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Opportunities and Risks of Digitalization for Climate Protection in Switzerland

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This report is complemented by a collection of supporting information that provides details on data and procedures that would have exceeded the scope of this document. The supporting information can be requested from the authors.

The project underlying this report was funded by Swisscom AG and WWF as part of their long-standing partnership with focus on climate actions and digitalization.

Foreword

For the last 10 years, Swisscom and WWF have been successfully collaborating to help Swisscom and its customers reduce their ecological footprint. To guide these efforts, we have agreed on ambitious targets to reduce greenhouse gas emissions. With this study, Swisscom and WWF build on this successful cooperation and take it to the next level.

As Switzerland's largest provider of ICT-services, Swisscom aims to offer key infrastructure and services that enable the sustainable development of the country's society and economy. As a part of this vision, Swisscom's sustainability strategy comprises a 2:1-goal, which guides its efforts to save double the amount of CO_2 through its ICT-services compared to what the company and its suppliers emit.

WWF's mission is to build a future in which people live in harmony with nature. As a leading conservation organization, WWF partners with businesses to minimize their negative effect on the environment, and, just as importantly, to increase their positive impact on the environment and society.

Swisscom and WWF see digitalization as a global development offering both risks and opportunities for a more sustainable and climate-friendly lifestyle. With this study, we explore the benefits and risks of digitalization for climate protection in Switzerland. The study shows that ICT has a significant carbon footprint and therefore contributes to climate change. However, ICT can also play a significant positive role for climate protection by enabling the reduction of greenhouse gas emissions. This analysis explores this potential and provides the necessary foundation for concrete steps to maximize the opportunities of digitalization for climate protection, while minimizing the respective risks.

Implementing climate-positive ICT solutions requires bold action, new thinking and pre-competitive collaboration between industry, civil society and government. WWF and Swisscom are ready to act on this challenge. We invite others to join us and together unleash the climate-positive potential of ICT and help build a sustainable future.

For this study, Swisscom and WWF collaborated with the group of Prof. Lorenz Hilty at the Department of Informatics of the University of Zurich. We would like to express our gratitude to our research partner. This research alliance has further

proven the importance of collaboration for finding innovative and evidence-based solutions for climate protection.

We hope this study contributes to a broader dialogue about the climate-positive potential of ICT. We look forward to feedback and suggestions.

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Executive Summary

Information and Communication Technology (ICT) is an important enabler for a low-carbon economy in Switzerland. ICT has the potential to avoid up to 3.37 times more greenhouse gas (GHG) emissions than the amount of emissions caused by the production, operation and disposal of ICT devices and infrastructures used in Switzerland in 2025. In absolute terms, ICT will enable the Swiss economy to save up to 6.99 Mt CO_2-equivalents (CO_2e) per year, with an own carbon footprint of 2.08 Mt CO_2e per year (see Figure 1).

This opportunity for the ICT sector to contribute to climate protection, however, can only be realized under optimistic assumptions. In particular, it is necessary that the existing technological and economic potentials are systematically exploited by taking ambitious and targeted actions. Such actions can be especially effective in the transportation, building and energy sectors, which have the highest potential for ICT-enabled ("smart") solutions to reduce GHG emissions. At the same time, the carbon footprint of the ICT sector itself must be reduced by 17%, which is technologically and economically feasible due to efficiency gains.

Measurement and projections of the ICT footprint are based on a consumption-based view, i.e., the footprint of ICT hardware and services consumed in Switzerland includes emissions occurring in other countries, such as the emissions caused by the production of imported ICT hardware ("embedded emissions"). For the estimation of the ICT-enabled GHG abatement, effects on emissions in foreign countries are also taken into account. As shown in Figure 1, a substantial part of the ICT sector GHG footprint occurs abroad, whereas almost the entire ICT-enabled GHG abatement happens in Switzerland.

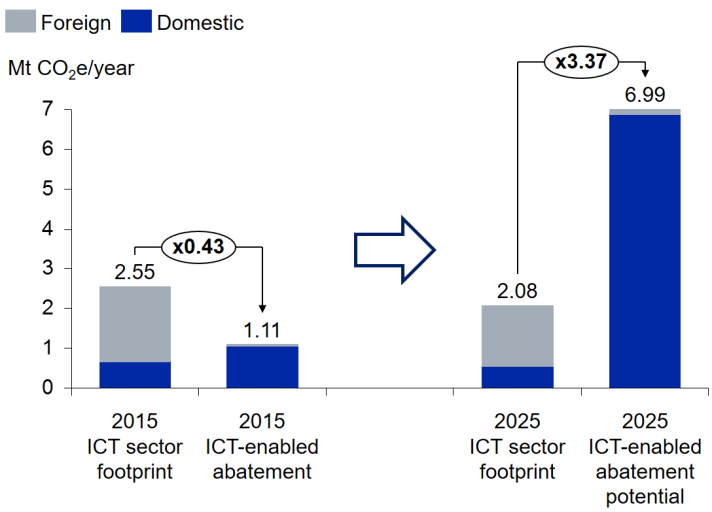

Figure 1: The Swiss ICT sector causes greenhouse gas emissions both in Switzerland and abroad. At the same time, the application of ICT in Switzerland contributes to greenhouse gas emission abatement in sectors other than ICT. Projection from 2015 to 2025.

The study reported here investigated opportunities and risks of digitalization for climate protection in Switzerland by focusing on the two aspects:

- the ICT sector's own footprint (direct effects of ICT on GHG emissions) and
- the abatement potential of ICT (indirect effects of ICT on GHG emissions).

The ICT sector's own footprint:

Our study found that the largest share of the ICT sector's GHG emissions comes from end-user devices. Currently, roughly ⅔ of the consumption-based GHG emissions of ICT in Switzerland are caused by desktop, laptop and tablet computers, smartphones and printers, while ⅓ of the emissions are caused by telecommunication network operators and datacenters (numbers from 2015).

Figure 2 shows how annual emissions are distributed over device types. It can be seen that phasing out stationary desktop computers ("traditional PCs") and replacing them by mobile devices, which are constrained in weight and power demand for reasons of convenience, provides an opportunity to reduce emissions both during production and use of the devices. Mobile devices (laptops, tablets, smartphones) could even be called "energy-sufficient" because their power consumption is kept at a low level in absolute terms to enable long battery life with small batteries. Thus, there is an opportunity to reduce the per-capita emissions caused by ICT consumption while improving user experience. With this shift to light and energy-sufficient mobile devices, the relative share of the production phase increases, which implies that it becomes more important for the ICT sector to engage in "greening" the supply chain and avoid "embedded" emissions, i.e., emissions that happen in the countries where the hardware is manufactured and the raw materials are mined. It is essential that the use of fossil energy is reduced over the entire life cycle of the products.

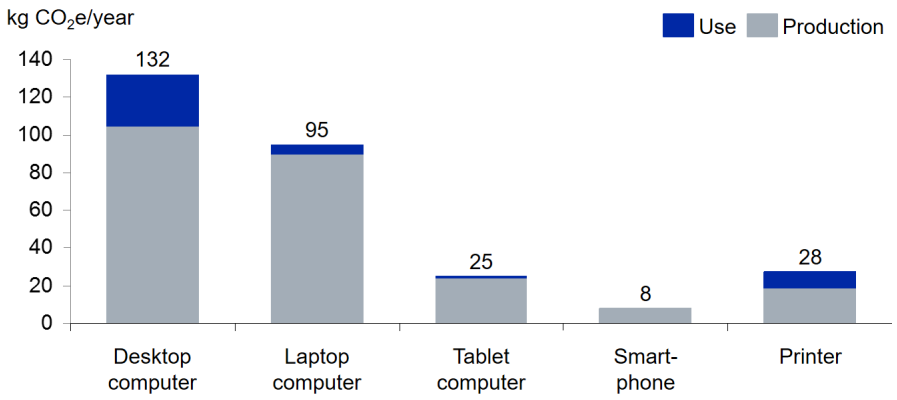

Figure 2: Average annual greenhouse gas emissions per end-user device during production and use by device type. The annual values of production emissions (grey) are based on current average useful lives of the devices.

The main risk for the development of the ICT sector's own footprint is that this positive trend is compensated or even overcompensated for by an increasing number of devices per capita and decreasing service lifetimes of the devices. The worst case would be a prevalent throw-away mentality with regard to digital electronics. This would substantially increase the footprint of the ICT sector, even under conditions of the well-established Swiss recycling system for waste electrical and electronic equipment. If the same amount (or even larger amounts) of scarce raw materials are distributed among larger numbers of devices, the dissipation of many scarce metals will increase. Resource depletion and the efforts to recover scarce material resources (also in terms of energy and GHG emissions), will grow as a consequence. A second risk is that Internet traffic, in particular machine-to-machine traffic, might grow faster than the energy efficiency of the infrastructure in the future, resulting in growing emissions of the large parts of the global Internet which will still be powered by non-renewable energies.

The GHG abatement potential of ICT:

Our study examined ten use cases discussed in literature, re-estimating adoption and impact parameters needed for our projection to 2025. We calculated three scenarios to reflect both, data uncertainty and the fact that the future is still to be shaped (Figure 3). The darkest parts of the bars in Figure 3 show the findings for the pessimistic scenario, resulting in a total abatement potential of 0.72 MT Mt CO_2e per year. For the optimistic scenario, the abatement potential amounts to 6.99 Mt CO_2e per year. The scenario which is to be expected under "business as usual" conditions yields 2.79 Mt CO_2e per year. All scenarios are based on use cases that could be realized with technologies already available and would provide a financial benefit to their users.

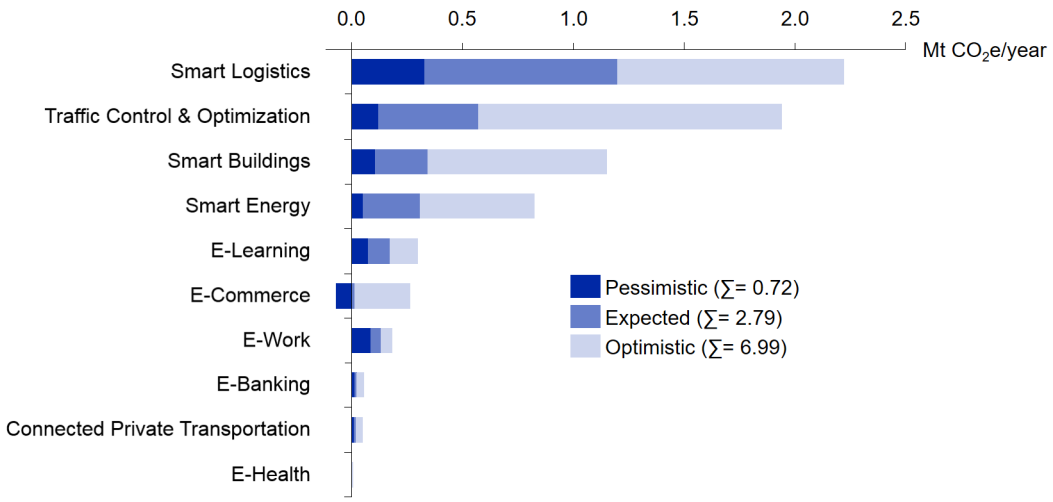

Figure 3: GHG abatement potential in 2025 in a pessimistic, expected and optimistic scenario by use case.

There is an unprecedented opportunity to take ambitious and targeted actions to implement ICT-based ("smart") low-carbon solutions, both in terms of technologies and business models, within less than one decade. This can mainly be done by further developing smart solutions in logistics, traffic control and optimization, buildings, and electric energy. Unleashing this GHG abatement potential would make a significant contribution to the Swiss GHG reduction goals.

The main risk for the contribution of ICT to climate protection is that the abatement potential could not be unleashed because the solutions will not be adopted by businesses and end consumers, resulting in the pessimistic scenario. ICT-based ("smart") solutions are only acceptable if businesses and end consumers can use them straightforward, safe, and be sure that the enormous amounts of data generated and processed are not used against their interests by anyone, including the government, competitors, and cybercriminals. In some application areas, rebound effects (i.e., increasing demands due to lower cost) compensating for the abatement, pose an additional risk.

