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Energy efficient telecommunication networks

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Zusammenfassung

Die Umweltauswirkungen und die Energieeffizienz des Kabelnetzwerks der upc cablecom in der Schweiz wurden mit Hilfe einer Ökobilanz bewertet. Dafür wurden die Energieverbräuche und physische Infrastruktur der Jahre 2012 und 2013 von Rechenzentren, Headend Zentralen, Points of Presence, Übertragungsnetzwerk mit Glasfaser und Koaxialkabelverbindungen, Verstärker (im Netz und bei den Endverbrauchern) und Geräte für den Datenempfang und -dekodierung erfasst. Die grössten Umweltauswirkungen über den Lebenszyklus werden durch den Stromverbrauch im Betrieb verursacht unabhängig von den untersuchten Bereichen. Den grössten Anteil der gesamten Umweltauswirkungen des Kabelnetzes werden von den Endgeräten zum Datenempfang und Dekodierung, an zweiter Stelle von den Verstärkern verursacht. Übertragungsnetzwerk und Datenzentren spielen gesamthaft eine untergeordnete Rolle. Spezifische Stromverbräuche von CPEs, deren hohe Stückzahl und die zum Teil schlechten oder ganz fehlenden Steuermöglichkeiten der Betriebszustände sind Gründe für die anteilsmässig grössten Umweltauswirkungen. Verstärker fallen von allem durch die hohe Stückzahl ins Gewicht. Drei verschiedene Szenarien wurden gebildet um zukünftige Entwicklungen abzubilden: ein Szenario in dem nur die energieeffizientesten Geräte eingesetzt werden, ein zweites Wachstumsszenario in dem die Zuwachsraten des Marketings abgebildet werden ohne spezifische Verbesserung der Energieeffizienz und ein drittes Szenario in dem ein moderates Wachstum unter Einhaltung der sich verschärfenden gesetzlichen Anforderungen abgebildet wurde. Die übertragenen Datenmengen im Kabelnetzwerk wurden ins Verhältnis zum Stromverbrauch gesetzt. Vergleiche mit Literaturwerten zeigen, dass Kabelnetzwerke im Vergleich zu reinen Internet Protokoll basierten Datennetzwerken sehr effizient Daten übertragen. Es ist jedoch zu bedenken, dass Daten im traditionellen Broadcast nur in eine Richtung übertragen werden und daher nicht direkt mit IP Netzwerken vergleichen werden können. Kabelnetzbetreiber sind sich ausserdem einig, dass sich die IP Datenübertragung langfristig durchsetzen wird. Um den grossen Anteil von Umweltauswirkungen von Endgeräten zur begrenzen sind effiziente Geräte und eine gute Steuerung daher im ganz besonderen Masse von Interesse.

Résumé

L'impact environnemental et l'efficacité énergétique du réseau câblé de upc cablecom en Suisse ont été évalués sur la base d'un bilan écologique. Pour cela, la consommation d'énergie et l'infrastructure physique des années 2012 et 2013 concernant les centres de calcul, centrales de têtes de réseau, points de présence, réseaux de transmission avec fibre optique et connexions par câble coaxial, amplificateurs (dans le réseau et chez les clients finaux) ainsi que les appareils pour la réception et le décodage des données ont été recensées. Indépendamment des domaines examinés, l'impact environnemental le plus significatif sur l'ensemble du cycle de vie est la conséquence de la consommation d’électricité nécessaire à l'exploitation. La plus grande part de l'impact environnemental global du réseau câblé est engendrée par les terminaux servant à la réception et au décodage des données. Les amplificateurs occupent la seconde place. Sur le plan global, le réseau de transmission et les centres de données jouent un rôle secondaire. La consommation d’électricité spécifique des CPE, leur nombre d'unités élevé et les possibilités de commande médiocres, voire même inexistantes, en termes de statuts de fonctionnement justifient l'impact environnemental proportionnellement dominant. Les amplificateurs pèsent lourdement dans la balance, notamment en raison de leur grand nombre d'unités. Trois scénarios différents ont été imaginés pour illustrer les développements futurs : un scénario utilisant uniquement les appareils les plus efficaces sur le plan énergétique, un second scénario illustrant les taux de croissance du marketing sans amélioration spécifique de l'efficacité énergétique et un troisième scénario représentant une croissance modérée tenant compte des exigences légales renforcées. Les quantités de données transmises au sein du réseau câblé ont été opposées à la consommation d’électricité. Les évaluations des sources littéraires indiquent que les réseaux câblés, en comparaison aux réseaux de données uniquement basés sur le protocole Internet, transmettent les données de manière très efficace. Il faut toutefois considérer que, dans le broadcast traditionnel, les données sont transmises uniquement dans une direction, ce qui empêche toute comparaison directe

