdependent elements or actions; "a set of doings and sayings." (Røpke 2009: 2491) Those practices include a complex set of conventions, cultural meanings, materials and skills. Moreover however, to exist, those practices need to be actively produced and reproduced.

From that, an understanding of consumer behavior follows that is based on the concrete practices consumers are engaged in during everyday life and which are shared by a number of people. Everyday life can thus be described as people being engaged in practices, cooking, eating, sleeping, care taking, playing sports, shopping, and working, consisting of a number smaller projects. Sorting, washing, drying, etc. are for example all elements of the practice of washing clothes. These daily activities are connected to the process of (material) consumption and have important consequence for environmental considerations:

> *"Performing a practice usually requires using various material artifacts, such as equipment, tools, materials, and infrastructures; however, this aspect does not make people conscious of the fact that they are consuming resources in their daily activities. Primarily, people are practitioners who indirectly, through performance of various practices, draw on resources."* (Røpke 2009: 2490)

Because people are engaged in a variety of practices, a description of daily life needs to account for how practitioners choose, select and combine different practices in their daily life. Time as a finite and limiting resource has been discussed as shaping and constraining the participation in various practices as agents have to integrate new practices in an already existing set of practices, having to deal with structural, spatial and temporal constraints. (Røpke 2009: 2493) Several arguments follow from an approach based on a concept of consumptive behavior as a set of practices in time: First, it is sensible to model daily life as a set of activities taking up time. Second, involved in routinized practices and habits consumers often neglect or disregard material aspects. Their unaware or unconscious engagement in routines therefore dampens the hope to change consumption patterns by introducing knowledge about the material consumption and promoting ecological values. (Røpke 2009, Gram-Hanssen 2008) Third, as practices reinforce themselves and reproduce over time, daily life has strong elements of path dependency attached to it. Several social norms and conventions co-evolve together with new and developing practices. For instance, the adoption of new appliances in the household like washing machines and dry cleaners introduced new ways to deal with clothes washing and cleanliness. Connected to their integration into the household a new set of norms and expectations about cleanliness developed (Shove 2003), changing further the predominant mode of provision for the inputs needed to perform these practices (Watson and Shove 2008). Such co-evolution can result in "lock-in" situations, where behavioral patterns are fixed in an unsustainable development path beyond the control of individual consumers to change them.

## 3.4 Path dependency and Lock-Ins

Such lock-ins have been described in other fields as well. For example, Sanne (2002) highlights the structural bias due to developments in industrial capitalism leaving little to no room for consumers to influence environmental impacts of societal consumption. This has been contested by Røpke (1999) who sees consumers as somewhere between 'locked-in and unwilling'. Still, the implication is that environmental policies targeted only at influencing conscious decision making through knowledge-raising won't do the trick.

Another type of path dependency has been described by Juliet Schor in her concept of a "work-and-spend" cycle. In modern capitalistic societies, the traditional translation of productivity into further production and higher wages constitutes a structural bias in labor markets. Because the predominant incentive structure in competitive markets is to reinvest in extending production and growing productive capacities, an alternative path of shortening working hours is impeded, which might reduce consumption. (Schor 1998, 2005)

## 3.5 A Temporal Approach to Consumption Activities

In conclusion, most consumption behavior happening in households is best attributed to the domain of ordinary consumption. Practices produce and co-evolve with a complex set of structural incentives and biases, norms and expectations; they are part of unconscious routines and habits – activities happening in time.

In that vein the economist Mikko Jalas argues that, as time is frequently featured as an important factor in analyzing everyday life in households, it makes sense to adopt a temporal activity-based approach to modeling consumption. (e.g. 2002, 2004)[6] Jalas is partially building on concepts derived from household economics seeing time as an input in the productive activities of households. However, criticizing the functionalistic approach attached to a rational actor model, he tries to add a broader view of human agency into the framework. He's doing so by introducing the concept of time spent of activities as a better way of integrating the diverse set of influences of consumption behavior into his analysis. Activities themselves are seen as the desired outcome of decision making processes. For example, while cooking can be seen as a necessary

[6] The concept of practices is distinct from a mere activity based approach in that it stresses the interrelatedness of different activities far more. They see practices as consisting of several activities which are closely connected through routines, etc.

process for having a meal and getting nutrition, preparing the meal is regarded as pleasant by some people. Therefore, different ways to satisfy the need to eat have very different personal attitudes and values attached to them – and different material rucksacks with them.

This can easily be connected to a practice approach. Shove and Pantzar for example mention how consumers are motivated by images of the activities they use commodities for. "Things are acquired, discarded and redesigned with reference to culturally and temporally specific expectations of doing *and* having – not of having alone" (Røpke 2009: 37), stressing the activity part of consumption behavior. (Røpke 2009)

Connecting an activity based approach with the material dimension Jalas (2005) regards consumption:

> *"as a set of temporal activities in which consumers utilize or engage with the various products of industrial systems and through which resource flows pass, virtually or in the sense of induced, indirect flows. Accordingly, resource flows enable the various ways in which consumers desire or come to spend their time and should be analyzed in respect to time use."* (132)

## 3.6 Technological innovation and time allocation

Modeling consumption behavior as a set of temporal activities and routines leaves open how such habitually engaged practices can be changed towards a sustainable path. Technological innovation is, as described before, seen as one way to introduce change into consumer patterns. Technological novelty is disruptive of former established patterns of activities; they add new variation, opening up new development paths within the constraints of existing sets of practices.

In contrast to the simple assumption of modernization theory, where higher efficiency through innovation automatically results in a reduced consumption of natural resources, technical innovation as a driver of change acts on several levels. Energy efficiency might be one way to reduce energy use, but an exclusive focus solely on introducing more efficient technologies into households could turn out to be counterproductive if it serves to sustain unsustainable patterns of consumption. As consumers think of themselves first of all as being involved in meaningful practices, rather than resource-intensive consumption, changes have to be analyzed by looking at how routines change and new practices are integrated. (Røpke 2003, 2009)

*"New technologies always demand a change in routines, as routines often involve daily practical handling of the material things that surround us, and if the material change, the routines also have to change […] However, we also see that users often rethink and reshape the technologies in ways that were not predicted by the designers."* (Gram-Hanssen 2008: 1188)

As practices shape or "make time" (Shove 2009) studies of changing time-allocations of household activities caused by the introduction of new household appliances and new technology, can be useful to see directions of change and possible dangers of new (or continued) path dependencies.

Changes in time-allocations and technology have been subject to some empirical studies. The household economist S.B. Linder describes how productivity gains increase the value of (leisure) time. As a result incentives to make non-work time more productive and save time are increased, resulting in what he calls a "harried leisure class". Consumers try to cope with such 'time famine' by adopting time-saving but resource-intensive goods and services. (Linder 1970; Godbey 1996) Such effects can be seen especially in regard to the introduction of appliances running in the background, like washing machines, dish washers or micro-waves as no additional time input is needed for such activities. A similar argument comes from Binswanger (2001) and Røpke (1999), who argue that time-saving innovations themselves results in additional material consumption. For example the adoption washing machines as time-saving equipment might lead to a decrease in busyness of household workers. In reality however the result was a bigger wash load, a specialization in washing procedures depending on cloth material and a higher washing frequency. (Røpke 1999: 413-414) As McMeekin and Southerton point out, effects similar to those of time-saving technologies can be found when looking at the introduction of so called time-shifting technologies like video recorders. The possibility to be engaged in more activities simultaneously and according to a specific rhythm can influence prevailing temporal organization of practices. (Røpke 2009)

Considering broader changes of daily habits, the integration of information and communication technologies (ICT) is influencing a variety of practices. The development to new practices like the 'staying in touch'-practice due to the adoption of the internet or mobile phones, contribute to some extent to an increase in direct and indirect energy consumption of households. (Røpke et al. 2008)

### 3.7 Summary

This chapter tried to highlight the complexity of consumer decision making. The general argument is that an activity-based analysis of households can grasp the complexity of consumers (non-market) behavior. Following the argument by Mikko Jalas mentioned above, a temporal approach to consumption will thus be adopted, viewing consumption as a set of temporal activities, which interact with products from the industrial system. In my opinion, this is capable of grasping some of the complexity of consumer behavior in order to analyze changes in societal consumption patterns linked to environmental considerations. The main focus of this study will therefore lie on changes in activities, changed and influenced by technological inputs into the daily life.

Such a description of allocations of time to different activities can show consumer decisions, durations of engagement with those activities and the material and energy dimension attributed to them. Thereby a societal time-style can be depicted, showing the current set-up of practices and its material side. The fact that most household consumption activities are part of ordinary consumption and engaged with in a much routinized manner (e.g. washing and cleaning, cooking) the effect of technological novelties as disruptors is important. It therefore makes sense to include time allocation and technical change into a system's view of households, whose current shape is strongly depending upon the co-evolution of household technology and its energy consumption patterns.

# 4. HOUSEHOLDS AND TECHNOLOGY

## 4.1 EVOLUTION OF HOUSEHOLD TECHNOLOGIES…

> *"All the technologies in our homes have gone through phases when they were new and fascinating and when they could be used to show status and wealth. However, all of the technologies mentioned are now in a phase when they have become normal and necessary, and something which it is difficult to choose not to have."* (Gram-Hanssen 2008: 1184)

The introduction of new technology into the household has shaped the way everyday life is organized. Røpke et al. (2010) list several rounds of household electrification starting with the introduction of the electric light, vacuum cleaners and first telecommunication services in the late 19th until the beginning of the 20th century. In the late 1950s, electricity for power and heating were "integrated into rapidly diffusing appliances" like fridges, freezers etc., "meant to ease household chores." (1766) This second round of change included the replacement of former collective arrangements by the adoption of appliances in private, single households. Additionally, the 1980s/90s saw a quick diffusion of appliances like the television set and other entertainment technologies into the household. The third round of household electrification recognized was possible by the emergence of the transistor and the microchip, which meant and made possible a number of devices and appliances using advanced data-processing. The personal computer and the mobile telephone probably represent some of the more important new technological additions to the household lately. Finally, today the diffusion of ICTs into the household affects both the direct electricity consumption and indirect energy consumption in the home, regarding both providing ICT-devices and operating ICT-infrastructure. (Røpke et al. 2010: 1765-1767) UK national statistics provides data for the integration of various technologies, which can be included in the latter rounds of household electrifications. While TV sets are standard in most households since at least the 1970s and the washing machine seems widely distributed since the early 1980s, both DVD-players and personal computers are just starting to get common in the late 1990s and at the beginning of this century. Table 1 lists the percentage of households owning domestic appliances between 1970 and 2009.

| | Washing machine | Tumble Dryer | Dish washer | TV | Video Recorder | DVD Player | Home Computer | Micro wave |
|---|---|---|---|---|---|---|---|---|
| **1970** | 65 | - | - | 92 | - | - | - | - |
| **1975** | 72 | - | - | 97 | - | - | - | - |
| **1980** | 79 | - | - | 98 | - | - | - | - |
| **1985** | 83 | - | - | 97 | 30 | - | 13 | - |
| **1990** | 86 | - | - | 97 | 61 | - | 17 | - |
| **1995** | 91 | 50 | 18 | 97 | 76 | - | .. | 70 |
| **2000** | 93 | 53 | 25 | 97 | 87 | - | 44 | 84 |
| **2005** | 95 | 58 | 35 | 98 | 86 | 79 | 65 | 91 |
| **2009** | 96 | 58 | 39 | 97 | 61 | 90 | 75 | 93 |

Table 1: Percentage of households owning domestic appliances. 1970 - 2009. (DECC 2010: 46)

## 4.2 … AND CHANGING ENERGY CONSUMPTION PATTERNS

The dramatic change in the technological set-up of households over the past decades came hand in hand with a rising efficiency of used appliances and technology. Still, future prospects regarding energy savings are not looking good. As shown by Røpke (2010) the different rounds of household electrification in the last decades continuously re-shaped the composition of household consumption patterns dramatically resulting in a higher total energy demand. (Table 1)

| | 1950 | 1970 | 1990 | 2006 |
|---|---|---|---|---|
| **Light** | 97 | 27 | 18 | 11 |
| **Heat and Power** | 3 | 66 | 68 | 59 |
| Cooking | 3 | 6 | 8 | 8 |
| Heating | 0 | 20 | 23 | 18 |
| Cooling | 0 | 30 | 24 | 18 |
| Laundry | 0 | 9 | 13 | 15 |
| **Miscellaneous** | 0 | 7 | 14 | 30 |
| TV, video, stereo | 0 | 6 | 10 | 12 |
| PC | - | - | 1 | 8 |
| **Total** | **100** | **100** | **100** | **100** |
| **Total Energy Consumption (GWh)** | **522** | **3341** | **8841** | **9401** |

Table 2: The composition of household electricity consumption in percent from 1950 - 2006. (Røpke, 2010: 1766)

Similar data can be found in publications by the *Organisation for Economic Co-Operation and Development* (OECD 2002) and the *European Environmental Agency* (EEA 2005). From 1973 to 1998 the energy consumption of households grew by 36%. (OECD 2002: 11) The share of household consumption in total energy consumption has increased in both the EU-15 and nearly all new member states (EEA 2004). Projections of future energy use in the household sector provided by Mantzos and colleagues show a steadily increase over the next 30 years, reaching 20% in 2030 (EEA 2005: 33). Studies for OECD countries give even higher figures showing a rise in energy use up to 35% until 2020. (OECD 2002: 11) Regarding greenhouse gas emissions the household sector has been contributing 10% of total EU-15 $CO_2$-emissions in 2002. This figure has been relatively stable in the period 1990 to 2002 as renewable energy sources balanced the increasing direct energy consumption of the household sector. (EEA 2005) However, a recent input-output analysis for UK households shows that $CO_2$-emissions attributable to the household sector were 15% higher in 2004 compared to 1994. Interestingly, while stressing the variances due to affluence in energy consumption in different groups, leisure and recreation are one of the top drivers accounting for one quarter emissions in an average household. However, a large amount of energy demand is locked up in basic household chores being still responsible for the majority $CO_2$-emissions attributable to households. (Druckman and Jackson 2009)

## 4.3 Offsetting Energy Efficiency

The hope of decreasing energy demand by eco-efficient goods and services has been offset by a number of factors. The EEA mentions the example of kitchen appliances, which have improved by a factor of 2 to 3 over the last decades, with a parallel increase in energy use due to a rise in the number of appliances used. The same picture holds for different household devices. The "average energy consumption per unit for large appliances such as washing machines, dishwashers and cold appliances such as refrigerators and freezers fell by 21 % between 1990 and 2002, while total energy consumption fell by just 2 %."(EEA 2005: 31) The reason identified for this being again a rise in total appliances due to several factors (demographic changes, mechanization of household work, etc.) on the one hand and a different use pattern on the other.

Looking more closely at the latest additions to the household, it can be seen that future prospects of ICTs and micro-processing devices are ambiguous as well. "The share of residential electricity consumption related to ICT (including consumer electronics) may rise to about 50 percent within the next one or two decades unless preventive action is taken." (Røpke 2010: 1764) Equally, according to Owen entertainment, computer and gadgets will be responsible for 45 percent of electricity use in households. (Røpke 2010: 1764) In this vein the *International Energy Agency* warns that recently total residential electricity use has been heavily influenced by electronic devices contributing to its recent growth and could become one of the largest end-use categories in the future. (IEA 2009)

In conclusion, although up to today household applications tend to get more efficient, the general trend regarding energy consumption is reverse. As the figures provided by the EEA (Fig. 3) show, total energy consumption has not been declining but increasing over the last decade by up to 10% from 1990. Household consumption has been one of the top consuming sectors rising by more than 15% from the data in 1990 (Fig.2).

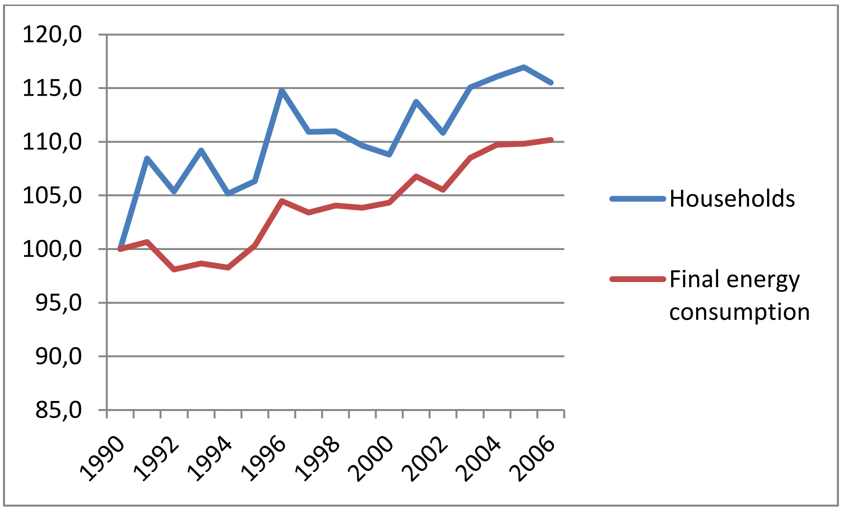


Figure 3: Relative growth of final and household energy consumption for EU-27, 1990-2006. (EEA 2009)

How technical innovation will affect household activities has therefore no straight forward answer. When and if technology leads towards sustainable consumption patterns will depend on how households adapt to and integrate new technologies into their organization of everyday-life.

One analytical approach to the paradoxical offsetting of possible energy and material savings due to changing use patterns induced by technological novelties has been discussed under the notion of a *rebound effect.* (Greening et al. 2000)

# 5. Rebound Effects

## 5.1 General Definition

While the concept originated in energy economics (Brookes 1978; Khazzoom 1980), it is now used as an 'umbrella term' in a number of fields of research. (Sorrell 2007) Basically a rebound effect describes the difference between hoped and actually realized energy savings as a result of changes in the behavior of users/consumers and/or the market as a whole. Most of the time rebound effects are calculated as a percentage of the expected savings not achieved. A 10% rebound effect means that only 90 percent of the efficiency savings were achieved. In the form of an equation this reads as:

$$rebound\ effect = \frac{\text{expected savings} - \text{actual savings}}{\text{expected savings}} * 100$$

In some cases technological novelty can result in a higher energy usage than before the implementation – a rebound effect higher than 100%. Such an effect is either called "backfire effect" (Alcott 2005) or more generally "Jevons' Paradox". (Wessely 2009)

The concept of rebound effects is rooted in the models of neoclassical economics including the rational actor model and the general equilibrium model of market exchange. As in this model prices or more general the *costs* of goods and services are seen as the main signal guiding consumers' decision making processes, the argument goes as follows: An increased energy efficiency either in its production or utilization phase causes the costs of a commodity to fall. Because it is getting cheaper to use or produce this good or service, the demand for the same product will increase. As a result, although the energy intensity of a single unit of product or service decreases, the increased utilization means less energy saved than without the change in use.

A more classical formulation (called K-B postulate after J.D. Khazzoom and L.G. Brookes) defines rebound effects as those effects where "with fixed real energy prices, energy-efficiency gains will *increase* energy consumption above where it would be without those gains" (Saunders 1992)

## 5.2 A taxonomy of rebound effects

Following Greening et al. (2000) and Sorrell (2007), a taxonomy of rebound effects can be created by distinguishing four different types of effects:

(1) *Direct* rebound effects (or pure price effects) are the direct consequence of the higher demand of the same – more energy efficient - good/service due to the connected fall in costs.

(2) *Secondary* or *indirect* rebound effects in contrast describe what impacts cost savings due to technological innovation have on other commodities.

(3) The aggregate result of both direct and indirect rebound is called *economy wide effect*. On the macro-level, a fall in the price of certain goods/services used in various production/consumption processes (most of the time this means the price of fuel/energy, which is used in almost all production processes) can lead either to a decrease in the general price level resulting in more goods being bought or a boost in the productivity level of an economy fueling further economic growth.

(4) A last type of rebound effect is mentioned by Greening et al. (2000). The so called *transformational rebound effect* includes broader changes in the way a society organizes its production/consumption patterns, as a result of a technical innovation, e.g. the changing of social institutions, consumer habits, etc.

A frequently given example of *direct rebound effects* describes the effect of a more efficient motor engine on driving behavior: An efficient engine burns less fuel per kilometer than the old one. Therefore the price for a kilometer driven is reduced and fuel could be saved. But, the new price leads the car driver to make use of the possibility to drive more frequently and/or further for the same costs, thus not saving fuel. (Sorrel and Herring 2009:4; Binswanger 2001: 120) To define the different aspects at work it is helpful to further decompose a direct rebound effect into two separate effects: (Sorrell 2007: 4)

- A *substitution effect*: the cost-saving effect of the technology leads to the more energy-efficient service to substitute for other services (while keeping the level of utility constant.)
- An *income effect*: the cost-saving make funds available for increased consumption of all goods and services

Using again the example of a more efficient car, the decreased costs per kilometer driven allow substituting using the car for ways, which were done by alternative means of transport, by train, by foot (substitution effect). Additionally, the money saved can be used to afford longer travel distances by car (income effect).

A similar decomposition of involved effects can be done in analyzing indirect rebound effects, again considering two aspects:

- *embodied energy*: to achieve a higher efficiency, energy is needed to either produce or install new technology. This new product has energy embodied which has been advanced in the production process; it has to be included in energy saving calculations. The example of energy-saving light bulbs illustrates this well: because the new bulbs need more energy in their production phase, the duration of their use phase is decisive for the actual energy saved, if there is any at all. Similar, the installation of new devices (e.g. thermal control measures) itself may use up energy in the process.
- *secondary effects:* this effect is similar to substitution processes. This time however other activities are substituted for the improved energy consuming service.

A classification has to further distinguish between rebound effects according to (1) the level of analysis (micro/macro level), (2) the system under analysis (households, national economies, firms, etc.) and (3) the time-frame, which is regarded (short-, medium-, long-term) (Sorrell 2007)

## 5.3 Calculating rebound effects

Empirical estimations of rebound effects are difficult and suffer from a clear definition and variety of different measuring approaches. Sorrell (2009a) lists two general types of calculations: one directly measuring rebound effects, and another deriving the impacts indirectly from econometric analysis of secondary data.

The direct measurement compares the situation before the implementation of technical advancement with the situation, where the new device is in place. This encounters several difficulties and is prone to two sources of error. On the one hand it is hard to calculate the exact scale of energy efficiency improvements that would have happened without behavioral change; this is necessary to isolate the direct rebound effect from other factors. Normally such figures are supplied by engineering models, but they are frequently off. On the other hand the situation prior technological improvements has to be known to have a basis of comparison. These difficulties in data availability are reasons few studies are conducted in this way. (28)

The indirect approach usually derives rebound effects from demand elasticities, which calculate the percentage change in one variable following a percentage change in another. Although it is feasible to get energy elasticities, usually price elasticities are taken for further analysis as the data availability is much better and price elasticities are common to economic theory. But the "use of price elasticities in this way implicitly equates the direct rebound effect to a behavioral response to the lower cost [...]. It therefore ignores any other reasons why the demand [...] may change following an improvement in energy efficiency." (30)

## 5.4 Evidence of (direct) rebound effects in households

The reality of rebound effects has been disputed (e.g. Lovins et al. 1988), but several studies conducted to estimate direct rebound effects of energy services seem to suggest that rebound effects are substantial enough to encourage additional research. (Sorrell 2007; Greening and Greene 1998; Wessely 2009) Further, although indirect rebound effects are less researched empirically, it has been suggested by Dimitropoulos (2007) that they are even more relevant as they model macro-level changes as well.

A number of studies on direct rebound effects have been conducted specifically for reviewing impacts in the household sector. Greening and colleagues (2000) describe in their survey on direct rebound effects the impacts on residual fuel demand for efficiency improvements in the areas space heating, space cooling, and personal automotive transportation. Basing their paper on a variety of different studies, they conclude that technological improvements in space heating will be successful in reducing energy consumption between 70% and 90%. Similar the efficiency rate of improved residential hot water heating systems will be 60% to 90%, and 80% to 95% for lightning technology respectively. Space cooling shows a wide variety of 50% to 100% efficiency increase. The estimated rebound effect for appliances in the household is calculated as being approximately zero. (394) Sorrell and Dimitropoulos (2008) list several estimates for space heating, cooling and other consumer services. Their summary shows a rather wide range of direct rebound effects for heating between 0.6 and 60 percent, for space cooling between 1 and 26 percent and a range of 0 to 41 for other consumer energy services. In this vein, Sorrell (2007) concludes that direct rebound effects for domestic energy services might average around 30% in the case of space heating (34) and less for other services declining with higher income. (Sorrell, 2009b: 38) A study by Davis in 2007 researching changes in clothes-washing "suggests that direct rebound effects for 'minor' energy services should be relatively small (i.e. <5 percent)." (Sorrell 2009b: 37) The conclusion that regarding residential energy consumption total rebound effects are relatively small has been shared by Haas and Schipper (1998).