Case studies on promising use cases:

To deepen the understanding of the drivers and barriers relevant to ICT-enabled GHG abatement, we analyzed five examples in detail:

- Collaborative logistics (example of smart logistics): ICT-based sharing of logistic assets among companies in road freight transport can increase the utilization of assets and reduce GHG emissions per ton kilometer. Flexible use of logistic assets can be a part of the "Industry 4.0" vision. Policies are needed to avoid an increase of demand for transport as a reaction to lower cost (rebound effect).
- Intelligent heating (example of smart buildings): Intelligent heating systems can reduce energy consumption by households significantly, without reducing the comfort of the residents. For buildings built before 1980 and one-family buildings, intelligent heating can be considered the "low-hanging fruit" of energy saving. The ICT sector and the heating industry as well as utility companies should cooperate to standardize and simplify the use of intelligent heating technology.
- Demand side management (DSM) in electricity consumption (example of smart energy): DSM supports the integration of renewable energies into the electricity grid and increases capacity utilization of existing infrastructure. For example, the operation of dishwashers could be postponed to shift the power consumption to times of lower demand or higher supply. Technical and regulatory standards are needed to enable adoption.
- Coworking (example of e-work): ICT is continuously increasing the portion of work that can be done independent of location. Active utilization of office space is low on the average, while the GHG emissions associated with building space are high. Coworking spaces can increase office space utilization, reduce commuting

distances and provide advantages compared to home-office work, such as the possibility to have physical meetings.
- Car sharing (example of connected private transportation): The leading role of Switzerland in car sharing could be used as a starting point to develop innovative car sharing schemes, such as free-floating car sharing. Cooperation between public authorities, public transport companies and car sharing providers is necessary to extend coverage of innovative car sharing schemes.

A comparison among these five examples shows a high potential for demand-side management if we assume that it plays a crucial role in the transformation of the energy system towards electricity from solely renewable sources. Collaborative logistics and intelligent heating both can make substantial contributions to the transition to a low-carbon economy. In direct comparison, the abatement potentials of coworking and car-sharing are smaller, but still worth exploring.

System boundaries:

This study provides quantitative results only for GHG emissions as one of several relevant environmental indicators, such as the depletion of scarce resources and toxicity. However, we show qualitatively that including the other indicators would not change the essential implications of our results.

The study does not take into account changes to the electricity mix (except in use cases where integration of renewables is the lever for the GHG abatement potential). We were using a constant electricity mix to show the impact of ICT as clearly as possible. The transition towards a higher share of renewable energy in the Swiss electricity mix has several effects on our results. In particular, it can decrease the use-phase emissions of end-user devices, telecommunication networks and data centers. A larger effect for climate protection, however, would result from a transition to low-carbon energy in countries where ICT hardware is produced.

Regarding the enabling effect of ICT, this study focused on use cases where a GHG abatement potential can be expected. It is possible that use cases exist where ICT enables or supports activities with high GHG emissions, thus bearing induction potentials (as opposed to abatement potentials). Induction potentials were excluded from the system under study.

Several developments in the ICT sector had to be excluded as well because predicting them would go beyond the scope of this study. This includes the general trend towards the "Internet of Things" (as far as direct effects are concerned) and applications of Artificial Intelligence such as self-driving cars and autonomous robots.

Taking the resulting uncertainty into account, we can derive the following robust recommendations from our results.

Recommendations:

- Swiss households and businesses can influence the direct environmental impacts by using mobile devices (laptops, tablets, smartphones) instead of old stationary devices and using them as long as possible.
- Swiss households and businesses should evaluate their individual benefit of adopting ICT-based ("smart") solutions in areas where investment in such solutions provides a substantial GHG abatement potential: Solutions such as demand-side management, intelligent heating, car sharing or the sharing of other assets can have substantial positive effects, but their impact is context-dependent and must be evaluated in each individual case.
- Swiss ICT companies including telecommunication network operators should consistently reduce their carbon emissions, both locally and by using their purchasing power to influence the supply chain for imported equipment in the direction of green and fair procurement.
- Swiss ICT companies including telecommunication network operators should use their potential to develop and provide ICT-based low-carbon solutions to their B2B and B2C customers in areas with high GHG abatement potential.
- Policy makers should develop framework conditions that enable and encourage safe and privacy-respecting ICT solutions.
- Policy makers should encourage the development of open technical standards and create incentives for the adoption of ICT-based low-carbon solutions, especially in areas with high GHG abatement potential (transportation, smart buildings, smart energy).

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1 Digitalization and Climate Protection

1.1 Introduction

Mankind has always been striving for technologies to store information (from cuneiform writing to the magnetic tape), to transmit information over larger distances (from smoke signals to radio waves), and to process information faster (from the abacus to the first computer). What makes our age special is that these three types of technologies have all become electronic and digital, a development that made it possible to merge them into one technology, now called (digital) ICT. Whatever can be stored, can also be transmitted, and vice versa. And because everything is stored and transmitted in digital form, it can also be algorithmically processed.

This process of digitalization has been changing our patterns of production and consumption already for decades now, and we may have seen only the beginning of its consequences. Since ICT is a transformative technology, it is an obvious question to ask if and how ICT will also contribute to the world-wide transformation that is so urgently needed – the one described in the UN 2030 Agenda for Sustainable Development (United Nations, 2016). The Agenda defines 17 sustainable development goals which are intended to "stimulate action over the next 15 years in areas of critical importance for humanity and the planet." (United Nations, 2016, 3)

1.2 Climate Change

Among the 17 sustainable development goals defined in the Agenda 2030, combatting climate change is considered "one of the greatest challenges of our time and its adverse impacts undermine the ability of all countries to achieve sustainable development" (United Nations, 2016, 6).

Combatting climate change by reducing greenhouse gas (GHG) emissions is therefore a necessary (not sufficient) condition for sustainable development. Without reducing GHG emission to keep global warming within acceptable limits, many other global problems such as poverty, hunger, lack of water and sanitation, inequality and conflict, land degradation, and biodiversity loss will become even more difficult to address.

1.3 ICT Impacts on Climate Change in the Literature

Research on the impact of ICT on activities that have implications on climate change began in the late 1980s with the pioneering work of P. L. Mokhtarian on the "Relationships between Telecommunications and Transportation" (Mokhtarian,

1989). An OECD report authored by F. Berkhout and J. Hertin introduced the distinction among first-, second- and third-order effects of ICT, which has been widely used in later literature: (1) "direct environmental effects of the production and use of ICTs", (2) indirect environmental impacts through the change of "production processes, products, and distribution systems", and (3) indirect environmental impacts "through impacts on life styles and value systems" (OECD, 2001, 2). A System Dynamics model of "The future impact of ICT on environmental sustainability" at the EU level was built in a project of the European Commission's Institute for Prospective Technological Studies (Erdmann et al., 2004, Hilty et al., 2004, 2006) and recently re-evaluated with new data (Ahmadi Achachlouei & Hilty, 2015).

The impact of ICT on the productivity and energy efficiency of the economy has been analyzed in several studies by J. A. Laitner and his colleagues (e.g., Laitner & Ehrhardt-Martinez, 2008; an overview is provided in Laitner, 2015). The Global e-Sustainability Initiative (GeSI) commissioned a series of studies to assess the GHG footprint and the GHG abatement potential of ICT (The Climate Group, 2008, GeSI & BCG, 2012, GeSI, 2015).

The energy demand of ICT devices and infrastructures has been analyzed for decades. Several authors provide recent overviews, for example for per-capita ICT electricity consumption (Aebischer & Hilty, 2015), grey energy in ICT devices (Hischier et al., 2015), electronic vs. print media and videoconferencing vs. travel (Coroama et al., 2015a), or Internet traffic (Coroama & Hilty, 2014).

1.4 Basic Definitions

An important distinction of ICT effects is made throughout literature and also in this report:

- direct effects, also called the "footprint" or "first-order effects" of ICT
- indirect effects, also called "enabling effects" or "second-order effects" of ICT

Since we are focusing on GHG emissions, the direct effects are, in the context of this study, *the GHG emissions caused by the fact that ICT devices and infrastructures must be produced, operated, and disposed of*. We will call the total of these GHG emissions *the carbon footprint (or GHG footprint) of the ICT sector.*

The indirect effects are, in our context, the *changes to the carbon footprint of other sectors* (such as the transport sector or the energy sector) *caused by applying ICT in those sectors.*

We use the unit "Mt CO_2e", or megatons carbon dioxide equivalent, to measure GHG emissions with respect to their global warming potential. GHGs other than CO_2 (although in our case almost irrelevant) are accounted for by multiplying them

with a factor expressing the relative global warming potential of the gas in relation to CO_2.

End-user devices	Desktop, laptop and tablet computers Monitors Fixed line phones Mobile phones Printers TVs Internet of Things (IoT) nodes
Telecommunication networks	Customer premises equipment Access networks (fixed, mobile) Edge and core networks Internet backbone
Data centers	Network data centers Third party provider data centers
Other ICT company activities	Buildings Fleet Business travel Employee commuting Logistics Waste treatment

Table 1: The ICT sector as defined for this study. Not all numbers concerning the ICT sector mentioned in this study are assuming the same system boundaries for the sector. Potential inconsistencies are discussed where necessary.

In line with current literature (see Section 2.1.), we define the ICT sector as the sum of ICT end-user devices, telecommunication networks, data centers and other activities by ICT companies (Table 1).

1.5 ICT Use in Switzerland

In 2016, 91% of Swiss households had an Internet connection, while the European average was 85%. The share of Swiss households with a mobile broadband connection increased from 20% in 2010 to 53% in 2014 (FSO, 2016). More than 99% of Swiss households had a mobile phone and more than 98% had a desktop or laptop computer in 2014 (FSO, 2017a). In 2012, more than 10% of the Swiss BIP was spent on ICT products or services (FSO, 2017b).

In April 2016, the Federal Council adopted the "Digital Switzerland" strategy, a core objective of which is to "use the opportunities which digitisation presents consistently and provide the necessary basis for these. Information and communications technology drives innovation, leading to value creation, economic growth and helps to secure prosperity" (OFCOM, 2017a).

2 Direct Effects of ICT on Climate Change

2.1 The Life Cycle of ICT Hardware

There are two emission accounting methods to assess GHG emissions (OECD, 2016):

- Production-based (or territorial) emission accounting considers emissions caused within a given territory (e.g., all GHG emissions in Switzerland).
- Consumption-based (or demand-based) emission accounting considers emissions caused by a given demand, no matter where the production to meet this demand takes place.

For example, assume that a smartphone is produced in China and shipped via the Netherlands to Switzerland, where it is used. With the production based approach, emissions caused during manufacturing and transport would be allocated to China and the Netherlands, and only the emissions caused by generating the Swiss electricity used to charge the phone to Switzerland. To be more precise, if a part of the electricity used for charging the phone is imported or if the servers used by an app are located outside Switzerland, this part would also be allocated to the other countries. By contrast, consumption-based emission accounting allocates all emissions to the country where the final service is consumed, i.e., the smartphone is used (OECD, 2016).

In our analysis, we apply consumption-based emission accounting using the method of life cycle assessment (LCA). This is a standardized method to assess all material and energy flows which are drawn or discarded into the environment during production, use and disposal of a good (ISO, 2006).

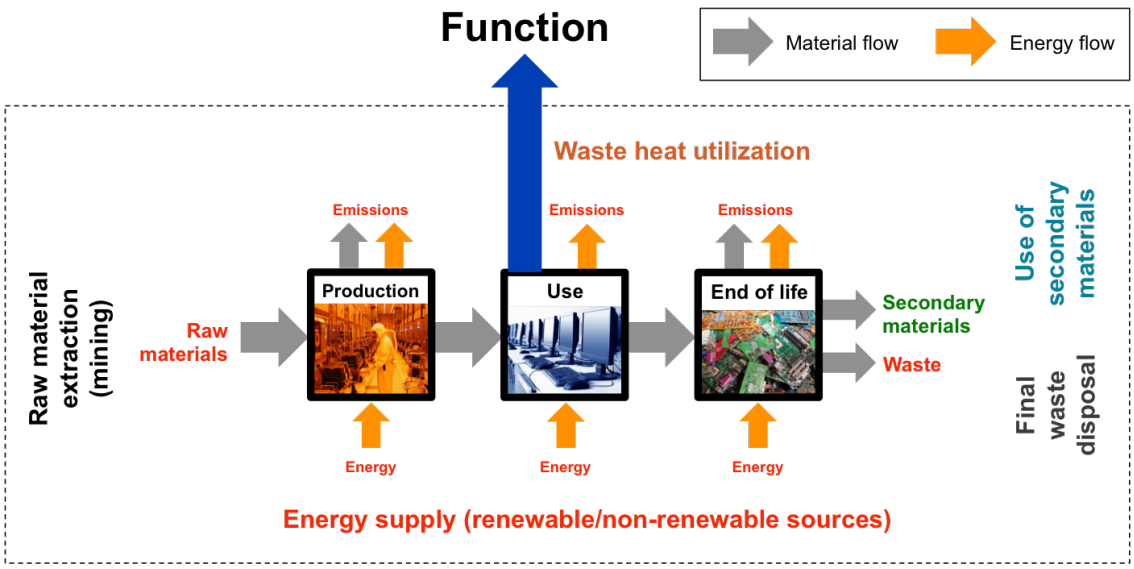

Figure 4: The life cycle of ICT hardware.