avec les réseaux IP. Les câblo-opérateurs sont par ailleurs unanimes sur le fait que la transmission de données IP s'établira à long terme. Pour limiter la majeure partie de l'impact environnemental des terminaux, des appareils efficaces et une commande appropriée sont par conséquent d'intérêt général à large échelle.

Summary

With the aid of life cycle assessment methods, this study evaluates the environmental impacts of energy consumption as well as the physical infrastructure of the upc cablecom telecommunication network in Switzerland. Taking the years 2012 and 2013 as starting points, three different scenarios have been developed. Scenario 1 describes an environmentally improved network with the best available technology (BAT) of consumer premises equipment (CPE) provided to all customers. The second is a moderate growth scenario which anticipates compliance of all appliances with energy saving requirements and assumes that all customers are provided with the most modern CPEs. The total number of CPEs was kept constant. The third is a growth scenario which extrapolates the marketing forecast of upc experts until 2015. Under this scenario only the currently available BAT was used. The life cycle assessment has shown that the largest overall environmental impact is caused by CPEs such as modems, complex set-top boxes and multimedia gateways as well as signal amplifiers. In contrast, the centralised services, such as data centres and transmitting infrastructure, only contribute a fourth or third of the total environmental impacts. This is due to the fact that CPEs are employed in large numbers. They also vary considerably in their energy demand as well as the ability to switch to energy saving modes when not being used. Centralised services as well as amplifiers have to be available all the time. As a telecommunication system is very hierarchical, centralised services are fewer in numbers and, hence, contribute less to the overall impact. The energy intensity of data transmission has been calculated by adding up transmission volumes of IP services (internet and telephone) and broadcast services. upc cablecom energy intensity of data transmission ranges at very low levels compared with those mentioned in the relevant literature. Future improvements can be achieved by employing the most efficient end user equipment and by avoiding multiple use of end user equipment. In the long term, the promotion of centralised services (cloud services) and exploiting the potential of smart electronics "beyond" end user equipment (such as modems and multimedia gateways) could decrease the energy demand of the telecommunication net-work.

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Abstract

Energy consumption of widely distributed telecommunication networks is becoming increasingly subject to pressure concerning energy saving policies, not only by regulatory frameworks but also due to the fact that energy comprises a large share of operating costs. Regulations range from requirements to continually improve the energy demand of specific devices as well as energy saving targets for an entire national telecommunication provider.

With the aid of life cycle assessment methods, this study evaluates the environmental impacts of energy consumption as well as the physical infrastructure of the upc cablecom telecommunication network in Switzerland. Taking the years 2012 and 2013 as starting points, three different scenarios have been developed. Scenario 1 describes an environmentally improved network with the best available technology (BAT) of consumer premises equipment (CPE) provided to all customers. The second is a moderate growth scenario which anticipates compliance of all appliances with energy saving requirements and assumes that all customers are provided with the most modern CPEs. The total number of CPEs was kept constant. The third is a growth scenario which extrapolates the marketing forecast of upc experts until 2015. Under this scenario only the currently available BAT was used. An additional data scenario was established which introduces a calculation method for broadcast data transmission rates, extrapolates historical data until 2016 and compares the energy consumption per transmitted data over time with published data in literature.