While this suggests that direct rebound effects are not decisive, recent studies show higher results looking at long as well as short-term effects. A study conducted for Catalonian households measuring direct rebound effects provides estimations of a 35% short-term and a 49% long-term direct rebound effect for all electricity energy services. (Freire González 2010: 2313) Another research analyzing South Korean households provides figures of a 38% short-term effect and 30% effects in the long run considering macro level changes. Singling out efficiency changes in air conditioning resulted in a rebound effect of 57 - 70%. (Jin 2007)

## 5.5 Limits to direct rebound effects

Still the significance of direct rebound effects is ambiguous at best and a number of secondary and economy wide effects are probably more decisive. In line with the argument laid out in chapter three however, technological innovations in disrupting former consumption patterns could go both ways, either having positive or negative side effects. This brings Hertwich (2005) to speak of the more neutral term *ripple effect* in order to better grasp this ambiguity. Estimations of changes induced by technological novelties in the household will have to account for those side effects as well as a wider range of influences on consumer decisions outside "the established notion of the rebound effect." (95)

Likewise, Binswanger (2001) stresses the fact that the direction of rebound effects is hard to know. He criticizes the frequent use of single-service models to derive rebound effects, because they neglect possible substitution effects between services as well as the importance of the household budget constraint (i.e. income effects). The problem with single service models is that consumers assumed to derive their utility from one single service, implying that one service utility is separable from others. As possible feedbacks triggered by technological novelty are ignored, results are either over- or underestimating rebound effects. Utilizing a two-service model, he shows that the results are highly dependent on the substitutability of and between different services. (126) Additionally, he finds that the assumption of reversibility of investments in stocks/infrastructure doesn't hold as the substitutability is highly dependent on the kind of decisions made before.

Another argument stresses the connection between the substitutability of energy and time and the current costs of time. Incorporating a time aspect in energy rebound effect, Sorrell et al. following Binswanger conclude that:

> *"If time costs continue to increase in importance relative to energy costs, the direct rebound effect for many energy services should become less important – since improvements in energy services will have an increasingly small impact on the total cost of useful work."* (Sorrell et al. 2009: 1363)

The study by Davis mentioned before shows that in activities with the biggest proportion of costs connected to time, little change will be induced by energy efficiency improvements. Therefore estimates of the direct rebound effect which do not include increases in time costs could potentially overestimate the direct rebound effect. (Sorrell 2009b)

Several conclusions can be drawn from these insights. Especially when incorporating the significant secondary effects, several aspects have to be regarded more closely:

- The degree of substitutability between different services is decisive for possible rebound effects. As they depend largely on infrastructural settings, past decisions and the types of services looked at, the possibility of substitution cannot be taken for granted.
- Costs limit the decision making process and thereby the rebound effect. Usually the budget constraint is the decisive factor, but costs can be attributed to other factors as well, like time costs. The role of time in energy rebound effects is getting more important.
- Other influences can play decisive role and should be part of the rebound effect concept.

As laid out in chapter three, discussions on consumer behavior suggest a temporal view of consumption and an activity-based view of consumption behavior. The growing interest inside the discourse on rebound effects is trying to include findings from other fields of research has led to the development of several approaches to time use rebound effects.

## 5.6 Concepts of Time Use Rebound Effects

If consumption is seen as a temporal activity closely connected to daily habits, life experiences and infrastructural constraints, the study of time adds to our understanding not only of the multi-dimensional decision making processes of consumers, but also broadens the scope of rebound effect analyses. (Jalas 2005) Technological advancements trigger transformations in the internal time structure of households, i.e. the allocation of time to activities. This opens up the possibility to better account for the concept of *transformational* rebound effects; the reshaping of consumption patterns on a broad level. (Jalas 2009) Additionally, a shift away from purchasing power and monetary budgets as the (only) factors limiting consumption is possible. In principle, limiting factors can include space (storage, traveling distance, displaying), skills, available information and last but not least available time. (Hofstetter and Madjar 2003: 6) Time has the advantage of a clear limitation (the 24h day), a clear metric and (at least in principle) enough available data on both historic and recent time use patterns. (Hofstetter and Madjar 2003) The discussion on time rebound effects in the literature can thus easily be connected to the temporal approach to consumer behavior.

A general concept of time rebound effects can be described as follows: Efficiency increases are achieved through technological innovation changing the energy efficiency in one or more activities. Consequently however, changes in the time allocation lead to a higher engagement in the same activity or a shift towards other activities. The reasons for such shifts can lie in the factors discussed in the previous chapters - socio-economic factors, the suitability for a prevailing set of practices, or a decrease in costs - related to various activities. Thus, the environmental dimension in time rebound effects can be seen in changing amounts of time allocated between alternative activities with different environmental impacts per unit of time.

Figure 4 gives a schematic view of this process. A new technology reduces the energy consumption of one activity. However, due to changing time allocations the total energy consumption is rising compared to before the technological change. By connecting environmental impacts and time use it becomes possible to calculate time rebound effects. A more detailed model has to distinguish between different aspects of time rebound effects, as again substitutability, the direction of change and good empirical methods are the main concerns.

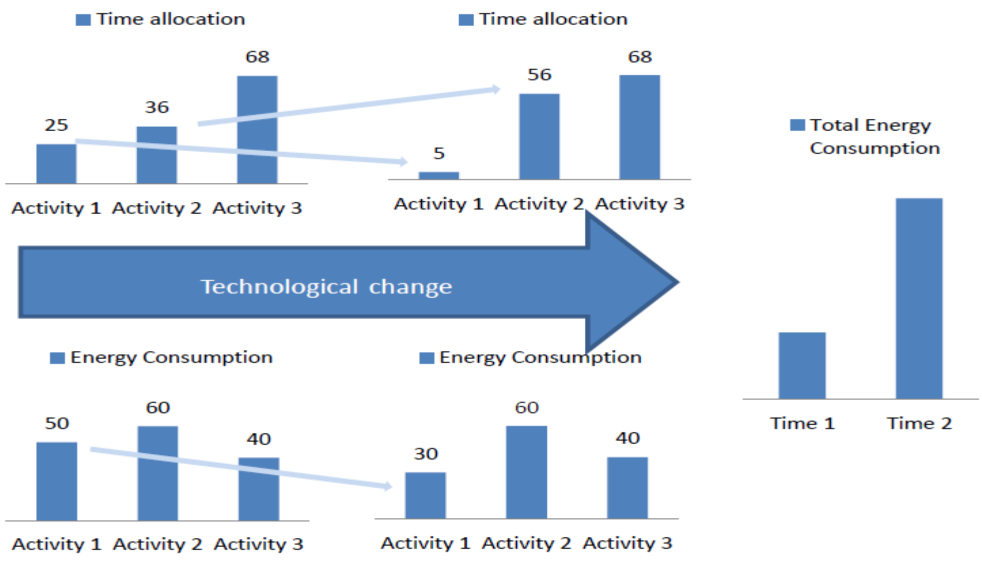


Figure 4: Concept of a time rebound effect. (own design)

According to Binswanger (2001, 2002) two kinds of rebound effects in connection with time can be distinguished. Deriving his results from calculations of household production functions, he first describes the effect, (1) where time and energy are substitutes for each other, while (2) the other focuses on a rebound effect in regards to time.

### 5.6.1 *Time and Energy as Substitutes*

Many technological advances aren't for the purpose of energy saving, but have been implemented and integrated into the household to save time. As has been mentioned in the chapter on household technology, household chores were substituted for automatic work done by machines and other products. Recently, e-commerce, internet, email, etc. can also function as time-saving devices. Such devices usually come with a higher energy demand and a higher ecological rucksack.

According to economic theories, the substitutability between time and energy is highly dependent on the current wage level. This is the case because the wage level determines the opportunity costs of time (the monetary value of time) measured in the amount of money lost when time is not invested into labor for income. When an income is high, more money would be lost when time is invested in non-labor time. Therefore the drive to incorporating time-saving innovations should increases with higher opportunity costs. As energy prices are generally lower, incentives to save time and invest in energy are rising. Coming back to the already used 'travelling-example', a car could be exchanged for other faster modes of transport like an air plane. This allows the consumer to save time, but raises the energy consumption as air travel is connected to a higher fuel demand. Binswanger therefore concludes that:

> *"Time-saving devices usually require more energy as is most evident from transport where an increase in the efficiency of time use (faster modes of transport) tends to be associated with a larger input of energy […] the overall effect of time-saving technological progress will be an increase in energy use."* (Binswanger 2001: 131)

### 5.6.2 Rebound effect in respect to time

However, even if time-saving innovations aren't connected to rising energy consumption, a rebound effect in respect to time could emerge due to higher time efficiency. Substitution and income effects as well as secondary effects can be connected to a temporal dimension. As time-saving innovations free up time, the newly available time resources can be either invested in the same activity; for example, a faster car allows you to travel longer distances in the same time. This time travel hypothesis has been mentioned in the literature in a study by Schipper and colleagues, who were the first to link time and energy consumption (Schipper et al. 1989) Additionally, the time-efficient activity allows a substitution for other activities, like the e-commerce being a substitute for going to the supermarket. Distinguishing different elements, the first case would be a (time) income effect while the second constitutes a substitution effect. More so, secondary effects are likely as freed-up time can also be invested in other consumption activities. For example, the introduction of washing machines allows the consumer to join in other activities, while the washing service will continue without an additional time input. If energy demand (or environmental burden as a whole) would rise due to such time shifting is then subject to the energy-intensity of the substitute activities.

Sorrell sums this up best: "[E]nergy consumption may be increased either, by trading off energy efficiency for time efficiency (e.g. choosing air travel rather than rail) and/or by the rebound effects with respect to time (e.g. choosing to travel further)." (Sorrell 2009b: 40)

### 5.6.3 Further research on time rebound effects

The time aspect is featured in several concepts of rebound effects. Jalas argues to switch from a description of household consumption as monetary spending and expenditures to calculating energy intensity of household activities; albeit connecting the temporal approach with rebound effects and calculating the necessary energy per unit of time spent engaged with an activity. His study conducted for Finish households in the periods between 1987-1990 and 1998- 2000 tried to calculate such energy intensity of different household activities in measuring the energy per time per person. (Jalas 2002) He provides two hypothetical examples to demonstrate his concept of time-use rebound effects (Fig. 5). As a starting point he uses the assumption that household activities are outsourced to the market.[7] To simplify the model all time spent in other household activities have the same average energy intensity. (118-119)

His first example describes market delivery substituting for shopping for daily goods. Time is saved as only the selection time over the internet is spent. The energy demand will be lowered as a delivery service can more efficiently serve a higher number of costumers. However, as time is substituted for other activities the hoped for energy savings are not realized fully – a rebound effect. Similar, the second example finds a commercial repair shop taking over the household chores of a handy-man. This time however the supposed savings due to a higher infrastructural utilization of a commercial repair shop is offset completely by the new activities the handy-man is engaged in.

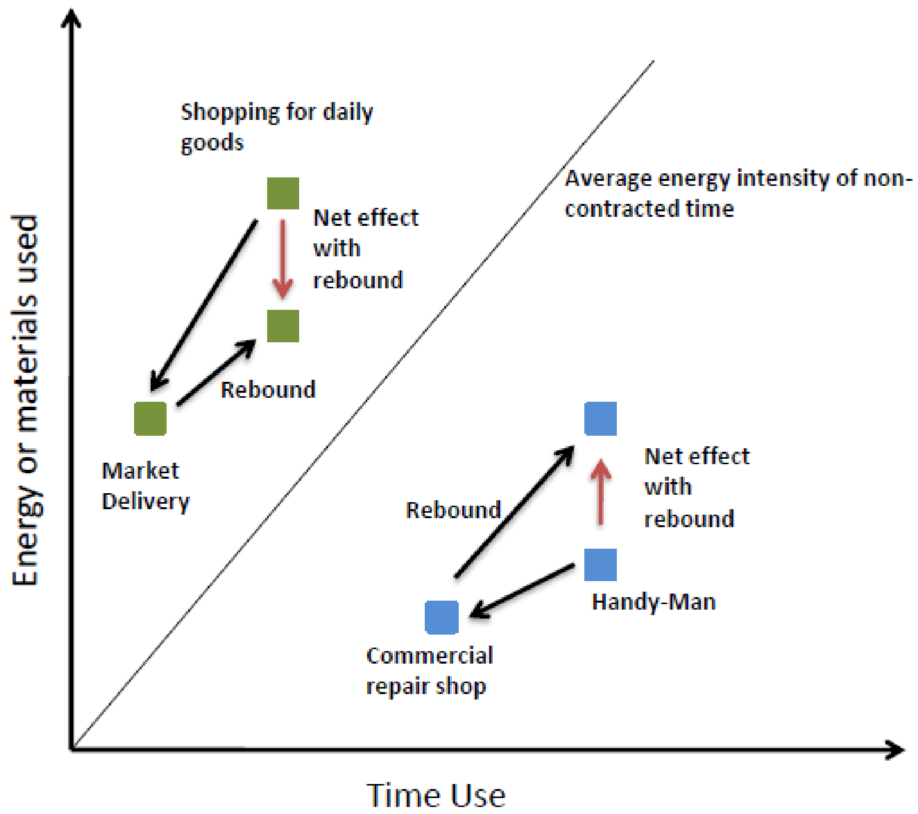


Figure 5: examples of time rebound effects, reproduced from Jalas (2002).

[7] Externalizing household activities has been proposed as a more efficient energy saving strategy, utilizing the market as the supposed best institution to raise efficiency.

It can be deducted from this, that the scale of the rebound effect depends on the kind of activity, which has been substituted. As the energy intensity of all non-market time is assumed constant, the energy intensity of the old activity is important. In this sense a rebound effect involving an activity in the lower right sector, i.e. an activity with a lower energy intensity, will be subject to higher substitution effects than an activity which has a higher than average energy intensity. Therefore, outsourcing activities like washing, cooking or driving might decrease the total energy requirement even when taking account of substitution effects. In contrast the replacement of low-intensity activities like cleaning, cultural events, watching TV or listening to radio should result in a rising energy demand. (Jalas 2002) Jalas mentions that activities demanding higher mobility of consumers tend to increase energy consumption as well. The proposal to outsource the preparation of meals to restaurants or cleaning to washing centers means that consumers have to get to those places and increase their traffic time.

Because the average energy intensity of the substituted time is considered as given, such hypothetical results don't take into account possible secondary effects, which depend on the kind of substitute activities. Is the energy intensity of the substitutes higher than average, the rebound effect will increase, or vice versa with low-intensity activities. The existence and range of rebound effects is thus dependent on the bundle of activities the freed up time is spent on. In a more recent example, Jalas (2009) theorizes about the use of commercial services as substituting for investment in self-owned household capital as a transformation process towards a service economy. Using the example of an exchange between an owned lawn mower and a commercial lawn-mowing service, he again stresses the feasibility of a temporal approach to analyzing changing consumption patterns on the macro level.

Combining the insights the magnitude of rebound effects depend on different factors: (1) the change in costs following the initial energy improvement in service and/or product (more costs – less rebound), where costs could mean different kind of costs (2) the amount of time saved by the efficiency increase (more time – more rebound), (3) the energy intensities of the activities substituting for the initial service and (4) the costs of those secondary activities. (Jalas 2009: 175)[8] In order to better analyze such secondary

[8] Jalas mentions other factors like the wage rate. While I consider this to be an important factor, I will disregard it for the analyses at hand as the study is more concerned with short-term changes.

effects the substitutes have to be known. Hofstetter and Madjar suggest the concept of time elasticities to better deal with this problem. (2003)

### 5.6.4 Time elasticity

While the term *elasticity* is borrowed from economics and used in estimating energy rebound effects (see chapter 5.3) the model proposed for calculating time elasticities is not grounded in full equilibrium models and econometric calculations usually applied. But, time elasticities describe a change in (time) demand due to changes in activities and depict simple relationships between activities; thus making substitution and secondary effects quantifiable. (Hofstetter and Madjar 2003).

### 5.6.5 Empirical estimations

Concrete empirical estimations of time rebound effects are rather scarce. Similar to the study by Jalas on Finish household, Van der Werf (2002) researched energy intensities per hour to study the energy consumption between different alternative activities. Using a hybrid energy analysis, energy statistics, figures on time use and expenditure data, he calculated changes in households" energy requirements. His results show that substituting newspaper by book reading will decrease energy consumption by 9 MJ, while another 2,6 MJ could be saved by switching to TV watching. (Hofstetter and Madjar 2003)

# 6. Objectives

The previous considerations have highlighted the importance of including time in an analysis of rebound effects. The uncertainty regarding the direction of change following an introduction of new technological devices suggests using the term *ripple effect* as being better suited to grasp this ambiguity. As has been mentioned before, questions concerning the substitutability between different household activities and the directionality of change, towards more or less energy-intensive activities, are still open for further research. Both aspects are important for analyzing the environmental consequences of new technologies - 'green' or general – as technological and behavioral change weigh heavily on developments in the ecological domain of sustainability. The described approach of a time rebound effect based on a view of consumption as consisting of different temporal activities is adopted.

Following results should be gained through this research:

- Energy intensities of time spent in different activities.
- A description of short-term changes in the time allocation to different activities following an introduction of a new technology.
- An analysis of these changes against the background of their respective environmental impacts, i.e. the environmental consequences of changing time allocations due to differing amounts of time spent in activities connected to certain energy intensities.

The period between 1990 and 2005 falls into the last wave of household electrification through the introduction of personal computers and ICTs mentioned above. (chapter 4) Analyzing transformational and short-term rebound effects, a comparison between time use patterns in households and the connected flows of energy in this period can shed some light on current trends in consumption patterns. Four questions are of specific interest:

1. Are consumption patterns 'locked-in' or are we seeing a significant change in the time spent on specific consumption activities?
2. If the latter is the case, which kinds of activities are taking up a growing amount of time? Are they energy-intensive or loaded with less environmental burden?
3. Is technology a driver behind these changing consumption patterns?

To analyze the impact of specific technological novelties this study has to focus on the latest technological wave due to older technology being almost completely integrated in today's household.[9] (see chapter 4) The **personal computer** has been chosen as an example for technological innovation as it is covered in the data-set, is connected (for better or worse) in a discussion about sustainability, and is relevant from a time use perspective. The personal computer is interesting in the latter regard, as theoretically it transforms the whole activity pattern of households. It therefore doesn't only alter time spent on existing, but introduces new activities while replacing others. The immediate short-term changes attributable to its introduction are compared within a subset of different groups.

[9] A more historic approach could be used to analyze former impacts on households' time and consumption patterns. Such studies have been conducted in sociology and history, but rarely with considerations to environmental impacts. However, such research could shed some light on the change triggered by housework technologies like the integration of washing machines and dish washer, which freed up a vast amount of time.

# 7. Methodological Approach

As has been described before, this study adopts the concept of a household metabolism and a temporal, activity-based approach to consumption. To get a better understanding of technological impacts on household energy, consumption energy intensities of household activities per time are calculated and changes over time analyzed. After a short conceptualization of a household metabolism the next part describes the adopted methods and the necessary data.

## 7.1 Conceptualizing a household Metabolism

Despite the consumptive nature of every production process and the productive aspect of many consumption activities, a production and a household sector will be distinguished (cf. chapter 2), connected through different exchange cycles. Following the household metabolism concept (Noorman and Uiterkamp 1998), different energy flows entering a household as inputs and outputs are necessary for the reproduction of its metabolism. As this study tries to model changing patterns of consumption activities, the internal dynamics were included in a system's view. To do that different stocks and flows inside a household system were identified.

As shown in Fig. 6, a household metabolism can be modeled as consisting of (1) two exchange cycles (a labour vs. income and a money vs. goods and services cycle), (2) three stocks (money, time and infrastructure), (3) flows of energy and time, and (4) the temporal setting of household activities

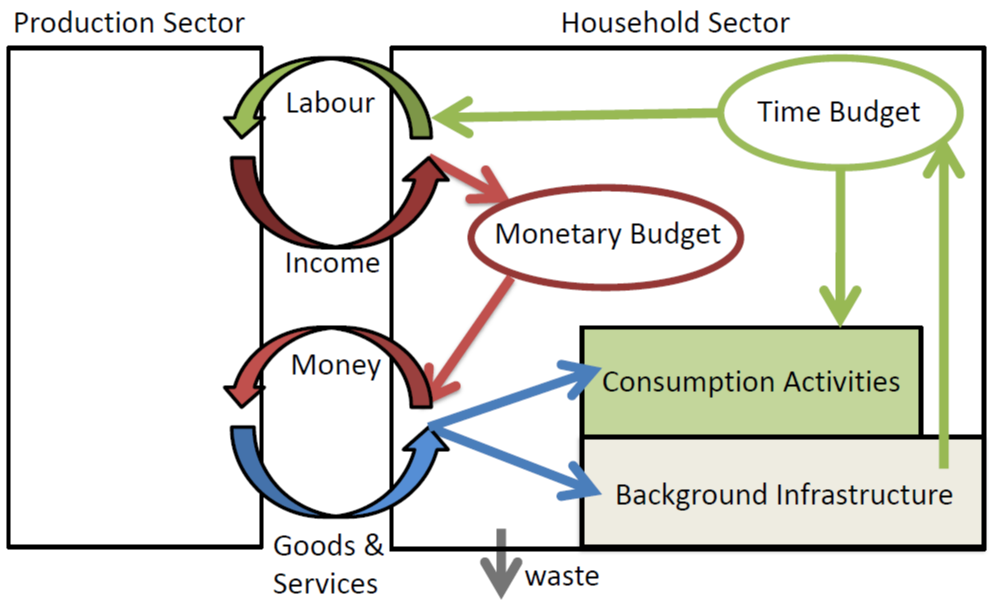


Figure 6: Scheme of a household metabolisms internal structure. Green represents time, red monetary and blue energy flows and stocks. (Own design)

### *7.1.1 The exchange cycles*

The connection between the household and the production sector is established over two exchange cycles (1) the labor vs. income cycle and (2) the money vs. goods and services cycle. Households exchange their labor power with the market to earn an income. At least theoretically more time spent on laboring in the market means a higher monetary income. Time is therefore exchanged for money.

In the second cycle the earned money is spent on goods and services, which can either be used for immediate consumptive activities or added to the built infrastructure of the household. The act of buying then builds an important link to the production process, enabling energy flows into the system. (see chapter 2; Noorman and Uiterkamp 1998)

### *7.1.2 The Stocks*

Three stocks can be distinguished, although they share different qualitative characteristics. The monetary stock is straight forward, insofar as it represents the monetary budget available for a single household. Its scale will depend on the in- and outflows connected to the described exchange cycles.

The infrastructural stock consists of all the existing appliances and is changed by technological innovations diffusing into a household. Depending on the types of appliances used, different energy flows will be attracted to the household system.

Furthermore the use of appliances running in the background – time-shifting or time-saving - impact on the time available for different activities. The infrastructural stock has to be maintained through continual (monetary) investment and be made useful through a continual flow of time and energy. Additionally dwelling, insulation and other housing related factors influence the energy consumption of households.

The time stock enables time flows being used for household activities and labor. This stock however has features quite different to the other stocks described insofar as an absolute limit in the 24 hour day exists. This time is not only available every day, but *has* to be used in some way or another for household activities or wage labor. While in this sense the scale of the time stock is not changing, the amount of time, which can be freely allocated, is depending on the infrastructural setting, i.e. technology decreasing the time necessary for certain tasks and making simultaneous activities possible.

### *7.1.3 ENERGY FLOWS*

Energy flows do not originate from a stock inside the household system,[10] but stem from the production system. Two types of energy inputs entering a system can be distinguished, both of which are obtained through the act of buying: (1) direct energy inputs and (2) indirect energy inputs. Households are integrated into a societal energy infrastructure and receive energy directly for various purposes. These direct energy inputs are provided by the production system as energy suppliers transform primary energy inputs into forms useable by households. Three forms of directly used energy are relevant to households; they include heat for space heating, electricity for lightning, cooling, washing etc., and motor fuel for transport. (Noorman and Uiterkamp 1998)

Commodities bought by households on the market for final consumption require a certain amount of energy in their production process. This necessary energy is embodied in the goods and services, which enter the household for further use in the respective activities. As in this case energy enters the household indirectly, they are called indirect energy inputs.

Both direct and indirect energy inputs are dependent on different modes of provision, the electricity grids, standard heating systems, and the general state of technology – all factors belonging to the production system. Therefore the relations between the

[10] Energy in human labor power is the exception.

different economic sectors are important to the energy flows entering the household system.

### 7.1.4 *THE TEMPORAL SETTING OF HOUSEHOLD ACTIVITIES*

The temporal, energy and (indirectly) monetary flows enable household activities. Every activity is connected to energy either in the form of acquired commodities or directly used energy and 'use up' time. Some activities depend on more or less energy and time than others. Household inhabitants participate in a certain activity pattern, building the temporal setting of different household activities. Which types of activity time and energy are allocated to, can further be distinguished in separate groups. The most prominent distinction sees one set of activities belonging to household chores, and the other to the field of leisure activities. Yet, it can be argued that household chores like cooking can be enjoyable for some, thus not being a chore. (cf. Jalas 2005). Therefore a better differentiation in necessary and unnecessary household activities could be useful. However, this study won't make use of those categorizations but has to work with the data at hand, which has different aggregates. A distinction between different leisure time activities and various household chores will be made. The activity groups used in this study are listed in the data section.

### 7.1.5 *SIMPLIFICATIONS AND METHODOLOGICAL DIFFICULTIES*

For modeling purposes several simplifications have been made. Furthermore, the available time for this diploma thesis allows only for a limited analysis.

(1) Following the discussion on the different dimensions influencing consumption behavior different time allocations will be seen as manifesting themselves in different routines and practices. However, there are several difficulties with this approach.
    a. First, the drivers determining such time allocations (e.g. comfort, conventions, etc.) will be presumed as given and not analyzed according to specific influences. Individual well-being and different quality of life aspects are neglected as well.[11]

[11] See for example Hofstetter and Madjar's (2003) summary of their approach to combine quality of life data with time use data and environmental data.

b. Second, activities can be acted out in different ways. Investing more time in travelling could mean travelling by plane or going hiking in the woods nearby. Similar, it makes a difference if shopping is done at some local grocery shop reachable by bike or at the shopping mall at the town limits. Thus calculating average time allocations connected to average energy intensities disregards individual choices shaping specific activities. This reduction to abstract time use classes therefore weighs heavily on the empirical outcome.