For ICT hardware, the main parts of the life cycle (the so-called foreground processes) are the production, the use and the end-of-life treatment (recycling or final disposal) of the devices. Additional processes (background processes) include the upstream processes for mining the raw materials and providing the energy in all phases, and the downstream processes after end-of-life treatment. Use of secondary materials and waste heat utilization in datacenters are usually accounted for by a negative burden (bonus) for avoided primary production of the materials or heat (Figure 4).

The use, storage and disposal of ICT devices in Switzerland has been investigated with a material flow analysis approach to better understand how precious or critical resources contained in the hardware pass through our society (Thiébaud et al., 2017a, b, c).

Various studies already assessed the ICT life cycle with regard to global warming potential. We briefly outline the most relevant and recent studies:

- Malmodin and Lundén (2016) identified a decline of the consumption-based GHG emissions of the ICT and entertainment sector in Sweden from 2010 until 2015. The decline is mainly caused by a substitution of large stationary devices (desktop computers and TVs) with mobile devices (smartphones and tablets) with smaller screens.
- The Swiss Federal Office of Energy (SFOE) estimated the electricity consumption of the use of ICT and entertainment devices in Switzerland (production-based method). Their results show that in 2015 ICT and entertainment devices cause 4.8% of total Swiss electricity consumption and are mainly used in households and the service sector (approximately at equal parts) and to some extent in the industrial sector (Prognos et. al., 2016). Their results show a decline of electricity consumption of ICT and entertainment devices from 2010 to 2015 due to more efficient screens of TVs and computers (Prognos, 2016).
- The Global e-Sustainability Initiative (2015) estimated the global ICT carbon footprint in 2030 to amount to 1.25 GT CO_2e or 1.97% of global GHG emissions. Compared to older studies by GeSI, the footprint is expected to decline from 2020 to 2030.

Despite different scopes and methods, these studies all find *decreasing* GHG emissions. However, neither of the available studies analyzed the total ICT sector GHG emissions in Switzerland with consumption-based emission accounting. The following analysis will fill this gap.

2.2 Estimation of GHG Emissions of the Swiss ICT Sector in 2015

2.2.1 Method

We assessed the GHG emissions caused by the ICT sector in Switzerland based on three main sources: reported emissions by Swiss telecommunication network operators (TNOs), the electricity consumption of data centers in Switzerland and the end-user devices used in Swiss households and the commercial sector. GHG emissions caused by electricity consumption in Switzerland were calculated based on the Swiss electricity supply mix with 149.4 g CO_2e/kWh (Messmer & Frischknecht, 2016). An increasing number of *TNOs report their GHG emissions* according to the GHG Protocol Standard[1]. The GHG Protocol encourages companies to report emissions caused by sources controlled by them (Scope 1), from their electricity and heat consumption (Scope 2) and from sources used as a consequence of their activities but not controlled by them (Scope 3) (WBCSD & WRI, 2015). If a company follows the GHG reporting standard, they cover the full life cycle of GHG emissions according to the life cycle assessment approach. In our calculation, we included the emissions caused by the largest Swiss TNOs, which are Swisscom, Sunrise, Salt and UPC who in common represent more than 80% of the fixed and more than 90% of the mobile Swiss TNO market (OFCOM, 2017b). For small TNOs and TNOs not reporting GHG emissions, we estimated the GHG emissions. Uncertainties stem from different reporting methods applied by the different providers. Second, we estimated the *emissions caused by electricity consumption of data centers in Switzerland*. Hereby, we included data centers run by professional ICT service providers (third party providers) and excluded internal data centers of other companies in Switzerland (Altenburger et. al., 2014). Third, we estimated the *emissions caused by end-user devices*. We built our estimation on statistics provided by the Federal Statistics Office (number of devices used in Swiss households), the Federal Office of Energy (electricity consumption of end-user devices in private households and in commercial use) and life cycle inventory data provided by ecoinvent v3.2. (FSO, 2017a, Prognos, 2016, Prognos et. al, 2016, ecoinvent Centre, 2015). For the production of mobile end-user devices (laptop, tablet, smartphone) we identified significant differences between the emission factors available in ecoinvent v3.2. and other sources, which is why we used the average of the available data points. To avoid double counting, we deducted the emissions from computers, monitors and smartphones within TNO emission reporting. This approach does not cover 3D printers, IoT nodes, a part of the fixed line phones, production and disposal of data center hardware, the Internet backbone and other activities by non-TNO ICT companies. We also analyzed emissions caused by TVs. However, we excluded TVs from all aggregated estimations, since these do not relate to the indirect effects analyzed in Chapter 3.

[1] Greenhouse Gas Protocol is a multi-stakeholder partnership which develops greenhouse gas reporting standards for businesses.

2.2.2 Results

In 2015, the Swiss ICT sector caused 2.55 Mt CO_2e or 308 kg CO_2e per capita. This equals 2.7% of total consumption-based GHG emissions in Switzerland.[2] *67% of ICT sector emissions are caused by the production, use and disposal of end-user devices and 33% by telecommunication networks, data centers and other TNO activities (Figure 5).*

In 2015, TNOs caused 0.64 Mt CO_2e. 25% of these are caused by the TNOs' direct consumption of energy for the operation of networks, data centers, buildings and fleets (GHG Protocol Scope 1 and 2). 75% stem from sources not controlled by the TNOs directly (Scope 3); mainly from the production of purchased goods and services, use and end-of-life treatment of sold products (customer premises equipment), employee commuting by car as well as up- and downstream logistics. Data center electricity consumption in Switzerland caused 0.20 Mt CO_2e in 2015. End-user devices in total caused 1.71 Mt CO_2e in 2015, which is significantly higher than the total emissions caused by networks, data centers and other TNO activities.

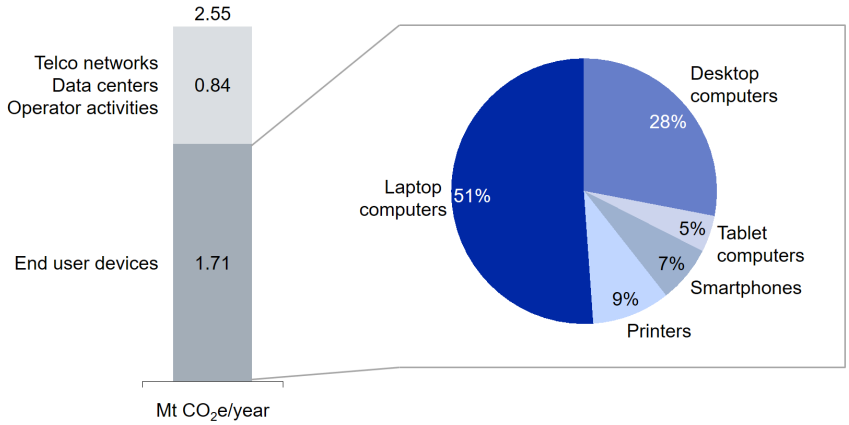

Figure 5: ICT sector GHG emissions in Switzerland in 2015 by sector elements and device type.

Mobile devices cause significantly less emissions per device than stationary devices, during both production and use.

The life cycle assessment of end-user devices shows that laptop computers cause roughly half of end-user device emissions in Switzerland, followed by desktop computers, whereas tablet computers and smartphones cause significantly less emissions (Figure 5). To understand the drivers behind these results, we have to analyze the lifecycle emissions per device type in detail (Figure 6). The effect of the end-of-life phase is not shown because the impact is in general very small, if treatment under industrial conditions is assumed (Hischier et al., 2015).

[2] We estimated the total consumption-based GHG emissions in Switzerland based on the domestic GHG emissions according to the GHG inventory and a markup factor for foreign GHG emissions, which equals roughly 100% (FOEN, 2017, Frischknecht et. al., 2014).

Comparing computer and phone devices shows that stationary devices (desktop computers) are significantly less efficient than mobile devices (laptop computers, tablet computers, smartphones). Switching from a desktop to a laptop computer, which often provide the same functionality, can save 28% of annual GHG emissions. The fact that laptop computers in total cause more emissions than desktop computers is due to the higher number of devices.

Looking only at the use phase, we find that GHG emissions caused per year by use of a desktop are more than five times higher than those of a laptop computer. This difference emphasizes the achievements in energy efficient design for long battery life. Beyond, the electricity mix affects the use phase GHG emissions. Swiss electricity production is based on nuclear and waterpower, causing few greenhouse gas emissions. However, Switzerland cannot cover its electricity demand through its own production and depends on electricity imports from other countries, which usually contain electricity from fossil fuels with a significantly higher GHG intensity.[3] Replacing all imported electricity with domestic electricity can reduce ICT sector GHG emissions by roughly 17%.[4]

For comparison, we also show the production and use phase emissions of TVs. TV emissions confirm that stationary devices are less energy efficient than mobile devices (in this case especially during production). Considering the high number of TVs used in Swiss households, the useful life of TVs should also be increased.

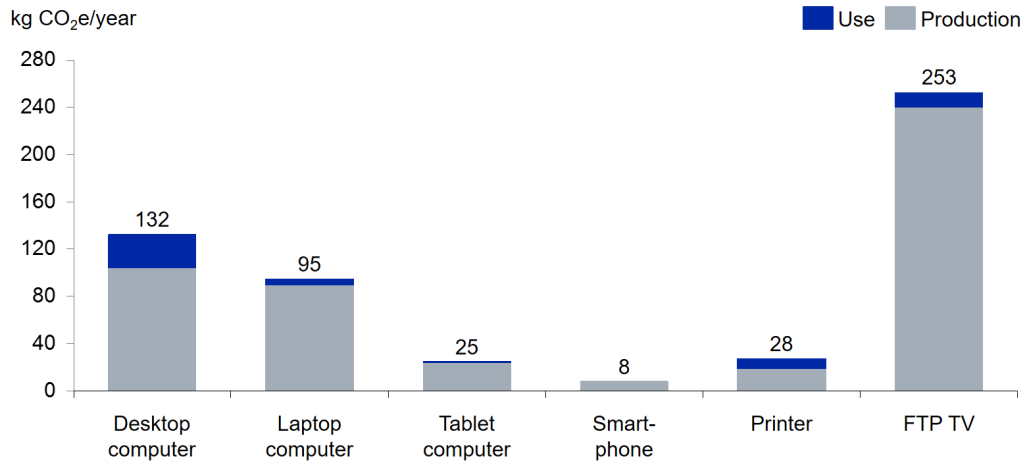

Figure 6: Average annual greenhouse gas emissions per end-user device during production and use by device type.[5]

[3] This results in the Swiss electricity supply mix with 149.4 g CO_2e/kWh according to Messmer and Frischknecht (2016).

[4] This results in the Swiss electricity production mix with 29.8 g CO_2e/kWh according to Messmer and Frischknecht (2016), mainly reducing the GHG footprint of the operation of telecommunication networks, data centers and the use phase of the end-user devices.

[5] For printers, we assumed that one printer prints 200 pages per year. FTP TVs are flat-panel display TVS. For FTP TVs we used the emission factors of a 40''-42'' LCD TV.

The impact of the production of mobile devices is more relevant than the electricity they consume during use.

For all devices, production of devices causes the major part of GHG emissions. The high number of different raw materials as well as complex manufacturing processes drive production emissions up. Increasing the useful life of end-user devices reduces the impact of production emissions. Once a device needs to be replaced, switching to a mobile alternative (e.g. from a desktop to a laptop computer) reduces emissions. Across the whole ICT sector, the share of GHG emissions caused in Switzerland is 26% and the share of GHG emissions caused in other countries (mainly production of end-user devices) is 74%.

2.3 Projection of GHG Emissions of the Swiss ICT Sector to 2025

2.3.1 Method

Using the ICT sector GHG emissions in 2015, we projected their development until 2025. We projected TNO and data center emissions based on the TNO publicly committed targets and a semi-structured interview with one Swiss TNO. We projected the number of end-user device emissions based on current trends in device sales and expectations about devices usage in 2025. To account for uncertainty about the future, we developed three scenarios (Table 2).

Scenario	Description
"pessimistic"	Based on projections assuming that TNOs do not achieve their emission reduction targets, number of devices per capita will significantly increase and no substitution of mobile for stationary devices will happen.
"expected"	Based on projections assuming that TNOs achieve their emission reduction targets, number of devices per capita will moderately increase and a moderate substitution of mobile for stationary devices will happen.
"optimistic"	Based on projections assuming that TNOs over-achieve their emission reduction targets, number of devices per capita will moderately decline and a significant substitution of mobile for stationary devices will happen.

Table 2: Scenarios used for estimation of direct effects.

2.3.2 Results

Under pessimistic assumptions, the annual GHG emissions of the Swiss ICT sector will increase by 8.0% from 2015 until 2025. Under optimistic assumptions, they will decrease by 17.0% (Figure 7).