The life cycle assessment has shown that the largest overall environmental impact is caused by CPEs such as modems, complex set-top boxes and multimedia gateways as well as signal amplifiers. In contrast, the centralised services, such as data centres and transmitting infrastructure, only contribute a fourth or third of the total environmental impacts. This is due to the fact that CPEs are employed in large numbers. They also vary considerably in their energy demand as well as the ability to switch to energy saving modes when not being used. Centralised services as well as amplifiers have to be available all the time. As a telecommunication system is very hierarchical, centralised services are fewer in numbers and, hence, contribute less to the overall impact.

233 GWh were consumed in 2012 increasing to 273 GWh or by 17%, by the end of 2013. The subscribed services from upc cablecom customers increased during the same period by only 3% and the installed end user equipment by only 1%. The greater energy demand is the result of an increased electricity demand per individual end user equipment. The scenarios show a reduction potential of 20 % assuming that the most efficient equipment is installed.

The energy intensity of data transmission has been calculated by adding up transmission volumes of IP services (internet and telephone) and broadcast services. upc cablecom energy intensity of data transmission ranges at very low levels compared with those mentioned in the relevant literature. Current values as

well as those in the forecasts until 2016 lie below 0.05 kWh/GB (energy demand per transmitted data volumes).

Future improvements can be achieved by employing the most efficient end user equipment and by avoiding multiple use of end user equipment. In the long term, the promotion of centralised services (cloud services) and exploiting the potential of smart electronics "beyond" end user equipment (such as modems and multimedia gateways) could decrease the energy demand of the telecommunication network.

1 Introduction

Whether or not information and communication technology (ICT) and in particular modern telecommunication networks contribute to sustainable development remains to be seen (e.g. (Masanet and Matthews 2010), Special issue of Journal of Industrial Ecology, reference list is not conclusive). After a protracted period during which energy consumption in the service sector was considered to be relatively low in comparison to the agricultural and producing sector, the increased use of office equipment, office space and, more recently, infrastructure for information and communication technology has led to a marked change of the situation. The demand and use of ICT equipment has created a lucrative business sector for hard and software producers, thus increasing the electricity demand of this sector. Early ICT equipment was designed without consideration of energy efficiency. Current soft and hardware is very short lived and mainly driven by the fast development of newer consumer applications, requiring software and -to a lesser degree- hardware replacement. In 2002 mobile smart phones accessing the internet became affordable for a majority of users. This led the way to a more centralized and hierarchical ICT infrastructure.

Today, modern telecommunication networks offer a vast range of services and applications, which have replaced traditional purchasing and consumption patterns. Two of the most prominent are: the virtual market place e.g. for audio products, which has replaced hardware sales of magnetic tapes, compact discs or other media; and the increase of electronic books instead of hardcopy products. Both were only made possible by the presence of a powerful but redundant infrastructure, available 24 hours a day, throughout the entire year. The environmental benefits of physical resource conservation - by means of avoided products, transport, sale stores and trade-offs from increased energy demand and hardware requirement- has been discussed in numerous papers (R. Hischier and Reichart 2003; Taylor and Koomey 2008; Laitner and Ehrhardt-Martinez 2009; Weber, Koomey, and Matthews 2010; Masanet and Matthews 2010; Malmodin et al. 2010; Hinton et al. 2011; Coroama, Moberg, and Hilty 2015).

Being part of a network means constant presence. For telecommunication networks the availability of connected devices is the defining factor for whether a device is part of the network or not. The automatic recognition and connection of network components - such as dynamic host configuration protocol (DHCP) is a technical standard, which allows access to and log off from the internet. Today, billions of devices are connected to telecommunication networks with trends indicating a marked increase in total numbers and connected time. However, not all aspects of this constant state of connectedness are productive, as protracted periods in standby mode of connected devices causes a considerable loss of electrical energy, curtailing the positive effects of telecommunication as a whole.

