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A multi-impact analysis of changing ICT consumption patterns for Sweden and the EU: Indirect rebound effects and evidence of decoupling

P. James Joyce[1]*, Göran Finnveden[1], Cecilia Håkansson[1] and Richard Wood[2]

1. Department of Sustainable Development, Environmental Science and Engineering (SEED), KTH Royal Institute of Technology, Stockholm SE 100-44, Sweden
2. Department of Energy and Process Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway

* Corresponding author - email: pjjoyce@kth.se, telephone: +46-73-765 22 01

Highlights (for review)

- Evidence of decoupling of environmental impacts from consumption of ICT in Sweden
- Strong environmental rebound effects associated with reduced ICT consumption
- First analysis of rebound effects on social measures for ICT
- Value added insensitive to changes in consumption patterns
- Net employment higher at EU level, lower in Sweden when energy consumption reduced

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1. Department of Sustainable Development, Environmental Science and Engineering (SEED), KTH Royal Institute of Technology, Stockholm SE 100-44, Sweden
2. Department of Energy and Process Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway

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Abstract

Information and Communication Technology (ICT) is one of the major areas of growth in consumption seen over the last two decades. The falling prices of ICT and increasing energy efficiency of ICT may lead to reduced spending on ICT and electricity in the future. However, lower spending in one area can trigger higher spending elsewhere, leading to 'rebound effects' which can reduce or even cancel out the environmental benefits associated with lower consumption of a given product or service, and reducing the efficacy of environmental policy. In this study we use Multi-Regional Input Output analysis to investigate trends in the consumption of, and environmental and social impacts associated with ICT products in Sweden and the EU. We find that ICT spending is linked to prosperity, with a clear fall as a result of the 2008 financial crisis, but a recovery since. There is some evidence that the environmental impact associated with ICT has begun to decouple from consumption in Sweden, but not at an EU level. Environmental rebound effects associated with reduced ICT consumption are strong – close to, and in most cases far above 100% (so called backfire effects). This backfire effect is strongest for energy use and total material footprint, which are both close to 200% in Sweden. This means that an increased spending on ICT products and services while keeping the overall consumption level constant, would decrease environmental impacts. Environmental rebound effects are much lower for reduced energy spending (as low as 2 percent), particularly at an EU level. Rebound effects in social indicators are assessed for the first time for ICT products. We find that value added in the EU is relatively insensitive to changes in spending patterns related to ICT and energy (rebound effects ~100%), however rebound effects in employment are seen, particularly resulting from decreased energy spending. At an EU level, reallocation of spending resulting from lower energy consumption results in a net increase in employment, while in Sweden the reverse is true. We conclude that policies focused on reducing energy spending are likely to have a greater overall environmental effect than measures which result in reduced consumer spending on ICT. However, in light of the conflicting social rebound effects at an EU and Swedish level, the importance of understanding the broader consequences of policy decision across a broad range of measures in advance of their implementation is once again highlighted.

Highlights

- Evidence of decoupling of environmental impacts from consumption of ICT in Sweden
- Strong environmental rebound effects associated with reduced ICT consumption
- First analysis of rebound effects on social measures for ICT
- Value added insensitive to changes in consumption patterns
- Net employment higher at EU level, lower in Sweden when energy consumption reduced

Keywords

ICT, Rebound effects, GHG emissions, Material footprint, Energy use, MRIO

1 Introduction

Responsible consumption and production is highlighted as one of the 17 sustainable development goals (SDGs) set by the UN (United Nations, 2015), and overconsumption of natural resources and energy is broadly considered to be a major environmental concern (Durning, 1991; Princen et al., 2002). Environmental impacts from consumption are influenced by the total level of consumption, but also by what is consumed, since different products and services have different environmental impacts (e.g. Fauré et al., 2018; Persson et al., 2018). A change in consumption patterns, leading to reduced demand side drivers has been argued to be a key strategy for sustainable consumption (Tukker et al., 2010), and for reaching the SDGs. Changes to consumption patterns towards products and services with lower environmental impacts can potentially lead to a decoupling effect, whereby consumption (and by extension economic growth) can continue to increase without a concomitant increase in environmental impacts. Such decoupling is often seen as a key strategy for sustainable development (e.g. Schandl et al., 2016). However, in order to understand the actual environmental implications of demand side changes it is important to have insight into the full consequences, including second order effects, of a change in consumption patterns (Alcott, 2008; Börjesson Rivera et al., 2014).

Information and communication technology (ICT) is developing rapidly. ICT products and services cause environmental impacts (Arushanyan et al., 2014; Malmodin et al., 2010) but ICT products and services have also a large potential for reducing environmental impacts in other sectors by substituting other products and services and making processes more efficient (Erdmann and Hilty, 2010).

Despite ever increasing levels of performance, prices of ICT equipment have been falling, year on year, for over four decades (Byrne and Corrado, 2016). Over a more recent timeframe, the costs associated with accessing high speed internet have rapidly decreased, with mobile broadband prices decreasing by almost 50% between 2013 and 2017 (ITU, 2017). At the same time, increases in the efficiency of ICT products, for example the transition from CRT to flat screen monitors (OSnews, 2011), and changes in consumer ICT habits, for example increasing use of tablets and smartphones over desktop computers (Hischier and Wäger, 2015), has led to a decrease in the amount of energy used by ICT products. Falling prices, exacerbated by a more favourable price/performance ratio, coupled with lower energy costs mean consumers can achieve the same utility for a lower cost, and therefore potentially have more money available to spend. How and where they spend this money has important environmental implications.

The environmental implications of altered spending patterns as a result of efficiency improvements are an example of *rebound effects* (Maxwell et al., 2011). Rebound effects are classified by different authors as *second-order effects* (Börjesson Rivera et al., 2014), *third-order effects* (Hilty et al., 2006b) and sometimes simply as *indirect effects* (Bieser and Hilty, 2018). Rebound effects can be broadly split into two types, direct and indirect (Maxwell et al., 2011). Direct rebound effects occur when a decrease in price for a given product leads to a concomitant increase in the consumption of that product, i.e. a decrease in the cost of ICT equipment means that consumers buy more, while spending the same amount. Indirect rebound effects occur when a decrease in cost of one product allows the consumer to reallocate the saving to other products.

The paucity of the current literature measuring rebound effects related to ICT is acknowledged in the recent literature review by Gossart (2015). Within the limited number of studies which exist, the metrics upon which the rebound effect is measured are also restricted to either observed changes in consumption patterns (e.g. increased consumption of office paper as a result of a move to an ICT rich "paperless office") (Maxwell et al., 2011)); tangible measures (e.g. increased mass of mobile phones in Switzerland as a result of miniaturisation) (Hilty et al., 2006b)); increased freight transport due to e-commerce (Weltevreden and Rotem-Mindali, 2009)); energy use (e.g. Hilty et al., 2006a); and greenhouse gas (GHG) emissions (e.g. Håkansson and Finnveden, 2015; Hilty et al., 2006a). To our knowledge rebound effects on social measures are yet to be studied for ICT products.

Environmentally extended input-output analysis (EEIO) has been used to study rebound effects (e.g. Lekve Bjelle et al., 2018; Thiesen et al., 2008; Thomas and Azevedo, 2013). Håkansson and Finnveden (2015) demonstrated how an EEIO approach can be used to gain a better understanding of the potential rebound effects for GHG emissions which result from a decrease in spending on ICT products and services in Sweden. Here we extend this analysis to a broader geographic scope, covering the whole of the EU, and a wider range of impact measures. For the first time for ICT products, this will encompass social as well as an extended range of environmental measures. Through the use of the multi-regional input output database (MRIO) EXIOBASE (Stadler et al., 2018; Wood et al., 2015), we are able to overcome one of the main limitations in the study conducted by Håkansson and Finnveden (2015), namely that imported goods were assumed to have the same impact as those produced in Sweden.