In the pessimistic scenario, the increase of emissions is mainly influenced by increasing numbers of mobile and stable numbers of stationary computing devices and increasing electricity consumption of TNOs and data centers. A reduction of indirect emission caused by TNOs (GHG Protocol Scope 3) can partly compensate this increase. In the optimistic scenario, emissions decrease due to a significant reduction in number of desktop computers, which are replaced by mainly tablet and partly laptop computers. A reduction in number of smartphones and printers have a small reducing effect. Beyond, TNOs manage to reduce their indirect emissions from downstream and upstream activities significantly.

Across all scenarios, the impact of smartphones is relatively small, compared to the impact of desktop, laptop (high emissions per device) and tablet computers (high increase in number of devices). The same is true for TNO's direct energy consumption compared to TNO's Scope 3 emissions.

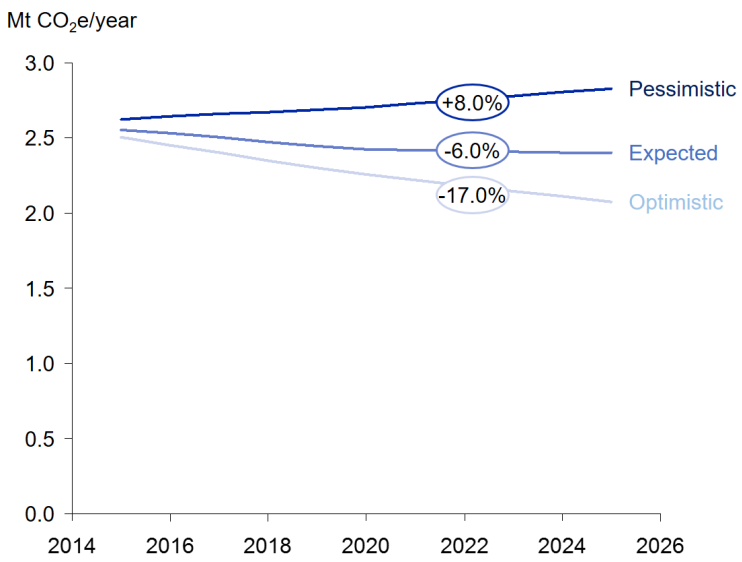

Figure 7: ICT sector GHG emission from 2015 until 2025 by scenario.

2.4 Discussion

The analysis shows that the ICT sector GHG emissions will decrease by 2025 unless we assume that TNOs will fail to achieve their emission reduction targets and the number of end-user devices will substantially increase. The most significant driver of the decreasing GHG footprint are the substitution of mobile for stationary devices and TNO's Scope 3 emissions.

However, our projections could not cover *all* factors that influence ICT sector emissions. For reasons of transparency, we will briefly discuss additional factors and their relevance:

- Growth of the Internet of Things (IoT): Forecasts of the number of things (everyday objects) that will become connected to the Internet in 2020 differ from 18 to 50 Billion (10^9) world-wide. Depending on how much electronics the "smart things" will contain and how many of them will be adopted in Switzerland, this could significantly contribute to the embedded emission of ICT. Potentially more important, there could be software-induced hardware obsolescence (Hilty, 2008a), which will not only affect the electronics part, but the whole "smart thing" in which it is embedded. Thus, obsolescence of everyday objects could be accelerated due to software innovation cycles. Recycling of smart things could also be adversely affected by their embedded ICT components (Köhler et al., 2011). For all these impacts, the risk that they will become relevant as a part of the ICT footprint is difficult to quantify today because there is a lack of standards that would make the technical designs and their life cycles more predictable, and the adoption rates are subject to high uncertainty.
- Diffusion of 3D printers: Similar to the IoT trend, the trend to 3D printing is difficult to predict. If we assume that 3D printers reach a high penetration rate, the embedded emissions of the printers and their electricity consumption could become a relevant factor. It is also possible that the 3D printing trend is declining.
- Changes in the hardware production process: We assumed that ICT hardware – as well as the raw materials going into it – will be produced with roughly the same amount of emission per kg hardware throughout our time horizon. It is possible that producing countries such as China will make progress towards energy-efficient and cleaner energy. It is, on the other hand, also possible that the decreasing accessibility of some scarce metals will increase the physical effort and therefore the amount energy needed for mining them.
- Unbalanced increase of Internet traffic: Energy intensity of Internet traffic, i.e., the amount of electric energy needed on average to transmit data from end to end through the global Internet is decreasing by roughly 30% per year due to technological progress (Coroama & Hilty, 2014) and is well below 0.1 kWh/GB today. This has been in some balance with the growth of data traffic. There is

some risk that data traffic will grow faster than the energy efficiency of the infrastructure in the future, resulting in growing emissions caused by the large parts of the global Internet which will still be powered with fossil energy. This risk of unbalanced growth cannot be quantified today. An important uncertain factor is the additional machine-to-machine (M2M) traffic from IoT nodes. M2M traffic is data traffic that is not initiated by a human, e.g. the user of a smartphone, but by an algorithm that decides automatically to send data such as a sensor value or the picture of a surveillance camera. It is generally assumed that M2M traffic will be the most important driver of Internet traffic in the coming years, but that growth will stay below 30% per year (Cisco Systems, 2016, Coroama et al., 2015b, Schien et al., 2015).

– Electricity mix: Improvements in the electricity mix used during device production, use or disposal will have a decreasing effect on GHG emissions. If we assume that emissions per device decrease by 1% yearly due to an improving electricity mix, ICT sector GHG emissions increase by 2.0% instead of an increase of 8.0% from 2015 until 2025 in the pessimistic scenario and decrease by 21.7% instead of 17.0% in the optimistic scenario.

These developments do not alter the recommendations and conclusions drawn from our results.

We also wish to point out that the life cycle inventory data of ICT devices is subject to considerable uncertainty (e.g., Hischier et al, 2014, Ercan et al, 2016), as is the energy intensity of network usage (Coroama & Hilty, 2014). Also, not all TNOs disclose their Scope 1-3 GHG emissions. Therefore, parts of the Scope 1-3 GHG emissions had to be estimated.

In addition, we discuss the relevance of environmental impact categories beyond global warming and thus the adequacy of using just GHG emissions as an indicator. More comprehensive LCA studies of ICT devices have shown that impact categories beyond global warming potential clearly matter throughout the life cycle. These categories, mainly particulate matter, photo-oxidant creation potential, acidification potential and eutrophication of fresh water, are however dominated by the production stage. Many of the toxic impacts are due to mining activities, e.g., for gold and copper (Ercan et. al., 2016). With regard to the environmental impacts that are not connected to energy consumption, it is important to aim for the substitution of scarce metals and to improve the recycling systems, both in terms of collection rates and recovery of scarce metals.

Including these categories reinforces our result that a significant part of the environmental footprint of consuming ICT services in Switzerland occurs abroad and that keeping the number of devices within limits while extending their useful

life is important to reduce impacts. It also confirms the necessity to take a consumption-based perspective.

Users should become aware that ICT hardware is a technology that contains more than 50 chemical elements, including several scarce metals (Wäger et al., 2015). Both mining these metals and any form of inadequate disposal has toxic impacts on humans and ecosystems. Although our Swiss recycling system for ICT devices is clean compared to the informal recycling taking place in poorer parts of the world (Böni et. al., 2015), there is some risk that the trend towards smaller and embedded devices will weaken the recycling system (Hilty, 2005). In any case, even under optimum conditions, only a subset of the elements contained in ICT hardware are recycled (Wäger et al., 2015). Resource depletion resulting from the use of scarce metals in ICT hardware may in the long term become the most important unsustainable impact of ICT.

3 Indirect Effects of ICT on Climate Change

3.1 Indirect Effects of ICT on Climate Change in Literature

Indirect effects of ICT are also called enabling effects and describe how ICT application changes existing processes and products in other sectors by enabling users to act differently. These effects may be favorable or unfavorable in terms of the indicators used for evaluating them, in our case GHG emissions (Hilty, 2008a, Hilty & Aebischer, 2015).

A number of studies analyzed indirect effects of ICT application on energy consumption and climate change:

- GeSI published the SMART2020, SMARTer2020 and SMARTer2030 reports, which mainly present estimates of GHG abatement potentials of ICT (The Climate Group, 2008, GeSI & BCG, 2012, GeSI, 2015). The most recent study analyzes twelve use cases of ICT, such as Smart Buildings or E-Commerce, and predicts that ICT has the potential to avoid 12.1 GT CO_2e in 2030 at the global level, which equals 20% of the global GHG emissions (GeSI, 2015).
- Laitner and Ehrhardt-Martinez (2008) estimated that for every kWh of electricity required to power ICT, the U.S. economy saved 8.6 kWh in 2006. Beyond, Laitner (2010) estimated that semiconductor technologies avoided 20% of total electricity consumption in the US economy in 2006, compared to an economy without these technologies.
- Erdmann and Hilty (2010) reviewed several studies on the impact of ICT on CO_2 emissions, comparing their approaches, methods and results.
- Other studies analyzed specific ICT applications in detail, for example: Coroama et al. (2012) showed the CO_2 reduction due to avoiding intercontinental flights by videoconferencing for a large international event. Moberg et. al. (2011) showed that production of an e-book reader causes the same amount of greenhouse gas emissions as the production of 30-40 printed books. Hence, sustainable use of an e-book reader starts after reading 30-40 books with it. Weber et. al. (2010) find that purchasing and delivering music online reduces the carbon dioxide emissions associated with music delivery by 40% to 80% compared to physical music delivery.

Since nowadays ICT has widely penetrated society, it is almost impossible to cover all indirect effects of ICT. Therefore, the scope of existing literature on indirect effects varies considerably and results are difficult to compare. Another difficulty is that determining a reduction potential depends on the chosen baseline (Hilty et al., 2014). To estimate an indirect effect of ICT, would we seriously define the baseline as a scenario without ICT? It is difficult to imagine how a world without ICT would look like. For example, if no telephone existed, our patterns of communication, our

lifestyles and ways of making business most probably would have developed in a different way. For specific use cases, however, there are ways of estimating indirect effects, e.g. to "freeze" the adoption and impact of specific application at an initial level to define a baseline. In the following analysis, we will estimate the indirect impact of ICT on climate change in Switzerland, reconsidering 10 use cases previously defined and discussed in a study commissioned by GeSI as a follow-up of SMARTer2030 (GeSI, 2015) focusing on Switzerland (Accenture Strategy, 2016).

3.2 Estimation of Indirect Effects of ICT on GHG Emissions in Switzerland in 2015 and 2025

3.2.1 Method

In the SMARTer 2030 study, GeSI estimated the GHG emission abatement potential through ICT application in 2030 for selected focus countries and on a global level. The abatement potential describes the emissions ICT can avoid in one year. GeSI analyzed twelve use cases of ICT. For each use case (e.g., E-Health), GeSI identified and quantified different GHG abatement levers (e.g., reduction in transport and reduction in facilities). In 2016, Swisscom received a derivation of the SMARTer 2030 study results for Switzerland by Accenture Strategy. Accenture estimated the Switzerland specific reduction potential for ten out of twelve SMARTer 2030 use cases (Table 3) (Accenture Strategy, 2016). In our analysis, we increased the validity of these results by refining the scope and by using Switzerland-specific data.

We focused our refinement on four methodological elements of the SMARTer 2030 study:

- *Allocation:* Accenture analyzed use cases, which are enabled by ICT. Accenture did not consider the significance of the ICT contribution to the abatement potential. We excluded selected abatement potentials if ICT was only a minor contributor to its realization.
- *Adoption rate:* Accenture estimated the share of the use case population (e.g., share of households using Smart Meters) adopting the ICT use cases for OECD and non-OECD countries for 2015 and 2030. We estimated the adoption rate specifically for Switzerland for 2015 and 2025.
- *Impact:* Accenture estimated the GHG emission abatement potential if one unit of the population adopts the ICT solution (e.g., each household saves 4% of GHG emissions through Smart Meters). We reevaluated the Accenture assumptions.
- *Rebound effect:* Rebound effects describe the phenomena, when increased productivity in production of a product or service increases the consumption of this product or service (Madlener & Alcott, 2011). We re-evaluated the assumptions about rebound effects used by Accenture.

The modification of the assumptions allowed us to recalculate an adapted GHG emission abatement potential per use case. Table 3 shows the use cases, a description of the use cases and the GHG emission abatement lever according to the scope of this assessment.