(2) Connected to the point above, available time and money will be seen as the only constraints considered in decision making processes, which excludes other possible limits. However it can be argued that other constraints can be included in those two factors. For example, space limits can be including into the time budget (e.g. travel time) or seen as infrastructural constraints, because of limited building space. Similarly, skills can be regarded as depending on wider infrastructural constraints (e.g. the neighborhood or districts enable certain skills and opportunities) or limited by the time and money available for education. (Hofstetter and Madjar 2005)

(3) This study focuses on energy flows entering a household. Thus, while inputs are included, wastes resulting from household activities are disregarded. [12] Furthermore, material flows – most importantly water flows – are ignored, although they make up a great share of the environmental impacts resulting from household consumption.

(4) The study will focus on the impact of one new technology. The rest of the technological infrastructure inside will be considered fixed, with no new technology and/or efficiency improvements.

(5) Moreover, technical progress inside the production system had to be taken as fixed at a certain point of time. Thus paradoxically, while this study focuses on consequences of technological progress, it can't do justice to incorporating general efficiency gains into the analysis.

(6) While the embodied energy of goods used for immediate consumption is included, the role of energy in the production phase of durable goods (as part of the infrastructural stock) is a more difficult matter. I will distinguish between

[12] This is a major simplification and will change the results significantly. While a hybrid input/output model or more thorough *Life Cycle Analyses* of certain products could be included, this would be beyond the scope of this diploma thesis.

durable goods and infrastructure necessary for all activities (lightning, heating, clothes, general furniture) and those specifically linked to certain activities as is the case with the personal computer. While the former will not be included in the analysis, the latter will be allocated to their respective activities. This is done, because they represent a necessary energy input for these activities and the appliance itself has to be maintained through continuous energy inputs. However, as most appliances used in household activities are produced for a longer use phase and thus reduce their environmental impact per time unit with a longer utilization span, this has a major effect for the results of this study. Rates of devaluation and/or deterioration might help to account for this, allocating the embodied energy proportionally as gradually spent over time. But, this could not be part of this study.

While these problems weigh heavily on the empirical outcome, I still think that highlighting the factors of substitutability and directionality of energy consuming activities has its merits by showing insights and possibilities for further analysis when adopting such methodological approach.

## 7.2 Methods and Data

### *7.2.1 Energy intensities of temporal activities*

To derive energy intensities per unit of time attributed to a specific activity three steps are necessary (Jalas 2002):

First, the energy inputs into the household are calculated. To account for the indirect energy inputs, an environmental input/output method is used combining an input/output table with energy statistics for each sector. As a result, energy intensity of different final demand categories can be derived, accounting for all the indirect energy flows in the production sector. (Miller and Blair 2009, Jalas 2002) Energy spent per monetary unit is calculated for each final demand category.

As this research is only an approximation and wants to focus on the time aspect of technological change and consumption, a rather superficial input/output analysis is used not accounting for the role of energy flows originating in foreign countries with different energy intensities. Similar, the technological setting and efficiency increases of the wider economy will be assumed fixed for each year (see above), focusing on the introduction of new technology in the household system. Another simplification is the neglect of government spending, which could provide an additional monetary income for households without being included in the final demand sector.

To integrate the direct energy flows into the analysis and account for total energy flows into the household system, energy services (energy consumed by appliances) were attributed to household consumption activities.

Second, it is necessary to link the indirect energy flows with households' monetary consumption connected to specific activities. This exchange is happening through the *income vs. goods & services* cycle. Thus money spent on the various products of the production system has to be connected to specific household activities.

Expenditure data has to be connected to both (1) energy flows and (2) activities classes. The scheme for attributing final demand categories to expenditure data (1) is described in the data sector below. [13]

The allocations of expenditure categories to (2) different household activities is difficult and to some extent arbitrary. Jalas (2002) lists several approaches to what has been termed matching process, which differ depending on data availability, study focus, etc. Some energy inputs and/or expenditures could not be attributed to specific activities as they are more or less equal for all activities. Heating, lightning and clothes/footwear are part of the infrastructure of a household system needed for every activity. They are therefore neglected in the analysis as they don't change with more intense activity time. (see above) However, other infrastructural appliances attributable to activities are included (e.g. TV, washing machine, etc.). Last, energy spent for shopping i.e. the time and energy needed to acquire different goods and services is difficult to allocate to the respective activities and remains as an independent time use category.

The energy embodied in the commodities entering a household system is thus given as energy used per monetary unit necessary for each activity, depending on the money expenditure of households/persons.

Finally, the energy embodied in the monetary flow is combined with a measure of the duration of different household activities, resulting in 'energy spent per unit of

[13] The UN is working on an correspondence between the now standardized COICOP (Classification of Individual Consumption by Purpose) codification for expenditure data and the NACE /classification used for industry sectors in I/O tables.

time', i.e. energy intensities of temporal activities. Following Jalas (2002) these variables are included in the analysis:

$t_i$ … duration of activity category

$d_i$…direct energy input of activity category

$e_j$… energy intensity of expenditure category (indirect)

$m_{ij}$… money spent in expenditure category related to an activity

i … activity category

j … expenditure category

Thus, the measurement of the energy consumption of a single activity, calculating their energy intensities per unit of time is given by the term $\frac{m_{ij}e_j+d_i}{t_i}$.

The following table summarizes the three steps, where $e_j$ and $d_i$ are the results of step 1. Next, $m_{ij}$ are combined in step 2 with $e_j$ to get the indirect energy input used by an average person in an average household making it possible to calculate the total energy input for a certain activity. Finally, energy intensities per time are calculated by including $t_i$, adding information from time use data:

| 1 step | 2 step | 3 step |
|---|---|---|
| energy/money $e_j$<br>energy $d_i$ | Total energy input<br>$m_{ij}e_j + d_i$ | energy/time<br>$\frac{m_{ij}e_j + d_i}{t_i}$ |
| per final demand category accounting for indirect flows<br>energy consumption of household appliances accounting for direct flows | per household expenditure attributable to activities (attributed to person): $m_{ij}e_j$<br>accounting for indirect and direct flows in the household | Energy allocated to activity categories per unit of time |
| Environmental I/O-Data<br>Energy Statistics | Household Expenditure Data | Time Use Data |

Table 3: Three steps to energy intensities per time. (own design)

With these environmental impacts attributed to time spent in different activities, consequence of changing time use patterns following an integration of a technology, i.e.

the personal computer, can be shown. The next chapter describes the methods to account for changing time use.

### 7.2.2 MODELING CHANGE

To model short-term changes over a period of time triggered by technological advances, the substitutability between activities has to be known. Therefore, time elasticities as suggested by Hofstetter and Madras (2003) are incorporated into the analysis. For that purpose the data of a longitudinal time use study (data description see below) is analyzed. Both a group of *PC-adopters* and a group of *Non-adopters* are defined. The first group acts as an example of changing behavior, while the second group represents a situation where no technological change has happened. In order to analyze differences between those two groups, mean values in time use changes were compared. Therefore, the data set was pooled and changes in time-use calculated by subtracting the individual time use data for each specific activity category in one year from its successive year. For the group *PC-adopters* the latter year meant the year a PC was integrated in the household. Using an independent T-Test, mean values of those differences were compared between the adopting and the non-adopting group.

Two aspects were thus researched:

- If the personal computer has any significant impact on the behavior of the adopting people at all, i.e. on the time allocated.
- The substitutability between different activities, i.e. the direction of change, depicted in the changing mean-values of time use per category. The integration of the PC means that a new time use category – *pc use* – was adopted, changing the allocation pattern of available time to different activities other than pc use as well.

The dataset was further analyzed for differences between gender, age, and household size. The sample was differentiated in three "age groups" with the first being age 18-35, group 2 age 36-50 and, group 3 51-65. Everybody younger and older has been excluded.[14] Household size was distinguished between small households with 1 to 2 people living in the household (group 1), middle sized households with 3 to 4 people (group 2) and large households with 5 and more people (group 3).

[14] However there were no cases for people younger than 18 in the sample used.

Short-term changes were analyzed against the background of the calculated energy-intensities to see trends towards more or less environmental friendly consequences.

### *7.2.3 Data description*

Each required step is depending on a set of statistical data from different sources. Following data is used in the study:

- An analytical input/output table (ONS 2010)
- Energy statistics per industry sector (ONS 2000)
- Energy statistics per household appliances and travelling distance (DECC 2010)
- *Family Expenditure Survey* covering the years 2000-2001 (ONS 2002)
- Time use statistics provided by *HomeOnline* study (Brynin 2002)

A combination of an analytical input/output table (I/O) conducted for the UK in 2005 provided by UK official national statistics (ONS 2010) with energy data disaggregated for different industries (ONS 2000) is produced. The study on energy data specifically mentions that its data is for modeling purposes only and results should be used cautiously. The I/O table consists of data categorized in 123 sectors, while the energy statistics are aggregates for 92 sectors. As both data use different aggregated categories, energy statistics are modified to match the I/O table classification. Due to matching problems some data has to be approximated by calculating proportional energy used by different I/O sectors respectively. This is the case in the following categories: *Food* used in energy data is the sum of I/O sectors 8-19 including various distinguished food categories, *textiles* comprises I/O codes 21-27, *pulp and paper* of codes 32 and 33, *metal products* includes codes 57-61, *machinery and equipment* 62-66, *electrical machinery* 70-72, *radio, television and communications* 73-75, *other transport equipment* 77-80, *other manufacturing and recycling* 81-85, *post and telecommunications* 98-99, *real estate* 103-105, *other business activities* 109-114 and *health and social work* 117-118. The I/O level of aggregation is used as it gives more specific information about final demand categories, especially distinguishing between books/magazines and television sets thus making it better compatible to expenditure categories and activity codes.[15] The calculated energy intensities are listed in Appendix 1.

Data by the Department of Energy & Climate Change (DECC 2010) is used as a source for direct energy consumed in different activities. The DECC provides detailed data for

[15] Normally an aggregation to a higher level should not be conducted, but is used nonetheless because of the better suitability with other data. However this could mean distortions in the energy intensities.

total energy use per household appliances per year for the years 1970 to 2010. This is used to derive average energy consumption per appliances per person in an average week for cold (fridges and freezers) and wet (washing machine, washing dryer, tumble dryer, dishwasher) appliances, consumer electronics (TV, DVD/VCR, Game Controllers), home computing devices, cooking devices[16] (E- and gas ovens as well as microwaves). Equally, transport data tables provide figures used to calculate energy spent on travelling. As a distinction between person and cargo travel is difficult for the transport modes air, rail and ship, only car use was used as an approximation to general energy demand of travelling time. Table 4 shows the different energy inputs necessary for different appliances/travelling.

| | **Total Consumption per appliance in 2000 (toe)** | **toe per week per person** | **kWh per week per person** |
|---|---|---|---|
| **Cold** | 1.467.884 | 0,000478 | 5,564443 |
| **Washing** | 884.276 | 0,000288 | 3,352106 |
| **Dishwasher** | 218.875 | 0,000071 | 0,829711 |
| **TV** | 797.188 | 0,000260 | 3,021974 |
| **DVD/VCR** | 303.252 | 0,000099 | 1,149567 |
| **Game Cons.** | 4.732 | 0,000002 | 0,017937 |
| **Computers** | 268.005 | 0,000087 | 1,015951 |
| **E-Oven** | 550.209 | 0,000179 | 2,085729 |
| **Microwave** | 177.055 | 0,000058 | 0,671180 |
| **Gas-cooking** | 694.369 | 0,000226 | 2,632208 |
| **Other cooking devices** | 345.278 | 0,000113 | 1,308878 |
| **Power Supply Units** | 304.727 | 0,000099 | 1,155156 |
| **Car travelling** | 25.926.412 | 0,008451 | 98,281631 |
| **Total consumption** | **6.015.851** | **0,001961** | **22,804841** |

Table 4: Direct energy use by appliance and travelling. (DECC 2010, own calculations)

Shopping time and travelling time are distinguished in the time use data. However it is not clear, how much travelling time contributes to the time to go to shops (and

[16] Both electricity and gas consumption for cooking were included; other fuel types like oil or solid fuel where dismissed because of a negligible contribution to the total energy amount.

appointments) as the shopping variable only codes for the time spent at the shop, while travel time codes the time spent commuting to and from different places (work, school, shops, etc.). Therefore neither direct nor indirect energy use could be attributed to the *shopping* activity. This is also the case for the variable *paid work* and *others*, which were left undefined in regards to energy intensity per time. However they remain as an independent class for analyzing time use change.

As has been mentioned before, both heating and lighting energy are excluded from the analysis as they are taken as more or less given for each activity.[17]

The *Family Expenditure Survey* covering the years 2000-2001 (ONS 2002) provides household expenditure data for the expenditure on the goods and services stemming from the production system.

The *HomeOnline* study (Brynin 2002) – description see below – was used for time spent per activity, and the basis for the classification of various household activities, which are depicted in table 5. The time use data is given as hours spent per week. Not every activity group has energy inputs attributed to them. *Sleep* has no further energy demand except the excluded energy on furniture and heating. Due to the aforementioned problems in allocating travelling time to shopping time, no energy was allocated to the *shopping* category. Moreover, *others* is left out of the analysis regarding energy intensities as it represents a filler variable. Last, paid work has no energy attributed to it, as the energy demand of *paid work* is highly dependent on the profession.

To combine the data on indirect energy flows, expenditure, direct energy input and time use, a matching scheme is necessary calculating energy intensities per time in the various activity classes. The detailed matching process is listed in the appendices 2 and 3. As different time scales and different units are used in the various data sets, the units are converted to match a weekly time scale and tones per oil equivalent (toe). Additionally the final results are given in kilowatt hours (kWh) as this unit is featured in some studies and makes it for a better comparison.

For the calculation of time elasticities, a weighted dataset from the *HomeOnline* study (Brynin 2002) is used.[18] The major advantage of this study is that it involves the same people over a period of three consecutive years (1999, 2000 and 2001). It consists of a

[17] Moreover, the exact time (night hours or hours with sunlight) would have to be known, which is not provided in the data, or would need too much data input for an analysis.

[18] For a complete data description see Gershuny (2002: 15 – 16).

7-day time use diary for a thousand households in the UK and an additional questionnaire to be filled out by an interviewer. All members of the household aged 16+ were asked to complete a time diary for every day for a week in each of the three years. However, due to the low response rate in the subsequent years, additional participants were added in the second and third year. The research group mentions a systematic bias in the sample because of the low response rate and an over representation of pc users, because of the study design. A total of 3593 people were interviewed and/or completed a diary over the period of three years. However, only those respondents, which participated for at least two years are interesting for this study, reducing the group to 681 people.[19] Furthermore, the pooling of the data set reduces the group to 654. As a consequence a single individual case is not representing actual individuals anymore.

Respondents, who got the new technology *personal computer (PC)* from wave 1 to 2, wave 2 to 3, or wave 1 to 3, were identified as *adopters*. All the rest – people who always or never had a computer – were included in a *Non-adopters* category. Those who got rid of their personal computer were also put into the latter category, since they were not statistically significant and the analysis was made easier. Information about the technological equipment in households was part of the questionnaire. Respondents were asked directly if they have a computer in each of the three waves ("Do you have a computer in your home?")[20] and the responses are coded in the variable (w)pchome; (w) standing for the respective wave (a=1, b=2, c=3).

The categorization of the time use data used in the analysis is shown in Table 5. As the original study design was conducted for different purposes[21], other categories/activities than the used ones would have been better for the purpose of this study.[22] The original activity data is grouped in different categories. Due to the focus on *pc use*, one category contains all time spent on working with the computer. Unfortunately the housework category does not allow distinguishing between different household chores. Most activity categories are pretty straight forward. Both *leisure outside* and *hobbies* contain however a set of quite contrasting types of activities with potential different energy intensities.

[19] The questionnaire was filled out by 1590 people over more than one year.

[20] Question H45 in wave 1 and H32 in wave 2 and 3 respectively. (Brynin 2002: User Guide Vol. 2.)

[21] Gershuny (2002), for example uses the data to study social behavior of internet users.

[22] An allocation of travel time to different activities would be possible, if the purpose of the travel would be included in the time use data.

The time use was coded in variables (w)wprim and (w)wsec and the respective code digit, accounting for weekly time spent on the activities as a primary or secondary activity. Time spent in activities as *total time* spent in activities is the prime focus. However, each secondary and primary time spent in an activity class is analyzed for comparison as well, as this could highlight differences between activities people are actively engaged with and background activities.

| New Code | Categories | Activities | Data-code |
|---|---|---|---|
| 1 | Sleep | Sleeping, resting | 1 |
| 2 | Personal Care | Washing, dressing | 2 |
| 3 | Meals at home | Eating at home | 3 |
| | | Cooking, food preparation | 4 |
| 4 | Care-taking | Care of won children or other adults in own home | 5 |
| 5 | Housework | Cleaning, tidying, clothes washing, ironing, sewing | 6 |
| | | Maintenance, odd jobs, DIY, gardening, pet care | 7 |
| 6 | Travel time | Travel (to and from work, shops, school, cinema, station, etc.) | 8 |
| 7 | Shopping | Shopping and appointments | 14 |
| 8 | Paid Work | Paid work at workplace | 9 |
| | | Paid work at home without PC | 10 |
| 9 | Studying | Study at home without PC | 11 |
| | | Education outside home | 12 |
| 10 | PC Use | PC-games | 28 |
| | | PC-email | 29 |
| | | Internet use | 30 |
| | | Study at home with PC | 31 |
| | | Work at home with PC | 32 |
| | | Other | 33 |
| 11 | Hobbies | Hobbies, games | 20 |
| 12 | TV | TV | 21 |
| 13 | Video | Video | 22 |
| 14 | Listening | radio, CD, etc. | 23 |
| 15 | Reading | Reading books, newspaper, etc. | 24 |
| 16 | Phones | Phone calls received | 26 |
| | | Phone calls made | 27 |
| 17 | Eating out | Eating out | 17 |
| 18 | Leisure outside | Concerts, etc. | 15 |
| | | Walks | 16 |
| | | Visits | 18 |
| | | Sport activities | 19 |
| 19 | Other | Voluntary work | 13 |
| | | Being visited | 25 |
| | | Doing nothing | 34 |
| | | Other | 35 |

Table 5: Activity Classes (Recoded from HomeOnline Study).

# 8. Results

## 8.1 Energy intensities of activities per time

Analyzing the different activity categories for total energy inputs required per hour shows that quite significant differences in the energy intensity per time exist. Table 6 gives a summary of the results providing figures on energy intensity per time, total time use, and total energy demand as well as direct and indirect demand separately. Figure 7 provides an overview of the energy intensities per time. The categories *paid work*, *shopping* and *others* are left out as no energy intensities were calculated. *Sleep* is not depicted in the figures as well as its energy demand and intensity is zero.

Grouping the activities in three categories according to their energy intensity per time, a first **high intensity group** (energy intensity of 3 kWh/h or higher) consists of both activities connected to food – *eating outside* and *meals at home* – *travel time*, two categories consisting of a variety of different activities – *hobbies* and *leisure out* – and *housework*. Surprisingly *housework* is at the end of the list with just over 3 kWh per hour. The first three activities in this group represent those categories with - by far - the highest energy intensity in this analysis. The third highest *meals at home* with an energy intensity of roughly 15,56 kWh/h is followed by the fourth activity *hobbies* with an intensity of 5,68, opening up a gap of nearly 10 kWh/h between these activities.

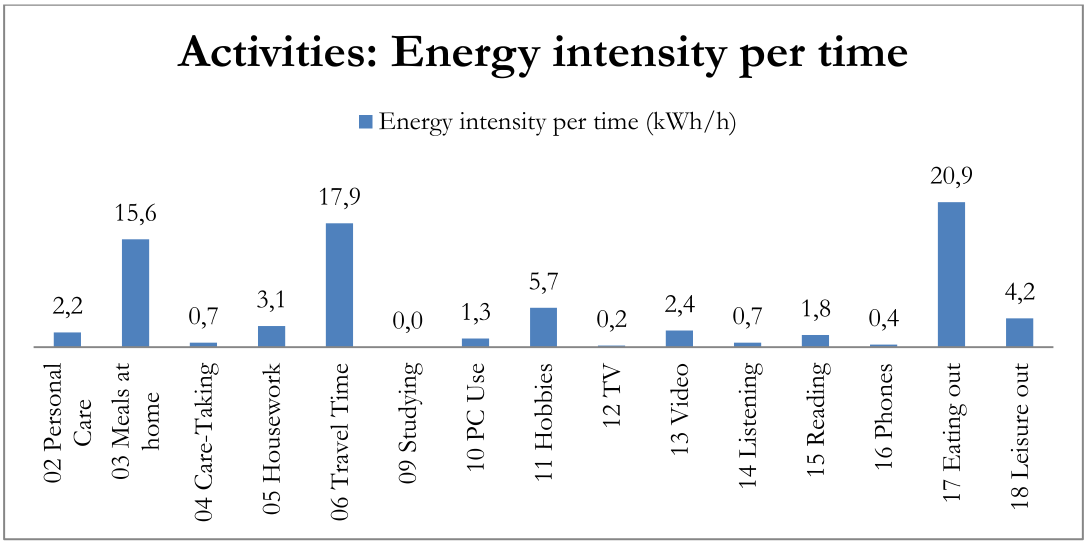


Figure 7: Energy intensity per time (kWh/h) for each activity class.

A **second middle-intensity** group (1-3 kWh/h) includes *video*, *personal care*, *reading*, *pc use*. Here the range is not as wide as in the previous group. *Video watching* is at the top with an intensity of roughly 2,41 kWh/h, closely followed by *personal care* (2,16 kWh/h) and *reading* (1,77 kWh/h). The category *pc use* has the lowest intensity with 1,27 kWh/h. Last, a **low-intensity group** (0-1 kWh/h) comprises of *care-taking*, *listening*, using *phones*, watching *TV*, *studying* and *sleep*. The latter two have no or nearly no energy intensity connected to it. *Phones* and *TV* (0,39 resp. 0,24 kWh/h) are in the middle range of the group. Both *care-taking* and *listening* are in the top section of this group with an energy intensity of 0,69 kWh/h and 0,68 kWh/h respectively.

Looking at the total energy demand of each activity disaggregated for direct and indirect energy demand shows that direct energy inputs into a household system are far lower than indirect energy consumption. Exceptions are *travel time* and *TV* watching, which both have a higher direct energy demand. Figure 8 shows the different energy demands.

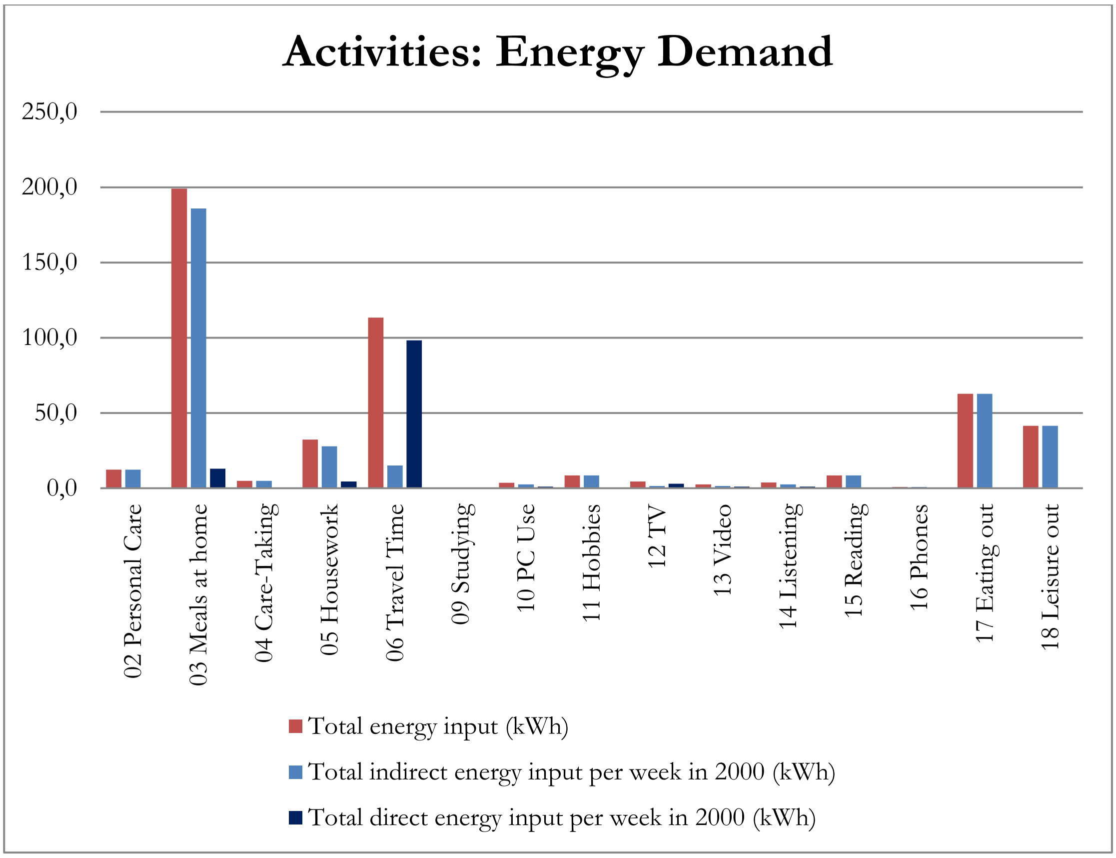


Figure 8: Total (red), total indirect (blue) and total direct (black) energy input used in an activity class in a week (kWh).

