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Green ICT Dynamics: Key Issues and Findings for Germany

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Summary: The role of information and communication technology (ICT) is discussed both with respect to economic growth and green global modernization. ICT stands for the most innovative sector in the EU and the US; high productivity growth and digital product innovations are characteristics of this sector, at the same time, ICT products are considered to be an enabling technology in other sectors. While digital technological progress may be anticipated – including the expansion of the Internet – to contribute to raising efficiency and more green economic growth, there are considerable risks of rebound effects in the ICT sector. The findings for the impact of an expansion of Green ICT in Germany show small significant effect on output and relatively more important effects on the reduction of greenhouse gases. Hence the simulation results from the PANTA RHEI model suggest that Green ICT dynamics could be a useful element of sustainable development in Germany and the EU, respectively.

Zusammenfassung: Es wird die Bedeutung der Informations- und Kommunikationstechnologie (IKT) für Wirtschaftswachstum und Globale Grüne Modernisierung diskutiert. IKT ist sowohl in der EU wie in den USA der innovativste Sektor; hohes Produktivitätswachstum und digitale Produktinnovationen sind charakteristisch für diesen Sektor, gleichzeitig schafft IKT erst technologische Voraussetzungen für andere Sektoren. Die Antizipation des digitalen technologischen Fortschritts - inklusive der Expansion des Internets - trägt zur gesteigerten Effizienz und höherem Grünen Wirtschaftswachstum bei, unterliegt aber den erheblichen Risiken von Rückschlägen im IKT-Sektor. Die Untersuchung der Auswirkungen einer Ausweitung von Grüner IKT zeigt signifikante Einflüsse auf Output und, relativ wichtiger, Einflüsse auf die Reduktion von Treibhausgasen. Die Simulationsergebnisse des PANTA-RHEI-Modells kommen zu dem Schluss, dass die Entwicklung Grüner IKT ein sinnvolles Element der nachhaltigen Entwicklung in Deutschland und der EU sein kann.

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1. Introduction

Long-term sustainability is a natural goal of policymakers and individuals who are concerned with global warming and long-run ecological development. Economic prosperity is increasing worldwide and the global population is growing, hence the amount of goods and services is increasing and this implies a rising use of non-renewable resources and energy, respectively. At the same time, there will be continuous technological progress, not least in the sector of information & communication technology. The European Commission has emphasized in its Europe 2020 project (EUROPEAN COMMISSION, 2011) - with emphasis on growth, employment, innovation and the achievement of a low-carbon society - that the field of a Digital Agenda for Europe (EUROPEAN COMMISSION, 2010) will be important; the Commission has emphasized the goal to stimulate online trade, the role of interoperability and norms as well as the crucial elements of innovation and e-skills. In the context of innovation dynamics and the emphasis on sustainability it will be crucial to focus on "green ICT", namely the potential of information and communication technology to raise energy efficiency within the ICT sector and in all other sectors as well.

The ICT sector has a high potential for cutting energy because it is highly innovative and enabling technology which affects all sectors; its workforce is relatively young – and partly influenced by environmental movement (dating back to the UN Stockholm Summit of 1972). Moreover, the sector is characterized by high growth, which will raise the absolute volume of energy use over time – this indirectly creates an incentive to raise energy efficiency as a means to cut costs and improve the image of the sector. Also, the important sub-sector software is crucial in the sense that the use of software requires full analysis of processes and products and this often means finding options for saving resources.

Many companies from the ICT sector have started to emphasize green technological progress in various forms, e.g. Google is a company that proudly emphasizes that its electricity is increasingly based on renewables and the same can be said about Deutsche Telekom AG whose network operations fully rely on renewable energy since 2009; various industry initiatives, as well as governments in various countries, have emphasized the opportunities of green ICT programs. Since the ICT sector keeps expanding in most countries of the world economy and since ICT is an enabling technology that has had an impact in all sectors, it is quite interesting to take a closer look at the potential that ICT holds for achieving green economic long-term growth and global sustainability, respectively. Moreover, various studies have shown that ICT has considerably contributed to economic growth (OLINER/SICHEL, 2000; AUDRETSCH/WELFENS, 2002; KHAN/SANTOS, 2007).