In this study we use MRIO analysis to investigate trends in ICT spending and the resulting environmental and social impact between 1995 and 2011. Using data for 2011, we then estimate the environmental implications of a change in consumer spending patterns as a result of decreased spending on ICT and electricity, and in doing so identifying the magnitude of potential rebound effects related to both ICT and electricity use. In doing this we also investigate environmental impacts of the ICT sector in the EU and in Sweden.

2 Material and Methods

Input/Output (IO) analysis makes use of the supply/use tables commonly maintained by national governments to trace the flow of goods and services between sectors in an economy (Miller and Blair, 2009). By incorporating sectoral data for emissions, resource use and other social indicators, the potential effect of changes to economic flows on these measures can be estimated (Suh, 2009). Using single country or region IO tables it is not possible to account for impacts which occur overseas as a result of imported goods. By linking these tables into Multi-regional IO models, this issue can be addressed. EXIOBASE is one such environmentally extended Multi-regional IO database (Wood et al., 2015).

In this work, we use the 3rd version of the EXIOBASE dataset (Stadler et al., 2018), and specifically the constant price version 3.3. The form of the input-output table is the product by product tables using the industry technology assumption (Majeau-Bettez et al., 2014). The data in EXIOBASE is downloadable from exiobase.eu and is available from 1995 – 2011. The time series allows us to identify recent trends in consumption patterns over this period, as well as the changes in the resulting environmental and social impacts.

IO analysis can be used to give the total impact in terms of environmental pressure or socio-economic requirements for a certain level of final demand, and is usually applied in an ex-post framework (based on historical linear relationships between production and consumption). The main components of IO analysis can be broken down into the multiplier vector (**q**) and the level of final demand (**y**). The multipliers show the total (supply-chain) impacts per unit of final demand of each product available in the economy. It is built up based on an environmental (or socio-economic) intensity vector (**s**) showing the environmental pressure per-unit of production (e.g. grams of CO_2 per € of electricity produced) multiplied by the Leontief inverse (**L**) or "total requirements" matrix. **L** shows the amount of production required in order to produce a product for final demand (e.g. € of steel needed to be produced per € of final computer products). The final demand shows the household, government and capital demand of a country in a certain year. The multiplication of **q** by the diagonalised demand gives the total impact for each product consumed in a country (here Sweden or EU) by country of final production in an MRIO setting: $\mathbf{f} = \mathbf{q}\hat{\mathbf{y}}$, which must be then aggregated to the total consumption of both imported and domestically produced goods in a certain region. As we are using a MRIO model here, the total impact for each product consumed includes the impacts in all regions of the world. For further details on basic IO methods, see Miller and Blair (2009), Wood (2017).

All results are calculated for global impact due to the final demand of ICT (and related products) in Sweden and Europe. ICT is not recorded as a single category in amongst the 200 different EXIOBASE categories (see Wood et al., 2014 for disaggregation details). Four separate product categories (designated by a product code in the form p##) are used to represent ICT in this study: Office machinery and computers (p30); Radio, television and communication equipment and apparatus (p32); Post and telecommunication services (p64); and, Computer and related services (p72). These four categories are considered together (ICT Total) and separately in the results. Electricity is represented by the product category Production of all electricity (p40.11). The link between these product groups and more detailed classifications such as the Classification of Products by Activity (CPA) is available online[1].

First results (Figure 1) simply show the total final demand (**y**) for relevant ICT categories over time in Sweden and Europe for both domestically produced and imported products. The valuation is in constant 2005 Euros based on the methods and data described in Stadler et al. (2018). Secondly, the total impact of the final demand for the relevant products (Figure 2) are extracted from the f vector as described above for each impact category, and aggregated over domestic and imported products for Sweden and Europe individually. The calculation is performed five times, once for each indicator.

In addition to GHG emissions, EXIOBASE allows an extended range of environmental and social impacts to be assessed. In this study we use 5 measures; 2 social (Employment and value added) and 3 environmental (GHG emissions, energy use, total material footprint). Employment data provides an indicator of the potential impact of changes in consumption patterns on the labour force within the economy, while value added provides an indicator of the effect on total net output. GHG emissions, energy use and material consumption are important and commonly used indicators of environmental impact.

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[1] https://github.com/rich-wood/ICT_rebound

A number of scenarios were then constructed in which to explore potential rebound effects from changes in final demand. The scenarios were constructed in order to give an exogenous demand-side shock to the model, with both decreases in consumption, and reallocation of savings to other consumption. A full description of the modelling of demand-side changes and rebounds in a IO framework (i.e. assuming linear production functions) is available in Wood et al. (2018). The same approach was applied here, but using average final demand as a means of re-allocating to savings to other demand. Using income elasticities of demand can better capture increased “discretionary” expenditure on certain product groups (Druckman et al., 2010; Font Vivanco and van der Voet, 2014; Lekve Bjelle et al., 2018; Wiebe et al., 2018; Wood et al., 2018), but were not available for EXIOBASE product groups at the time of this study. However, it is expected that the overall affect is small.

Rebound effects were calculated for the latest available year of the database (2011). The rebound effect can be quantified as the proportion of the reduction in an impact which is negated by the increased impact of second order effects. Formally this was calculated using the following formula:

$$\text{Rebound effect (percent)} \; = \; (1 - \; \text{ACE}/\text{PCE}) * 100$$

Where PCE is the potential change in emissions resulting from a reduction in consumer demand (the initial change in **y**), and ACE is the actual change in emissions which occurs, including rebound effects (after including exogenous information on the re-spending of savings so that whilst the structure of **y** is changed, the overall quantity is maintained).

When investigating rebound effects in the ICT sector, energy efficiency during the use phase is also of relevance. Developments in the ICT sector which increase energy efficiency will reduce costs for electricity use. The scenarios studied here therefore include both reduced spending in ICT in total as well as electricity, and the amount saved is used either for increased spending across all product groups or specifically on ICT products and services. Three main scenarios are considered when calculating the rebound effect and these are as follows:

1. 10% reduction in ICT total; proportional increase in spending across all product groups
2. 10% reduction in electricity; proportional increase in spending across all product groups
3. 10% reduction in electricity; corresponding increase in spending in ICT total

In addition, the rebound effect was calculated for each of the four product categories within ICT total, resulting in an additional 28 scenarios. The full code is available at https://github.com/rich-wood/ICT_rebound.

3 Results

3.1 Emissions and consumption from the ICT-sector over time

Patterns of expenditure on ICT related products over the period 1995 – 2008 in both Sweden specifically and at the EU level are shown in Figure 1. The overall trend shows an increase over this period; however the effect of the 2008 financial crash is clearly visible (Table 1). Total ICT consumption fell by 11% both in Sweden and in the EU as a whole between 2008 and 2009. At an EU level this was mainly driven by a 25% fall in radio, television and communication apparatus, while in Sweden the main driver was an 18% fall in computers and related services. Consumption of electricity continued to rise over this time period in Sweden (+11%) and only decreased slightly at an

EU level (-0.7%). Total ICT consumption has been increasing since 2009, but has not yet recovered to 2008 levels at either geographic scale.