Analyzing both activities connected to eating, preparing a *meal at home* has a larger total energy demand connected to it, but a lower energy intensity per time contrasting *eating out*side of the home.

Interestingly, although lots of appliances are used in the *housework* category and it has the third highest direct energy input next to *travelling* and *meals at home*, it's at the lower end of the high-intensity group. More so, while *housework* has a large total energy demand compared to other activities from the middle-intensity group, the gap is closing when looking at energy intensities due to a large amount of time spent in *housework*. Next to *sleeping*, *studying* is the activity with both the lowest absolute energy consumption and the lowest energy intensity.

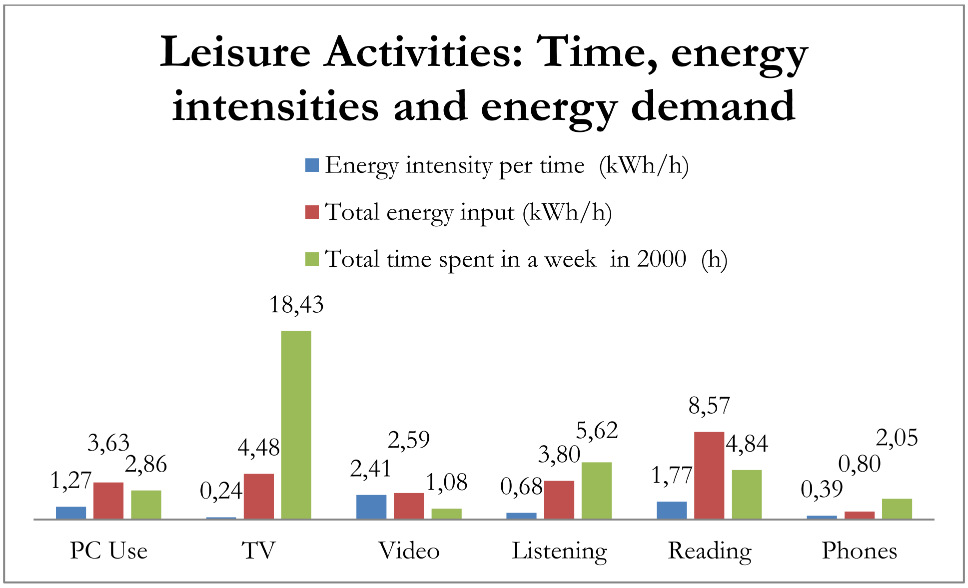


Figure 9: Energy intensity (blue), total energy input (red) and total time invested (green) in a week for specific leisure class activities.

Comparing leisure time activities not included in the categories *hobbies*, *leisure out* or *eating out* (Fig. 9), i.e. *pc use*, *TV*, *video*, *listening*, *reading* and *phones*, highlights that *video* watching is the activity with the highest intensity by far (2,41 kWh/h). However, it also has a very low total energy demand. *Reading* and *pc using* stand out as both having a higher energy intensity (1,77 resp., 1,27 kWh/h) and a higher energy demand than the other activities. *Listening* to audio devices has an average total energy demand, but a low energy intensity. Interestingly, the category *TV* watching (0,24 kWh/h) is at the lowest end in regard to energy intensities in general. But, it is also the activity, which stands out as having the highest amount of time invested in it with an average total energy demand considering this class of leisure activities and a low total energy demand considering all activities. Using the *phone* is on the lower end of both total energy consumption and energy intensities. Regarding the high-intensity group three activity categories claim a larger amount of time per week than others. *Meals at hom*e, *housework* and *leisure out* together account for 33,24 h of a week, meaning 30% of the waking hours. *Eating out* on the other hand takes up a rather low amount of time with 3 hours per week. Interestingly, *TV* watching has the second highest amount of time attributed to it and at the same time has the forth lowest energy intensities of all the activities.

Distinguishing between activities, which are considered household chores (*personal care, meals at home, care-taking, housework, studying*) and activities belonging to leisure time (*hobbies, reading, pc use, video, listening, TV, phones, eating out, leisure out*) some interesting results can be seen (Fig. 10).

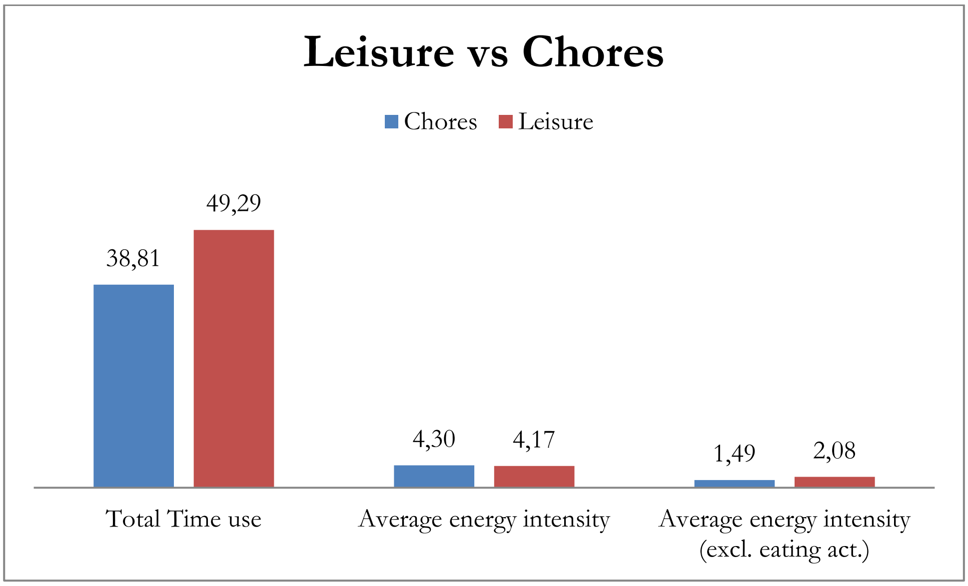


Figure 10: Comparison between leisure activities (red) and household chores (blue) according to total time use, avg. energy intensity and avg. energy intensity excluding eating out resp. meals at home.

Household chores are characterized by an average energy intensity of 4,30 kWh per hour, while leisure activities have an intensity of 4,17 kWh/h, thus having a rather similar energy intensity. Excluding both eating activities due to their exceptionally high intensity, the average intensity of household chores reaches 1,49 kWh/h, while leisure activities reach 2,08 kWh/h. At the same time leisure activities and household chores account for roughly 49,29 hours (46, 29 excl. *eating out*) resp. 38,8 hours (26,01 hours excl. *meals at home*) spent in a week. However the high intensity activity *travel time* has not been allocated to specific activities and *shopping* time is not featured in the analysis of energy intensities, which might heighten the average intensity of household chores. In sum household chores are responsible for a total energy demand of 248,82 kWh, while leisure time activities account for only 136,7 kWh; meaning 49,9% resp. 27,4 % regarding total energy demand of all household activities.

| Activities classes | Total time spent in a week in 2000 (h) | Total indirect energy input per week in 2000 (toe) | Total direct energy input per week in 2000 (toe) | Total energy input (toe) | Energy intensity per time (toe /h) | Energy intensity per time (kWh/h) |
|---|---|---|---|---|---|---|
| **01 Sleep** | 59,99 | 0 | 0 | 0 | **0** | **0** |
| **02 Personal Care** | 5,75 | 0,001068 | 0 | 0,001068 | **0,000186** | **2,159290** |
| **03 Meals at home** | 12,79 | 0,015986 | 0,001126 | 0,017111 | **0,001338** | **15,557074** |
| **04 Care-Taking** | 7,19 | 0,000419 | 0,000000 | 0,000419 | **0,000058** | **0,678530** |
| **05 Housework** | 10,54 | 0,002402 | 0,000388 | 0,002790 | **0,000265** | **3,076592** |
| **06 Travel Time** | 6,34 | 0,001293 | 0,008451 | 0,009744 | **0,001536** | **17,866390** |
| **07 Shopping** | 3,94 | - | - | - | **-** | **-** |
| **08 Paid Work** | 19,86 | - | - | - | **-** | **-** |
| **09 Studying** | 2,53 | 0,000007 | 0 | 0,000007 | **0,000003** | **0,032117** |
| **10 PC Use** | 2,86 | 0,000224 | 0,000089 | 0,000312 | **0,000109** | **1,270451** |
| **11 Hobbies** | 1,51 | 0,000738 | 0 | 0,000738 | **0,000489** | **5,684507** |
| **12 TV** | 18,43 | 0,000126 | 0,000260 | 0,000385 | **0,000021** | **0,243248** |
| **13 Video** | 1,08 | 0,000124 | 0,000099 | 0,000223 | **0,000207** | **2,408906** |
| **14 Listening** | 5,62 | 0,000227 | 0,000099 | 0,000327 | **0,000058** | **0,676389** |
| **15 Reading** | 4,84 | 0,000737 | 0 | 0,000737 | **0,000152** | **1,772397** |
| **16 Phones** | 2,05 | 0,000069 | 0 | 0,000069 | **0,000034** | **0,390860** |
| **17 Eating out** | 3,00 | 0,005392 | 0 | 0,005392 | **0,001796** | **20,891256** |
| **18 Leisure out** | 9,91 | 0,003571 | 0 | 0,003571 | **0,000360** | **4,191005** |
| **19 Others** | 6,85 | - | - | - | **-** | **-** |

Table 6: Energy intensities per time in toe/h and kWh/h, as well as total time spent, energy input (total, indirect and direct) per week for each activity class.

## 8.2 Patterns of change

For *adopters* and *Non-adopters* average short term changes in time use are analyzed and depicted in the following paragraphs. The analysis distinguishes between differences in total time use and time use regarding primary activities resp. secondary activities only. Furthermore differences according to gender, age and household size are looked at.

The changes in time use considering all time spent in activities are shown in Table 7. Six activities show a highly significant t-value (p< 0,01): *Sleep, personal care, meals at home, travel time, paid work, studying, pc use*, while a significant t-value (p< 0,05) exists for two activities, namely *TV* watching and *shopping*. Looking just at these activities, the hypothesis that a significant difference in the mean values of time use changes between *PC-adopters* and *Non-adopters* holds. Interestingly, just one activity attributable to leisure activities – *TV* watching – has a significant t-value.

| **Activities** | | **Adopters** | **Non-Adopters** | | |
|---|---|---|---|---|---|
| | N= | 165 | 489 | | |
| | | **mean** | **mean** | **Sig (2-tailed)** | **Diff.** |
| **Sleep** | | -2,5697 | 0,6933 | 0,001** | **-3,263** |
| **Personal Care** | | -0,4803 | 0,8246 | 0,000** | -1,3049 |
| **Meals at home** | | -2,3061 | 1,0317 | 0,000** | **-3,3378** |
| **Care-Taking** | | -0,847 | 0,2894 | 0,571 | -1,1364 |
| **Housework** | | -0,0061 | 1,2275 | 0,252 | -1,2336 |
| **Traveltime** | | 2,2894 | -0,2546 | 0,000** | **2,5440** |
| **Shopping** | | -1,1212 | -0,0726 | 0,014* | -1,0486 |
| **Paid Work** | | 8,9424 | -0,3517 | 0,000** | **9,2941** |
| **Studying** | | 3,0091 | -1,5567 | 0,000** | **4,5658** |
| **PC Use** | | 4,1682 | -0,7679 | 0,000** | **4,9361** |
| **Hobbies** | | -0,4364 | 0,0818 | 0,395 | -0,5182 |
| **TV** | | 2,0682 | -0,6442 | 0,013* | **2,7124** |
| **Video** | | -0,4939 | 0,0291 | 0,098 | -0,5230 |
| **Listening** | | 1,8348 | 0,6856 | 0,253 | 1,1492 |
| **Reading** | | -0,5848 | 0,4652 | 0,084 | -1,0500 |
| **Phones** | | 0,3076 | 0,2255 | 0,847 | 0,0821 |
| **Eating out** | | 0,5288 | 0,5639 | 0,941 | -0,0351 |
| **Leisure Outside** | | -0,2561 | -0,2260 | 0,977 | -0,0301 |
| **Other** | | -0,5864 | 1,6907 | 0,101 | **2,2771** |

Table 7: Results from independent T-Tests showing differences in total time use between *adopters* and *Non-adopters* according to each activity class. Significance levels: p< 0,05*; p< 0,01**.

Within the remaining activities with a significant t-value, *personal care*, *meals at home*, *shopping* and *studying* can be attributed to household chores, leaving *sleep* and *travel-time* as activity categories not included in either chores or leisure.

The next figure 11 provides the direction of change in the various activity categories distinguishing between *adopters* and *Non-adopters*. In 14 of 19 activities the direction of change is the opposite comparing *adopters* and *Non-adopters*. While quite big differences exist within some activities – *sleep, meals at home, travel-time, paid work, studying, pc use, TV* watching, and *others*, they are less prominent (*personal care, care-taking, housework)* to marginal in others *(hobbies, video, reading)*.

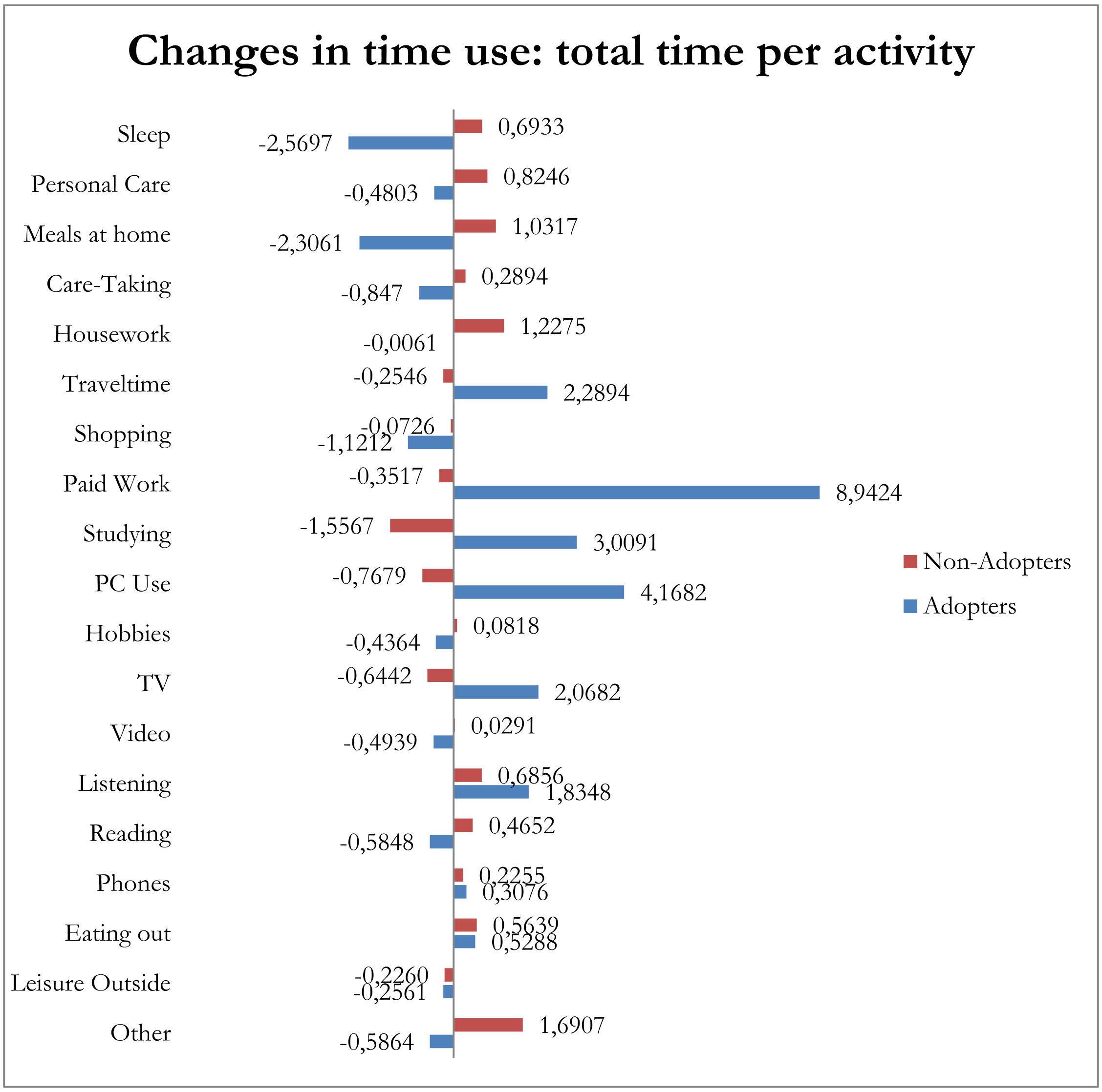


Figure 11: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red).

The remaining five activities demonstrate changes in the same direction by both *adopters* and *Non-adopters*. Time spent with *shopping* and *leisure outside* has decreased, while time invested in *eating out,* using *phones,* and *listening* has increased. In contrast to the other three, the scale of time spent in *shopping* and *listening* show some considerable differences.

Within activities featuring opposing directions of change, what stands out is that *adopters* work 8,94 hours longer than before getting a personal computer. At the same time *Non-adopters* decreased their time spent in paid work by 0,35 hours, a difference of 9,29 hours a week. Similar *adopters* study 3 hours more per week and travel 2,89 hours more. In contrast, *Non-adopters* spent 1,56 hours resp. 0,25 hours less per week on these activities; resulting in differences of 4,57 and 2,54 hours.

Considering leisure activities, *pc use* and *TV* watching stand out, as both increased within *adopters* by 4,19 resp. 2,07 hours per week and decreased within *Non-adopters* by 0,77 resp. 0,64 hours. The *listening* activity shows quite a large increase for *adopters* with an additional 1,83 hours in a week. But this growth in time use is partly paralleled with an increase in the *Non-adopters* group with 0,69 hours.

A reverse directionality of change – a decrease in *adopters*' and an increase in non-*adopters'* time – is happening in following activity categories. *Sleep*, *personal care* and *meals at home* saw a decrease of time spent by *adopters*. They slept 2,57 hours less, spent nearly half an hour less on *personal care* and 2,3 hours less on preparing and eating *meals at home.* This direction is contrasted by an increase in additional time spent by *Non-adopters*, who *slept* 0,69 hours more, spent 0,82 hours more on *personal car*e and 1,03 hours more on *meals at home*.

In general the changes in the non-adopting group are less pronounced than in the adopting group.

*Eating out*, *hobbies* and *leisure out* as part of high-intensity activities show nearly no differences between *adopters* and *Non-adopters*. *Housework* saw an increase of 1,23 hours in the *Non-adopters* group, with a fairly constant time use considering *adopters* (-0,01h). It's the reverse with *travel* activities as here *adopters* contrast the non-adopting time change with additional 2,54 hours. Only *meals at home* stands as the sole high intensity activity with a significant time use change. The middle-intensity activities show few changes in their time use. Adopters decrease their time spent in *video*, *personal care* and *reading* (0,49h, 0,48h, 0,58h), while *Non-adopters* increase theirs (0,03h, 0,82h, 0,47h). Only pc use demonstrates a larger change, as *adopters* and *Non-adopters* have a plus of 4,17 hours and a minus 0,77 hours respectively, reaching a difference of 4,94 hours.

More interesting is the low-intensity group, where *sleep* and *studying* indicate a large difference between *adopters* and *Non-adopters* albeit in different directions. *TV* watching is considerably increased by *adopters* being one of the activities showing a larger time difference with more than two hours (2,71h); *listening*, care-taking show a marginal difference, and *phones* nearly no difference at all.

Considering the impact of personal computers in the household on time use, it seems like an increased time spent on *pc use* due to the adoption of a pc, correlates with decreasing time spent in some household chores. It has to be said however, that *housework* and *care-taking* don't change too much at all, and show no significant t-values. There exists a connection between having a personal computer and a large increase in *paid work*, *study* time and *travelling* time, featuring highly significant t-values. The same is true for the chores *meals at home* and *personal care,* where the former possesses a high absolute difference in time use. At the same time, difference within leisure activities – with the exception of the activities *TV* watching and *reading* – are less distinct, with the time use more or less constant in most leisure activities.

The next table (8) and two figures (12, 13) distinguish between time spent in activity categories separating primary and secondary activities.

For time spent in primary activities some trends appear to be similar; the same activities show significant difference between *adopters* and *Non-adopters* regarding mean time use changes. *Paid work*, *studying*, *travel time*, *pc use* and *TV* watching still demonstrate a major increase in time use regarding *adopters* and a decrease in the *Non-adopters* group. However, the difference is even larger analyzing primary activities in the case of *TV* watching, as *Non-adopters* use 1,53 hours less for watching *TV* as a primary activity, while *adopters* invest 3 hours more, totaling a difference of 4,53 hours. Similar, *personal care* and *care-taking* both suggest similar trends as described before, but the scale of time invested by *adopters* decreased even further; 3,12 resp. 2,76 in contrast to 0,48 resp. 0,85 hours.

| Activities | Adopters | Non-Adopters | | Adopters | Non-Adopters | |
|---|---|---|---|---|---|---|
| n | 165 | 489 | | 165 | 489 | |
| | mean (prim) | mean (prim) | Sig (2-tailed) | mean (sec) | mean (sec) | Sig (2-tailed) |
| **Sleep** | -2,1864 | 0,568 | 0,005** | -0,3833 | 0,1253 | 0,010* |
| **Personal Care** | -3,121 | 0,7929 | 0,000** | -0,1682 | 0,0317 | 0,027* |
| **Meals at home** | -1,3045 | 1,0123 | 0,002** | -1,0015 | 0,0194 | 0,000** |
| **Care-Taking** | -2,7591 | -0,6437 | 0,162 | 1,9121 | 0,933 | 0,34 |
| **Housework** | 0,297 | 1,0767 | 0,433 | -0,303 | 0,1508 | 0,157 |
| **Traveltime** | 2,4576 | -0,317 | 0,000** | -0,1682 | 0,0624 | 0,05* |
| **Shopping** | -0,9 | -0,0573 | 0,043* | -0,2212 | -0,0153 | 0,066 |
| **Paid Work** | 9,0182 | -0,3098 | 0,000** | -0,0758 | -0,0419 | 0,791 |
| **Studying** | 3,0091 | -1,5337 | 0,000** | 0 | -0,023 | 0,664 |
| **PC Use** | 3,2803 | -0,6892 | 0,000** | 0,8879 | -0,0787 | 0,000** |
| **Hobbies** | 0,0379 | -0,0199 | 0,896 | -0,4742 | 0,1017 | 0,006* |
| **TV** | 3,0091 | -1,5337 | 0,000** | -0,9409 | 0,8896 | 0,001** |
| **Video** | -0,35 | 0,0639 | 0,138 | -0,1439 | -0,0348 | 0,325 |
| **Listening** | -0,6924 | -0,0516 | 0,06 | 2,5273 | 0,7372 | 0,052 |
| **Reading** | -0,2712 | -0,0394 | 0,624 | -0,3136 | 0,5046 | 0,014* |
| **Phones** | 0,3136 | 0,489 | 0,1708 | -0,0061 | 0,0547 | 0,857 |
| **Eating out** | 0,3318 | 0,681 | 0,5204 | 0,197 | 0,0435 | 0,087 |
| **Leisure Outside** | 0,3 | 0,0097 | 0,777 | -0,2242 | 0,2848 | 0,209 |
| **Other** | -0,8818 | 1,2076 | 0,071 | 0,6091 | 0,6539 | 0,951 |

Table 8: Results from independent T-Tests showing differences in time use between *adopters* and *Non-adopters* according to each activity class, distinguishing between primary and secondary activities. Significance levels: p<0,05*; p<0,01**.

Interestingly *listening* decreased in the *adopters* and *Non-adopters* group, although it increased when looking at total time use. The opposite happened in the *leisure outside* activity. Apparently *listening* is more of a secondary activity, while *leisure out* is an activity one has to be actively engaged with.