ICT accounts for a rising share of investment and R&D in OECD countries and is thus of particular relevance for growth, employment, structural change and economic competitiveness. ICT expanded strongly in the 1990s when it became a major driver of growth in the US, the EU and Asia. ICT essentially consists of three pillars (EITO, 2002, p. 454)

- information technology, including IT services
- telecommunications equipment

- telecommunications services

In terms of markets, ICT is comprised of ICT equipment (hardware for office machines, data processing equipment, data communications equipment, software and IT services), software products, and information and carrier services. ICT is an enabling technology that stimulates economic development around the world and more and more people are using ICT services and devices, respectively. The mobile digital phone has been the most quickly adopted technology in history: At the end of 2009 an estimated 4.6 billion mobile telecommunications subscribers were active around the globe (ITU, 2009) and by 2015 there will be more mobile phones than people. By 2010 more than a quarter of the world's population was using the Internet and by 2020 almost everybody will use or have access to the Internet.

With the global population expected to reach about 9 billion by 2050 (medium variant of UN forecast) – up from 6 billion in 2000 – and per capita income in the world economy to grow by at least 2% p.a. in the first half of the 21st century, it is obvious that there will be serious ecological challenges on the planet; including global warming (STERN, 2006; BLEISCHWITZ/WELFENS/ZHANG, 2009; SCHMIDT-BLEEK, 2009; WELFENS/PERRET/ERDEM, 2010a): Not for everybody and not in every country but in many parts of the world, and indeed in a world economy where labor and capital will continue to show a high international mobility. The implication is that regions and countries with serious environmental problems might be double losers in the sense that both skilled and unskilled people will leave the country while foreign direct investment will increasingly favor those countries where political, economic and ecological stability is achieved. This statement could stand for a *contradictio in adjecto* if international factor mobility were so large that major instabilities and conflicts would be created in countries that are facing emigration and net foreign direct investment outflows, while the recipient countries – or at least some of them – would be destabilized by sudden strong changes in factor endowment. Careful reflections about such a destabilization potential will include the prospects for technological progress and also raise the issue of to what extent national policymakers as well as global policymakers and NGOs could come up with impulses that would help to stabilize the world economy and major regions of the world, respectively.

As regards sustainability in the world economy, four fields related to the economic sphere can be identified:

- Production of goods and services: The higher the per capita production and the higher the global population, the larger ceteris paribus the ecological burden associated with production.
- The energy sector: Particular focus on the energy sector, which is related to both production and consumption. The energy sector has high capital-intensity, so decisions of investors have shaped the sector and its resource intensity/emission intensity for decades.
- Level of per capita consumption and lifestyles: A higher per capita consumption will go along with the use of more material inputs and energy and also cause additional effluents and emissions. However, the typical lifestyle will also affect the green balance in the field of consumption.
- The housing sector is also of particular relevance because the capita intensity here is high and the retrofitting of existing real estate is quite costly. The decision to buy

a particular house is part of one's lifestyle and it is not surprising that the housing lifestyle affects the more general behavioral pattern: FLADE ET AL. (2003) have shown that passive house dwellers consider themselves to be ecological pioneers and have began to start saving energy in other fields as well: Instead of a rebound effect, it has a frontrunner effect.

The expansion of ICT in OECD countries and worldwide allows for the creation of new networks, achieving high productivity growth and creating new digital markets. Besides the creation of new firms and new markets in the digital economy, ICT is also relevant in the manufacturing industry. ICT is facilitating the international fragmentation of the value-added chain, both in the manufacturing industry and in the services sector; the latter thus also raises new challenges for skilled labor (MANN, 2003), which, so far, has been under rather limited pressure from outsourcing and offshoring. The European Commission notes (ECFIN, 2005, p. 15) that "ICT is affecting production structures: International specialization according to Ricardo's comparative advantage applies increasingly to segments of the product cycle rather than to complete products. The growing share of parts and components in world trade […] indicates the increasing fragmentation of manufacturing production. ICT has been a fundamental contributor to the dramatically changed tradability of goods and services […] Services are affected: While modularity and fragmentation of manufacturing production is not a new phenomenon, it is now also applied to services. Many jobs previously considered as non-tradable are suddenly exposed to international competition and may risk being dislocated."