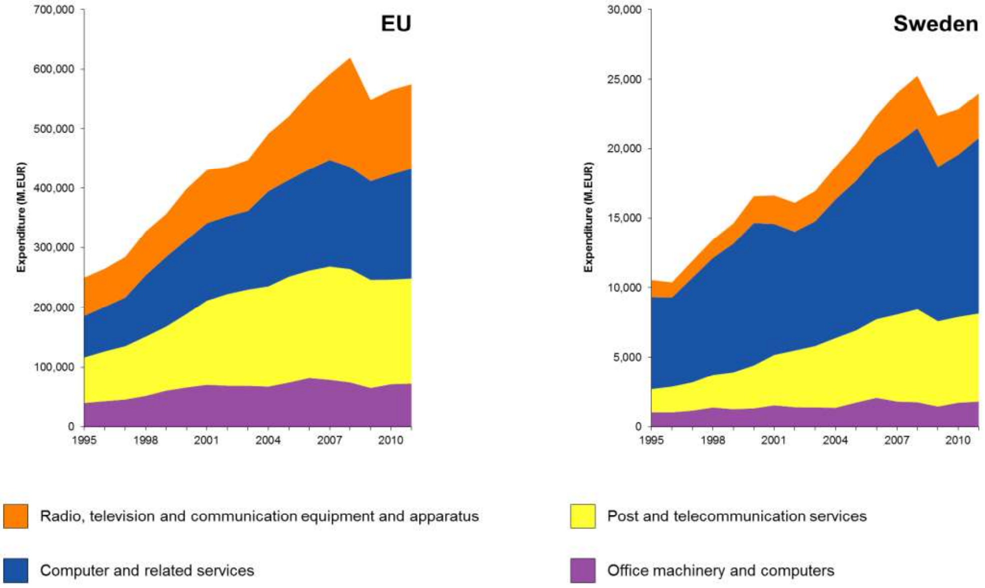


Figure 1 Annual expenditure on ICT related categories in the EU and Sweden in the period 1995 to 2011

In Sweden, expenditure in *computer and related services* declined between 2000 and 2002 before beginning to rise again to its 2008 peak, leading to a plateau in overall ICT expenditure between 2000 and 2001, and an overall decline between 2001 and 2002.

Table 1 Percentage change in overall expenditure between 2008 and 2009 for each expenditure category in the EU and Sweden

Category	EU	Sweden
Electricity	-0.7%	+10.9%
Office machinery and computers	-12.4%	-17.5%
Radio, television and communication equipment and apparatus	-25.5%	-3.0%
Post and telecommunication services	-4.6%	-8.4%
Computer and related services	-3.4%	-14.7%
ICT Total	*-11.4%*	*-11.5%*

3.2 General patterns for consumption and environmental/social impacts

In both Sweden and the EU, the expenditure pattern is mirrored in the absolute impact for value added and broadly mirrored for the employment indicator (Figure 2). At an EU level, this is true for all three environmental impact categories also. In Sweden however, absolute GHG impact, energy use and material footprint resulting from ICT consumption all declined from 2010-2011, despite an increase in expenditure. This is a sign of decoupling between the expenditures on ICT and the potential environmental impacts of ICT consumption. This is mainly due to a decrease in the intensity (impact per million euros expenditure) of 15% for GHG emissions, 16% for energy use and 14% for material footprint associated with *radio, television and communication equipment* in this time period.

3.3 Rebound scenarios

Rebound effects based on 2011 data for each of the three main scenarios are shown in Table 2. The rebound effects for value added cancel out the potential changes in all scenarios for both the EU and Sweden. Employment is reduced in scenario 1 (reduction in ICT, increase in all products) at both geographic scales, however in scenarios 2 and 3, in which electricity consumption is decreased, the pattern for the EU is different to that seen in Sweden. At an EU level overall employment is increased as a result of decreased electricity consumption and subsequent reallocation of spending, however the reverse is true in Sweden.

For GHG emissions, the rebound effects due to a reduction in ICT consumption are far above 100 percent, both at an EU level and in Sweden. Rebound effects above 100 percent, known as *backfire* effects, indicate that despite efficiency improvements, overall emissions will increase.

This result stands in contrast to the relatively low rebound effects found in scenario 2 and 3. In these scenarios the overall decrease in emissions is far greater at the EU level than in Sweden. This is due to the lower GHG impact resulting from electricity production in Sweden, where the primary electricity generation technologies are hydropower and nuclear, leading to a lower PCE value.

The rebound effect leads to an overall increase in total energy use in scenario 1. In scenarios 2 and 3, the rebound effect for energy use is minimal. Large backfire effects are also seen for the material footprint of scenario 1. The rebound effect for materials at an EU level in scenarios 2 and 3 is low (5 - 8%), but in Sweden is higher (29 - 55%). As above for GHG emissions, this is likely due to the lower materials intensity associated with the largely non-fossil derived electricity grid in Sweden.

Table 2 Rebound effects (2011 data) for the three main scenarios

Impact measure	Location	Scenario 1 (reduction in ICT spending)	Scenario 2 (reduction in electricity use)	Scenario 3 (reduction in elec, increase in ICT)
Value added	**EU**	101%	100%	99%
	Sweden	102%	98%	97%
Employment	**EU**	95%	121%	128%
	Sweden	91%	68%	75%
GHG Emissions	**EU**	123%	9%	7%
	Sweden	131%	67%	51%
Total Energy Use	**EU**	141%	8%	6%
	Sweden	186%	5%	2%
Total Material Footprint	**EU**	153%	8%	5%
	Sweden	190%	55%	29%