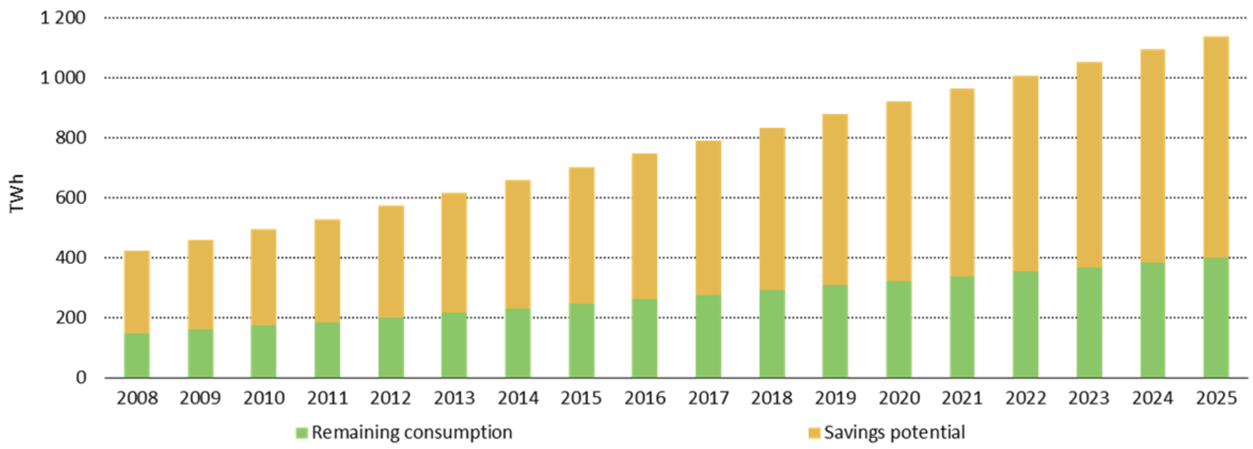


Figure 1 ***"Current and projected global network-enabled device electricity consumption and savings potential"*** **(International Energy Agency; 2014), projections starting in 2012.**

The International Energy Agency (IEA) identified a saving potential of 372 TWh/a in 2012 by implementing the best available technology for network-enabled devices. Projections until 2025 reveal a saving potential of 739 TWh/a, which is "…more than the current total final electricity consumption of Canada, Denmark, Finland and Norway combined" (International Energy Agency; 2014).

ICT electricity consumption has evolved in step with the rapid evolution of ICT applications. With increasing centralisation, data centre infrastructures are targeted to become more energy efficient. On a global average roughly the same amount of energy consumed for server structures is used for cooling down the excess of produced heat. But the growth of device energy demand stemming from end-user equipment connected to the network is even stronger when compared to that of data centres and personal computers - see Figure 2 in which electricity use of network devices, PCs and data centres can be seen to have increased to a greater extent than that of worldwide electricity consumption, network devices taking the lead (Van Heddeghem et al. 2014).

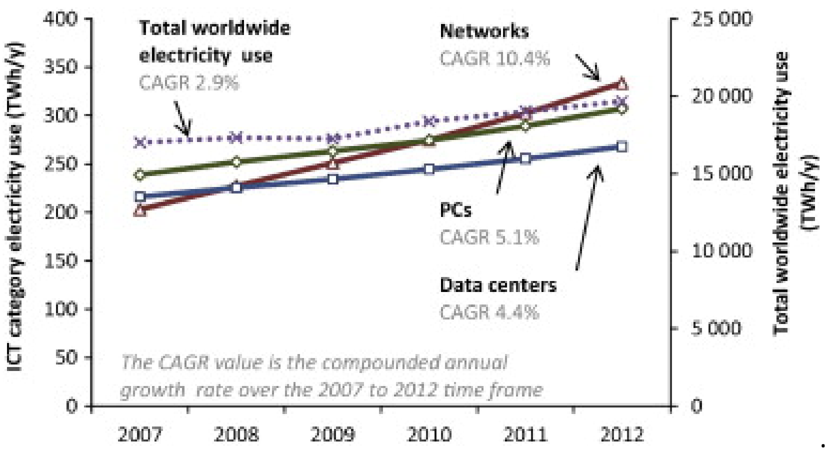


Figure 2 Growth in global electricity consumption of communication networks, PCs and data centres (solid lines, left axis) compared with total worldwide electricity use (dotted line, right axis). In 2012 each category accounts for roughly 1.5% of the worldwide electricity. Compound annual groth rates (CAGR) in grey (Van Heddeghem et al. 2014).