At the beginning of the 21st century Information and Communication Technology (ICT) is the technologically most dynamic sector of OECD countries. There are four different aspects that make ICT expansion particularly relevant for green modernization and global sustainability, respectively:

- One sub-sector, software development, is quite crucial for achieving high productivity growth as the use of software amounts to flexible use of technologies on the one hand, on the other hand, using software requires that production processes or the provision of services become standardized on a broad scale, this in turn allowing a flexible, efficiency-enhancing profitable reconfiguration of value-added chains. With few global software companies being the industry leaders and given the fact that the ICT sector has a long tradition in defining common protocols and adopting common electronic standards, there are new opportunities for global productivity gains through the use of software; software is like technology – it is a non-rival input factor and therefore it has an enormous green potential.
- There is high rate of technological progress in the ICT producing sector, so the relative price of ICT goods is expected to fall in the long run; thus the share of ICT capital in the overall capital stock will rise. As ICT goods have a higher energy efficiency and to some extent also a better resource efficiency – in a cradle-to-grave perspective (read: calculated over the whole life-cycle) – than other investment goods, the long-term modernization of the capital stock contributes to sustainability.
- The expansion of the Internet and the growing global access to digital networks reduces international communication costs, information costs and transaction costs: Global trade will thus continue to increase and this implies sustained per capita real income growth in the context of global specialization gains and enhanced international competition. For the first time, in large parts of the services sector as well, digital product innovations and the Internet itself help bring service providers and service users together.

- There is a potential offsetting effect from the Internet that creates global transparency in living standards and lifestyles: To the extent that western lifestyles shape the lifestyles in Africa and Asia, there is obviously the problem that the expansion of the Internet is not enhancing much of the sustainability at the global level. A potential counter-argument is that the Internet could be a platform to accelerate global diffusion of environmental-friendly lifestyles.

The following analysis looks into some key issues of Green ICT (section 2) and also presents results from a simulation model for Germany (section 3). These results suggest indeed that a pro-ecological use of information and communication technology can contribute to lower greenhouse gas emissions and hence to sustainable development.

2. Information and Communication Technology and Green Innovation Dynamics

In real terms, ICT has roughly doubled its share in national output in the US and Germany – it reached roughly 10% of GDP in 2000 and there is a medium-term tendency for further growth of the ICT share in gross domestic output (WELFENS et al., 2005). While the nominal share of ICT value-added in total output has only slightly increased over time in OECD countries in 1990-2000, its real share has strongly increased; the fact that relative ICT prices have been falling over time has often been overlooked by politicians who tend to underestimate the role of the ICT sector.

The contribution to economic growth in the US in the 1996-2000 period reached about 1 percentage point (OLINER/SICHEL, 2002), while it was only about half of that in Canada in 1995-2000 (KHAN/SANTOS, 2002); in both Canada and the United States it is obvious that the share of ICT capital in total capital has increased over time. Most OECD countries recorded a smaller growth impulse from the use of ICT than the US. However, even if the contribution was only in the range of 0.5-1-percentage point, this is a very remarkable impulse for overall economic growth; up to 1/5 of the overall economic growth in the US and Canada came from ICT in the 1990s. An earlier study by WELFENS/JUNGMITTAG (2002) has shown that the contribution of the use of telecommunications to economic growth was also about 1/5, namely in the period 1964-1995. Therefore, it may be emphasized two aspects: The use of ICT has contributed to higher economic growth. With per capita income rising, the demand for clean environment typically grows, therefore ICT is a double driver of green development.

ICT and R&D

ICT – broadly defined – is a strong driver of innovation dynamics in OECD countries. According to the European Innovation Scoreboard of 2005 and 2008, electrical and optical equipment and ICT information and communication technologies, as well as computer and related activities, show the highest ranking of average innovation performance by sector.

This indicates a strong relevance of ICT for growth and structural change. R&D activities in ICT are strongly internationalized in some sub-sectors, including software development. (The US, the EU, China, India and Japan are strong centers of software development; some of the US and EU firms' activities in China and India partly reflect the search for comparative advantage and cost cutting. There is, however, also pressure by the governments of these big countries, namely to only give access to markets under the condition that firms establish a development center.)