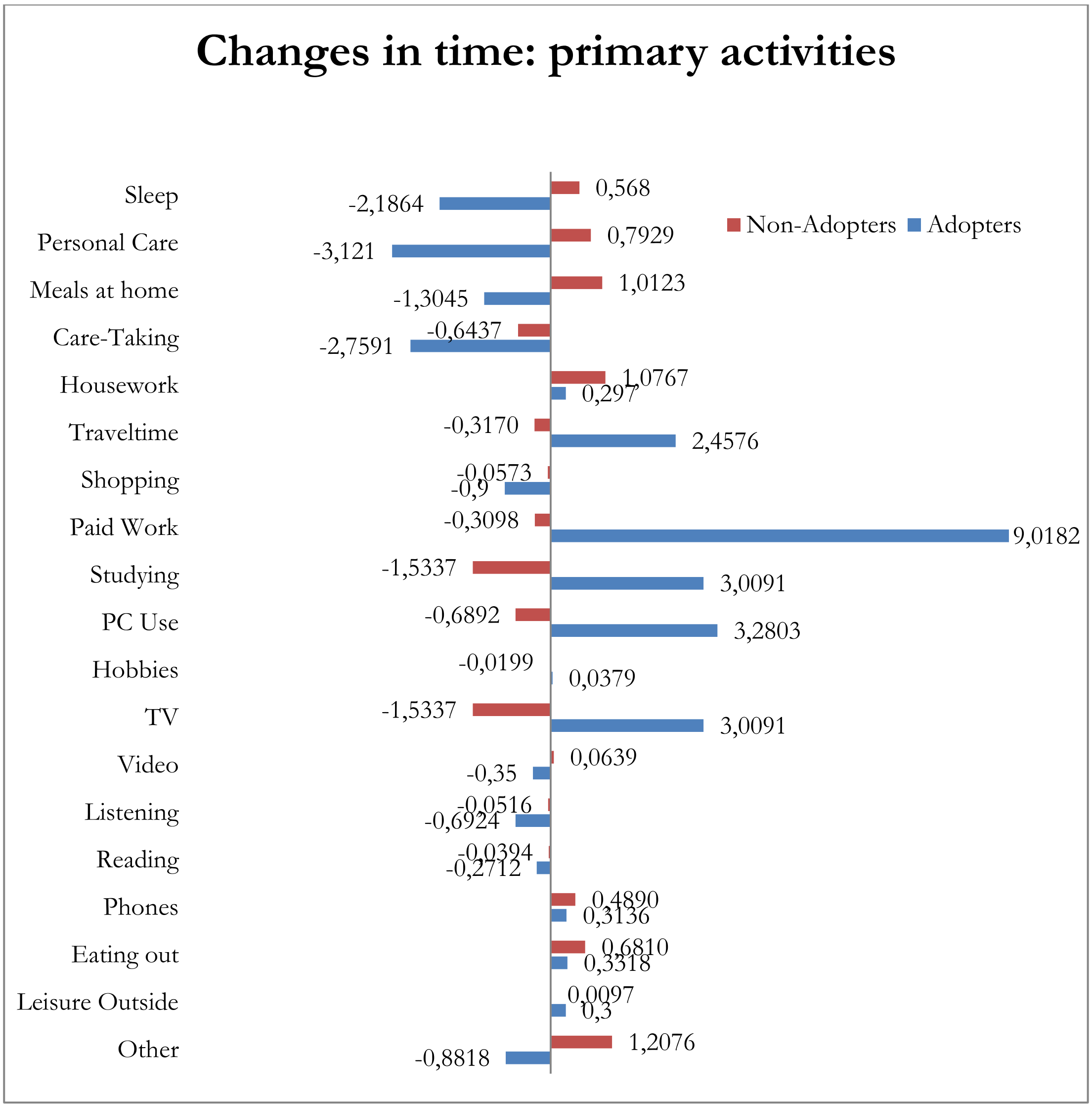


Figure 12: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Primary activities only.

Looking at time use regarding secondary activities, fewer activities show a significant difference in mean values. Regarding total time use, *paid work, studying* and *shopping* all show significant differences. These activities also demonstrate nearly no changes in time use at all. However, both *reading* and *hobbies* now show a close correlation with the adoption of a personal computer.

In general, time use changes considering only secondary activities are less distinct. As has been mentioned, only the *listening* activity stands out with an increase of 2,52 hours in the *adopters* group and an increase of 0,74 hours in the *Non-adopters* group. Most activities show little difference between *adopters* and *Non-adopters* or are in line with the general trend. An exception is *care-taking*, which increases for both *adopters* and *Non-adopters* by 1,91h resp. 0,93h.

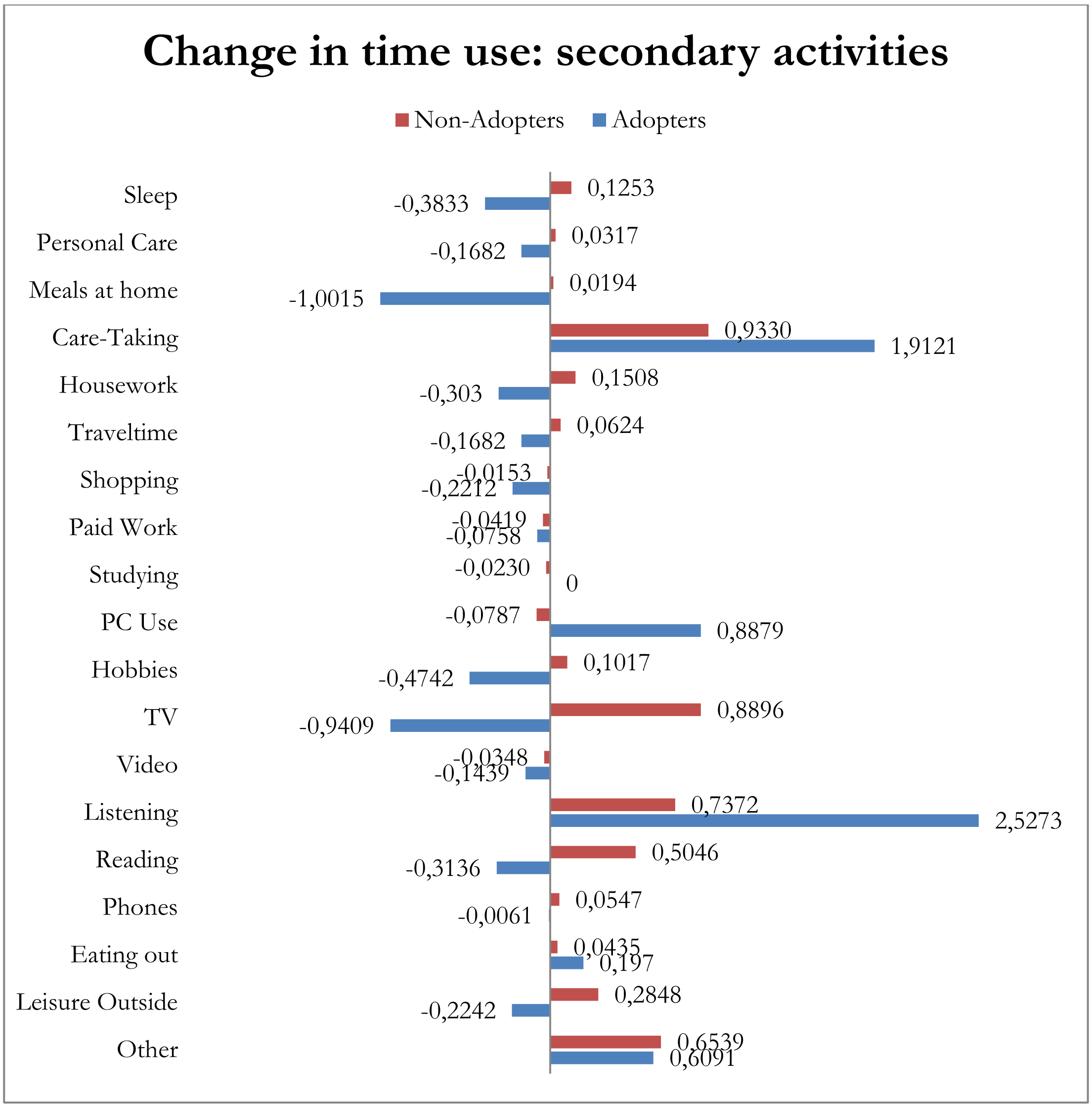


Figure 13: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Secondary activities only.

Interestingly *TV* watching shows an opposite trend to the general one as here the *adopters* group decreases the activity by 0,94h, while the *Non-adopters* increase their time by 0,89 hours. Equally *care-taking* as a secondary activity increases in both groups by 0,93 and 1,91 hours, while a decrease is happening when looking at primary activities.

A further analysis of possible gender differences (Tab. 9) shows some interesting distinctions between women (Fig. 14) and men (Fig.15) The same activities as in the general trend show significant t-values, with the exception of *shopping* in both gender groups and *TV* watching for women, which don't possess significant t-values in these subgroups.

| Activities | Adopters | Non-Adopters | | Adopters | Non-Adopters | |
|---|---|---|---|---|---|---|
| | female | Female | | male | male | |
| n | 87 | 238 | | 63 | 198 | |
| | mean | Mean | Sig (2-tailed) | mean | mean | Sig (2-tailed) |
| **Sleep** | -3,6149 | -0,354 | 0,015* | -1,869 | 2,048 | 0,029 |
| **Personal Care** | -0,8276 | 0,562 | 0,001** | -0,1429 | 1,2399 | 0,012* |
| **Meals at home** | -3,5948 | 0,1019 | 0,002** | -0,6111 | 2,4558 | 0,022* |
| **Care-Taking** | -2,3017 | -3,2952 | 0,749 | -0,1944 | 3,7083 | 0,105 |
| **Housework** | -0,8822 | -0,4254 | 0,758 | 0,7063 | 3,6654 | 0,092 |
| **Traveltime** | 2,8707 | 0,3046 | 0,003** | 1,4286 | -0,8965 | 0,042* |
| **Shopping** | -1,8448 | -0,8529 | 0,118 | -0,119 | 0,5997 | 0,221 |
| **Paid Work** | 10,6207 | 2,0231 | 0,007** | 9,1706 | -3,9962 | 0,001** |
| **Studying** | 2,1897 | -1,2679 | 0,015* | 3,4087 | -2,0732 | 0,002** |
| **PC Use** | 4,1207 | -0,1607 | 0,000** | 3,873 | -1,5379 | 0,000** |
| **Hobbies** | -0,5287 | -0,1513 | 0,691 | -0,0794 | 0,221 | 0,662 |
| **TV** | 0,8649 | -0,8729 | 0,269 | 3,2341 | -0,6477 | 0,014* |
| **Video** | -0,4339 | -0,0431 | 0,311 | -0,754 | 0,1528 | 0,132 |
| **Listening** | 2,1408 | 0,7857 | 0,369 | 2,9802 | 0,471 | 0,081 |
| **Reading** | 0,4914 | 0,0294 | 0,518 | -1,5913 | 0,0644 | 0,097 |
| **Phones** | 0,477 | 0,0116 | 0,388 | 0,3056 | 0,5644 | 0,727 |
| **Eating out** | 1,4971 | 0,9496 | 0,404 | -0,7222 | 4,507 | 0,175 |
| **Leisure Outside** | 1,5948 | 0,6092 | 0,492 | -2,1587 | -0,4975 | 0,328 |
| **Other** | -2,9626 | 2,1439 | 0,011 | 2,2579 | 1,399 | 0,669 |

Table 9: Results from independent T-Tests showing differences in time use between *adopters* and *Non-adopters* according to each activity class, distinguishing according to gender. Significance levels: p<0,05*; p<0,01**.

Additionally, general trends like the increase in *paid work*, *studying*, *pc use* and *travel time* hold. Interestingly however both adopting and non-adopting women work longer. Both gender groups *adopters* invest fewer hours in *sleep*. However, this change is more prominent in the female group (-3,61) than within its male counterpart (-1,87). This contrasts the non-adopting group, where males have 2,05 hours more *sleep*, while females keep the *sleep* more or less constant (-0,35).

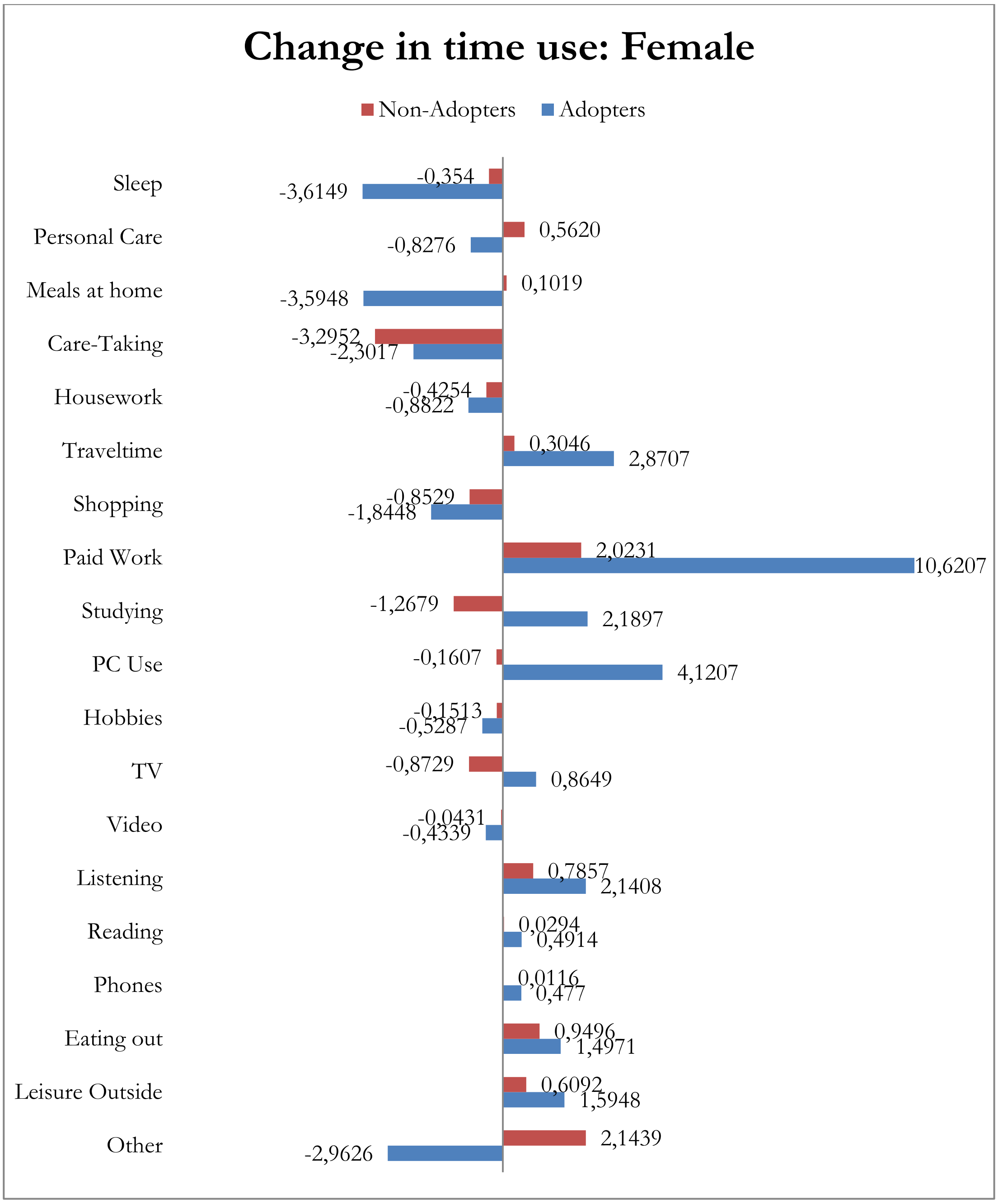


Figure 14: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Women only.

Looking at high-intensity activities non-adopting women spent just 0,1 hours more in *meals at home*, while female *adopters* decrease their time by 3,59 hours. *Eating out* lies in the general trend. The non-adopting male group stands out as adding quite some time to both eating activities, with an increase in *eating out* by 4,51 hours and in *meals at home* by 2,46 hours. *Housework* decreases for both female groups marginally (0,43h and 0,88h for *Non-adopters* and *adopters* resp.), while we see an increase for both male groups. Here the *Non-adopters* increase their time spent in *housework* by 3,67h and *adopters* by 0,71h.

Another difference turns up within the low-intensity activity *care-taking*, where non-adopting males increase their time by 3,71 hours, while *Non-adopters* decrease the time by 0,19 hours. Within the female group a general decrease in both *adopters* and *Non-adopters* happened (-3,3 hours resp. -2,3 hours)

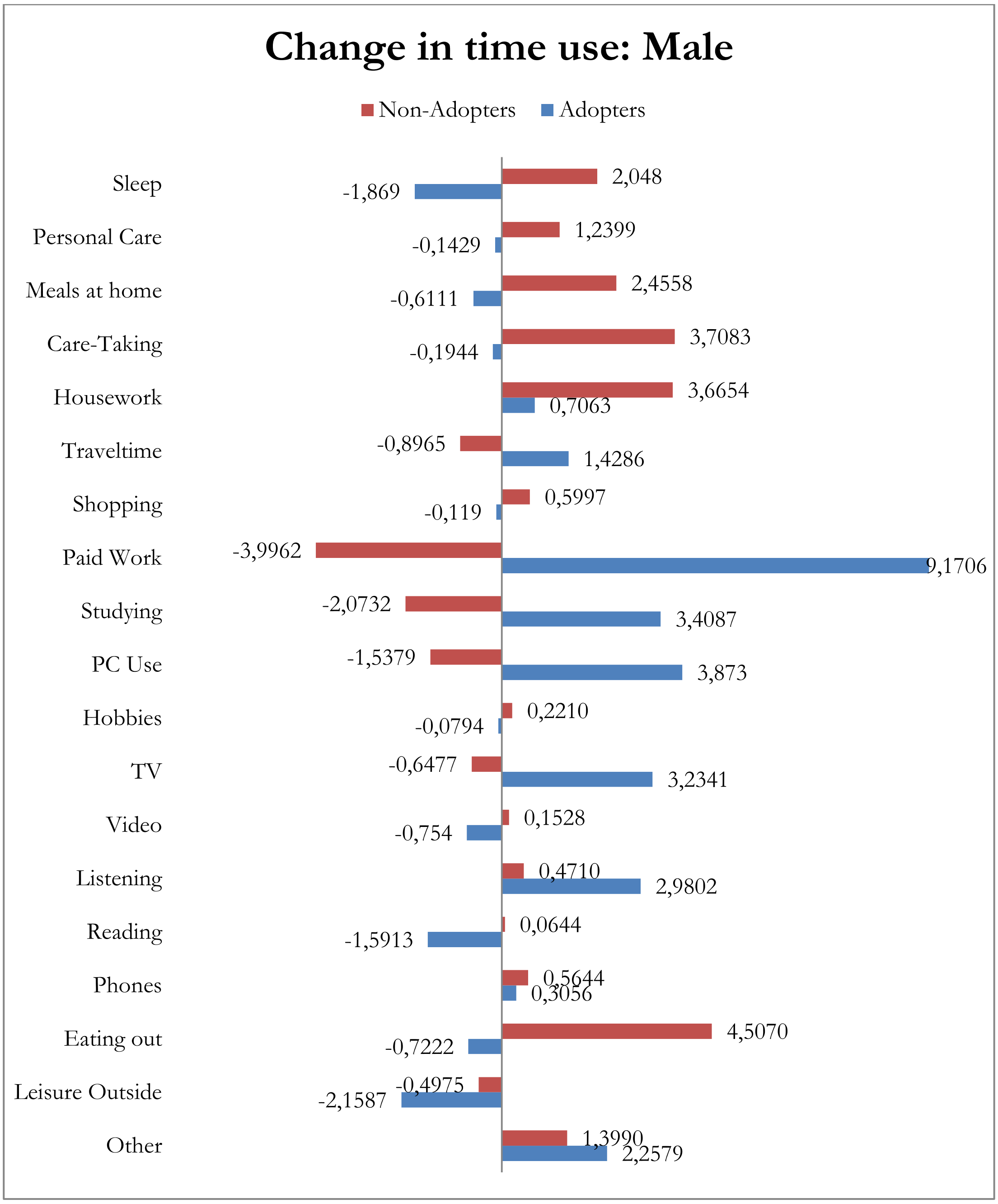


Figure 15: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Men only.

Generally the male group shows more distinct changes in the categories for *adopters* and *Non-adopters*. Interestingly, *Non-adopters* seem to increase their time invested in household chores (except studying) and sleep, while decreasing or keeping their time rather constant in leisure activities. An exception is the mentioned *eating out* category. Adopters demonstrate an opposite trend, as household chores and *sleep* tend to decrease or increase less (except again *studying*). However only some leisure activities tend to increase (*TV, pc use, listening, phones*) while other decrease (*video, reading, eating out, leisure outside*) or don't change much at all.

The female group on the other side keeps their leisure activities fairly constant; resp. changes happening are rather similar for *adopters* and *Non-adopters*. Exceptions are *pc use* and *TV* watching.

Making a distinction between small, middle and large households (Fig. 16-18), only the first group shows significant t-values in the same activities as with total time use.

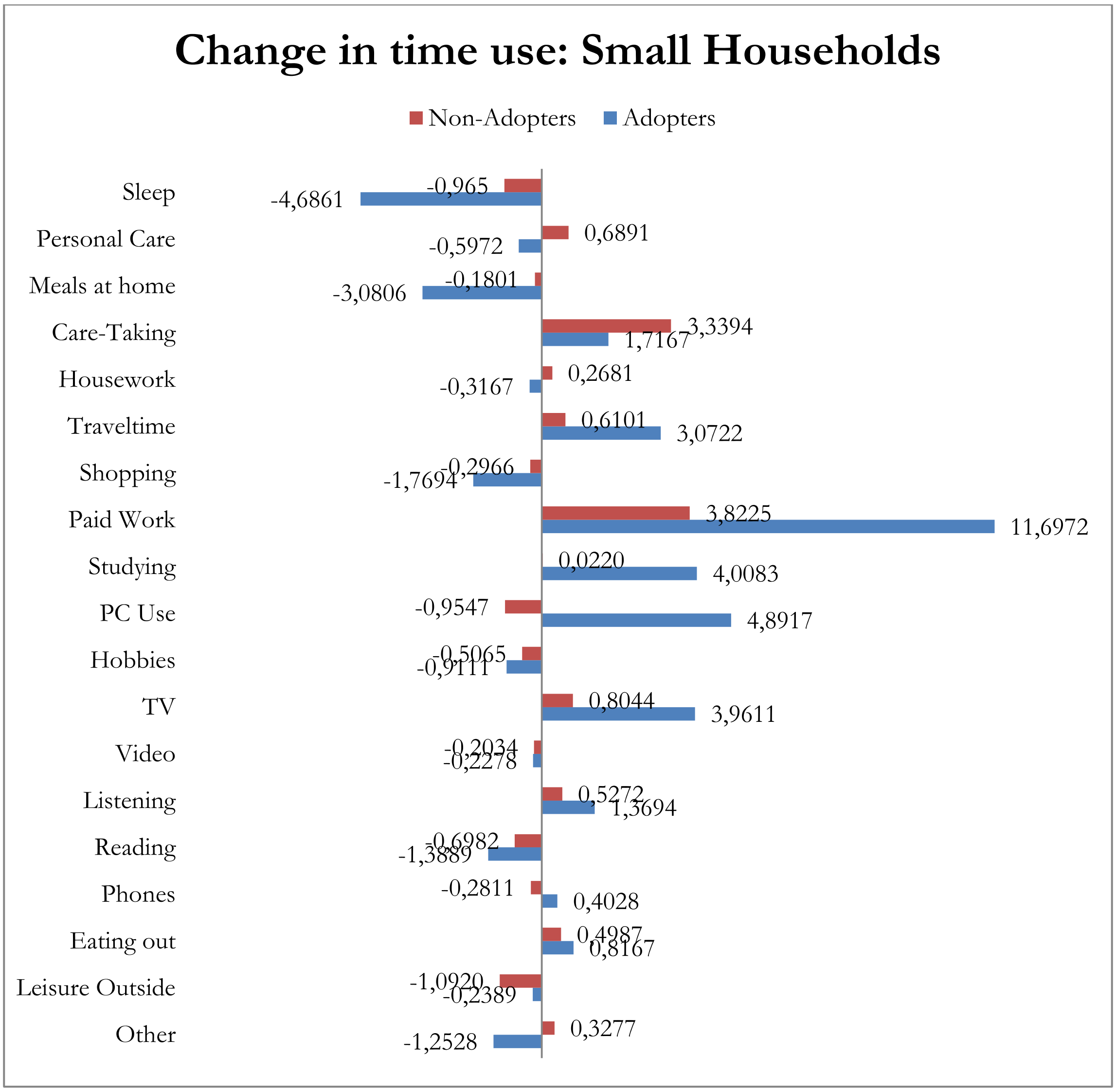


Figure 16: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Small households (1 or 2 inhabitants) only.

Within the other two, fewer activities possess a significant correlation with getting a personal computer. In middle-sized household only *personal care, meals at home, paid work, studying, pc use* and (in contrast to the general trend) *listening* demonstrate a significant difference between *adopters* and *Non-adopters*. In the biggest households only *meals at home*, *travel time* and *pc use* (and others) have significant t-values (Tab. 10).