Use Case	**Description**	**GHG emission abatement lever**
E-Health	E-Health describes the use of ICT in the healthcare sector to enable remote treatment of patients using telepresence technology	E-Health avoids patient travel to healthcare facilities
E-Learning	E-Learning describes the use of ICT in education to enable location independent learning (e.g., online courses in higher education and company training)	E-Learning avoids travel to education facilities
Smart Energy	Smart Energy describes the use of Smart Meters which monitor (electric) energy consumption, and provide consumption data to consumers	Smart Energy influences consumer behavior and reduces their consumption of energy
Smart Buildings	Smart Buildings describes the integration of ICT devices into building infrastructure, which measure changes in the environment and react accordingly (e.g., automatic adaption of heating to presence of residents)	Smart Buildings avoid unnecessary energy consumption, which does not contribute to the residents' comfort
Connected Private Transportation	Connected Private Transportation describes car and ride sharing	Connected Private Transportation reduces the total distance of private motorized transport and the number of cars produced
Traffic Control & Optimization	Traffic Control & Optimization describes ICT which allows private drivers to identify more fuel efficient routes (e.g., GPS, live traffic information) Beyond, ICT increases the convenience of public transportation (e.g., through real time information systems)	Traffic Control & Optimization reduces the total distance driven, decreases average fuel consumption of cars and substitutes private automotive transport for public transport
Smart Logistics	Smart Logistics describe the use of ICT to enable route optimization, increase capacity utilization, enable logistic asset sharing between companies and ICT assisted eco driving in road, train, air and water freight	Smart Logistics reduces the total number of ton kilometers in freight transport
E-Commerce	E-Commerce describes the trade of goods on virtual platforms instead of physical stores. Goods are distributed to consumers instead of consumers travelling to shops	E-Commerce reduces emissions if the emissions saved by avoided trips to physical stores are higher than the emissions caused by distribution of online ordered goods
E-Banking	E-Banking describes conducting bank transactions on virtual platforms instead of physical bank branches	E-Banking avoids consumer travel to banks
E-Work	E-Work describes the use of ICT to work location independent, while still being able to access and process work relevant information and collaborate in teams remotely	E-Work avoids employees travel to work facilities and business trips (e.g., through audio and video conferencing)

Table 3: Analyzed use cases and description of GHG emission reduction lever.

We based our analysis on available data in research and in practice. To deal with uncertainty about the future and show potentials of directed actions we developed three different scenarios for the indirect effects in 2025 (Table 4). Across the scenarios,

we changed the adoption rate as well as the impact. The magnitude of the difference between the scenarios reflects the uncertainty.

Scenario	Description
"pessimistic"	The pessimistic scenario combines – an adoption rate assuming that planned actions to increase penetration of the use case are not taken with – the lower boundary of the data points for the impact identified in latest research.
"expected"	The expected scenario combines – an adoption rate that can be expected according to measures currently implemented or planned (business as usual) with – the average of the data points for the impact identified in latest research.
"optimistic"	The optimistic scenario combines – an adoption rate assuming that actions accelerating penetration of the use case are taken with – the upper boundary of the data points for the impact identified in latest research.

Table 4: Scenarios used for the estimation of indirect effects.

3.2.2 Results

ICT has a reducing effect on the GHG footprint of important other sectors.

In 2015, the use cases analyzed in total avoided 1.11 Mt CO_2e in Switzerland (Figure 8). Our forecast until 2025 shows that we still have the chance to influence ICT's environmental impact. With current expectations about future development, in 2025 ICT can avoid 2.79 Mt CO_2e (+152% vs. 2015). In the optimistic scenario of the adoption rate and the GHG abatement impact, the abatement potential can even increase to 6.99 Mt CO_2e (+532% vs. 2015). However, if current measure to increase ICT adoption are not taken and expected impacts cannot be realized, abatement potential decreases to 0.72 Mt CO_2e (-35%) (Figure 8).

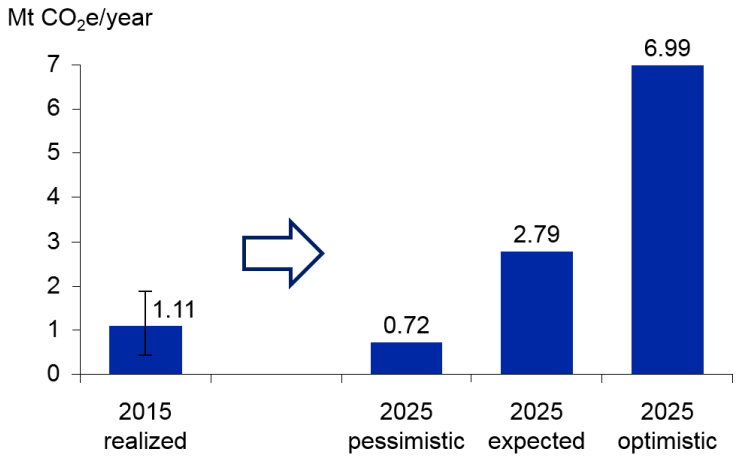

Figure 8: Realized abatement in 2015 and abatement potential in 2025 by scenario.

The largest abatement potentials are found in ICT applications to transportation, buildings and energy.

Abatement potential varies significantly across use cases. Largest potentials lie within energy intensive sectors, which provide products and services continuously required by the whole society. Especially transportation, buildings and the energy sector cause a high amount of GHG emission, while bearing significant optimization potential. Sectors such as health or banking are comparatively small and therefore provide less GHG emission abatement potential (Figure 9).

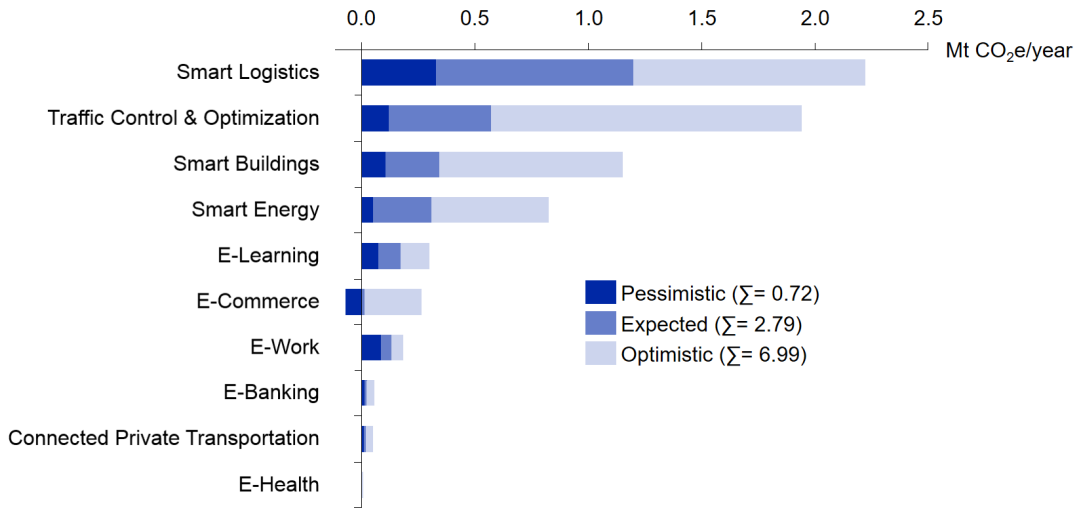

Figure 9: GHG abatement potential in 2025 in a pessimistic, expected and optimistic scenario by use case.

For each use case, we analyzed different GHG emission abatement levers. The GHG abatement potential varies across different levers. For example, for Traffic Control and Optimization the optimization of vehicle routes provides more GHG emission abatement potential than an ICT enabled shift to public transportation. In Table 5 we describe the levers with the highest GHG abatement potential.

Use Case	**Main GHG emission abatement lever**
Smart Logistics	Sharing of logistic increases utilization of existing logistic assets and reduces transportation distances
Traffic control & optimization	ICT enabled route optimization reduces transportation distances
Smart Buildings	Building management systems reduce energy consumption of buildings
Smart Energy	Smart Metering can reduce energy consumption in households
E-Learning	E-Learning avoids learning related transportation (i.e. for company training)
E-Commerce	E-Commerce avoids shopping related transportation but increases logistic transportation for distribution of goods
E-Work	E-Work avoids work related transportation (commuting and business trips)
E-Banking	E-Banking avoids banking related transportation

Connected Private Transportation	Car and ride sharing reduces transportation with private vehicles
E-Health	E-Health avoids health related transportation

Table 5: GHG emission abatement levers with highest abatement potential by use case.

To explore these potentials, it is important to account for rebound effects: Time or cost savings can lead to increasing demand, compensating for the savings. The size of the rebound effect depends on the use case.

Rebound effects occur when efficiency improvements lead to increased consumption of products and services (Madlener & Alcott, 2011). For example, Smart Logistics decrease the cost per unit of logistic services and thereby increase demand for logistic services. The use cases showed two general types of efficiency improvements:

- *Saved time per unit of service:* E-Health, E-Learning, E-Commerce, E-Banking, E-Work[6]
- *Saved cost per unit of service:* All use cases

For example, E-Work can free up employee time and money spent on commuting to work. Saved money can be spent on other energy intensive activities such as car trips or vacations by plane. On average, time related rebound effects seem to be stronger than cost related rebound effects. Table 6 shows the rebound effects identified and used in our analysis.

Use Case	**Effect**	**Description**
Smart Logistics	18%	Cost: Cost reduction in freight logistics increase the demand for freight
Traffic Control & Optimization	20%	Cost: Reduction in cost of transportation increases transportation for other purposes
Smart Buildings	4%	Cost: Reduction in energy consumption for buildings increases consumption for other purposes
Smart Energy	4%	Cost: Reduction in energy consumption increases consumption for other purposes
E-Learning	23%	Time and cost: Reduction in transportation for learning increases transportation for other purposes.
E-Commerce	37%	Time and cost: Reduction in transportation for purchases increases transport for other purposes
E-Work	31%	Time and cost: Reduction in transportation for work increases transportation for other purposes.
E-Banking	17%	Time and cost: Reduction in transportation for banking increases transportation for other purposes
Connected Private Transportation	20%	Cost: Reduction in cost of transportation increases transportation for other purposes
E-Health	37%	Time and cost: Reduction in transportation for health service increases transportation for other purposes.

Table 6: Rebound effects and description of major effects by use case.[7]

[6] For these use cases, time savings are very high. Other use cases can also lead to time savings.

We can also interpret rebound effects as growth and increase in welfare, since households or businesses can spend their gained resource on other value generating activities. However, only after consideration of all external costs (e.g., noise, air pollution or congestion) the value of an activity and its contribution to welfare can be determined (Llorca & Jamasb, 2017).

3.3 Discussion

Our analysis shows that ICT has a considerable potential to reduce GHG emissions in other sectors, in particular transport, buildings, and energy. Our estimates for the abatement potentials are lower than the ones presented by Accenture Strategy (2016) for the same use cases, even in our optimistic scenario. This is partly explained by the difference in time horizons (Accenture Strategy: 2030, our study: 2025), partly by our method which we tried to keep as neutral as possible with regard to the potential benefits of ICT.

For reasons of transparency, we would like to point out some limitations of our method (which also apply to other studies of this type):

- The use cases analyzed are a selection of ICT applications based on existing literature; it is in principle impossible to analyze "all" future ICT applications that are potentially relevant for GHG abatement. In other words, we cannot exclude the possibility that a disruptive application will change the situation more fundamentally than our projections can assume. This may include even better prospects for GHG abatement (some ideas are formulated in Hilty, 2015).
- The approach we adopted from the GeSI studies focuses on use cases for which we can expect enabling effects that are favorable with regard to GHG abatement. However, enabling effects can also be unfavorable, i.e., we cannot exclude that there are use cases based on solutions which increase GHG emissions, e.g., if we think of software-induced obsolescence even outside the ICT sector. We did not search for such use cases to keep our study comparable with the existing studies and because it would be difficult to quantify such induction potentials (as the counterpart of abatement potentials).
- Rebound effects are known to play an important role in ICT applications (Gossart, 2015, Hilty, 2008a). We did include rebound effects in our calculations, however, they are subject to high uncertainty. Rebound effects are based on demand elasticities, which are difficult to predict in the long term.

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[7] The table provides the average rebound effects across all levers by use case in the expected scenario. In the optimistic and pessimistic scenarios, the average rebound effects by use case slightly vary due to different adoption rates and impacts of the use case levers.

– We did not consider privacy and security threats that could counteract the adoption of ICT applications.

Major uncertainties of the approach stem from a lack of data and transparency of previous studies. Data on the baseline GHG emissions per use case in the SMARTer 2030 report are not available, nor are the parameters that were used for transferring their findings to the Swiss case. Due to these limitations of our method and the bias they might introduce, comparative statements (e.g., among use cases) may represent more robust conclusions from the results than absolute statements.

4 Comparison of Direct and Indirect ICT Effects

In 2015, the abatement potential of the use cases mainly discussed in literature roughly equaled 43% of the footprint of the ICT sector. Assuming that the GHG abatement potential is systematically explored in energy-intensive domains and direct effects of ICT are minimized, ICT can save 3.37 times more GHG emissions than it produces in 2025 (Figure 10).