As regards links between the US, the EU and Japan, the role of international R&D alliances should be emphasized. These became rather important in the 1980s and 1990s in OECD countries – not only in ICT. Few industries are as globally organized as the sector of information and communication technology, where the industry itself sets many global technology standards. Strategic R&D alliances played an increasing role in the EU in the late 1980s, as globalization and the run-up to the single market program, as well as higher EU funds for cooperative R&D projects stimulated the internationalization of European R&D (NARULA, 2000); the IT sector and biotechnology played a particular role in this respect. Moreover, there have also been renewed dynamics in R&D in the form of both asset-exploiting and asset-seeking FDI in the EU and the US. CRISCUOLO/NARULA/VERSPAGEN (2005) argue that R&D facility's capacity to exploit technological competences is a function of not just its own resources, but also of the efficiency with which it can utilize complementary resources associated with the relevant local innovation system. The empirical analysis indicates that both EU (US) affiliates in the US (EU) strongly rely on home regional knowledge sources, although they appear to exploit the host knowledge base as well. The crucial emphasis on home knowledge suggests doubts about a potential R&D strategy of the EU, which would neglect the EU countries as prime locations for leading edge R&D in technologically dynamic sectors, in particular the ICT sector. The issue must also be raised to what extent the expansion of ICT requires reforms of the innovation system and, in particular, a stronger role of virtual research networks and "Digital Universities." Optimal linkages between R&D facilities and firms in technology-intensive sectors are crucial, which will naturally include foreign investors.

Both the US and the EU belong to the group of major source countries and host countries, while Japan is mainly a source country of FDI – at least if Japanese statistics are to be believed (note: according to US FDI outflow statistics, Japan should have high US FDI inflows). In the US and the EU, innovation plays a crucial role for economic growth. The US and several EU countries achieved rather high growth rates of per capita income and total factor productivity in the 1990s, and the expansion of information and communication technologies (ICT) played a particular role. From a theoretical perspective, the endogenous growth model of ZON/MUYSKEN (2005) may be emphasized, who highlighted in a refined LUCAS-model the role of ICT in a modern growth model, where the ICT capital intensity has a positive impact on the knowledge accumulation process. ICT is important both in final goods production and in knowledge accumulation. The expansion of knowledge and the rise in ICT capital intensity contribute to a higher steady state growth of output. Knowledge accumulation thus plays an important role in economic growth. The implication is that the long-run increase in ICT capital intensity in OECD countries and NICs – fuelled by falling relative prices of ICT capital goods – will reinforce the role of knowledge in production. As regards long-term dynamics, the problems of information markets that suffer from market imperfections should not be ignored. The special aspects of ICT and growth will not be analyzed here as many special aspects would have to be emphasized, including the considerable role of intangible assets, network effects as a dynamic demand side-effect and static, as well as dynamic economies of scale in several sub-sectors. ICT seems to facilitate the outsourcing of services as it supports virtual mobility of the supply and demand side. With the role of digital services increasing in modern economies, it may be found that the macroeconomic production function is characterized by economies of scale at the aggregate level; however, there is no clear evidence of this.

The ICT sector has also become a major driver of the innovation process and of productivity growth. High Schumpeterian dynamics are not only observed in ICT production but also in the use of ICT. Hence ICT investment relative to overall investment may be expected to grow continuously, not least because falling relative prices of software and hardware stimulate ICT investment. With digital (broadband and narrowband) networks expanding in Europe, North America, Asia, and in other regions of the world, a further acceleration may be anticipated in digital knowledge creation and information, as well as e-commerce – often associated with favorable network effects as well.

The ICT sector has a special feature that makes adequate financing of innovation projects difficult in the continental EU countries. Many sub-sectors of ICT are characterized by a high share of intangible assets, which undermines bank financing. The typical bank will always want collateral, and neither intangible assets (e.g., software) nor computer equipment – whose price absolutely falls over time – can serve as collateral for bank financing. This implies enormous problems for many Euro zone countries in financing innovative young ICT firms. Interestingly, there are some big companies such as Siemens, SAP and Deutsche Telekom that have set up special venture capital funds. However, the general conclusion is that Euro zone countries should move more towards a capital market system and thus imitate part of the Anglo-Saxon ways in terms of the financial market system – with due emphasis on the venture capital market.