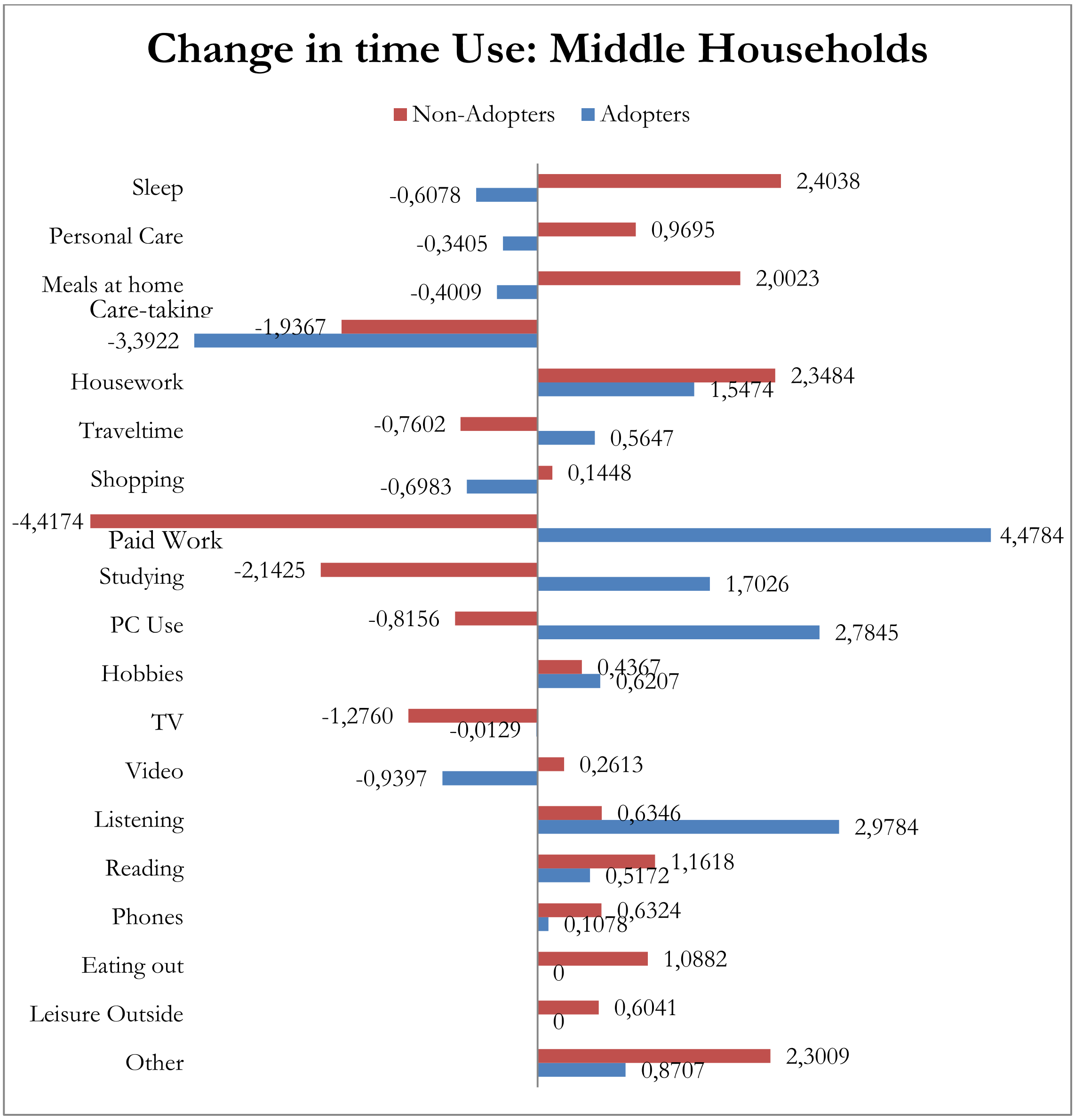


Figure 17: Comparison of time use changes in hours per week between *adopters* (blue) and *NNon-adopters* (red). Middle households (3 or 4 inhabitants) only.

Some activities feature interesting differences according to time use. Inhabitants of small households *sleep* 4,69 hours less; in middle-sized households 0,61 hours less. In big households however, *adopters sleep* 2,2 hours more. Non-adopting inhabitants in the middle-sized households *sleep* 2,4 hours more, while both other household-sizes show a slight decline in time invested in *sleep*.

*Care-taking* vastly differs between household sizes. While both big and middle households see a major decrease of time invested in this activity for *adopters* (5,77h resp. 3,39h) and a decisive decline for *Non-adopters* (1,74h resp. 1,94h), in small households more time is invested regardless whether *adopters* (1,72h) or *Non-adopters* (3,34h).

Interestingly, big households' inhabitants save 5,03 hours within the high-energy intensity activity *meals at home* when getting a pc, while *Non-adopters* add 1,18 hours to their *home meal* time. Small households and middle households parallel this development to some degree, albeit with different scales. In small households *adopters* save 3,08 hours and *Non-adopters* saving 0,18h, while in middle household only 0,4 hours are saved by *adopters*. But, in this case *Non-adopters* add 2 hours to their *meal time*.

While small households show a more or less equal change in time attributed to *housework*, big households have *adopters* investing 4,5 hours less in *housework*, while non-*adopters* invest 0,44 hours more. In middle class households time spent in *housework* however increases significantly for both *adopters* and *Non-adopters* (1,55h resp. 2,35h).

Big households demonstrate an untypically higher difference between *adopters* and *Non-adopters* with the former adding 4,38 hours to *travel time* and the latter subtracting 1,2 hours. Interestingly, while big and small households feature a major increase in *paid work* for *adopters* and only a slight increase for *Non-adopters*, middle-sized households' *adopters* in contrast work not that much more (still 4,48h) but *Non-adopters* decrease their working time by 4,42 hours.

Looking at *TV* watching which has one of the lowest energy-intensities and features a rather high increase in time use for *adopters* in general, within small households *adopters* seem to increase their *TV* watching time by such an amount, that its decrease in big and middle sized households seems to be compensated. Another low-intensity activity *listening* stands out as having a rather high increase for *adopters* within middle-sized households.

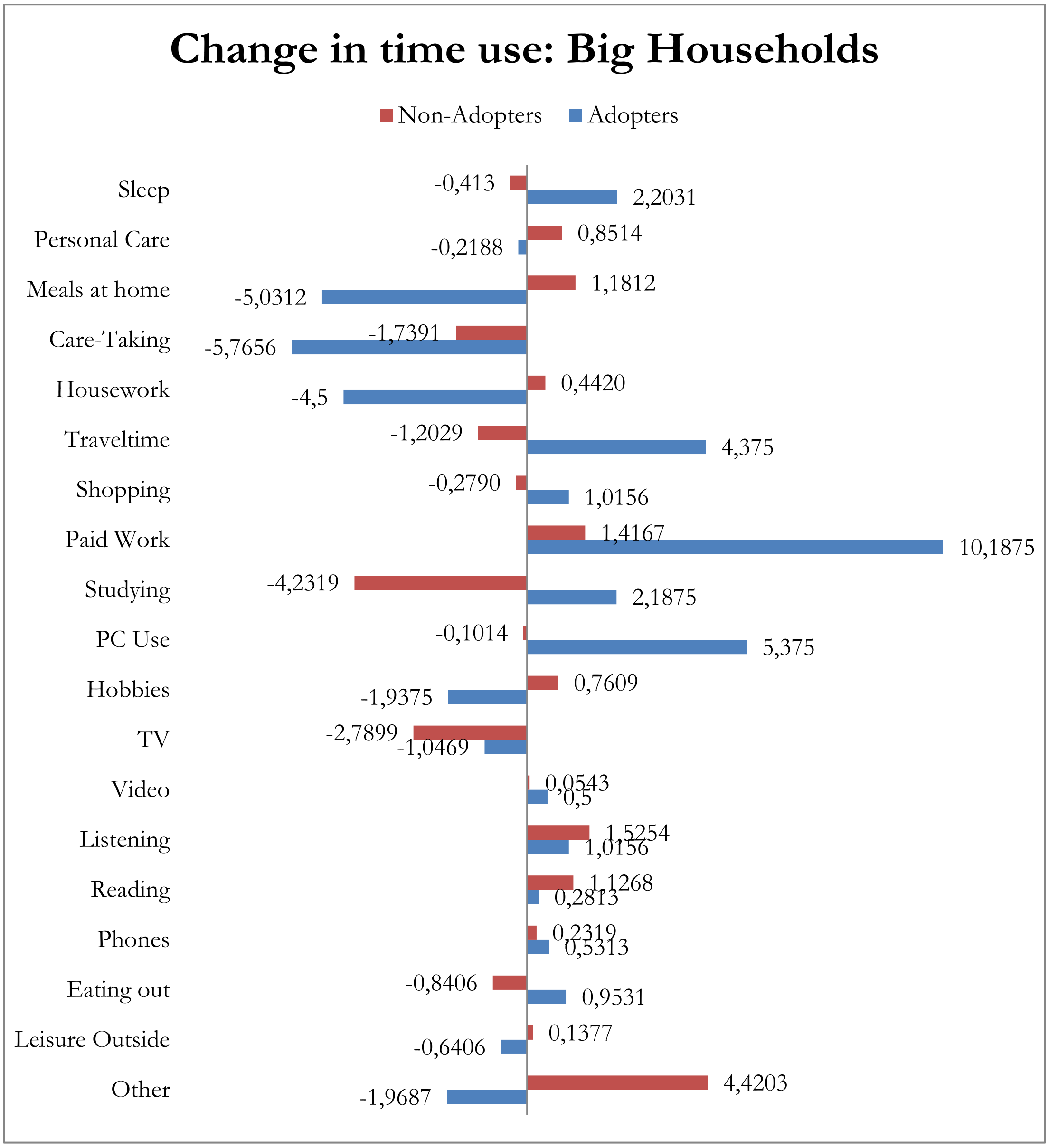


Figure 18: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Big households (5+ inhabitants) only.

Other activities don't show major deviations either from the general trend as well as from each other. However, it is interesting to notice that *adopters* in both *eating out* and *leisure outside* (two high-intensity activities) demonstrate no change at all in time use for middle sized households.

| Activities | Adopters | Non-Adopters | | Adopters | Non-Adopters | | Adopters | Non-Adopters | |
|---|---|---|---|---|---|---|---|---|---|
| | 90 | 193 | | 58 | 221 | | 16 | 69 | |
| | HSIZE 1 | | | HSIZE 2 | | | HSIZE 3 | | |
| | mean | mean | Sig (2-tailed) | mean | mean | Sig (2-tailed) | mean | mean | Sig (2-tailed) |
| **Sleep** | -4,6861 | -0,965 | 0,005** | -0,6078 | 2,4038 | 0,055 | 2,2031 | -0,413 | 0,278 |
| **Personal Care** | -0,5972 | 0,6891 | 0,004** | -0,3405 | 0,9695 | 0,004** | -0,2188 | 0,8514 | 0,33 |
| **Meals at home** | -3,0806 | -0,1801 | 0,017* | -0,4009 | 2,0023 | 0,036* | -5,0312 | 1,1812 | 0,02* |
| **Care-Taking** | 1,7167 | 3,3394 | 0,468 | -3,3922 | -1,9367 | 0,68 | -5,7656 | -1,7391 | 0,627 |
| **Housework** | -0,3167 | 0,2681 | 0,684 | 1,5474 | 2,3484 | 0,655 | -4,5 | 0,442 | 0,088 |
| **Traveltime** | 3,0722 | 0,6101 | 0,006** | 0,5647 | -0,7602 | 0,207 | 4,375 | -1,2029 | 0,014* |
| **Shopping** | -1,7694 | -0,2966 | 0,02* | -0,6983 | 0,1448 | 0,215 | 1,0156 | -0,279 | 0,269 |
| **Paid Work** | 11,6972 | 3,8225 | 0,023* | 4,4784 | -4,4174 | 0,018* | 10,1875 | 1,4167 | 0,26 |
| **Studying** | 4,0083 | 0,022 | 0,004** | 1,7026 | -2,1425 | 0,02* | 2,1875 | -4,2319 | 0,057 |
| **PC Use** | 4,8917 | -0,9547 | 0,000** | 2,7845 | -0,8156 | 0,000** | 5,375 | -0,1014 | 0,023* |
| **Hobbies** | -0,9111 | -0,5065 | 0,649 | 0,6207 | 0,4367 | 0,826 | -1,9375 | 0,7609 | 0,176 |
| **TV** | 3,9611 | 0,8044 | 0,033* | -0,0129 | -1,276 | 0,489 | -1,0469 | -2,7899 | 0,624 |
| **Video** | -0,2278 | -0,2034 | 0,957 | -0,9397 | 0,2613 | 0,031* | 0,5 | 0,0543 | 0,517 |
| **Listening** | 1,3694 | 0,5272 | 0,545 | 2,9784 | 0,6346 | 0,191 | 1,0156 | 1,5254 | 0,829 |
| **Reading** | -1,3889 | -0,6982 | 0,478 | 0,5172 | 1,1618 | 0,466 | 0,2813 | 1,1268 | 0,545 |
| **Phones** | 0,4028 | -0,2811 | 0,307 | 0,1078 | 0,6324 | 0,419 | 0,5313 | 0,2319 | 0,791 |
| **Eating out** | 0,8167 | 0,4987 | 0,586 | 0 | 1,0882 | 0,206 | 0,9531 | -0,8406 | 0,216 |
| **Leisure Outside** | -0,2389 | -1,092 | 0,597 | 0 | 0,6041 | 0,717 | -0,6406 | 0,1377 | 0,794 |
| **Other** | -1,2528 | 0,3277 | 0,488 | 0,8707 | 2,3009 | 0,475 | -1,9687 | 4,4203 | 0,001** |

Table 10: Results from independent T-Tests showing differences in time use between *adopters* and *Non-adopters* according to each activity class, distinguishing between different household sizes (1=small: 1 to 2 inhabitants; 2=middle: 3 to 4 inhabitants; 3=big: 5+inhabitants). Significance levels: $p<0,05$*; $p<0,01$**.

The analysis of different age groups (Tab. 11) shows that the group of people aged 50 to 65 (Fig.19) in general follows the trend. In fact this is the case for the significances as well as the general pattern of time changes. However the youngest (Fig. 20) and the middle aged group (Fig. 21) demonstrate some interesting deviations. In these groups only *pc use* has a significant t-value in both, and *paid work* in the middle aged group.

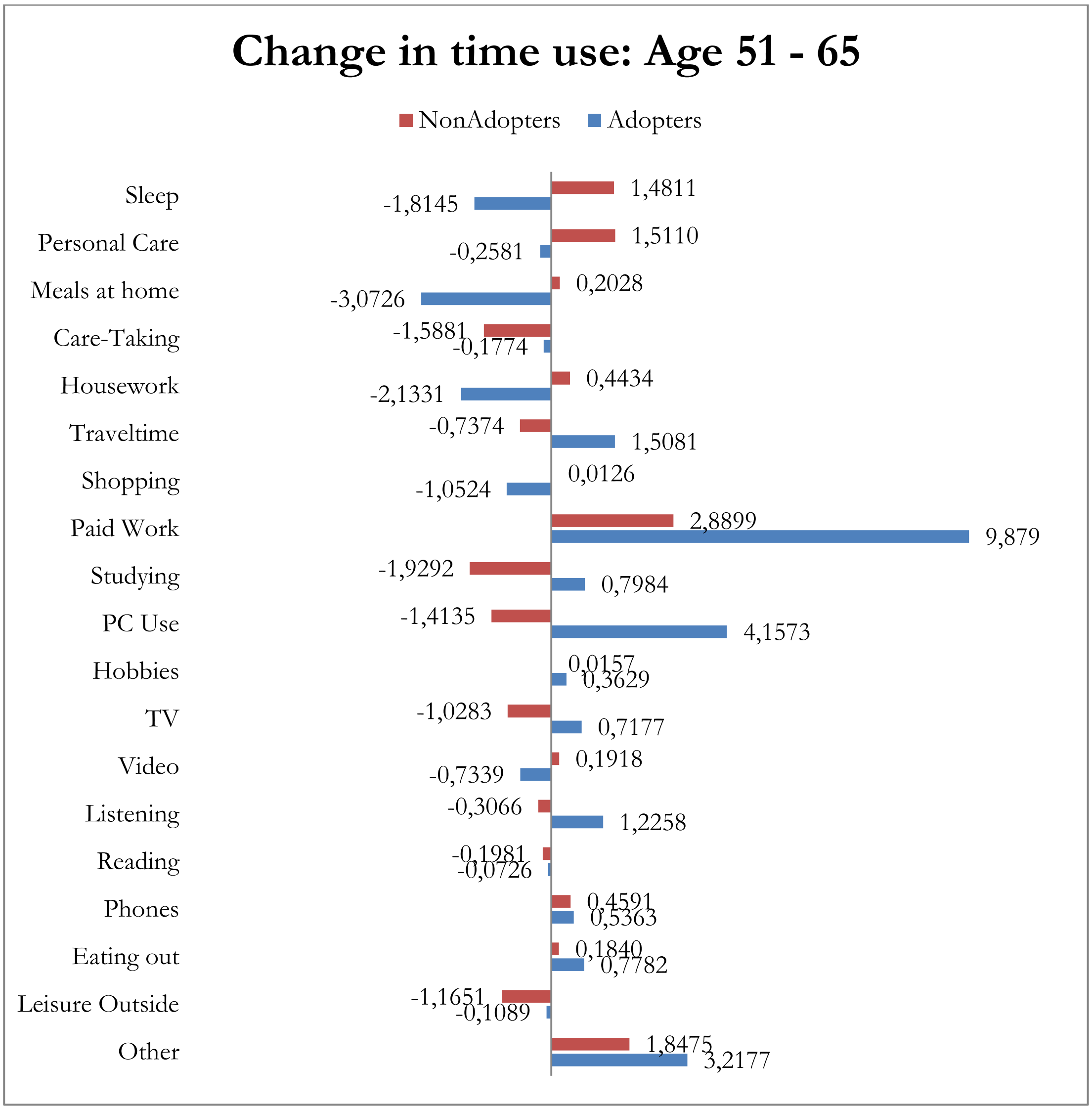


Figure 19: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Age group 3 (51-65) only.

The youngest group is the only one where *PC-adopters* add similar time to *sleeping* as the non-adopting group. In contrast *adopters* and *Non-adopters* between 35 and 50 decrease their *sleeping* time. This group also increases their time spent with *meals at home*. Again the trend is similar for *adopters* and *Non-adopters*, although the former increase their time more. This is against the general trend, which saw the *adopters* decreasing their *meals at home* time, while *Non-adopters* marginally increased theirs.

The youngest and the middle-aged group possess major differences between the *adopters* and the *Non-adopters* group in *care-taking*. Within people aged 35 to 50 *PC-adopters* spent 4,6 hours less on *taking care* of others, while *Non-adopters* spent 4,49 hours more in this activity; resulting in a difference of over 9 hours. The young demonstrate an even larger difference, as *adopters* decrease their time by 7,63 hours contrasting *Non-adopters*, who increase theirs by 6,59 hours; making a total difference of 14,23 hours. However *care-taking* shows no significant difference in mean values between *adopters* and *Non-adopters*.

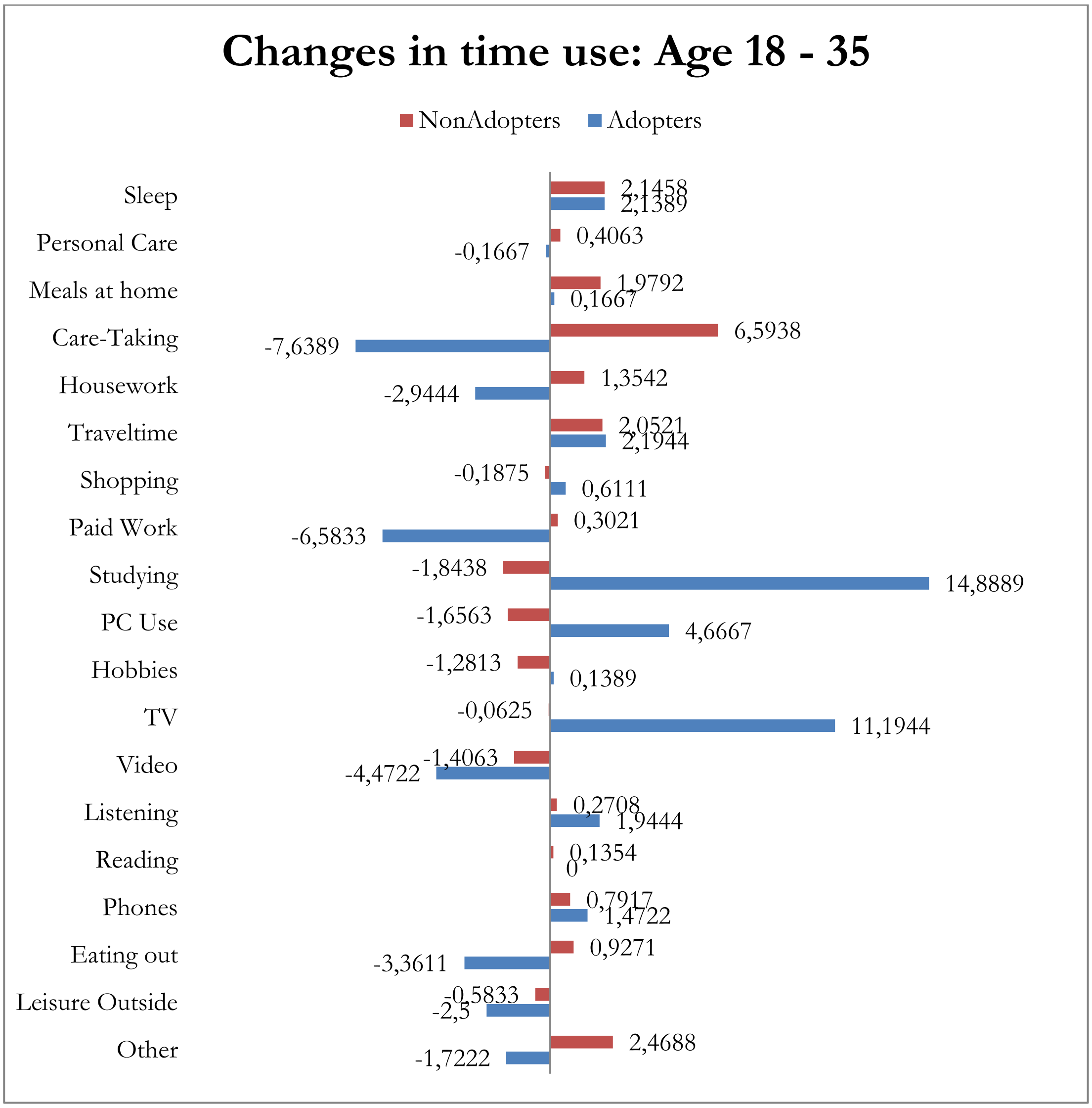


Figure 20: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Age group 1 (18-35) only.

A similar difference is seen in the *studying* activity. Young *PC-adopters* increase their *studying* time by 14,89 hours contrary to young *Non-adopters*, who spend 1,84 hours less. This sums up to a total difference of 16,73 hours; arguably the highest difference in this study and a significant one as well.

Unsurprisingly the middle-aged group doesn't change their *paid work* that much, keeping it fairly steady. In general the group aged 35-50 differs from the general trend in so far as the *adopters* increase their activity in the majority of household activities, which is not the case when in the whole sample. This includes the three high-intensity activities *housework*, *meals at home* and *travel time*, which feature a significant increase in time use by *adopters* contrary to the general picture. However, *Non-adopters* seem to follow the trend.

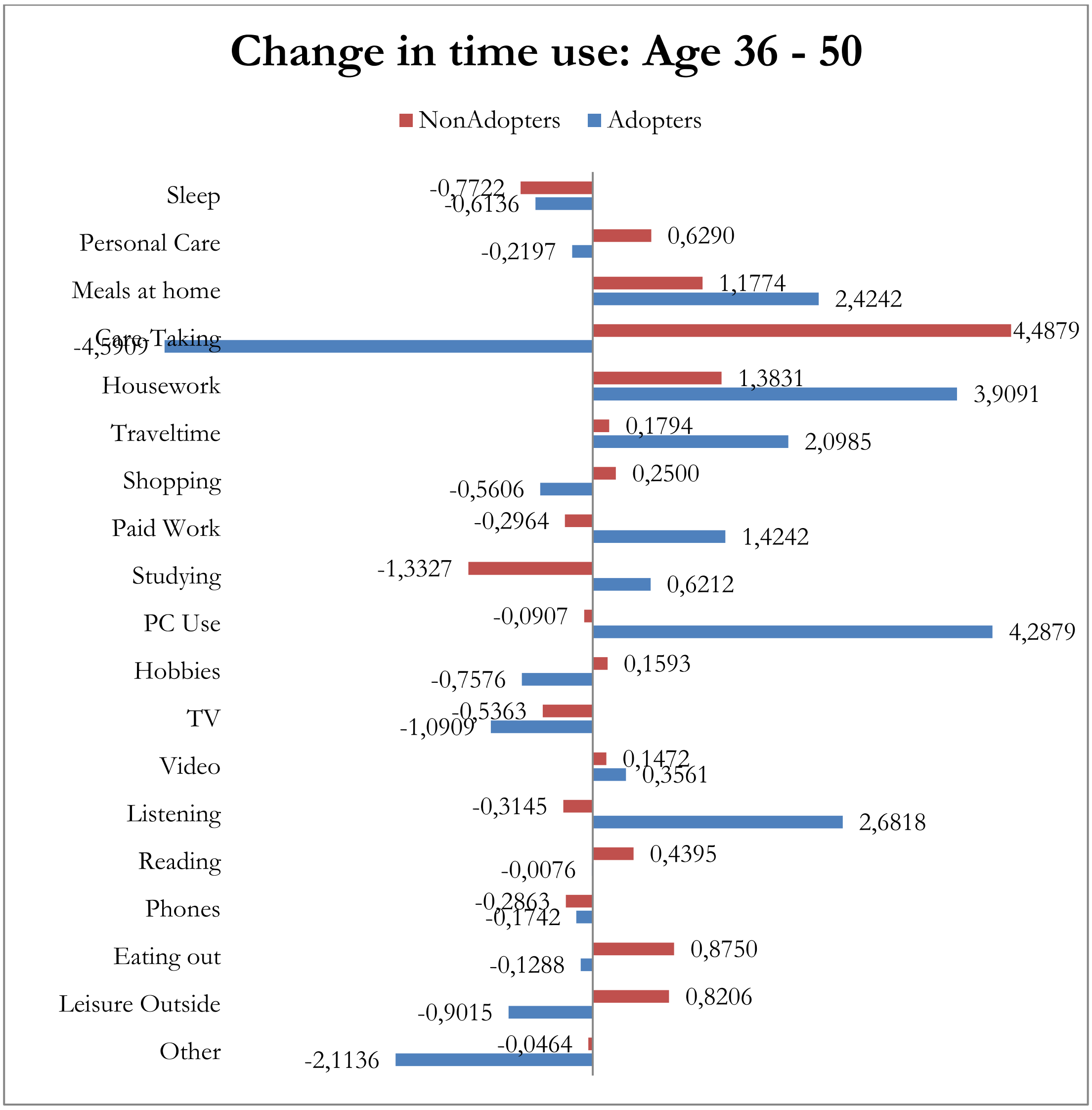


Figure 21: Comparison of time use changes in hours per week between *adopters* (blue) and *Non-adopters* (red). Age group 2 (36-50) only.