Several studies have been undertaken, investigating the energy demand of internet infrastructure, excluding customer premises equipment (CPE) or end-user equipment (such as PCs, notebooks, mobile phones and television screens). These studies provide an interesting view of modern infrastructure, such as fibre optic submarine cables or satellite connections. Coroama highlighted specific characteristics of worldwide fibre optical data transmission, showing that energy consumption occurs mainly at sender and recipient local nodes and not during long distance data transport through submarine cables (Coroama et al. 2013). A follow up study by the same authors conducted a literature review investigating the considerable range of the energy consumption of telecommunication sectors (Coroama and Hilty 2014). The authors classify the ten investigated studies according to the methodical approach chosen:

- *"Top-down approach: According to* (Chan et al. 2013) *top-down analyses are the ones taking into account the total electricity consumption estimated for the Internet and the Internet traffic for a region or a country within a defined time period. Dividing the former quantity by the latter yields the average energy consumption per data transferred.*
- *Model-based approach: By contrast, model-based approaches model parts of the Internet (i.e., deployed number of devices of each type) based on network design principles. Such a model combined with manufacturer's consumption data on typical network equipment leads to the overall energy consumption* (Hinton et al. 2011)*, which is then related to the corresponding data traffic.*
- *Bottom-up analysis: Finally, bottom-up analyses are based on direct observations made in one or more case studies, leading to energy intensity values for specific cases and a discussion of the generalizability of the results."*

  (Coroama and Hilty 2014)

Estimates from six different studies of the energy demand per data volume transferred diverge by up to two orders of magnitude from 0.057 kilowatt-hours per gigabyte (kWh/GB) to 1.8 kWh/GB. Other studies, which were taken into account in this review, included end-user devices such as desktop, notebook or tablet computers. The results show a higher energy demand per transferred data volume. Values range between 7 and 136 kWh/GB. The authors conclude that two factors are mainly responsible for the energy demand per data volume, these are a) the year of the investigation with a clear tendency towards energy efficiency increase over time and b) the system boundaries, that is, whether or not end-user equipment, which is the main contributor to the kWh/GB consumed, is included in energy accounting or not.

Very recently Malmodin et al. published a life cycle assessment of the largest Swedish telecommunication provider. The investigated telecommunication system comprised the entire network including "*end user equipment via core network to international fiber connections and external data centers for e.g. search motors and social network."* (Malmodin et al. 2014a). They included also G2 and G3 mobile networks and applied all three of the above mentioned approaches: The top-down approach and model based approach - to derive the amount of material and energy consumed by multiplying the end user equipment used in Sweden with the average energy consumption. Covered by this approach were consumer premises equipment (modem, routers, gateways, set-top boxes) and end user equipment (PCs, mobile phones, notebooks, televisions etc.). And the bottom up approach - by measuring the material and energy intensity of TeliaSonera' s network infrastructure (access network, operator activities and IP core network). Please see also supporting information (Malmodin et al. 2014b).

Another set of studies investigated the impact of internet use, looking firstly at the physical infrastructure including end-user equipment (Müller and Widmer 2010) and secondly at the environmental impact over the entire life cycle (Müller, Widmer, and Orthlieb 2012; Müller et al. 2013). The study calculated key values for the use of the internet in Switzerland in 2009 such as:

- the specific energy demand of 9kWh/GB(transmitted); and
- the specific material demand of 0.032 kg/GB(transmitted).

Modern telecommunication service providers offer 'all-in-one packages' with telephone, television, internet browsing, virtual private networks or virtual sever networks -known as Cloud services- delivered in a single bundle. With the move away from traditional services, in which end-users received a separate signal for telephone, television and internet, came a move towards an increased energy demand, brought about by the increased functionality of the machines themselves as well as the infrastructure required. However, one should be wary of assuming that the overall demands of energy and resources will likewise rise. If future telecommunication networks operate more frequently with virtual server structures providing services instantly on demand, and if server centres work to their full capacities, a considerable increase in energy and resource efficiency may be achieved.