Slow growth in the Euro zone over many years – in particular in Germany and Italy – should be a wake-up call for many continental EU countries to modernize the innovation system and to put more emphasis on R&D funding; this must, at the same time, become more efficient. Conditional tax credits should play a larger role than traditional subsidies, which effectively favor large firms that can afford to spend considerable sums of money on active lobbying. R&D tax credits would be less distorting in the sense that large countries and SMEs would act on a more level playing field. Since innovative SMEs are so important in R&D in the ICT sector – and since Germany/the Euro zone is lagging behind the US –the reform proposals made here (and others made subsequently) should be seriously considered.

The ICT sector consists of sub-sectors, which do not all fall under the field of high technology (MEIJERS/DACHS/WELFENS, 2008), however, ICT to a large extent is a high technology sector with short innovation cycles and ongoing internationalization. Whenever ICT markets are global markets, innovating firms will find it easier to recover fixed R&D costs; such fixed R&D costs are very high in the sub-sectors’ software and telecommunications equipment. The increasing amount of ICT goods and ICT investment, respectively, suggests that a broader analysis of the life cycle of electrical and electronic equipment is required.

The OECD (2009) has analyzed 92 government programs and business initiatives – mainly with a triple focus:

- Stimulation of R&D and innovation; where many OECD member countries are active (e.g. Japan's Green IT Project; Germany also has a green ICT pillar in its national ICT summits)
- Increasing green ICT diffusion and ICT applications: more than ½ of programs put the focus on benchmarking, diffusion of best practices and the use of eco labels and standards; governments often lead users and promote diffusion of green technologies, tele-working; and, of course, e-government and e-business.
- Promoting environmental-related ICT skills and awareness: Improving management skills (job-related training schemes), smart metering and certain green ICT pilot projects supported by governments are important here.

With respect to OECD countries, the German government has organized a Delphi study, which rests on the responses of experts from all around the world. The main findings with respect to green ICT perspectives were as follows (BMWT, 2009, p.22). ICT-based infrastructures will become a standard feature after 2015 in Germany; as regards the EU, it will be impossible to achieve a stable and secure provision of energy without massive ICT investment in the energy sector. Using ICT in traffic, telematics, energy and housing will reduce global CO_2 emissions by 15% by 2020. Given the growing awareness about the necessity to make progress in the field of sustainability, a broad modernization of the technical infrastructure, equipments and digital services may be expected by 2020; as regards the US, this could already occur in 2015. As regards Germany, experts expect telecommunications networks to decrease the use of energy by 90% in 2025-30, compared to the benchmark year of 2009. This potential for energy saving will be largely exploited in the US and Europe by about 2020-25. Wider use of ICT-based modernization of the stock of housing will help to achieve a saving of about 30% in energy by 2020 (compared to 2009). This all sounds very optimistic but the rebound effects should not be underestimated: As relative prices of ICT products will continue to fall, more people in the world economy will use more mobile phones, more computers and other digital equipment. As regards the role of e-commerce, there is considerable skepticism (BEHRENDT/WÜRTEN-BERGER/FISCHER, 2003) that e-commerce will contribute to ecological progress: the overall impact on the use of energy and resources is expected to be neutral.

An important study about the impact of ICT on environmental sustainability is a report commissioned by the European Commission's Institute for Prospective Technological Studies (IPTS, 2004), which comes up with the following selected findings. In a best-case assumption, ICT can avoid up to 17% of future freight transport, mainly in the context of dematerialization of the economy; a broad shift from products to services (virtual goods) and material efficiency gains in manufacturing industry leads to a fall in material throughput which in turn leads to a diminishing freight transport volume – but there is considerable uncertainty about the effects, since the results of simulations for freight transport are in the range of -17% to +31%. However, there will be rebound effects since the use of ICT will contribute to a fall in relative transport prices and this will stimulate freight transportation: this increase is expected to be in the range of 12-28% by 2020.

An important analytical catalyst is the International Telecommunications Union – a UN sub-organization – that has presented an interesting study (ITU, 2008) on the link between ICT expansion and global warming. In the subsequent analysis key findings on the German economy are presented which are based on the PANTA RHEI model which has been used in several studies for the Germany government and the European Commission, respectively.