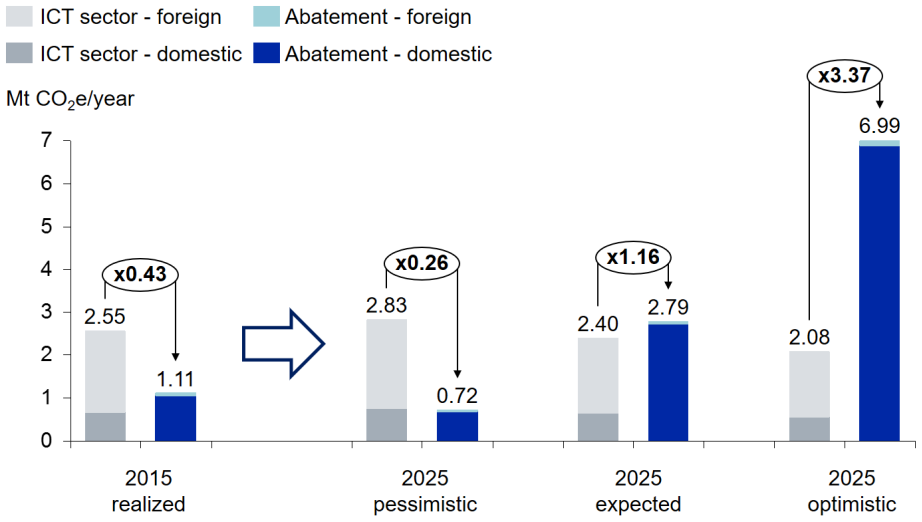

Figure 10: Comparison of ICT sector GHG emissions, realized abatement in 2015 and abatement potential by scenario in 2025.

In 2015, the use cases discussed in Chapter 3 in total avoided 1.11 Mt CO_2e in Switzerland. This equaled 43% of the footprint of the ICT sector. Our forecast until 2025 shows that we still have the chance to influence ICT's environmental impact. With current expectations about the ICT sector footprint and the abatement potential of the analyzed use cases, positive and negative effects of ICT tend to roughly cancel each other out in 2025 (expected scenario – factor 1.16). If we manage to systematically explore ICT reduction potentials and reduce ICT's own footprint, we can significantly increase the reduction potentials while reducing ICT's own footprint (optimistic scenario – factor 3.37). However, if we promote ICT adoption in areas without positive environmental impacts, we run the risk to increase negative effects while reducing positive effects (pessimistic scenario – factor 0.26).

We would like to point out the following limitations of these results:

- The ICT sector footprint in 2025 does not include potential improvements in energy efficiency during production and use of ICT, neither Internet of Things devices, which are essential for several use cases.
- Our estimate of the GHG abatement potential considers the technical and economic abatement potential of ten use cases discussed in literature. Further ICT use cases exist.

– ICT has environmental impacts beyond GHG emissions, which were not part of this analysis. ICT also has other economic and social effects, which were not within the scope of this study. The climate change impact of ICT is one part of the picture and needs to be complemented by other perspectives.

5 Use Case Deep Dive

5.1 Selection of Use Case Examples

In order to deepen the understanding of the challenges of adoption, we conducted a detailed analysis of five examples which are concretizations of selected use cases. We selected examples that bear economic relevance, potential environmental benefits and the possibility of consumers, businesses and policy makers to influence adoption. We selected the following examples of use cases described in Section 3.2:

- Collaborative logistics (example of smart logistics)
- Intelligent heating (example of smart buildings)
- Demand side management (DSM) in electricity consumption (example of smart energy)
- Coworking (example of e-work)
- Car sharing (example of connected private transportation)

5.2 Collaborative Logistics

Sharing logistic assets among companies in road freight transport can increase utilization of assets and reduce GHG emissions of logistics.

In 2015, truck and van transport caused 17% of Swiss road transport GHG emissions, equaling 2.58 Mt CO_2e (FOEN, 2017). However, utilization of road logistics is relatively low. A study of 53 truck fleets in the UK showed that average weight utilization was 69% and deck area utilization was 53% (McKinnon, 2010). Many reasons can decrease utilization of trucks such as strict delivery windows (4flow, 2013), regulation (e.g., regulation for cabotage[8]) or insufficient customer orders. Increasing utilization of trucks can reduce GHG emissions if total truck and van kilometers driven and the number of trucks produced is reduced.

Collaborative logistics can improve the environmental performance of road freight logistics. Collaborative logistics describe partnerships of two or more organizations to optimize transportation by sharing equipment, vehicles, information or carriers in order to improve capacity utilization, optimize inventory and reduce cost (Bestlogisticsguide, n.d.). Vertical collaboration occurs between customers and service providers, horizontal collaboration among competitors or non-competitors (Barrat, 2004). In collaborative logistics, ICT facilitates the communication and the optimization of logistics across several companies. The Industry 4.0 trend is conducive to the technical integration of companies and thereby also supports collaborative logistics.

[8] Cabotage describes carriage of goods in one country by carriers from other countries (European Commission, 2017). Cabotage is strongly regulated and increases the number of empty trips by carriers.

Collaborative logistics can reduce negative environmental impacts of transport, including GHG emissions, while reducing cost of logistics, especially for partnerships within related industries.

Selected case studies of horizontal collaboration in road freight show GHG emissions reduction potentials through reduced transport between 23% and 27%, for example through truck and warehouse sharing (Ballot & Fontane, 2010, 4flow, 2013). Optimization potential increases if companies in the same or related industries collaborate, since their logistic processes are comparable (DHL, 2017). Assuming that the average utilization of truck and van transport in 2015 was 53% and increases to 80%, fuel consumption equaling 0.87 Mt CO_2e could be avoided. Further GHG emission savings can be realized through extension of cooperation with additional companies (Ballot & Fontante, 2010), extension of delivery windows, reduction in delivery frequency or relocation of distribution hubs (4flow, 2013). However, not only GHG emissions but also other environmental factors benefit from optimized logistics, for example traffic congestion and noise (Hitachi, n.d.).

Beyond, collaborative logistics can also have positive financial impacts. Companies can reduce their fixed logistic assets as well as their variable cost, while increasing customer service through increased order fill rates and order accuracy (Langley, 2015). However, logistic sharing also requires investment. Partners must invest in common infrastructure, integrate their ICT systems and share sensitive information with each other (Prajogo & Olhager, 2012, Ballot and Fontane, 2010). Therefore, companies should enter collaborations with long-term and strategic partners who enjoy their trust (Prajogo & Olhager, 2012). This will also facilitate negotiations about distribution of benefits generated through the cooperation (Cooke, 2011).

Public authorities should develop policies to mitigate increase of transportation as a reaction to decreasing cost of transportation.

Rebound effects in the transportation sector are relatively high. Reducing time or cost of transportation will, in the short or long term, increase demand of logistic services. An analysis of road freight logistics in Europe showed that from 1992 until 2012 fuel intensity of road freight transport decreased by roughly 20%, whereas demand for road freight transport increased by more than 15% (Llorca & Jamasb, 2016). In Switzerland, GHG emissions from truck and van transport increased by 12% from 1990 until 2015 (FOEN, 2017). Possible ways to mitigate rebound effects are increasing prices for fuel or shift from road freight to train freight logistics.

5.3 Intelligent Heating

Intelligent heating systems can reduce energy consumption by households significantly, without reducing the comfort of the residents.

Heating is the largest consumer of energy in private households in Switzerland. In 2015, 67% of energy consumed in Swiss homes was used for heating (Figure 11). In many cases heating energy is consumed without the actual requirement to heat rooms, e.g., because nobody is at home or because the ambient temperature is convenient. Conventional heaters used in households do not offer convenient adjustment of heater capacity according to actual needs. ICT devices can help to bridge this gap. Intelligent heating is the need-based use of energy through intelligent monitoring and control systems (Girod et. al., 2014). Heaters are equipped with Internet enabled sensors and actuators, which automatically adapt to the requirements of the present residents. If rooms are empty, the heater will lower its capacity and increase its capacity, shortly before residents return home. If the system is set up well, residents do not even recognize any reductions in comfort. Girod et. al. (2014) estimate the energy saving potential through intelligent heating systems in Switzerland to be 9.5% of total heating energy consumption of residential buildings. In 2015, this equaled approximately 0.55 Mt CO_2e.

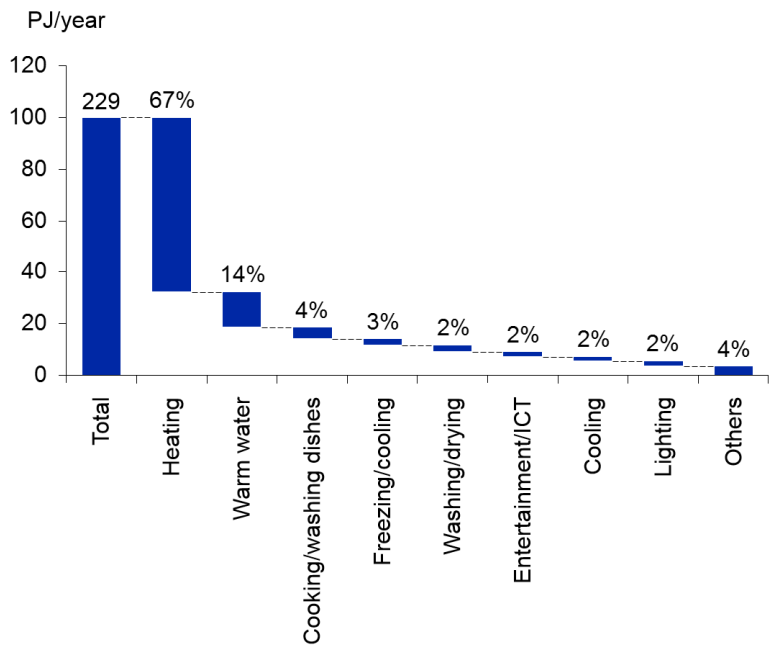

Figure 11: Final energy consumption of private households in Switzerland in 2015 (Prognos et. al., 2016)

For buildings built before 1980 and one-family buildings, intelligent heating is especially effective.

Energy saving potential through intelligent heating is not the same for all Swiss households. The main factors influencing the energy saving potential are the energy sources used as well as the insulation of the building (Girod et. al., 2014). Switzerland still uses a significant amount of fossil energies for room heating (Prognos et. al., 2016). Changing from fossil to renewable heating energy (e.g., solar energy) is the most effective measure to reduce heating caused GHG emissions, followed by improving the insulation of the building (Girod et. al., 2014). With respect to intelligent heating, Girod et al. find that energy saving potential is highest for one family buildings built before 1980, due to energy losses to the environment. However, intelligent heating can also achieve energy savings for apartment buildings and buildings built after 1980.

For many households, intelligent heating reduces energy consumption and saves money. Households should not spend saved money on other energy-intensive activities (e.g., air travel).

Intelligent heating systems can also provide financial benefits for households. Investment cost for intelligent heating systems are relatively low and can be amortized through energy savings after 2-3 years. For houses built after 2000 energy savings are significantly lower and cannot amortize investment cost of intelligent heating systems (Girod et. al., 2014). Therefore, if a retrofit of the building cover (improvement in insulation) is planned within the next three years, households should evaluate if an intelligent heating system is environmental and economic beneficial.

If households achieve energy savings the available financial budget increases, which can be spent on other energy intensive activities. If money saved on energy is used for average household consumption, 4% of the achieved energy savings are compensated. If households spend the additional budget on air travel, the compensation factor increases to 58%. Generally, households should consider the energy intensity of their spending (Girod et. al., 2014).

ICT, heating industry and utility companies should cooperate to standardize and simplify the use of intelligent heating technology.

Although a variety of intelligent heating vendors evolved in the last years, knowledge of society about intelligent heating and its benefits is relatively low (Girod et. al., 2014). Intensified communication by policy makers and businesses about the potential benefits for households can help overcome these challenges. Besides informational deficits, the oversupply of different standards and the often complex installation and especially configuration of the systems can overwhelm customers. Once consumers decide for one vendor, they might also face a lock-in

effect with their supplier, preventing investment in first place (Girod et. al., 2014). Therefore, providers of intelligent heating systems should cooperate to find common standards to ensure current and future compatibility of systems.

5.4 Demand Side Management

Demand side management (DSM) of electricity consumption in Switzerland can improve the integration of renewable energies in the electricity grid and increase the utilization of the grid infrastructure.