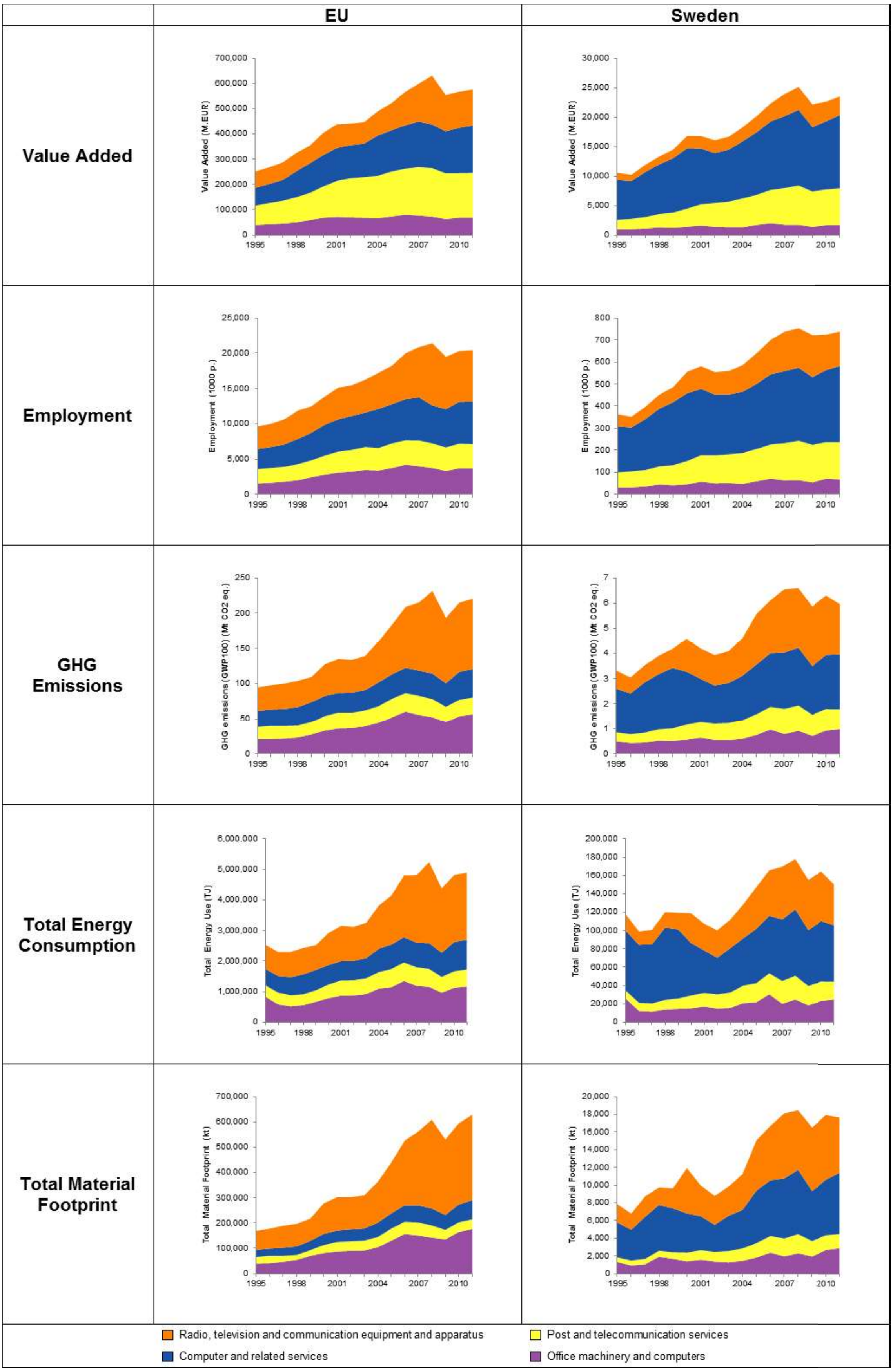
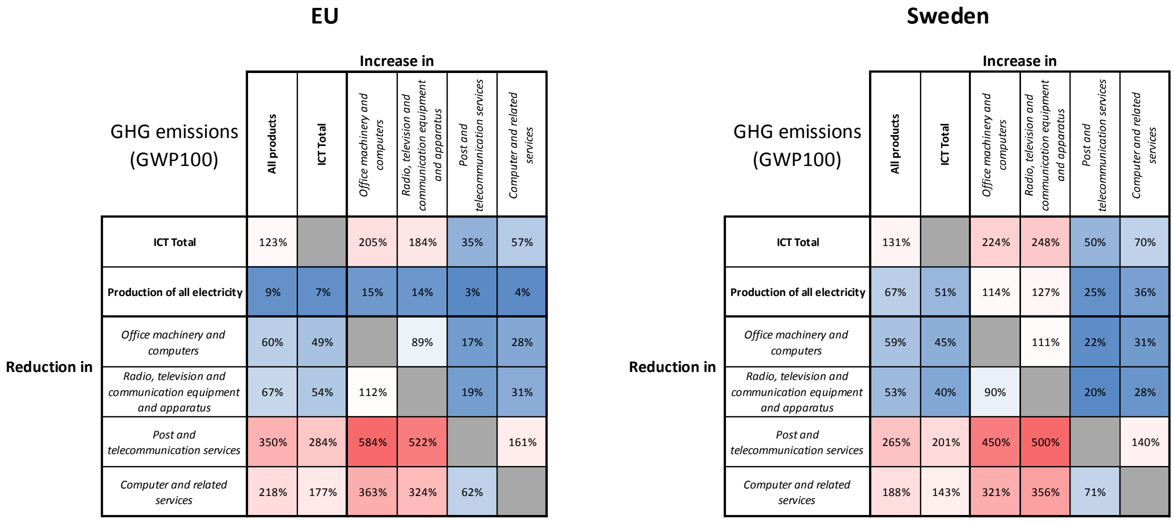


Figure 2 Total annual absolute impact on value added, employment, GHG emissions, total energy consumption and total material footprint in the EU and Sweden in the period 1995 to 2011



EU

GHG emissions (GWP100)		Increase in: All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
Reduction in	ICT Total	123%		205%	184%	35%	57%
	Production of all electricity	9%	7%	15%	14%	3%	4%
	Office machinery and computers	60%	49%		89%	17%	28%
	Radio, television and communication equipment and apparatus	67%	54%	112%		19%	31%
	Post and telecommunication services	350%	284%	584%	522%		161%
	Computer and related services	218%	177%	363%	324%	62%	

Sweden

GHG emissions (GWP100)		Increase in: All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
Reduction in	ICT Total	131%		224%	248%	50%	70%
	Production of all electricity	67%	51%	114%	127%	25%	36%
	Office machinery and computers	59%	45%		111%	22%	31%
	Radio, television and communication equipment and apparatus	53%	40%	90%		20%	28%
	Post and telecommunication services	265%	201%	450%	500%		140%
	Computer and related services	188%	143%	321%	356%	71%	

Figure 3 Rebound effect for GHG emissions (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).

3.4 Rebound effect for ICT subsectors

The magnitude of the rebound effect for ICT differs depending upon which subsector is considered. Figure 3 shows this effect for GHG emissions at both and EU and Swedish level. Similar figures for all other impacts considered are available in the electronic supplementary materials. When a reduction in overall ICT spending is coupled with an increase in either *office equipment* or *radio and television equipment*, rebound effects above 100% are seen for employment (Figure S2) and for all three environmental impact categories (Figure 3 and Figures S4 and S5). Conversely when spending is shifted from ICT in general to *post and telecommunications* or *computers and related services*, rebound effects are below 100%. The smallest rebound effects within the ICT subsectors are seen when spending in *office machinery* or *radio and television equipment* is shifted to *post and telecommunication services*.

4 Discussion

Rebound effects for social indicators are measured here for the first time for ICT products. Total value added, which is analogous to economy wide expenditure, shows a very slight net increase in the EU and in Sweden as a result of scenario 1 (reduction in ICT consumption, increase in consumption of all products), and a slight decrease in the other two scenarios, where electricity consumption is decreased. The same cannot be said for employment however. On this indicator, a small overall decrease in employment is seen at a Swedish and EU level as a result of a decrease in ICT consumption (scenario 1). In scenarios where electricity consumption is decreased however, the effect on employment is more marked, and differs between the two geographic scopes. Rebound effects below 100% are seen in Sweden, i.e. the overall employment goes down, whereas rebound effects above 100% are seen for the EU. This is due to the relatively high domestic employment intensity of electricity, particularly in Sweden, combined with a higher reliance on EU supply chains for consumption of other products. That is, a decrease in electricity consumption in scenario 2 and 3 has a significant impact on Swedish employment. The "rebound" on consumption of other goods and services will only partially offset this decrease in Sweden, and have a more pronounced effect in the EU. This result is to be expected, considering that electricity supply chains are short, compared to those of ICT.

Strong environmental rebound effects, commonly greater than 100% (backfire effects), related to reduced spending on ICT products in Sweden were seen in this study, with weaker rebound effects associated with reduced spending on electricity. This is a similar pattern to that reported by to Håkansson and Finnveden (2015) for GHG emissions in Sweden. Here we see that this pattern extends to an EU level, although the rebound effect for GHG emissions and total material footprint associated with reduced electricity spending is far lower at an EU level, due to the higher impact of the energy mix in the EU compared to Sweden.