3. Economic Impact of Green ICT Germany

3.1 Methodology

The economy-energy-environment model PANTA RHEI is at the core of our methodological approach. PANTA RHEI (LUTZ et al., 2005, LEHR et al., 2008, MEYER et al. 2012) is an extended environmental version of the econometric simulation and forecasting model INFORGE (AHLERT et al., 2009, MEYER et al., 2007). A detailed description of the economic part of the model is presented in MAIER et al. (2012). Among others it has been used for economic evaluation of different energy scenarios that have been the basis for the German energy concept in 2010 (LINDENBERGER et al., 2010, NAGEL et al., 2011). A similar model with the same structure for Austria (STOCKER et al., 2011) has recently been applied to the sustainable energy development till 2020. The paper gives very detailed insight into the model philosophy and structure.

The behavioral equations reflect bounded rationality rather than optimizing behavior of agents. All parameters are estimated econometrically from time series data (1991 – 2008). Producer prices are the result of mark-up calculations of firms. Output decisions follow observable historic developments, including observed inefficiencies rather than optimal choices. The use of econometrically estimated equations means that agents have only myopic expectations. They follow routines developed in the past. This implies that in contrast to the optimization model, markets will not necessarily be in an optimum and non-market (energy) policy interventions can have positive economic impacts.

Structural equations are modeled on the 59 sector level (according to the European 2 digit NACE classification of economic activities) of the input-output accounting framework of the official system of national accounts (SNA) and the corresponding macro variables are then endogenously calculated by explicit aggregation. In that sense the model has a bottom-up structure. The input-output part is consistently integrated into the SNA accounts, which fully reflect the circular flow of generation, distribution, redistribution and use of income.

The core of PANTA RHEI is the economic module, which calculates final demand (consumption, investment, exports) and intermediate demand (domestic and imported) for goods, capital stocks, employment, wages, unit costs and producer as well as consumer prices in deep disaggregation of 59 industries. The disaggregated system also calculates taxes on goods and on production. The corresponding equations are integrated into the balance equations of the input-output system.

Value added of the different branches is aggregated and gives the base for the SNA that calculates distribution and redistribution of income, use of disposable income, capital account and financial account for financial enterprises, non financial enterprises, private households, the government and the rest of the world. Macro variables like disposable income of private households and disposable income of the government as well as demographic variables represent important determinants of sectoral final demand for goods. Another important outcome of the macro SNA system are net savings and governmental debt as its stock. Both are important indicators for the evaluation of policies. The demand side of the labor market is modeled in deep sectoral disaggregation. Wages per head are explained using Philips curve specifications. The aggregate labor supply is driven by demographic developments.

The model is empirically evaluated: The parameters of the structural equations are econometrically estimated. On the time-consuming model-specification stage, various sets of competing theoretical hypotheses are empirically tested. Since the resulting structure is characterized by highly nonlinear and interdependent dynamics, the economic core of the model has furthermore been tested in dynamic ex-post simulations. Thus the model is solved by an iterative procedure year by year.

The energy module captures the dependence between economic development, energy input and CO_2 emissions. It contains the full energy balance with primary energy input, transformation and final energy consumption for 20 energy consumption sectors, 27 fossil energy carriers and the satellite balance for renewable energy (AGEB, 2011). The energy module is fully integrated into the economic part of the model.

To examine the economic effects of increased application of green ICT in Germany the analysis applies PANTA RHEI to a set of scenarios and compares the resulting economic outcomes.

Scenarios and model results

Scenarios, in contrast to forecasts, present consistently derived different possible future developments. They enable a "what-if" analysis. The scenario technique is often applied when future development depends on the some crucial quantities, whose development is highly uncertain. General assumptions about parameters, which are typically set exogenously for studies like international energy prices, demographic development etc. are used in all scenarios according to the scenarios for the German energy concept (PROGNOS et al. 2010). Only a few parameters, which are directly influenced by green ICT, are changed between the scenarios. The overall economic and environmental impacts are then the result of these assumptions in the model context. These assumptions define two scenarios: A reference scenario which builds on the baseline of the energy scenarios for the German energy concept (PROGNOS et al., 2010), which is quite ambitious about the energy saving development in the future. The second scenario is a green ICT scenario with additional application of ICT and related energy savings. These parameters are taken from different studies for the German ICT sector. A study of FRAUNHOFER IZM AND FRAUNHOFER ISI (2009) for the German Ministry of Economy projects an electricity savings potential of 11 GWh for a green ICT scenario in 2020. This is lower than the energy and emission savings potential in a similar study from the Global E-Sustainability

Initiative and the Boston Consulting Group (2009). As the baseline scenario in this second study is less ambitious than the first one, both analyses report the same magnitude of green ICT impacts. Following the definition of the second study, only the direct impacts of green ICT are taken into account.