The leisure activity *TV* watching has the biggest increase in the youngest age group, with an additional 11,19 hours a week. The other two age groups feature only a slight increase (0,72h: age 50-65) or diminishing time use (1,09h: age 35-50).

In conclusion the results show that in distinguished sub-groups some trends seem to hold, while others feature prominent deviations from the general trend seen in the analysis of total time use.

| Activities | Adopters | Non-Adopters | | Adopters | Non-Adopters | | Adopters | Non-Adopters | |
|---|---|---|---|---|---|---|---|---|---|
| n | 9 | 24 | | 33 | 124 | | 62 | 159 | |
| | Age 1 | | | Age 2 | | | Age 3 | | |
| | **mean** | **mean** | **Sig (2-tailed)** | **mean** | **mean** | **Sig (2-tailed)** | **mean** | **mean** | **Sig (2-tailed)** |
| **Sleep** | 2,1389 | 2,1458 | 0,999 | -0,6136 | -0,7722 | 0,928 | -1,8145 | 1,4811 | 0,026* |
| **Personal Care** | -0,1667 | 0,4063 | 0,741 | -0,2197 | 0,629 | 0,061 | -0,2581 | 1,511 | 0,001** |
| **Meals at home** | 0,1667 | 1,9792 | 0,507 | 2,4242 | 1,1774 | 0,363 | -3,0726 | 0,2028 | 0,019* |
| **Care-Taking** | -7,6389 | 6,5938 | 0,136 | -4,5909 | 4,4879 | 0,115 | -0,1774 | -1,5881 | 0,615 |
| **Housework** | -2,9444 | 1,3542 | 0,203 | 3,9091 | 1,3831 | 0,235 | -2,1331 | 0,4434 | 0,164 |
| **Traveltime** | 2,1944 | 2,0521 | 0,948 | 2,0985 | 0,1794 | 0,209 | 1,5081 | -0,7374 | 0,042* |
| **Shopping** | 0,6111 | -0,1875 | 0,688 | -0,5606 | 0,25 | 0,341 | -1,0524 | 0,0126 | 0,113 |
| **Paid Work** | -6,5833 | 0,3021 | 0,517 | 1,4242 | -0,2964 | 0,691 | 9,879 | 2,8899 | 0,084 |
| **Studying** | 14,8889 | -1,8438 | 0,036* | 0,6212 | -1,3327 | 0,454 | 0,7984 | -1,9292 | 0,033* |
| **PC Use** | 4,6667 | -1,6563 | 0,026* | 4,2879 | -0,0907 | 0,007** | 4,1573 | -1,4135 | 0,000** |
| **Hobbies** | 0,1389 | -1,2813 | 0,296 | -0,7576 | 0,1593 | 0,464 | 0,3629 | 0,0157 | 0,699 |
| **TV** | 11,1944 | -0,0625 | 0,157 | -1,0909 | -0,5363 | 0,844 | 0,7177 | -1,0283 | 0,262 |
| **Video** | -4,4722 | -1,4063 | 0,313 | 0,3561 | 0,1472 | 0,73 | -0,7339 | 0,1918 | 0,046 |
| **Listening** | 1,9444 | 0,2708 | 0,729 | 2,6818 | -0,3145 | 0,094 | 1,2258 | -0,3066 | 0,285 |
| **Reading** | 0 | 0,1354 | 0,947 | -0,0076 | 0,4395 | 0,592 | -0,0726 | -0,1981 | 0,903 |
| **Phones** | 1,4722 | 0,7917 | 0,115 | -0,1742 | -0,2863 | 0,384 | 0,5363 | 0,4591 | 0,922 |
| **Eating out** | -3,3611 | 0,9271 | 0,661 | -0,1288 | 0,875 | 0,373 | 0,7782 | 0,184 | 0,404 |
| **Leisure Outside** | -2,5 | -0,5833 | 0,744 | -0,9015 | 0,8206 | 0,384 | -0,1089 | -1,1651 | 0,57 |
| **Other** | -1,7222 | 2,4688 | 0,138 | -2,1136 | -0,0464 | 0,423 | 3,2177 | 1,8475 | 0,492 |

Table 11: Results from independent T-Tests showing differences in time use between *adopters* and *Non-adopters* according to each activity class, distinguishing between different age groups (1=18-35; 2=36-50; 3=51-65). Significance levels: p<0,05*; p<0,01**.

## 8.3 Trends in changing energy consumption

The different changes in the respective time use patterns for *PC-adopters* and *Non-adopters* have environmental consequences. Figure 22 shows the changing energy demand of all household activities and of leisure activities and household chores separately.

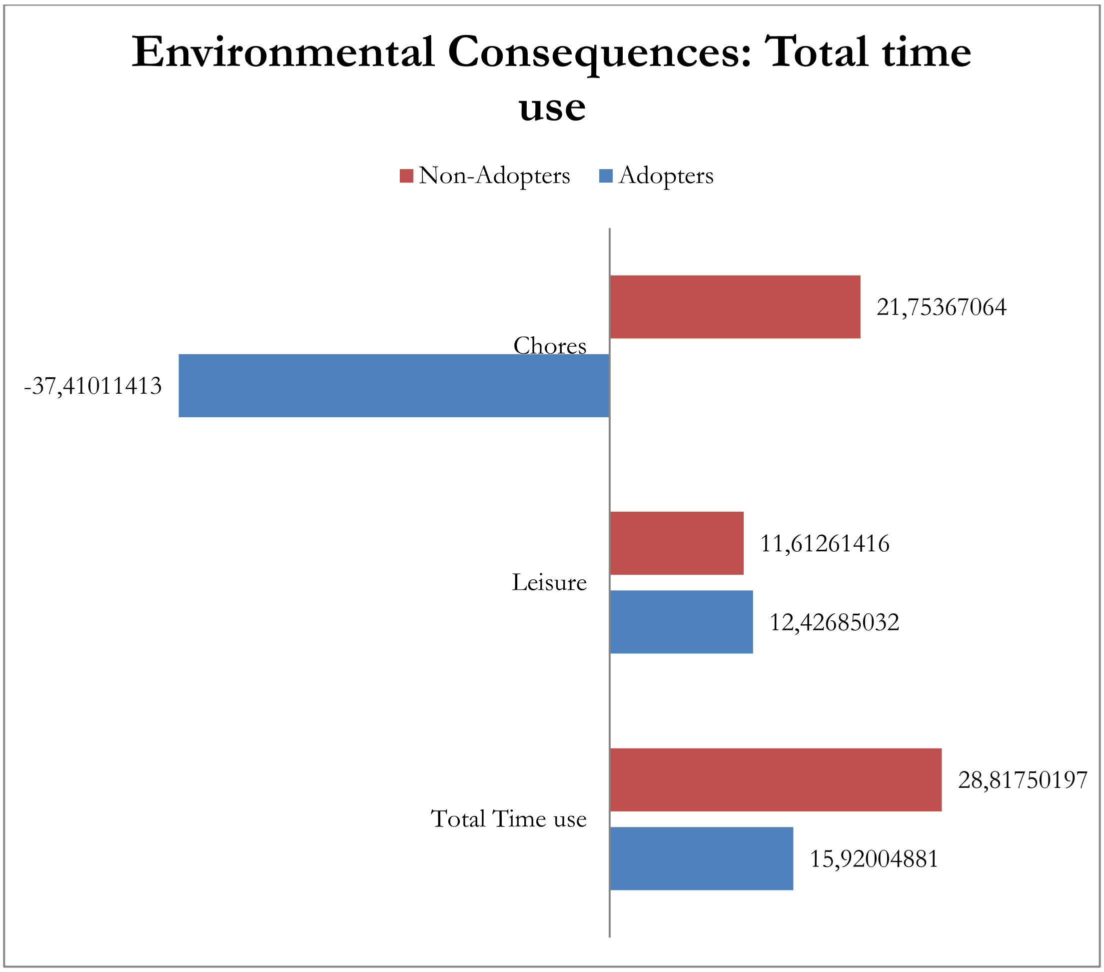


Figure 22: Differences between *adopters* (blue) and *Non-adopters* (red) according to changes in energy use as a result of time use changes (in kWh).

Considering total time use, the *adopters* group has an additional energy demand of 15,92 kWh in a week. *Non-adopters* however have an even larger increase in their energy demand with 28,82 kWh per week. This means that in contrast to a situation without the adoption of a personal computer roughly 12,9 kWh are saved per week.

Distinguishing between leisure and chores generates an intriguing result. Within leisure activities the environmental impact stays nearly the same with *adopters* enlarging their energy demand slightly more (0,81 kWh). But, within household chores the difference between *adopters* and *Non-adopters* rises to nearly 60 kWh (59,16) in favor of the *adopters* group.

This trend can also be seen when distinguishing between primary and secondary activities (Fig. 23). The trend in primary activities is similar to the characteristics of changes in total time use. However, total time use now more or less increases parallel with a slightly higher increase on the adopters' side (roughly 0,12 kWh).

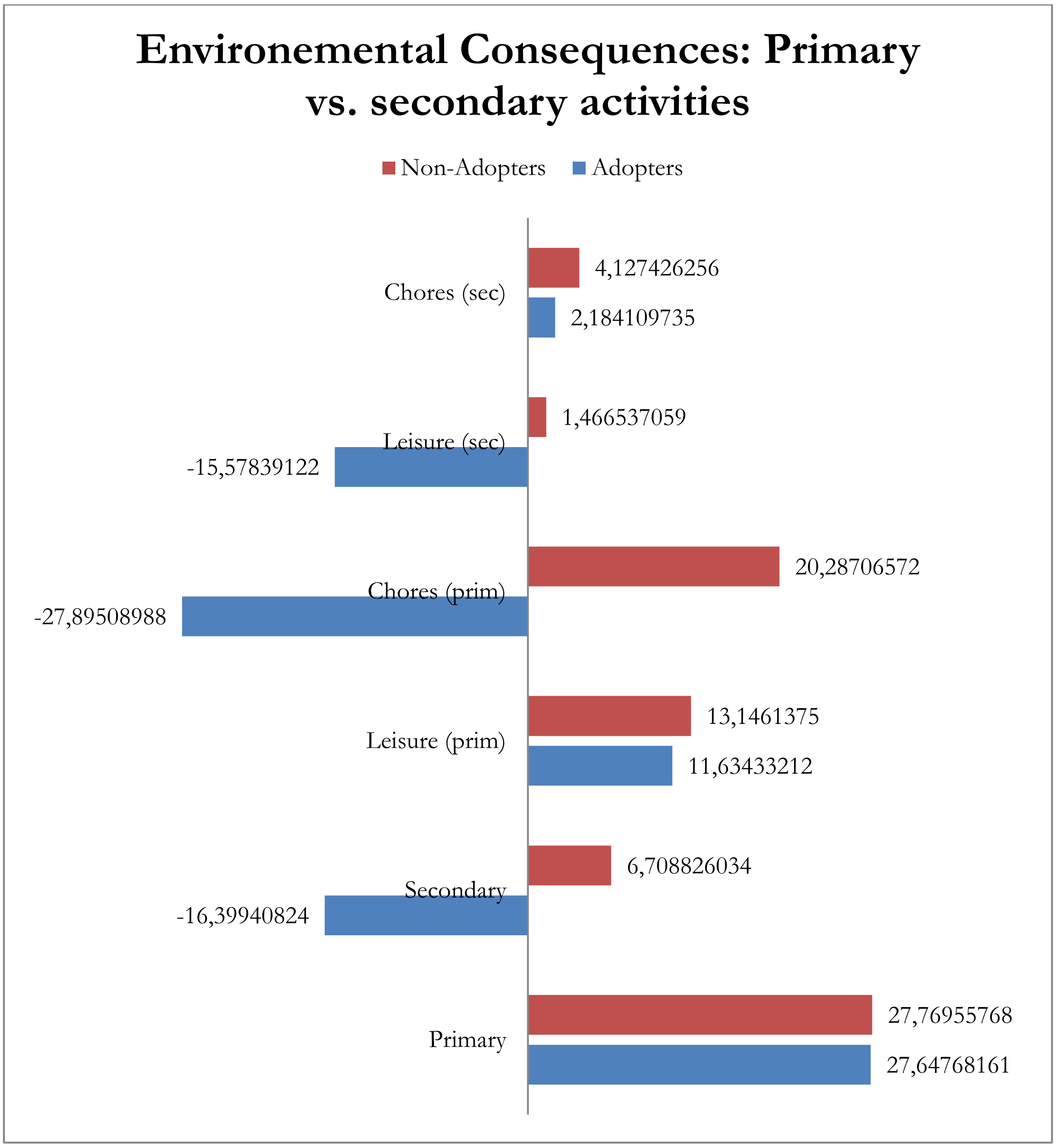


Figure 23: Differences between *adopters* (blue) and *Non-adopters* (red) according to changes in energy use as a result of time use changes (in kWh). Separated between primary and secondary activities in general and within leisure activities and household chores.

Interestingly however, an analysis of secondary activities draws another picture. *Adopters* need less energy in all three categories than *Non-adopters*; the difference in total time use being 23,1 kWh a week. This time it is the chores which are similar (a difference of

1,93kWh), while *adopters'* leisure activities actually cause less energy consumption with a reduction of -15,58 kWh a week; a difference of 17,05 kWh.

Similar to the results before, environmental consequences are different when looking at the various subgroups (Fig. 24).

Strikingly, the increase of energy demand by male *Non-adopters* is extremely large with just of over 130 kWh. In contrast, *adopters* actually reduce their energy demand by 3,52 kWh. Female *adopters* and *Non-adopters* on the other hand have a similar trend with a slight plus of 4,98 kWh on the *adopters'* side.

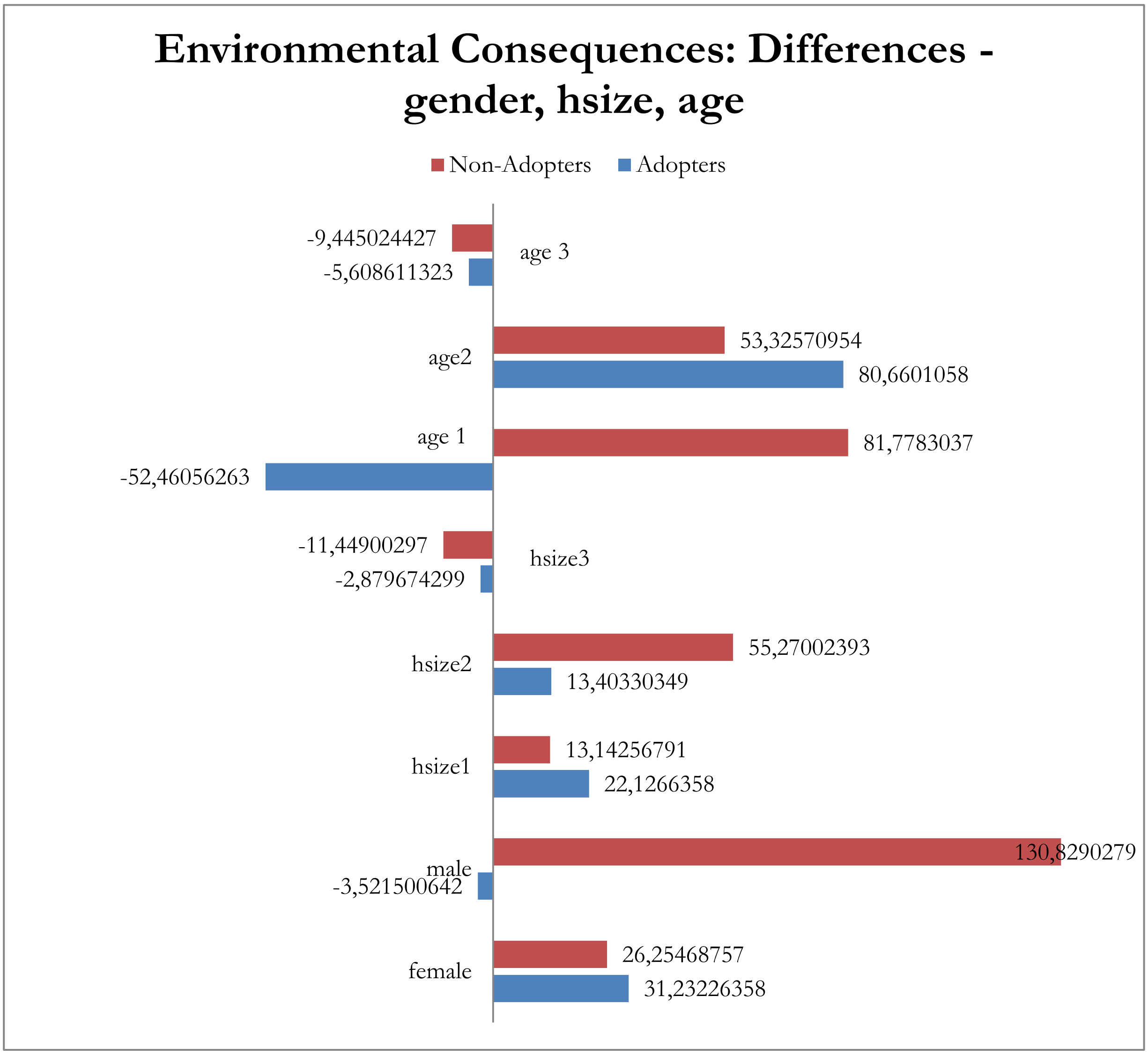


Figure 23: Differences between *adopters* (blue) and *Non-adopters* (red) according to changes in energy use as a result of time use changes (in kWh). Separated age groups (1=18-35; 2=36-50; 3=51-65), household size (1=small; 2=middle, 3=big) and gender.

Differentiating between different household sizes, the middle-sized households stand out as again *Non-adopters* increase their energy consumption vastly (a plus of 55,27 kWh), while *adopters* have lower plus of just 13,4kWh. Bigger households actually decrease their environmental burden regardless whether *adopters* and *Non-adopters*, with the former reducing their energy consumption by 11,45kWh against a reduction of just 2,88 kWh by the adopters group. In small households *Non-adopters* increase their energy demand by 8,99kWh less than their adopting counterpart.

Last, a distinction between the different age groups sees the oldest age group indicating a similar trend for both *adopters* and *Non-adopters* with the former saving 9,45kWh and the latter 5,61kWh. While the middle-aged group has both *adopters* and *Non-adopters* increasing their energy demand significantly (80,66kWh resp. 53,33kWh), it's the youngest group that has the most outstanding changes. While the *Non-adopting* group increases their energy consumption by 81,78kWh, the *adopters* group decreases theirs by 52,46kWh, reaching a total difference of 134,24kWh.

In conclusion, the adoption of a personal computer seems to indicate a smaller increase in energy consumption compared to a situation where no personal computer has been integrated into the household. However, the analyses of the various subgroups indicates that one group of each subtype seems mostly responsible, demonstrating a major increases in energy demand for the non-adopting side. In contrast, the others seem to suggest a slightly more balanced picture, where *Non-adopters'* energy consumption actually tends to be actually less energy demanding. Moreover, the omission of time spent in *paid work*, which heavily increases on the *adopters'* side could cause environmental consequences outside the household sector.

Other than that, household chores seem to make the major difference between *adopters* and *Non-adopters'* changing energy consumption, while leisure activities adding energy demand in both groups.

# 9. Discussion and Conclusion

The purpose of this study is to analyze changes in households' energy consumption by adopting a temporal, activity based method and bringing to light possible influences of new technical devices in the household. The personal computer as one increasingly wide-spread new technology was singled out, possibly shedding some light on drivers behind the growing energy consumption caused by households. Its role in some concepts of dematerialization related to technological solutions to sustainability problems put forward by promoters of green technology makes the environmental effects after integration into the households even more interesting.

Regarding energy trends, the results seem to be in line with general trends concerning households' environmental burdens. The weekly growth of energy consumption by both *adopters* and *Non-adopters* of 15,92kWh resp. 44,74kWh hints at continuously rising energy demands. This corresponds with the figures provided by the EEA which indicate a major increase in energy demand within the household sector during the years 1999 to 2001, making the sector one of the top consuming one (EEA 2009). Similar, a study by Druckman and Jackson (2010) points at the rising carbon footprint caused by household consumption patterns, while Spanenberg and Lorek (2002) argue that next to housing, travel and eating are the main concerns for energy reductions.

This agrees with the results provided by this study, which identified two activities as major contributors to rising energy consumption. *Eating* and *travelling* stand out, not just by causing the highest proportion of the total energy consumption, but also by having the highest energy intensities of the analyzed activities. These findings are supported again by the study from Druckman and Jackson (2010) and studies by Jalas (2002, 2005). Druckman and Jackson, for example, attribute 18% of the total carbon footprint to eating activities at home and 5% to eating out. Moreover 27% are due to transport activities. Similar they calculate that 27% of total carbon footprint are attributable to recreation and leisure. However, only 47% are attributable to direct and indirect energy use by households with the rest being part of travel-related energy demand. (Druckman and Jackson 2010: 17) As this study suggests a temporal view of household activities, energy intensities are even more relevant. Both eating and travelling correspond here with the general picture as part of the high intensity activities.

Comparing the calculated energy intensities with previous findings, they generally fit well in terms of hierarchy between activities. There appear to be some major deviations however, when looking at the concrete empirical results. In comparison with Jalas' analyses of Finnish households, this study attributes much higher temporal energy intensities to eating at home and eating out. While the results of this analysis show energy intensities of 20,89kWh per hour for eating outside of the home, Jalas calculates an energy intensity of just 11kWh/h. Similar, eating at home differs by 3,17kWh/h (Jalas:11,39kWh/h; here: 15,56 kWh/h). In contrast, this study's findings show lower energy intensities for housework (5,28kWh/h against ~3kWh) and travelling. In his 2005 paper, Jalas distinguishes between different travel related purposes, getting energy intensities for leisure-travel and work and education of 23,06kWh/h resp. 20,28kWh, which both exceed the calculated 17,86kWh here. The difference could be due to differences in the structural characteristics between Finnish and British economies or different matching procedures of activities to direct and indirect energy consumption. Still, the results are within a similar range. Another deviation is to find in the energy intensities for reading which Jalas finds to be 0,94kWh/h lower than the calculations here.

Interestingly, TV watching seems to constitute a time sink. While a major part of time is invested in TV watching, it has one of the lowest energy intensities of all leisure related activities. Time is thereby "wasted" without consuming too much energy in the process. This analysis is strengthened by the empirical findings of Jalas (2002) and van der Werf (Hofstetter and Madjar 2003). Both compared the leisure activities reading with TV watching and find that energy could be saved when switching from reading to TV watching.

One major concern of this study was to deal with possible influences the integration of the personal computer has on other activities. There seems to exist a connection between an adoption of a personal computer and time use changes regarding some activities. Generally however, there is no clear tendency towards a substitution of pc time for either high-intensity or low-intensity activities. While the high-intensity activities like eating meals at home or travelling are decreasing in the *adopters* group, sleep and studying, two low-intensity activities are decreasing compared to *Non-adopters*. At the same time, the increasing share of the time budget occupied by the middle-intensity activity pc use is more or less paralleled by an increase in low-intensity activities TV watching and listening.

Surprisingly, the empirical findings seem to suggest thatthe adoption of a pc mostly affects household chores and personal recreation (sleep, personal care). The additional time spent in using a personal computer is withdrawn from these activities, while time spent in alternative leisure activities is changing little (with few exceptions). This is a very interesting point, as it could be expected that household chores have a more robust way of doing things, because they have established a certain way of practice. (see chapter 3.3) Although pc use poses no direct alternative to household chores, there exist significant differences in time use changes within these categories indicating that the adoption of a personal computer might act as a disruption of former established patterns. From an environmental perspective, this reduction in household chores represents the main reason behind the lower growth in energy demand by people getting a personal computer.

Contrary to that, time allocations seem to be more robust to change within the field of leisure activities as there is no indication that time allocations between *PC-adopters* and *Non-adopters* differ significantly. The exceptions are TV watching and PC use, which increase their share of the time budget. As the former is a low-intensity and the latter a middle-intensity activity, the time relocated towards these activities, especially from high-intensity activities like meals at home, would mean a substitution for lower intensity activities. In that sense a personal computer would indeed – albeit not decrease energy consumption – at least dampen the environmental effects by diminishing energy growth.