Today's electricity grid provides electricity to businesses and consumers, whenever they need it. This implies that supply of electricity always matches or exceeds demand. Ensuring continuous availability of electricity is challenging for electricity production and distribution, since

- Electricity demand fluctuates: Consumption of electricity varies significantly according to time of the day and to changing seasons
- Electricity supply fluctuates: Production of electricity varies with changing environmental conditions, especially production of electricity from renewable energies (for solar power, more (less) sun equals more (less) electricity)
- Electricity cannot efficiently be stored or transported over long distances. Therefore, electricity needs to be produced when and where it is needed

Hence, ensuring stable supply of electricity requires electricity suppliers and grid operators to maintain excess capacity, which is costly from an economic and environmental perspective (Strbac, 2008). DSM tackles this conundrum: Instead of flexibly adapting electricity supply to demand, DSM flexibly adapts consumption to availability of electricity. Consumers and businesses often can postpone their use of electricity without reducing their individual utility. For example, if 50% of all consumers who run their dishwasher after dinner postpone the dishwasher program to midnight, electricity consumption in the evening decreases and increases at night, leading to an overall smoothening of electricity demand. In Swiss households and businesses, many so-called flexible capacities are available. Within DSM, ICT can be used to make use of these flexible capacities to control electricity demand according to availability of electricity. This also has a reducing effect on greenhouse gas emissions by (Strbac, 2008):

- Better integration of renewable energies into the electricity grid: Electricity consumption can be shifted to times with high availability of electricity from renewable energies
- Increased capacity utilization of existing infrastructure: The possibility to smoothen electricity demand peaks reduces the amount of excess capacity required.

In Switzerland, better utilization of existing electricity infrastructure also has the potential to reduce dependency on foreign imports of electricity, produced from fossil resources. If we assume that Switzerland eliminates its dependency on foreign electricity imports and shifts to 100% electricity from renewable energy sources in Switzerland, GHG emissions from electricity production could be lowered by 81% or 7.05 Mt CO_2e in 2015.

Public authorities, utility companies and ICT companies should define standards for DSM and test DSM technology in practice to prepare for nation-wide rollout.

For DSM, households and businesses need to identify flexible capacities, which can be used for load shifting (DENA, n.d.). Due to their capacity to store energy, heating and cooling devices (e.g., refrigerators) are favorable for DSM. In most cases, these devices can be switched off for a certain amount of time, without reduction in comfort (Gutzwiller et. al., 2008). To establish DSM, an ICT system integrating households, businesses, grid operators, electricity suppliers and regulators needs to be built. Sensors need to monitor electricity production, ICT systems need to analyze demand and supply, and actuators in businesses and households need to switch off electricity consuming devices automatically and in real time. Due to its complexity, implementing DSM is a long-term project, which gradually adds additional actors and functionalities (Federal Ministry for Economic Affairs and Energy, n.d.). To decrease complexity, it is recommend to start implementation with businesses who provide large flexible capacities. Their experiences can be used for nation-wide rollout to households (Horvath & Partners, 2012). Nevertheless, actors who join DSM in the beginning need to be sure their investment pays off. Therefore, policy makers need to define DSM standards to ensure technology and processes rolled out today are designed for long-term use and will be compatible with future DSM technology (Gutzwiller et. al., 2008). Policy makers, utility companies and ICT companies should cooperate to test DSM technology in practice and define sustainable standards.

Acceptance by businesses and households will increase when technical and regulatory standards are in place, privacy is respected and cost savings for the users are demonstrated.

Today, households and businesses enjoy high availability of electricity; hence, incentives to adopt DSM technology are relatively low. To reduce the burden of households and businesses, the opportunities DSM offers need to be demonstrated, while risks and concerns need to be addressed and mitigated with a high degree of transparency. Sidler (2015) states that collection and distribution of data as well as generation of individual consumption profiles are relevant threats of Smart Metering to privacy. Giving consumers transparency and access control about collected data is central to gain their trust and increase adoption (Department of Energy and Climate Change, 2012).

Major DSM opportunities for consumers are reduction in cost of electricity by shifting consumption to times when supply of electricity is high and costs are low. A dynamic electricity market regulating electricity prices in real time according to supply and demand can provide these incentives (SFOE, 2015). Beyond, businesses and households who provide flexible capacities also receive financial benefits (DENA, n.d.). Today, electricity markets do not offer dynamic electricity prices to consumers. Hence, policy makers and electricity companies should commonly define the future framework of dynamic electricity markets for households and businesses. This will help to demonstrate financial incentives of DSM to consumers, while reducing investment risk.

To participate in DSM households and businesses need to integrate ICT devices into their facilities, which communicate with the electricity grid and regulators. Real time data about individual electricity consumption is shared with other actors. Hence, DSM systems need to protect the privacy of all involved actors (Federal Ministry for Economic Affairs and Energy, n.d.). Due to the complexity of the system, privacy should be an essential design parameter during definition of standards and during development of DSM systems.

5.5 Coworking

Office space in Switzerland causes a significant amount of GHG emissions, whereas utilization is relatively low.

Active utilization of office space is relatively low. An analysis of twelve Swiss office spaces showed that approximately 40% of worktime workplaces are not used (Windlinger et. al., 2016). Beyond, vacancy of office space increases and was at 5.6% in the 20 largest agglomerations in Switzerland (CSL Immobilien, 2015). Increasing the utilization of office space is desirable from an economic and an environmental perspective. A study by the federal ministry of energy showed that in 2004 each square meter of office space caused 0.5 t CO_2 emissions per year, which was relatively high in a European average (Hohmann et. al., 2007).

Offering mobile work to employees reduces commuting, frees up office space and saves time and cost for employees and employers.

Mobile work is increasing in Switzerland. In 2015/2016, 28% of Swiss working age population worked at least half a day per week at home. In contrast, 72% do not work from home, out of which 29% would like to do so (Deloitte, 2016). Working from home can have several environmental advantages (Reitan, 2014). Reduction in commuting decreases the environmental footprint of transportation and reduction in office space reduces the environmental footprint of buildings and frees up space for other purposes. Besides, employers and employees have further advantages of

mobile work (Reitan, 2014). Reduction in commuting saves time and money spent on transportation. Reduction in office space saves money spent office space buildings. However, if saved time or money is spent on other energy intensive activities (e.g., air travel), environmental rebound effects can be high (Girod et. al., 2014). Therefore, employees and employers should reduce the average energy intensity of their activities.

Employers can increase utilization of office space by offering its office space to external workers or allowing employees to work in coworking spaces.

Besides working from home, coworking has been evolving in Switzerland in recent years. Coworking describes the possibility of employees from different companies working at the same place, often at coworking spaces (DTZ, 2014). Coworking spaces are organizations offering offices and meeting space, which can be booked flexibly. By offering employees to work in coworking spaces, businesses can reduce their need for own office space. Alternatively, businesses who have unused office space can offer workplaces to employees from other companies (Deloitte, 2016). However, to successfully implement coworking several issues have to be addressed. Employees dealing with sensitive data require special tools and training to ensure data safety outside the company's own walls (Spinuzzi, 2012). Mobile employees require tools to facilitate collaboration with other team members to bridge the geographic distance. Partly, employment contracts need to be adapted to allow for mobile work (Weichbrodt, n.d.). If we assume that 33% of office space in the 20 largest agglomerations in Switzerland in 2015 is transferred into flexible office space and its utilization increases from 60% to 80%, an amount of 0.17 Mt CO_2 could be avoided[9]. However, it still needs to be evaluated to what extent coworking reduces GHG emissions in the long term. For example, if employees substitute working from home for working in coworking spaces, required office space and commuting increases.

5.6 Car Sharing

Switzerland is leading in car sharing. New innovative car sharing schemes bring new potentials.

We distinguish three car sharing schemes (Becker et. al., 2017):

- *Station-based car sharing:* Station based car sharing requires car sharing users to pick-up and drop-off cars at designate car sharing stations.
- *Free-floating car sharing:* Free-floating car sharing "allows customers to pick-up and drop-off the vehicle anywhere within a city-wide service area".

[9] Assumed that each square meter causes 0.05 t CO_2e per year.

– *Peer-to-peer car sharing:* Peer-to-peer car sharing allows car owners to offer their cars to other people. Renters can rent available cars paying a specific fee to the car owner.

Car sharing has a long tradition in Switzerland. In 2016, Mobility (station-based) car sharing had 131.700 customers, which is more than 1.5% of Swiss population and very high compared to other European countries (Mobility, 2017). A study by the SFOE stated that 500.000 customers is a theoretical upper limit of car sharing users in Switzerland (Haefeli et. al., 2006). However, this analysis was based on the concept of station-based car sharing, which was the only available car sharing scheme in Switzerland back then. In recent years free-floating and peer-to-peer car sharing evolved in Switzerland, which is why the upper limit might be outdated.

Car sharing can reduce the GHG footprint of transportation. Especially, households and businesses who privately own cars should evaluate if their mobility needs can be satisfied through car sharing and public transportation instead.

Environmental benefits of car sharing can be manifold. Car sharing impacts:

– Private ownership of cars and thereby the number of cars produced (Mobility, 2016)
– Distances driven with cars and public transport in Switzerland (Interface, n.d.)
– Space required for parking (Mobility, 2016)

A Swiss study analyzed the distances driven with private cars, Mobility car sharing and public transport (Figure 12). The study showed that active Mobility customers tend to cause 300 kg CO_2 less per year compared to their use of transportation means without car sharing (Interface, n.d.). Beyond, Mobility analyzed car ownership among its users and found that one Mobility car replaces ten privately owned cars in Switzerland (Mobility, 2016). If we assume that Switzerland had 500.000 active car sharing users in 2015 and one car sharing car replaced ten privately owned cars, 0.08 MT CO_2e could have been avoided. However, environmental benefits can vary across different car sharing schemes. Free-floating car sharing schemes provide fast and convenient transportation and thereby attract users of public transportation (Becker et. al., 2017). Trips originally conducted with public transport are substituted for road transport. However, if innovative car sharing schemes manage to attract car owners or businesses who reduce their car ownership and increase their use of public transport, car sharing is environmental beneficial. Strategic cooperation between public transportation companies and car sharing providers can yield attractive mobility packages meeting the needs of these customer groups (Loose, 2010).

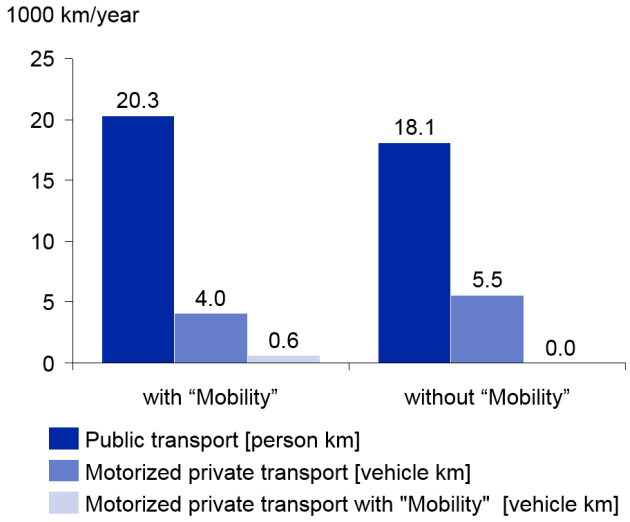

Figure 12: Average distance travelled by households with and without Mobility subscription (Based on: Interface, n.d.).

Depending on individual mobility patterns car sharing can be also financially beneficial. Loose (2010) estimated that for private customers driving between 10.000 and 12.000 km annually, car sharing cost are lower than cost of owning a car. However, cost advantages are often not visible to customers since car owners do not apply total-cost-of-ownership thinking for privately owned cars and only compare variable cost. In Switzerland, car sharing can only reach a critical mass if society critically reflects on car ownership and does not take it for granted.

Beyond, car sharing providers also need to extend their service. So far, car sharing schemes provide urban transport solutions, however no solutions for countrywide transport. Cooperation with rental car companies could close this gap.

Public authorities and car sharing providers should collaborate to reduce the GHG intensity of the Swiss (car sharing) fleet and increase coverage of innovative car sharing schemes.

Only if coverage and availability of car sharing is high, it can be a serious alternative to private car ownership. So far, coverage of free-floating car sharing is low in Switzerland. Car sharing providers and policy makers need to discuss possibilities to increase car sharing coverage and use (e.g., use of public parking space for car sharing) (Haefeli et. al., 2006). Beyond, there is still limited understanding in Swiss society about the concept and the benefits of car sharing (Loose, 2010). Policy makers and car sharing providers should also identify strategies to communicate the concept and the benefits of car sharing as an alternative to private motorized transport.

GHG intensity of cars in Switzerland is very high in comparison to other European countries. The GHG intensity of the Mobility fleet is lower than the GHG intensity of private cars in Switzerland, however relative high compared to the GHG intensity of other car sharing fleets in Europe (Loose, 2010). Policy makers and car sharing providers should identify ways to decrease the GHG intensity of cars in Switzerland (e.g., through promotion of smaller cars for urban use).