The green ICT scenario will reduce CO_2 emissions against the reference by about 10 Mt in 2020. Overall electricity consumption will be around 2% lower. Green ICT measures like smart meters or demand side management will significantly reduce electricity price peaks. Using a conservative estimate average, electricity prices can be about 0.5 EuroCent/kWh lower for all consumers. This equals price reductions of around 4 % for industry and about 2% for households and services.

The green ICT scenario is relatively small, but may have significant positive economic impacts in the year 2020 (see table 1). GDP is about 1.5 Billion Euro higher in the green ICT scenario and employment increases by around 14 thousand. Both these changes will be less than 0.5 %. In contrast the percentage impact of electricity consumption (12 GWh or -2%) and CO_2 emissions (-7 Mt or 1.2 %) is significantly higher. Hence the additional use of green ICT will be a cheaper alternative to further reduce CO_2 emissions.

Table 1: Impacts of green ICT scenarios against the reference in 2020

	Green ICT	neutral Green ICT
GDP (in Billion Euro)	+ 1.5	-
Employment (thousand)	+ 14	-
Electricity consumption (GWh)	-12	-14
CO_2 emissions (Mt)	-7	-9

To account for the rebound effect a GDP and electricity price neutral Green ICT, additional scenario has been developed. Economic activity and electricity prices are set to their levels in the reference scenario to decompose different components of the overall impact of the green ICT scenario. The rebound effect is around 15% of the electricity consumption, i.e. 15% of the potential electricity saving cannot be deployed due to higher economic activity and the lower electricity price. For CO_2 emissions the rebound is a bit higher with around 22%. These results are in line with other model based analyses, which concentrate on economy-wide rebound effects, but other authors also report significantly higher rebound effects (SORRELL 2007, 2009; SCHETTKAT, 2011; IRREK, 2011). According to the classification in a recent report on the rebound effect for DG Environment (MAXWELL et al. 2011) our analysis looks at economy-wide rebound effects.

Discussion and Conclusions

Our analysis shows possible positive impacts of green ICT deployment in Germany. The environmental impact is relatively large and there is a positive impact on related economy. The overall impact of green ICT could be much higher for two reasons. First, the reference scenario already includes substantial green ICT driven energy savings until 2020 against today, which are excluded from the scenario comparison. Second, different studies report much higher potential for indirect impacts of green ICT in relation to direct impacts included in the analysis here. The largest additional contribution may come from smart buildings, smart logistics and smart motors (GESI/BCG 2009, p. 29). This is also supported by a recent analysis on overall energy efficiency potentials in Germany (IFEU et al. 2011), which includes some of these indirect effects. It reports positive economic impacts of its deployment which are about 10 times higher than the ones reported above.

Additional application of green ICT could also make German products more competitive on global markets and create additional export possibilities and related positive economic impacts beyond simple price advantages of lower electricity consumption, which are taken into account.

The interrelations between green ICT, technological change and economic growth are still not fully understood. Further research should focus on the debate about directed technological change (ACEMOGLU et al., 2012), which still has to be developed from the simple 2-sector/2-country case, to a more disaggregated models like PANTA RHEI for a more realistic description of green ICT deployment. Concerning the scenario development future efforts should try to better describe the green ICT specifics and to take related R&D spending more explicitly into account; moreover, as the relative price of ICT capital goods are falling over time there is an important endogenous increase in the demand for ICT investment in the long run. As ICT becomes increasingly important in the capital stock of the economy in the long run, green ICT effects might be larger in the long run compared to the medium term impacts presented here. It also remains to be analyzed to which extent a substitution of hardware for software will contribute to capital-saving technological progress in the long run and such progress in turn will raise the average resource productivity in the overall economy. Germany’s position as a leading global exporter of goods and services – often with embodied ICT inputs – stands well to benefit from relative cost advantages associated with such progress and hence there will be international pressure for imitation. Therefore the overall impact with respect to lowering global CO2 emissions could increase in the long run.

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