However, caution is due because of several reasons: First, the concentration on one technology excluded the adoption of other technological devices. Especially, time-saving device like the microwave and the dishwasher could alter the time allocated to cooking and thus reduce the time in this category, while freeing up time for leisure activities. Both technologies were on the rise in the early 2000s (Table 1). A study conducted by Brenčič and Young (2009) hints at the role of time-saving devices for the time allocation to leisure activities. However while they see a positive correlation with some leisure activities, the influence could go both way depending on factors like income (Brenčič and Young 2009: 2864). An inclusion of further technological devices in the study design would thus be useful (cf. Hofstetter and Madjar 2003, Brenčič and Young 2009).

Second, empirical findings provided by study on Japanese households (Ozawa and Hofstetter 2004) actually suggest a different picture. Distinguishing between gender and weekday or holidays, they too analyze the role of a personal computer in changing household's energy demand and time use. Their results indicate that women decrease their leisure activities on holidays as well as their work hours during a week. At the same time, more hours are spent in "house-keeping and care-taking". Males differ from this trend as they increase their leisure time during the week. But, they spent less time doing leisure activities on holidays and weekends as well. However, Ozawa and Hofstetter do not distinguish between different leisure time activities.

Third, the majority of time change of *adopters* is not between chores and leisure time, but towards paid work and travelling, which are either not allocated to specific activities or had no energy intensities attributed to it. As both constitute high-intensity activities, an inclusion of both would properly alter dramatically. As major portions of time are shifted to both paid work and travel time, possible rebound effects could turn up as middle or low-intensity activities are substituted for these high-intensity activities.

The scale of energy consumption happening at the work place is thereby not only contingent on the kind of work people are engaged with. But, 'normal' consumption activities like eating, using the computer or going on trips and restaurants can be part of a normal work day – activities otherwise falling into the domestic domain (Røpke 2004). Moreover, this phenomenon could be connected to the theories by Juliet Schor (see chapter 3) and her hypothesis of a work and spend cycle, continuously driving energy demand through increase commodity consumption. (Schor 1998) A further analysis of the different income levels and expenditures for *adopters* and *Non-adopters* could give an indication, if the increasing paid work has a connection to higher provision of goods and services in the household.

The high increase in paid work time by *adopters* of personal computers is however to be explained itself. It's unclear how the personal computer could cause the increase in paid work time, as in this study work done using the home-computer is not included in the activity *paid work*. There are, however, two other explanations, which turn the causality around. According to Inge Røpke technological advances are often introduced into the household after people get in contact with them at work. People get used to new consumer goods at their workplace, which lays the groundwork for changes in the domestic sphere. In this sense the increased work time could have been the precondition for the adoption of a personal computer (Røpke 2004).

Still, the drastic difference between energy savings by *adopters* and energy increase within the *Non-adopters* group regarding household chores at least indicates that households adopting new technologies tend to decrease their energy consumption. It would therefore be interesting to see, if *adopters* of personal computers also adopt other technological devices more easily, being generally more tech-friendly.

The findings of this study highlight another important aspect. While technology seems to be connected to changes in certain consumption activities, the analysis of different subsection according to age, gender, or household size suggest that this impact varies depending on the subgroup looked at. For example, people between 35 and 50 – a group just in the middle of their working years – show the least significant differences considering time use changes. On the other hand, the youngest have some activities changing drastically (studying, watching TV), while others are kept fairly constant. Different life stages seem to make a difference on the substitutability between different activities and the direction of change. The analysis of the different subgroups regarding environmental consequences is even more variable. Men, for example, show the greatest difference in energy consumption between *adopters* and *Non-adopters* and are largely responsible for the high energy demand of *Non-adopters* in general. The reason seems to be the increase in meals consumed not at home. Without further analysis it is hard to understand, why this is the case as it is likely to be caused by other factors than higher computer use and there is no statistically significant difference in the mean time change between male *PC-adopters* and *Non-adopters* considering eating out.

Some methodological problems using a temporal, activity-based concept became apparent during the study. Apart from some problems easily solvable by a different data set (e.g. the allocation of travel time to specific activities), some are more fundamental. While a time use approach seems to integrate some aspects of changing human behavior, it only partially deals with the multi-layered decision making processes. Therefore the additional inclusion of income levels and gender (e.g. Hofstetter and Madjar 2003, Ozawa and Hofstetter 2004), household size (Jalas 2002) and age in defining different household "lifestyles" (Duchin 2003) at the beginning of a study design could be helpful for a better understanding of behavioral change.

Furthermore the inclusions of expenditure data distinguishing between technology-*adopters* and *Non-adopters* would better account for differing energy intensities per time. This could open up a further research in possible work and spend cycles due to increasing work time.

To conclude, while the findings of this study are inconclusive in regards to the environmental impact of new technology in the form of the computer, they do suggest that technological innovation is a driver behind changes in time allocations affecting at least some activities, influencing households' energy consumption. The strength of the approach is that it provides a blueprint to analyze changes in behavioral patterns of households' inhabitants. Accounting for possible substitute activities thus helps finding possible rebound effects, when considering different sustainable development paths and technological solutions.

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# Appendices

## Appendix 1: Energy intensities per final demand category

| I/O code | EA Code | I/O classification | Energy- intensities koe/£ | Energy intensities toe/£ |
|---|---|---|---|---|
| 1 | 1 | Agriculture | 0,29140505 | 0,0002914050 |
| 2 | 2 | Forestry | 0,23936661 | 0,0002393666 |
| 3 | 3 | Fishing | 0,3757778 | 0,0003757778 |
| 4 | 4 | Coal extraction | 0,41184343 | 0,0004118434 |
| 5 | 5 | Oil and gas extraction | 0,24091407 | 0,0002409141 |
| 6-7 | 6 | Metal ores extraction, Other mining and quarrying | 0,34560863 | 0,0003456086 |
| 8 | 8 | Meat processing | 0,29509526 | 0,0002950953 |
| 9 | 8 | Fish and fruit processing | 0,25911773 | 0,0002591177 |
| 10 | 8 | Oils and fats processing | 0,20703495 | 0,0002070350 |
| 11 | 8 | Dairy products | 0,31877771 | 0,0003187777 |
| 12 | 8 | Grain milling and starch | 0,25323112 | 0,0002532311 |
| 13 | 8 | Animal feed | 0,2401594 | 0,0002401594 |
| 14 | 8 | Bread, biscuits, etc | 0,21687626 | 0,0002168763 |
| 15 | 8 | Sugar | 0,20424094 | 0,0002042409 |
| 16 | 8 | Confectionery | 0,2013317 | 0,0002013317 |
| 17 | 8 | Other food products | 0,22095291 | 0,0002209529 |
| 18 | 8 | Alcoholic beverages | 0,2078799 | 0,0002078799 |
| 19 | 8 | Soft drinks & mineral waters | 0,2376488 | 0,0002376488 |
| 20 | 9 | Tobacco products | 0,1384771 | 0,0001384771 |
| 21 | 10 | Textile fibres, Textile weaving, Textile finishing | 0,34354797 | 0,0003435480 |
| 24 | 10 | Made-up textiles, Carpets and rugs, Other textiles, Knitted goods | 0,30637826 | 0,0003063783 |
| 28 | 11 | Wearing apparel & fur products | 0,16795184 | 0,0001679518 |
| 29 | 12 | Leather goods, Footwear | 0,1726918 | 0,0001726918 |
| 31 | 13 | Wood and wood products | 0,24422235 | 0,0002442224 |
| 32 | 14 | Pulp, paper and paperboard | 0,41206751 | 0,0004120675 |
| 33 | 14 | Paper and paperboard products | 0,29436383 | 0,0002943638 |
| 34 | 15 | Printing and publishing | 0,11887169 | 0,0001188717 |
| 35 | 16-18 | Coke ovens, refined petroleum & nuclear fuel | 0,5007378 | 0,0005007378 |
| 36 | 19 | Industrial gases and dyes | 0,65098384 | 0,0006509838 |
| 37 | 20 | Inorganic chemicals, Organic chemicals | 0,66990226 | 0,0006699023 |
| 39 | 22 | Fertilisers, Plastics & Synthetic resins etc, Pesticides | 0,49891285 | 0,0004989129 |

| | | | | |
|---|---|---|---|---|
| 42 | 25 | Paints, varnishes, printing ink etc | 0,11101174 | 0,0001110117 |
| 43 | 26 | Pharmaceuticals | 0,10363985 | 0,0001036399 |
| 44 | 27 | Soap and toilet preparations | 0,13920801 | 0,0001392080 |
| 45 | 28 | Other Chemical products, Man-made fibres | 0,21677922 | 0,0002167792 |
| 47 | 30 | Rubber products | 0,28788708 | 0,0002878871 |
| 48 | 31 | Plastic products | 0,24607632 | 0,0002460763 |
| 49 | 32 | Glass and glass products | 0,46529593 | 0,0004652959 |
| 50 | 33 | Ceramic goods | 0,45185446 | 0,0004518545 |
| 51 | 34 | Structural clay products, Cement, lime and plaster | 0,47787433 | 0,0004778743 |
| 53 | 36 | Articles of concrete, stone etc | 0,25970984 | 0,0002597098 |
| 54 | 37 | Iron and steel, Non-ferrous metals, Metal castings | 0,88968466 | 0,0008896847 |
| 57 | 41 | Structural metal products | 0,29465384 | 0,0002946538 |
| 58 | 41 | Metal boilers & radiators | 0,21954089 | 0,0002195409 |
| 59 | 41 | Metal forging, pressing, etc | 0,20296571 | 0,0002029657 |
| 60 | 41 | Cutlery, tools etc | 0,13067143 | 0,0001306714 |
| 61 | 41 | Other Metal products | 0,19982175 | 0,0001998218 |
| 62 | 42 | Mechanical power equipment | 0,18540212 | 0,0001854021 |
| 63 | 42 | General purpose machinery | 0,19720975 | 0,0001972098 |
| 64 | 42 | Agricultural machinery | 0,19338506 | 0,0001933851 |
| 65 | 42 | Machine tools | 0,18256413 | 0,0001825641 |
| 66 | 42 | Special purpose machinery | 0,17173849 | 0,0001717385 |
| 67 | 42 | Weapons and ammunition | 0,1873046 | 0,0001873046 |
| 68 | 42 | Domestic appliances nec | 0,20676171 | 0,0002067617 |
| 69 | 43 | Office machinery & computers | 0,10158475 | 0,0001015847 |
| 70-71 | 44 | Electric motors and generators etc, Insulated wire and cable | 0,16939086 | 0,0001693909 |
| 72 | 44 | Electrical equipment nec | 0,12614029 | 0,0001261403 |
| 73 | 45 | Electronic components | 0,09864366 | 0,0000986437 |
| 74 | 45 | Transmitters for TV, radio and phone | 0,11925226 | 0,0001192523 |
| 75 | 45 | Receivers for TV and radio | 0,10476421 | 0,0001047642 |
| 76 | 46 | Medical and precision instruments | 0,10432644 | 0,0001043264 |
| 77 | 47 | Motor vehicles | 0,16291414 | 0,0001629141 |
| 78 | 48 | Shipbuilding and repair | 0,2482465 | 0,0002482465 |
| 79 | 48 | Other transport equipment | 0,14965042 | 0,0001496504 |
| 80 | 48 | Aircraft and spacecraft | 0,11894476 | 0,0001189448 |
| 81 | 49-50 | Furniture | 0,21908346 | 0,0002190835 |
| 82 | 49-50 | Jewellery & related products | 0,24363438 | 0,0002436344 |
| 83 | 49-50 | Sports goods and toys | 0,24149584 | 0,0002414958 |
| 84 | 49-50 | Miscellaneous manufacturing nec, recycling | 0,18575618 | 0,0001857562 |
| 85 | 51-55 | Electricity production & distribution | 2,45438202 | 0,0024543820 |

| | | | | |
|---|---|---|---|---|
| 86 | 56 | Gas distribution | 0,5547935 | 0,0005547935 |
| 87 | 57 | Water supply | 0,33600856 | 0,0003360086 |
| 88 | 58 | Construction | 0,10703888 | 0,0001070389 |
| 89 | 59 | Motor vehicle distribution & repair, fuel | 0,08427905 | 0,0000842791 |
| 90 | 60 | Wholesale distribution | 0,10627666 | 0,0001062767 |
| 91 | 61 | Retail distribution | 0,08943277 | 0,0000894328 |
| 92 | 62 | Hotels, catering, pubs etc | 0,09976679 | 0,0000997668 |
| 93 | 63 | Railway transport | 0,18705294 | 0,0001870529 |
| 94 | 64-68 | Other land transport | 0,32440748 | 0,0003244075 |
| 95 | 69 | Water transport | 0,61000941 | 0,0006100094 |
| 96 | 70 | Air Transport | 0,91844144 | 0,0009184414 |
| 97 | 71 | Ancillary Transport services | 0,07951421 | 0,0000795142 |
| 98 | 72 | Postal and courier services | 0,09615277 | 0,0000961528 |
| 99 | 72 | Telecommunications | 0,06913364 | 0,0000691336 |
| 100 | 73 | Banking and finance | 0,04513759 | 0,0000451376 |
| 101 | 74 | Insurance and pension funds | 0,07717243 | 0,0000771724 |
| 102 | 75 | Auxiliary financial services | 0,06938388 | 0,0000693839 |
| 103 | 76 | Owning and dealing in real estate | 0,05649309 | 0,0000564931 |
| 104 | 76 | Letting of dwellings | 0,02219395 | 0,0000221940 |
| 105 | 76 | Estate agent activities | 0,02636321 | 0,0000263632 |
| 106 | 77 | Renting of machinery etc | 0,09244564 | 0,0000924456 |
| 107 | 78 | Computer services | 0,0464191 | 0,0000464191 |
| 108 | 79 | Research and development | 0,08052308 | 0,0000805231 |
| 109 | 80 | Legal activities | 0,03900879 | 0,0000390088 |
| 110 | 80 | Accountancy services | 0,04480453 | 0,0000448045 |
| 111 | 80 | Market research, management consultancy | 0,04123924 | 0,0000412392 |
| 112 | 80 | Architectural activities & Tech. Consult | 0,0749449 | 0,0000749449 |
| 113 | 80 | Advertising | 0,06026384 | 0,0000602638 |
| 114 | 80 | Other business services | 0,04551666 | 0,0000455167 |
| 115 | 81-82 | Public administration & defence | 0,28695494 | 0,0002869549 |
| 116 | 83 | Education | 0,13290685 | 0,0001329069 |
| 117 | 84 | Health and veterinary services | 0,11340303 | 0,0001134030 |
| 118 | 84 | Social work activities | 0,14418727 | 0,0001441873 |
| 119 | 85-87 | Sewage and Sanitary services | 0,13858617 | 0,0001385862 |
| 120 | 88 | Membership organisations nec | 0,07983327 | 0,0000798333 |
| 121 | 89 | Recreational services | 0,05110594 | 0,0000511059 |
| 122 | 90 | Other service activities | 0,06688 | 0,0000668800 |
| 123 | 91 | Private Households with employed persons | 0,01419303 | 0,0000141930 |

## Appendix 2: Indirect Energy Consumption per activity

| Activities and code | | Expenditure connected to activity | Expenditure Code | Final Demand Category | I/O Code |
|---|---|---|---|---|---|
| Sleep | 1 | no expenditure | - | no final demand | |
| Personal Care | 2 | Toilet paper | .07.05 | Soap and toilet preparations | 44 |
| | | Cosmetics/toilet requisites | .09.01 | Soap and toilet preparations | 44 |
| | | Hairdressing, beauty treatments and wigs etc. | .09.06 | Soap and toilet preparations | 44 |
| Meals at home | 3 | Food (except food not eaten at home) | .03.01-.03.11; .03.17 | Diverse food classes except alcoholic beverages and animal feed | 8 -12; 14-17; 19 |
| | | Alcohol bought off licensed premises | .04.01 | Alcoholic beverages | 18 |
| | | Electric cookers, combined electric/gas cookers | .07.02.01 | Domestic appliances | 68 |
| | | Electric refrigerators, freezers | .07.02.03 | Domestic appliances | 68 |
| | | Dishwashers, microwaves. other major appliances | .07.02.04 | Domestic appliances | 68 |
| | | Kitchen utensils and equipment, | .07.03.01 | Cutlery, tools etc. | 60 |
| | | Kitchen disposables | .07.03.02 | Plastic goods | 48 |
| | | China, glass pottery | .07.03.03 | ceramic and glass products | 49; 50 |
| | | Gas cookers | .07.02.07 | Domestic appliances | 68 |
| Care-Taking | 4 | Baby toiletries and accessories | .09.03.01 | Soap and toilet preparations | 44 |
| | | Medicines and medical goods | .09.04 | Pharmaceuticals | 43 |
| Housework | 5 | Tools | .01.05.02 | Cutlery, tools etc. | 60 |
| | | | | Machine tools | 65 |
| | | Paint, wallpaper, timber | .01.05.03 | Paints, varnishes, printing ink etc | 42 |
| | | | | Pulp, paper and paperboard | 32 |
| | | Electric washing machines, spin dryers | .07.02.02 | Domestic appliances | 68 |
| | | Electrical tools | .07.02.05 | Machine tools | 65 |
| | | Cleaning materials | .07.04 | Soap and toilet preparations | 44 |
| | | Pet food | .07.06.01 | Animal feed | 13 |
| | | Garden equipment | .07.07.01 | Machine tools | 65 |
| | | Garden tools | .07.07.02 | Cutlery, tools etc. | 60 |
| | | Seeds and fertilizers | .07.07.03 | Fertilizers, plastics… | 39 |
| Travel Time | 6 | only direct energy allocated | - | - | - |
| Shopping | 7 | no expenditure allocated | - | no indirect energy allocated | |
| Paid Work | 8 | no expenditure allocated | - | no indirect energy allocated | |
| Studying | 9 | education and training | .13.03 | Education | 116 |

| | | | | | |
|---|---|---|---|---|---|
| PC Use | 10 | Personal computers, printers and calculators | .12.01.06 | Office machinery and computers | 69 |
| | | Computer software and games cartridges | .12.01.12 | Office machinery and computers | 69 |
| Hobbies, Leisure inside | 11 | Musical instruments | | Sports goods and toys | 84 |
| | | Toys, hobbies, photography | .12.04 | Sports goods and toys | 84 |
| TV | 12 | Television sets | .12.01.01 | Electrical equipment; Transmitters for TV, radio and phone; receivers for TV and radio | 72; 74; 75 |
| Video | 13 | Video recorders | .12.01.04 | Electrical equipment and components | 72; 73 |
| | | Blank, pre-recorded video cassettes | | Electrical components | 73 |
| Listening | 14 | Audio equipment | .12.01.05 | Electrical equipment; Transmitters for TV, radio and phone; receivers for TV and radio | 72; 74; 75 |
| | | Records, CDs, cassettes, discs etc. | .12.01.08 | Electrical components | 73 |
| | | Accessories for audio equipment | .12.01.09 | Electrical components | 73 |
| Reading | 15 | Newspaper, magazines, books, stationery | .12.03 | Printing and publishing | 34 |
| Phones | 16 | telephone purchase + mobile | .08.02.02 + .05 | electrical equipment ; transmitters for TV, radio and phone | 72; 74 |
| Eating Out | 17 | Food and non-alcoholic drink from catering establishments | .03.14 | Diverse food classes except alcoholic beverages and animal feed | 8 -12; 14-17; 19 |
| | | Food from other outlets not eaten at home | .03.15 | Diverse food classes except alcoholic beverages and animal feed | 8 -12; 14-17; 19 |
| | | Meals snakes not eaten at home | .03.16 | Diverse food classes except alcoholic beverages and animal feed | 8 -12; 14-17; 19 |
| Leisure Outside | 16 | Alcohol bought and consumed on licensed premises | .04.02 | Alcoholic beverages | 18 |
| | | Sports, camping and outdoor goods and equipment | .12.02.01 | Sports goods and toys | 84 |
| | | Entertainments, social events, sport | .13.01 | Sports goods and toys | 84 |
| | | Hotels and holiday expenses | .13.04 | Hotels, catering, pubs etc | 92 |
| Others | 19 | | | | |

## Appendix 3: Direct Energy per activity

| Activities Class | Direct Energy Class | Direct energy per week per person per app (toe) | Total direct energy per week (toe) |
|---|---|---|---|
| 01 Sleep | - | 0 | **0** |
| 02 Personal Care | no direct energy allocated | - | **-** |
| 03 Meals at home | | | **0,001125722** |
| | Ovens | 0,000179340 | |
| | Cold appliances | 0,000478456 | |
| | Dishwasher, microwaves, others | 0,000241597 | |
| | Gas Cooking | 0,000226329 | |
| 04 Care-Taking | no direct energy allocated | - | **-** |
| 05 Housework | | | **0,000387555** |
| | Power Supply Units | 0,000099326 | |
| | Washing | 0,000288229 | |
| 06 Travel Time | | | **0,006888210** |
| | Travelling passenger road (80%) | 0,006888210 | |
| 07 Shopping | | | **0,001562489** |
| | Travelling passenger road (20%) | 0,001562489 | |
| 08 Paid Work | no direct energy allocated | - | **-** |
| 09 Studying | no direct energy allocated | - | **-** |
| 10 PC Use | | | **0,000088898** |
| | Computers | 0,000087356 | |
| | Game Con. | 0,000001542 | |
| 11 Hobbies | no direct energy allocated | - | **-** |
| 12 TV | | | |
| | TV | 0,000259843 | |
| 13 Video | | | |
| | DVD/VCR | 9,8845E-05 | |
| 14 Listening | | | |
| | Power Supply Units | 9,93256E-05 | |
| 15 Reading | no direct energy allocated | - | **-** |
| 16 Phones | no direct energy allocated | - | **-** |
| 17 Eating out | no direct energy allocated | - | **-** |
| 18 Leisure out | no direct energy allocated | - | **-** |
| 19 Others | Undefined | - | **-** |

# English Abstract

Technological innovation is promoted as one way to cope with increasing energy consumption in the household sector. The behavioral and environmental consequences caused by the introduction of new technological devices in the household are, however, unclear at best. Starting from a discussion on consumer behavior and rebound effects, the purpose of this study was to analyze changes in households' energy consumption by adopting a temporal, activity based method. Time use patterns are seen as a way to describe behavioral patterns, opening up the possibility to model changes happening after the adoption of new technology as changing time use. The study analyzed the impact of the personal computer on UK households in the period 1999 to 2001. Combining environmental data with statistics on time use, it was possible to model short term changes in time use patterns comparing a group of pc adopters and a group not adopting a personal computer. This allowed for an analysis of substitution effects between different household activities as well as the consequences on energy consumption, focusing on the possible influences triggered by the new technology.

The results indicates that the adoption of a personal computer has a beneficial environmental effect as low and middle intensity activities are substitutes for high-intensity activities, resulting in a decreasing energy demand. However the results are inconclusive as further analysis distinguishing between different subgroups (age, gender, and household size) seems to suggest different trends.

# GERMAN ABSTRACT

Dem wachsenden Energieverbrauch von Haushalten werden technologischen Neuheiten als Lösung entgegen gehalten. Allerdings sind weder deren Auswirkungen auf das Verhalten der Menschen noch auf die Umwelt klar. Diese Diplomarbeit hat es sich daher zum Ziel gesetzt, ausgehend von einer Diskussion über KonsumentInnenverhalten und Rebound Effekte, Veränderungen im Energieverbrauch von Haushalten zu untersuchen. Hierfür wurde eine die Veränderungen in der Zeit ins Zentrum stellende, auf der Analyse von Aktivitäten basierende Methode angewandt. Zeitallokationen werden hierbei als ein Weg gesehen, Verhaltensmuster zu beschreiben und ihre Veränderungen, beispielsweise durch die Einführung einer neuen Technologie, abzubilden. Im Rahmen dieser Diplomarbeit wurde der Einfluss des *Personal Computers (PC)* auf UK-Haushalte in den Jahren von 1999 bis 2001 untersucht. Umweltdaten und Zeitverwendungsstatistiken wurden verknüpft, um die Unterschiede zwischen einer Gruppe von Menschen, die einen PC in den Haushalt neu integrieren, und einer Kontrollgruppe zu analysieren. Hierdurch konnten einerseits die Substitutionseffekte zwischen einzelnen Aktivitäten, sowie andererseits die Auswirkungen auf den Energieverbrauch beschrieben und der Einfluss neuer Technologien herausgearbeitet werden.

Die Ergebnisse deuten darauf hin, dass sich die Einführung eines PCs positiv auf die Energieintensitäten auswirkt, da Aktivitäten mit niedriger und mittlerer Energieintensität Aktivitäten mit hoher Intensität ersetzen und den Energieverbrauch dadurch verringern. Die Ergebnisse sind allerdings nicht allgemein gültig, da sich zwischen verschiedenen Subgruppen unterschiedliche Bilder ergeben.

# Curriculum Vitae

Persönliche Angaben

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Schulbildung

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|---|---|
| 1994 – 2002 | Realgymnasium Aloisianum, Linz<br>Matura mit gutem Erfolg<br>Schwerpunkt: Biologie und Physik |
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| Seit 2009 | Trainer im Bereich der Erwachsenenbildung am Berufsausbildungszentrum, bfi Wien |
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| | Recherchearbeit im Bereich Klimatechnologien, Institut für Technikfolgenabschätzung (ITA) |
| 2004 – 2009 | Behindertenbetreuer für den ‚Verein GIN' |
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