In order to design modern telecommunication systems that provide services, which are in demand and do not waste energy and materials, comprehensive research is required to

- investigate the current state of telecommunication infrastructures;
- take into account immediate changes triggered by technological innovation and changes of consumer behaviour; and
- identify potentials for improvements.

Currently, the provision of a fast, sufficient and secure connection to the internet is an asset which private homes and businesses take almost for granted. This has, in part, to do with neat, easy to handle and affordable end-user appliances, often simple input-output tools which rely on a powerful infrastructure. It has also been brought about by innovative businesses providing software, memory space and computing power services, rather than machines and hardware which have to be configured, maintained and powered by individual users. Fast, sufficient and secure connections to the internet have also contributed to the situation.

The study on hand investigates the energy and material intensity of the largest cable network provider in Switzerland: upc cablecom. Similarly to the above mentioned studies the cable network is also a hierarchical structure which undergoes fast technological and managerial chances. Unanimous agreement prevails, that data transmission in form of internet protocol (IP) based services will increase. For a cable network provider this is particularly challenging as traditional broadcast services have to be redesigned or partly reinvented. upc cablecom aims to better understand the current situation and exploit the potential energy savings and environmental improvement which comes along such changes.

The report is structured in an introductory part of the normative and legal framework (chapter 2) and used methods in this study (chapter 3). Goal and scope to the Life Cycle Assessment (chapter 4) are followed by the inventory analysis (chapter 5). The Results of the energy and material intensity of upc cablecom network in 2012 and 2013 are contrasted with several scenarios (chapter 6), followed by interpretation and concluding remarks (chapter 7). Detailed LCA inventory data can be found in the Annexes. Unpublished data of the internal assessment must be requested by upc cablecom directly.

2 Legal background

Hardware and service providers of telecommunication systems undergo particularly rigorous supervision, as far as energy demand is concerned. Particularly the *European Directive for energy-related products*, often called *Eco-Design Directive* (EU, 2009/125/EC 2009), has triggered a quasi-worldwide standardisation process, assessing energy consumption values for (energy-related) products. Specific regulations define maximum allowed energy consumption values, which certain categories of imported or manufactured products in the EU have to comply with.

2.1 EUROPEAN UNION

Until recently, telecommunication gateways have been categorised under the ErP process as *set top boxes* (simple or complex) -the name stemming from the location in which the boxes were placed, traditionally on bulky television sets. Industries launched an initiative to develop self-regulation which was successfully launched as *Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU* (Industry Group 2011) (VA). The signatories started implementing the VA in June 2011, the latest version 3.1 dating back to the 19 June 2013[1]. The EU Commission unofficially acknowledged the VA in February 2011, which was then officially acknowledged and published by the EU Council and EU Parliament on the 22 November 2012 *(Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for complex set-top boxes*[2]). The ErP regulation foresees such agreements as an implementing option; nevertheless the EU Commission reserves the right to release a regulatory measure if agreed targets are not achieved. The first report by an independent inspector was compiled and published in Mai 2012, the second report in April 2013 [3] (Molenbroek, van Doorn, and Wartmann 2013; Molenbroek, van Doorn, and Wartmann 2012).

Signatories of the VA commit themselves that at least 90 % of all CSTB models placed on the market and/or put into service comply with the energy consumption targets agreed for the relevant period of time. In order to decide whether a CSTB is compliant, the measured typical energy consumption (TEC value) has to be lower than the maximum energy consumption target of the individual appliance.

TEC values of an individual appliance is calculated with a formula adding up the power consumption of a specific state the appliance in set, multiplied with the hours of the day the specific state is active (see Equation 2 and Equation 3 on page 77). For Complex Set Top Boxes (CSTB) the duty cycle per day is 9

[1] http://cstb.eu/home/wp-content/uploads/2013/09/Voluntary-Industry-Agreement-CSTBs-V-3-1-Final.pdf

[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2012:0392:FIN:EN:PDF

[3] http://cstb.eu/?page_id=16

hours active and 15 hours standby or 4.5 hours active, 4.5 hours in standby from Auto-Power-Down[4] and 15 hours standby (the base duty cycle is shown in Table 35 in the Annex). The maximum energy consumption target is generically created by adding up *annual energy allowances* in kWh/year of the *base functionalities* and the *additional functionalities* which are granted for a specific CSTB (Industry Group 2011).