The results show that environmental impacts from consumption not only depend on the total level of consumption, but also on *what* is consumed. A shift from the current average expenditures towards increased consumption of ICT products and services would decrease the overall environmental impacts. This was called a reverse rebound effect in Håkansson and Finnveden (2015) where an increased consumption in one sector would lead to decreased environmental impacts.

The sub-sectoral analysis presented here suggests that it also matters which ICT products and services are bought. A move to telecommunications based ICT services may have environmental benefits over physical ICT products. This could be consistent with the idea that migration of data and processing power to the cloud may be a more sustainable model for the future of ICT services.

The results presented above show that the rebound effect of reduced electricity consumption is limited. Improved energy efficiency leading to reduced electricity use therefore leads to improvements in terms of greenhouse gases, energy use and material consumption. Greenhouse gases are reduced to a larger extent in the EU which uses more fossil-based power production compared to Sweden.

This study is focused on indirect rebound effects where it is assumed that the overall level of consumption is constant. Increased ICT use will however lead also to other second order effects (Ahmadi Achachlouei and Hilty, 2015). For example, increased ICT use can lead to system-wide rebound effects which could include overall economic growth, with an increased level of consumption. Increased ICT use can also induce new social practices with both increased and decreased environmental impacts (Börjesson Rivera et al., 2014). An increased use of ICT can therefore lead to both positive and negative environmental impacts.

In this paper the focus is on consumption of ICT in general. The impacts will however depend on what the ICT is used for. Townsend and Coroama (2018) discuss the risk for system-wide rebound effect where increased ICT that is used for optimization of industrial processes can accelerate production and consumption leading to an overall increased energy use. They identify however two cases where ICT has a clear role: when it pushes the production and adoption of an environmental beneficial product, i.e. products described as *cleantech*, and when it supports processes specific to the circular economy (ibid). This illustrates that in order to reach the overall sustainable development goals, including the one on sustainable consumption and production it is necessary to understand and utilise the rebound and other second-order effects by steering towards lower impact consumption and also control the overall consumption of different products and services.

In addition to the rebound effects seen, the time series analysis provides additional insights. The two most striking aspect of the trends of ICT related consumption and its consequent social and environmental impact between 1995 and 2011 are the clear signal of the 2008 financial crisis in the EU and Sweden, and the apparent decoupling of consumption and environmental impact in Sweden since 2010. The decrease in spending in all subcategories of ICT between 2008 and 2009 suggests that both a decrease in household income and business investment as a result of the financial crisis led to decreased ICT consumption. The relatively slow rate of recovery of ICT consumption from 2009-2011 is consistent with the observation that at a global level the ICT sector has stopped growing (Malmodin and Lundén, 2018). Goel et al. (2006) suggested that income elasticity of demand for internet services in OECD countries in 2000 was greater than unity, and is therefore considered a 'luxury'. While further estimates of the income elasticity of demand for ICT related products are unavailable, this is consistent with the perception that ICTs are luxury products and would explain the decrease in consumption over this period. In contrast the income elasticity of demand for electricity in G7 countries is considered to be inelastic (Narayan et al., 2007). This is consistent with the observation that electricity consumption rose in Sweden over this time and fell by a markedly smaller percentage in the EU as a whole, and the perception of electricity is a necessity in developed countries. This overall picture may however have changed during the last decade. During this time period, ICT has become much more integrated in everyday life and it may now be seen more as a necessity then before. New studies of income elasticities of demand for ICT related products could therefore be of interest.

The apparent decoupling of expenditure and environmental impact associated with ICTs in Sweden is mirrored in the study of Malmodin and Lundén (2016), in which the energy and carbon footprints of ICT and Entertainment and Media products in Sweden were noted to have peaked in 2010, and subsequently declined to 2015. Malmodin and Lundén (2016) use a bottom-up approach, in contrast to the top-down approach taken in this study, hence the agreement of the results is noteworthy. Decoupling GDP growth from environmental impact is of great importance to sustainable development and is central to the mandate of the UNEP International Resource Panel (UNEP, 2011).

The results for greenhouse gas emissions for the ICT sector for Sweden presented here can be compared with previous studies by Malmodin et al (2010) and Malmodin and Lundén (2018, 2016). Although the general trend over time is similar, the magnitude is quite different. The emissions according to this study are approximately 6 Mton of CO2-eq from ICT products and services used in Sweden, whereas it is approximately 3 Mton in Malmodin and Lundén (2016) although the latter study also includes emissions from the use phase of the ICT equipment. This apparent discrepancy may have several reasons. One is that the present study includes rather broadly defined product groups, which may include products and services which are not considered as ICT products and services in the Malmodin and Lundén study. Another reason may be that the bottom-up study includes more precise and relevant data whereas the input-output data used here are averages of broad product groups. A third reason may be that the bottom-up approach by necessity includes truncation errors (e.g. Lenzen, 2000; Majeau-Bettez et al., 2011) which leads to an underestimation of the overall impacts. In any case, this difference is so large that a more in-depth study would be useful.

5 Conclusions

The general upward trend in consumption of ICT products suggests that falling prices have not resulted in lower spending. Indeed, the only fall in spending on ICT products seen between 1995 and 2011 is related to a fall in income. Subsequent rising prosperity has seen an increase in ICT spending at an EU and Swedish level. Significantly however, in Sweden, there is evidence that the environmental impacts associated with ICT products have begun to decouple from their consumption, which is a very positive step. Strong environmental rebound effects and weaker social rebound effects, leading to lower overall employment, suggest that policy measures which result in reducing consumer spending on ICT products may not produce the environmental and social benefits which may be expected. On the contrary, increased spending on ICT products and services can lead to decreased environmental impacts, if the overall spending is constant. In contrast, policy measures designed to promote energy efficiency, both in the ICT sector and more broadly, are likely to have a net positive environmental effect, thanks to a lower rebound effect, particularly at the EU level. Caution is warranted however, as while these measures have a positive effect on employment at an EU level, a negative effect on employment is seen in Sweden. This analysis serves to highlight the importance of understanding the broader consequences of policy decision across a broad range of measures in advance of their implementation.

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Figure 1

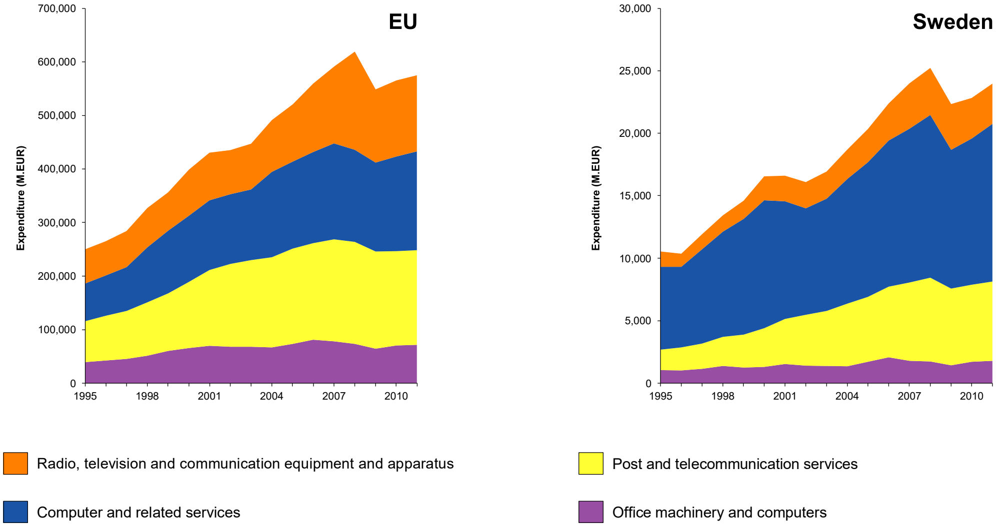

EU
Expenditure (M.EUR)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1995
1998
2001
2004
2007
2010
Sweden
Expenditure (M.EUR)
30,000
25,000
20,000
15,000
10,000
5,000
0
1995
1998
2001
2004
2007
2010
Radio, television and communication equipment and apparatus
Post and telecommunication services
Computer and related services
Office machinery and computers