5.7 Major Challenges

To summarize this chapter, we provide an overview of the main challenges towards adoption of the five example use cases (Table 7). We analyzed technical, organizational as well as behavioral challenges. On the technical level, several use cases require standards for the interoperability of the ICT and other technical systems involved. On the organizational level, trustful collaboration between businesses, public authorities and consumers is crucial for the adoption of use cases. On the behavioral level, the main challenge for businesses and consumers is to critically reflect on their current patterns of consumption and evaluate their potential benefit of adopting selected use cases (e.g. car sharing instead of owning cars). Addressing these challenges is crucial to further develop the solutions and exploit their GHG abatement potential.

Challenge type	Description	Collaborative logistics	Intelligent heating	Demand side management	Coworking	Car sharing
Technical	Specialized hardware needs to be rolled out to enable users to participate in use case.		x	x	(x)	(x)
Technical	ICT systems need to be integrated to enable seamless information exchange between involved actors.	x		x		(x)
Technical	ICT systems and corresponding policies need to be designed to ensure privacy to gain trust of users.	(x)	x	x		
Technical	Technical standards have to be developed to ensure interoperability across systems and decrease investment risk of involved actors.		x	x		
Technical	ICT systems must be designed with a high degree of usability to increase user acceptance and ensure intended application.		x	x		(x)
Organizational	Policies need to be developed to regulate interaction of involved actors and allow for profitable business models.			x		(x)
Organizational	Public authorities and businesses need to collaborate to facilitate use case adoption.			x		x
Organizational	Implementation of the use case is complex and requires considerable upfront investment.	x		x	(x)	
Organizational	Businesses need to be willing to participate and invest resources in the use case.	x		x	x	
Organizational	Businesses need to adapt existing processes and structures to participate in the use case.	x		(x)	x	(x)
Organizational	Businesses need to collaborate trustfully to enable the use case.	x		x	x	(x)

Behavioral	Users need to become aware of the use case and its potential benefits. Public authorities need to educate users.		x	x	x	x
Behavioral	Users need to be willing to partly delegate control over their consumption to other actors.	(x)	x	x	(x)	
Behavioral	Users need to change their current patterns of consumption (e.g., owning a car as a status symbol).	x	x	x	x	x

Table 7: Major challenges to increase adoption of the example use cases by challenge type and use case. Challenges which influence a use case significantly are marked with "x", challenges which influence a use case moderately are marked with "(x)".

6 Interpretation of the Results in a Broader Context

6.1 Two Separate Political Arenas

There are two separate political discussions that both provide important context for the interpretation of our results:

- National GHG reduction targets
- Privacy and cybersecurity

The first discussion leads to the question how the net abatement potential relates to the Swiss reduction targets, the second to the question whether increasing concerns about privacy and cybersecurity may become a major barrier to the adoption of smart solutions in the coming years, a development which would prevent the exploitation of the GHG abatement potentials we identified in this study.

6.2 National GHG Reduction Targets

Switzerland has set the goal to reduce its annual GHG emissions by 50% until 2030 compared to 1990. 30%-points of the reduction shall be achieved inside Switzerland and 20%-points outside of Switzerland (Detec, 2016). The federal council of Switzerland adopted the target in November 2014. In the end of 2015, the United Nations agreed on a new international climate target to succeed the Kyoto Protocol. The target binds all participating countries to limit global warming below 2 °C, if possible below 1.5 °C, above pre-industrial levels (UNFCCC, 2015). In order to align the Swiss climate strategy with the Paris agreement, Switzerland needs to reduce annual domestic GHG emissions by 40% in 2030 compared to 1990, instead of 30% (Swisscleantech, 2016).

ICT can contribute to the achievement of this target. To assess the contribution of ICT we calculated the required reduction from 2015 until 2030, if Switzerland wants to reduce its annual GHG emissions by 40% from 1990 until 2030. Assuming a linear reduction, Switzerland needs to reduce its annual GHG emissions by 10.6 MT CO_2e from 2015 until 2025. ICT can contribute to this development through direct and indirect effects. Summing up the development of the ICT sector GHG emissions and the abatement potential from 2015 until 2025 in the pessimistic, expected and optimistic scenario, shows *ICT's net contribution to achieve the target is between 2% and 49%* (Figure 13). For this estimation, we only considered the ICT sector GHG emissions and abatement potential *inside* Switzerland. By excluding foreign emissions, we changed from a consumption-based to a production-based perspective. This was necessary to make this comparison possible because the reduction goals provided by Swisscleantech are production-based as well.

The large difference in the future ICT contribution (2%–49%) roots in the uncertainty inherent to studies of this type: Because the future can be influenced, our predictions are based on scenarios ("what-if"). This means that it lies in the hands of the Swiss ICT industry, ICT users, and policy makers to take action that will lead us closer to the 49% than to the 2% contribution to achieving the Swiss climate protection targets.

Successful ICT-based innovations for the future low-carbon economy will not only work in Switzerland, but also be exportable to other countries, where the abatement potential of these solutions might even be higher due to higher current emission levels.

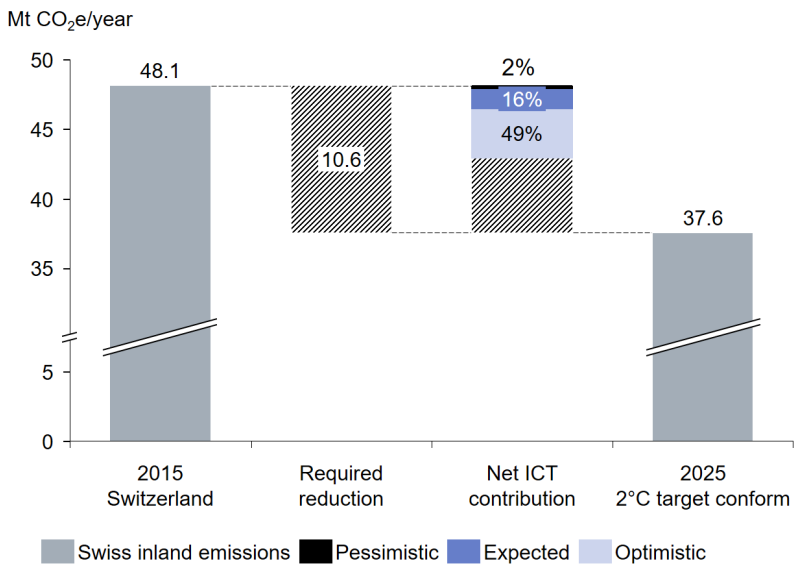

Figure 13: ICT contribution to GHG emission reduction targets according to the Paris 2°C climate agreement. The third bar shows pessimistic, expected and optimistic scenarios for annual net domestic abatement potentials in 2025 in % of the reduction target.

6.3 Privacy and Cybersecurity

The cyberspace is not a safe place, as we can learn from an increasing number of events that threaten our privacy and security. The vision of the Internet of things as well as most use cases we analyzed in this study are based on a closer integration of the cyberspace with our physical world.

Businesses will not invest in smart solutions such as logistics collaboration, coworking or demand-side management if they recognize that this induces a risk of industrial espionage or additional vulnerability to cyber attacks. Most private persons will probably continue to trust services offered in the cyberspace until a major security event will change their perception. ICT networks are becoming critical infrastructures and major tools of surveillance at the same time (Hilty, 2008b, Hilty et al., 2012). There are huge legal and ethical challenges for businesses using

"Big Data" technologies, as the Swiss Academy of Engineering Sciences (SATW) points out (Hauser et al., 2017).

The main risk for the contribution of ICT to climate protection is that the GHG abatement potential cannot be unleashed because the solutions will not be adopted by businesses and end consumers, resulting in our pessimistic scenario. ICT-based solutions, which make things smart and are based on "Big Data" technologies, are only acceptable if businesses and end consumers can use them straightforward, safe, and be sure that the enormous amounts of data generated and processed are not used against their interests by anyone, including competitors, government, and cybercriminals.

7 Conclusion and Recommendations

The study reported here investigated opportunities and risks of digitalization for climate protection in Switzerland from 2015 to 2025, taking into account both the ICT sector's own carbon footprint and the GHG abatement potential of ICT. Greenhouse gas accounting was done with a consumption-based approach, which includes emissions that are caused in foreign countries by domestic consumption.

Information and Communication Technology (ICT) is an important enabler for a low-carbon economy in Switzerland. ICT has the technological and economic potential to avoid up to 3.37 times more GHG emissions than the amount of emissions caused by the production, operation and disposal of ICT devices and infrastructures, in 2025. In absolute terms, ICT could enable the Swiss economy to save up to 6.99 Mt CO_2-equivalents per year, with an own carbon footprint of 2.08 Mt CO_2e per year (see Figure 1 – optimistic scenario).

This opportunity to contribute to climate protection with ICT can only be realized if the existing technological and economic potentials are systematically exploited by taking ambitious and targeted actions:

- The carbon footprint of the ICT sector itself must be reduced by 17%, which is technologically and economically feasible due to efficiency gains.
- Ambitious actions must be taken in the transportation, building and energy sectors, which have the highest potential for ICT-enabled ("smart") solutions to reduce GHG emissions.

Our study found that the largest share of the ICT sector's GHG emissions comes from the end-user devices. Currently, roughly ⅔ of the consumption-based GHG emissions of ICT in Switzerland are caused by desktop, laptop and tablet computers, smartphones and printers. With the continued shift to light and energy-sufficient mobile devices, the relative share of the production phase increases, which implies that it becomes more important for the ICT sector to engage in "greening" the supply chain and avoid "embedded" emissions, i.e., emissions that happen in the countries where the hardware is manufactured and the raw materials are mined.

The main risk for the development of ICT sector's own footprint is that this positive trend is compensated (as described by Hischier & Wäger, 2015) or even overcompensated for by an increasing number of devices per capita and decreasing service lifetimes of the devices. The worst case would be a prevalent throw-away mentality with regard to digital electronics (for which there is currently no empirical evidence in Switzerland, see Thiébaud, 2017c). The depletion of scarce metal resources would grow as a consequence despite recycling efforts. A second risk is that Internet traffic, in particular machine-to-machine traffic, might grow faster than the energy efficien-

cy of the infrastructure in the future, resulting in growing emissions of the large parts of the global Internet which will still be powered by non-renewable energies.

Regarding GHG abatement, there is an unprecedented opportunity and a resulting social responsibility for the ICT sector to take ambitious and targeted actions to enable other sectors to implement ICT-based ("smart") low-carbon solutions, both in terms of technologies and business models, within less than one decade. This can mainly be done by further developing smart solutions in logistics, traffic optimization and control, buildings, and energy. Unleashing this GHG abatement potential would make a significant contribution to the Swiss GHG reduction goals. However, ICT-based ("smart") solutions will only be adopted if businesses and end consumers can use them straightforward, safe, and be sure that the enormous amounts of data generated and processed are not used against their interests. Rebound effects (increasing demands due to lower cost), compensating for the abatement, pose an additional risk.

In our assessment of the direct and indirect climate change effects of ICT in Switzerland from 2015 until 2025, we kept the electricity mixes (both domestic and abroad) constant. This allowed us to show "pure" effects of the ICT sector and ICT applications. However, it should be noted that the electricity mix is a significant external factor to all our scenarios. Improving (i.e., reducing) the GHG emission intensity of the electricity used in Switzerland and other countries (especially where devices are produced or data is processed) reduces the environmental burden of the whole ICT lifecycle and the sectors in which ICT is applied. It can also reduce the abatement effect of ICT, but not in use cases where fossil fuels are directly consumed, e.g., for moving vehicles or for heating.

We derive the following recommendations from the results of our study, which are to be understood as necessary conditions of making digitalization a success for climate protection:

Swiss households and businesses

- can and should influence the direct environmental impacts of ICT by using mobile devices (laptops, tablets, smartphones) instead of old stationary devices and by extending the useful life of the devices.
- should evaluate their individual benefit of adopting ICT-based ("smart") solutions in areas where investment in such solutions provides a substantial GHG abatement potential: Solutions such as demand-side management, intelligent heating, car sharing or the sharing of other assets can have substantial positive effects, but their impact is context-dependent and must be evaluated in each individual case.

Swiss ICT companies including telecommunication network operators

- should consistently reduce their carbon emissions, both locally and by using their purchasing power to influence the supply chain for imported equipment in the direction of green and fair procurement.
- should use their potential to develop and provide ICT-based low-carbon solutions to their B2B and B2C customers in areas with high GHG abatement potential.
- in cooperation with solution providers from other sectors, should develop technological standards for data protection and security for involved actors, and long-term compatibility to decrease investment risk; this can especially increase adoption of intelligent heating and DSM.

Policy makers

- should develop framework conditions that enable and encourage safe and privacy-respecting ICT solutions; in particular for DSM and car sharing, it is important to provide the regulatory framework and incentives for solution providers and users.
- should encourage the development of open technical standards and create incentives for the adoption of ICT-based low-carbon solutions, especially in areas with high GHG potential (transportation, smart buildings, smart energy).

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