Figure 2

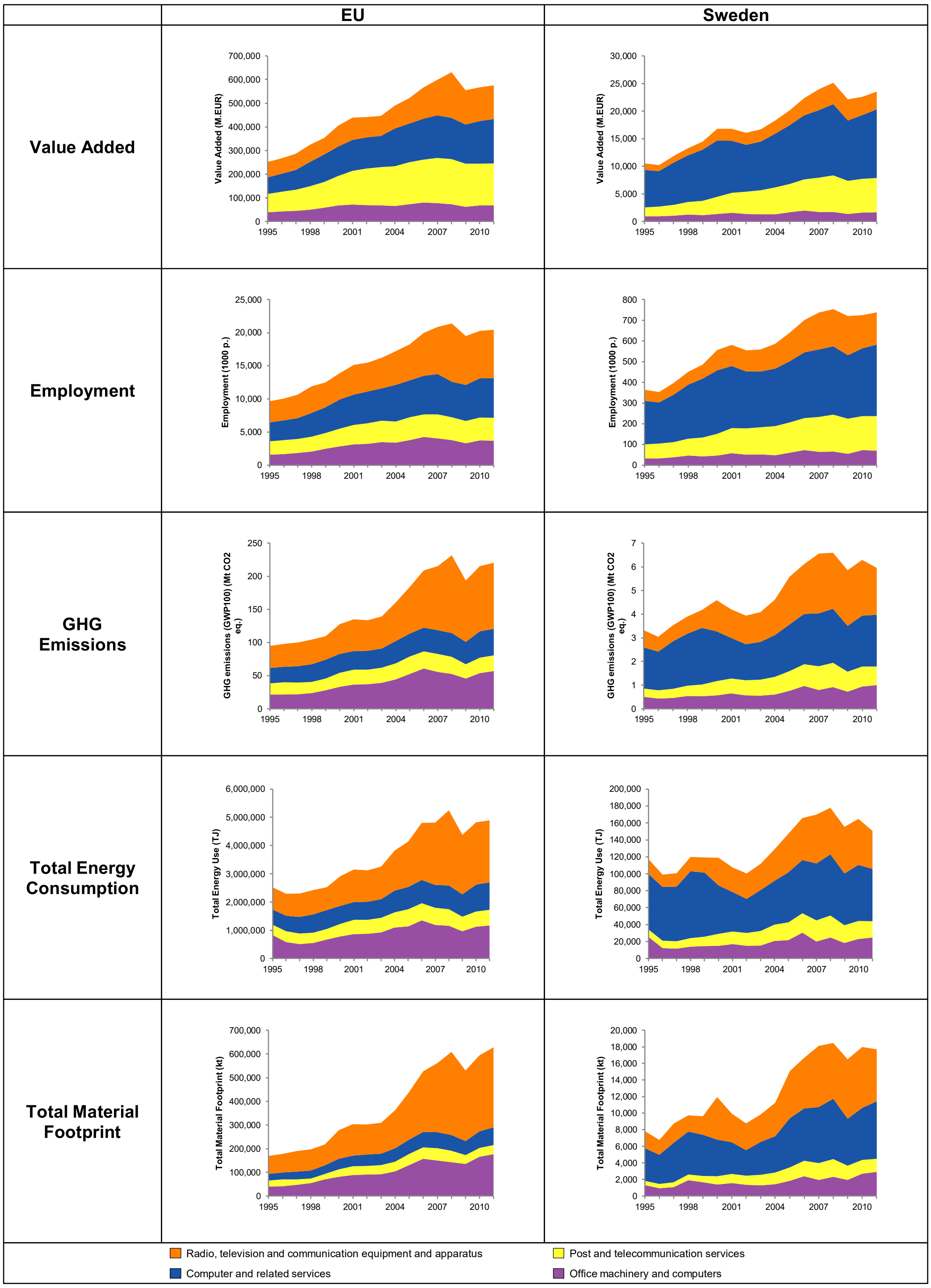
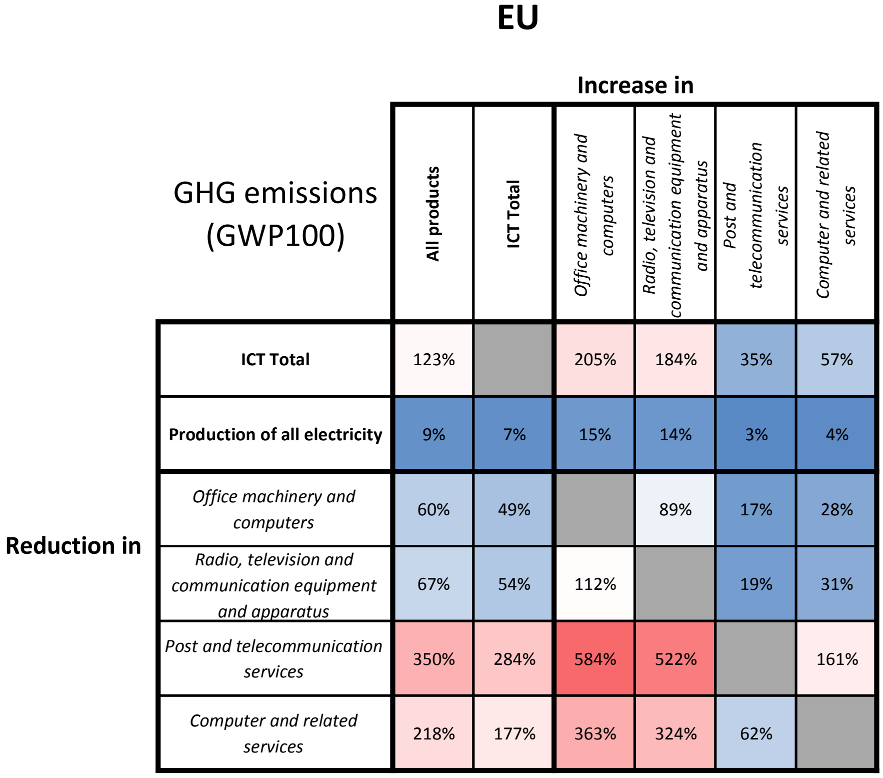

EU
Sweden
Value Added
Value Added (M.EUR)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
30,000
25,000
20,000
15,000
10,000
5,000
0
Employment
Employment (1000 p.)
25,000
20,000
15,000
10,000
5,000
0
800
700
600
500
400
300
200
100
0
GHG Emissions
GHG emissions (GWP100) (Mt CO2 eq.)
250
200
150
100
50
0
7
6
5
4
3
2
1
0
Total Energy Consumption
Total Energy Use (TJ)
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Total Material Footprint
Total Material Footprint (kt)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1995
1998
2001
2004
2007
2010
Radio, television and communication equipment and apparatus
Post and telecommunication services
Computer and related services
Office machinery and computers

Figure 3



EU

Increase in

Reduction in

GHG emissions (GWP100)	**All products**	**ICT Total**	*Office machinery and computers*	*Radio, television and communication equipment and apparatus*	*Post and telecommunication services*	*Computer and related services*
ICT Total	123%		205%	184%	35%	57%
Production of all electricity	9%	7%	15%	14%	3%	4%
Office machinery and computers	60%	49%		89%	17%	28%
Radio, television and communication equipment and apparatus	67%	54%	112%		19%	31%
Post and telecommunication services	350%	284%	584%	522%		161%
Computer and related services	218%	177%	363%	324%	62%	

Figure captions

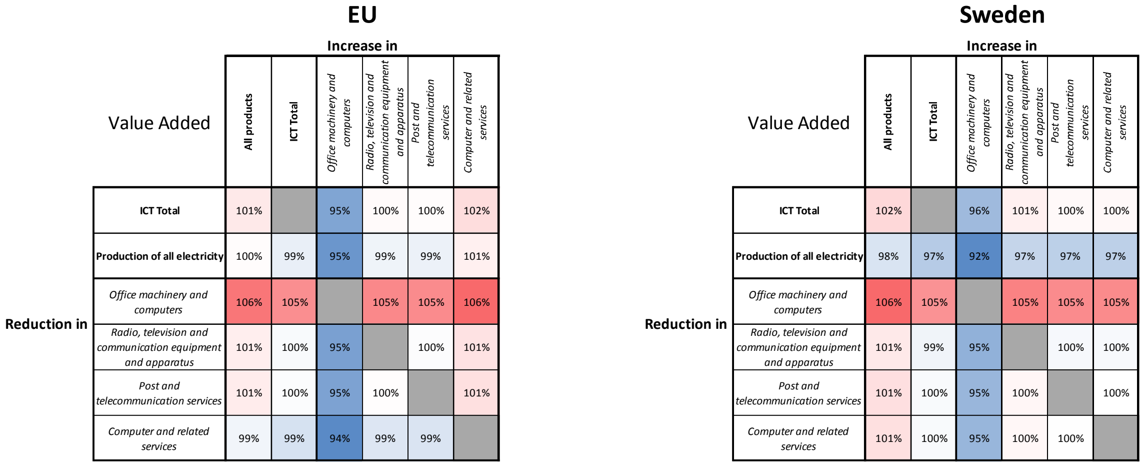
Figure 1 Annual expenditure on ICT related categories in the EU and Sweden in the period 1995 to 2011

Figure 2 Total annual absolute impact on value added, employment, GHG emissions, total energy consumption and total material footprint in the EU and Sweden in the period 1995 to 2011

Figure 3 Figure 3 Rebound effect for GHG emissions (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).

A multi-impact analysis of changing ICT consumption patterns for Sweden and the EU: Indirect rebound effects and evidence of decoupling

Appendix A: Supplementary results



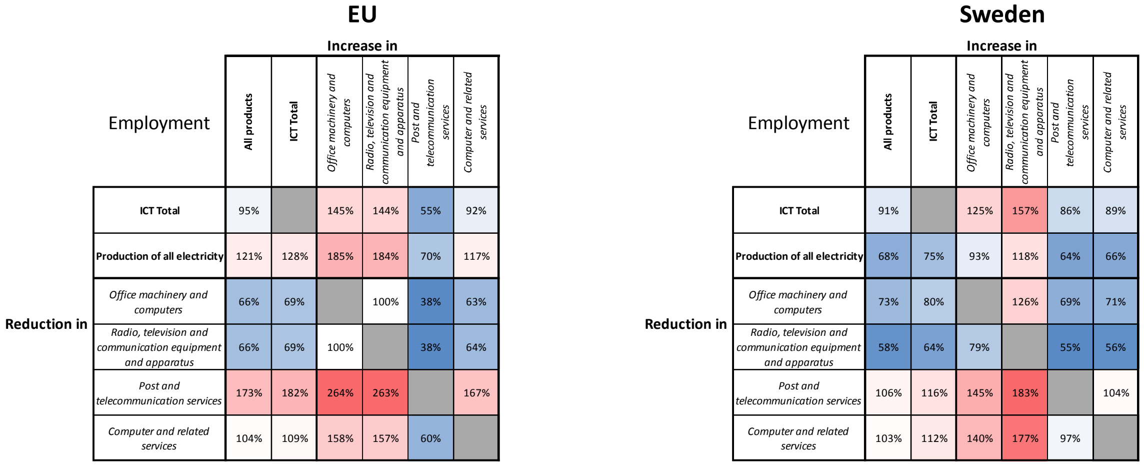
EU

		Increase in					
	Value Added	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
Reduction in	ICT Total	101%		95%	100%	100%	102%
	Production of all electricity	100%	99%	95%	99%	99%	101%
	Office machinery and computers	106%	105%		105%	105%	106%
	Radio, television and communication equipment and apparatus	101%	100%	95%		100%	101%
	Post and telecommunication services	101%	100%	95%	100%		101%
	Computer and related services	99%	99%	94%	99%	99%	

Sweden

		Increase in					
	Value Added	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
Reduction in	ICT Total	102%		96%	101%	100%	100%
	Production of all electricity	98%	97%	92%	97%	97%	97%
	Office machinery and computers	106%	105%		105%	105%	105%
	Radio, television and communication equipment and apparatus	101%	99%	95%		100%	100%
	Post and telecommunication services	101%	100%	95%	100%		100%
	Computer and related services	101%	100%	95%	100%	100%	

Figure S1 Rebound effect for value added (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).



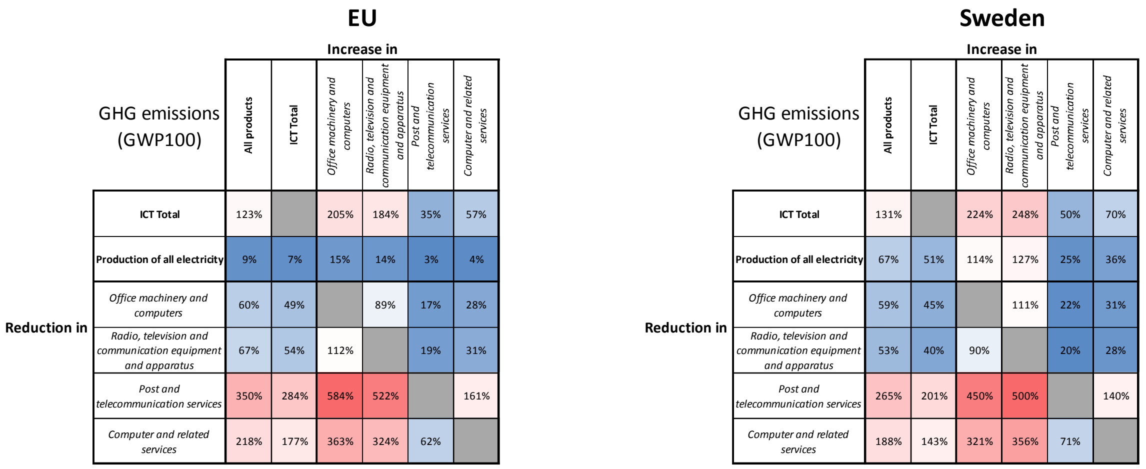
EU

		Increase in					
	Employment	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
Reduction in	ICT Total	95%		145%	144%	55%	92%
	Production of all electricity	121%	128%	185%	184%	70%	117%
	Office machinery and computers	66%	69%		100%	38%	63%
	Radio, television and communication equipment and apparatus	66%	69%	100%		38%	64%
	Post and telecommunication services	173%	182%	264%	263%		167%
	Computer and related services	104%	109%	158%	157%	60%	

Sweden

		Increase in					
	Employment	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
Reduction in	ICT Total	91%		125%	157%	86%	89%
	Production of all electricity	68%	75%	93%	118%	64%	66%
	Office machinery and computers	73%	80%		126%	69%	71%
	Radio, television and communication equipment and apparatus	58%	64%	79%		55%	56%
	Post and telecommunication services	106%	116%	145%	183%		104%
	Computer and related services	103%	112%	140%	177%	97%	

Figure S2 Rebound effect for employment (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).



EU

Increase in

Reduction in

GHG emissions (GWP100)	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
ICT Total	123%		205%	184%	35%	57%
Production of all electricity	9%	7%	15%	14%	3%	4%
Office machinery and computers	60%	49%		89%	17%	28%
Radio, television and communication equipment and apparatus	67%	54%	112%		19%	31%
Post and telecommunication services	350%	284%	584%	522%		161%
Computer and related services	218%	177%	363%	324%	62%	

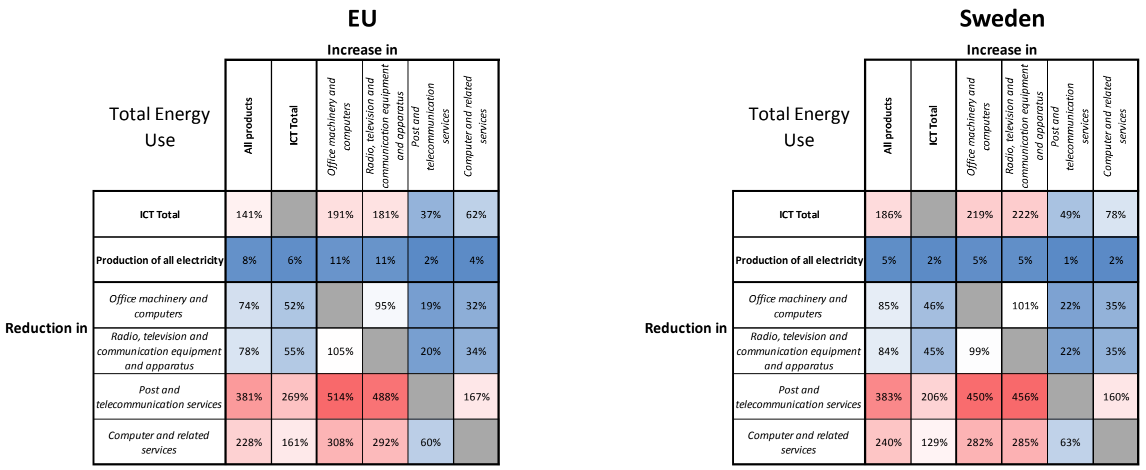
Sweden

Increase in

Reduction in

GHG emissions (GWP100)	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
ICT Total	131%		224%	248%	50%	70%
Production of all electricity	67%	51%	114%	127%	25%	36%
Office machinery and computers	59%	45%		111%	22%	31%
Radio, television and communication equipment and apparatus	53%	40%	90%		20%	28%
Post and telecommunication services	265%	201%	450%	500%		140%
Computer and related services	188%	143%	321%	356%	71%	

Figure S3 Rebound effect for GHG emissions (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).



EU

Increase in

Reduction in

Total Energy Use	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
ICT Total	141%		191%	181%	37%	62%
Production of all electricity	8%	6%	11%	11%	2%	4%
Office machinery and computers	74%	52%		95%	19%	32%
Radio, television and communication equipment and apparatus	78%	55%	105%		20%	34%
Post and telecommunication services	381%	269%	514%	488%		167%
Computer and related services	228%	161%	308%	292%	60%	

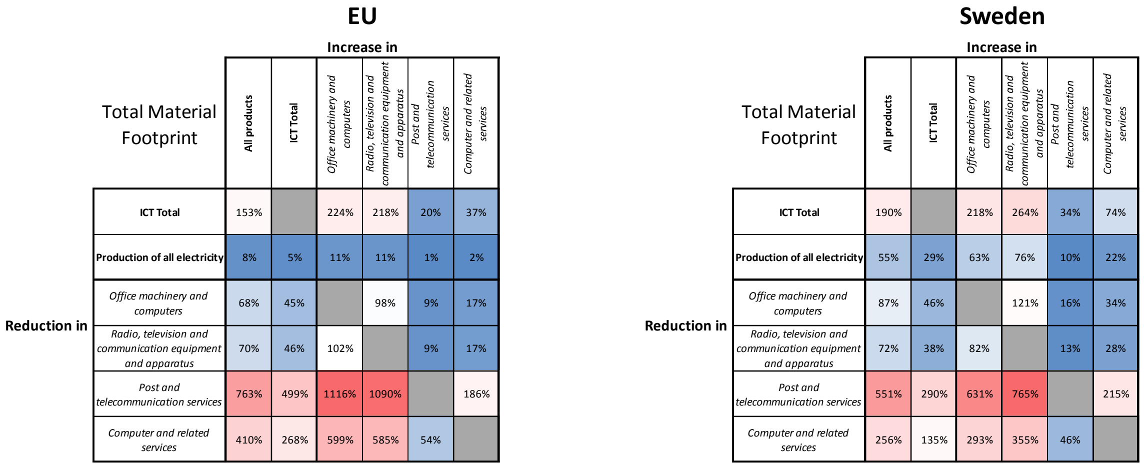
Sweden

Increase in

Reduction in

Total Energy Use	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
ICT Total	186%		219%	222%	49%	78%
Production of all electricity	5%	2%	5%	5%	1%	2%
Office machinery and computers	85%	46%		101%	22%	35%
Radio, television and communication equipment and apparatus	84%	45%	99%		22%	35%
Post and telecommunication services	383%	206%	450%	456%		160%
Computer and related services	240%	129%	282%	285%	63%	

Figure S4 Rebound effect for total energy use (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).



EU

Increase in

Total Material Footprint	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
ICT Total	153%		224%	218%	20%	37%
Production of all electricity	8%	5%	11%	11%	1%	2%
Office machinery and computers	68%	45%		98%	9%	17%
Radio, television and communication equipment and apparatus	70%	46%	102%		9%	17%
Post and telecommunication services	763%	499%	1116%	1090%		186%
Computer and related services	410%	268%	599%	585%	54%	

Reduction in

Sweden

Increase in

Total Material Footprint	All products	ICT Total	Office machinery and computers	Radio, television and communication equipment and apparatus	Post and telecommunication services	Computer and related services
ICT Total	190%		218%	264%	34%	74%
Production of all electricity	55%	29%	63%	76%	10%	22%
Office machinery and computers	87%	46%		121%	16%	34%
Radio, television and communication equipment and apparatus	72%	38%	82%		13%	28%
Post and telecommunication services	551%	290%	631%	765%		215%
Computer and related services	256%	135%	293%	355%	46%	

Reduction in

Figure S5 Rebound effect for total material footprint (2011 data) for each of the ICT subcategories. Red indicates a backfire effect (rebound effect > 100%), white indicates a neutral effect (rebound effect ~100%) and blue indicates a net decrease in impact including the rebound effect (rebound effect < 100%).

Supplementary - Matlab code