Despite the implementation of the voluntary agreement, the regulatory measurement for the *ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment* from the year 2008 (EU, No 1275/2008 2008) has been amended. This so called "standby regulation" now includes specified requirements for appliances which can access a communication network (EU, No 801/2013 2013). Such requirements were absent in the original EU regulation and have been assessed in detail by an ErP pre-study. With this amended "standby regulation", a step-by-step improvement of the standby of networked products is required. Specifically defined "network equipment" is categorised according to its functionality as having either a "high network availability" - that is, constantly "online"-, or a reduced network availability -only being called into an active mode within a set time frame. The regulation defines three different product categories. The definition of Article 2 is presented in verbatim below:

- *1.-16.…*
- *17. “networked equipment” means equipment that can connect to a network and has one or more network ports;*
- *18. “networked equipment with high network availability” (HiNA equipment) means equipment with one or more of the following functionalities, but no other, as the main function(s): router, network switch, wireless network access point, hub, modem, VoIP telephone, video phone;*
- *19. “networked equipment with high network availability functionality” (equipment with HiNA functionality) means equipment with the functionality of a router, network switch, wireless network access point or combination thereof included, but not being HiNA equipment;*

A “network port” means a wired or wireless physical interface of the network connection, located on the equipment and by which the equipment can be remotely activated. Additionally, several definitions of HiNA equipment (point 18. and 19.) were also defined in the amendment.

- *20. “router” means a network device whose primary function is to determine the optimal path along which network traffic should be forwarded. Routers forward packets from one network to another, based on network layer information (L3);*

[4] Auto -Power-Down is a *"Automatically switch(s) from the On state to a standby state after a period of time without user input, generally based on the amount of time the unit has remained “idle” from last active use, i.e., user input such as channel change, volume change, menu access, etc."* (CoC 2009, page 10).

- *21. "network switch" means a network device whose primary function is to filter, forward and distribute frames based on the destination address of each frame. All switches operate at least at the data link layer (L2);*
- *22. "wireless network access point" means a device whose primary function is to provide IEEE 802.11 (Wi-Fi) connectivity to multiple clients;*
- *23. "hub" means a network device that contains multiple ports and is used to connect segments of a Local Area Network;*
- *24. "modem" means a device whose primary function is to transmit and receive digitally modulated analogue signals over a wired network;*

Any type of network equipment that can be connected to a wireless network must be equipped with a power management function, which automatically switches equipment into a networked standby mode after the shortest possible period –this being set at 20 minutes. This requirement does not apply to products which rely on a single wireless network connection with no wired network connection.

Products are considered to be in a network standby mode when not providing their main functions -unless the network standby mode is inappropriate for the intended use, or when other energy-using products are not dependent on their functions. No definitions are given for multifunctional products which include a router, wireless access point, a complex set-top box or two of the above in one product. Three different product categories and their maximal power consumption levels in the network standby mode are summarized in Table 1. The requirements for maximal power consumption are becoming stricter. New products have to comply with the values given in Table 1.

Table 1: product categories, maximum power consumption and time schedule according to EU, Nr. 801/2013

–	Tier 1 (01.Jan 2015)	Tier 2 (01.Jan 2017)	Tier 3 (01.Jan 2019)
Networked equipment with high network availability (HiNA)	12 W	8 W	8 W
Networked equipment with high network availability functionality (HiNA functionality)	12 W	8 W	8 W
Networked equipment with low network availability (LoNA)	6 W	3 W	2 W

2.2 SWITZERLAND

Switzerland has included a reference in its energy regulation (EnV (730.1) 1998 2015) - not to the Voluntary Agreement, but to another initiative called *Code of Conduct on Energy Efficiency of Digital TV Service Systems Version 9.0*[5] (CoC; 2013). Different Codes of Conduct have been developed by the Joint Research Center Ispra of the European Commission, one of which is the above mentioned CoC 2013 valid since 01

[5] http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/code_of_conduct_digital_tv_service_systems_v9_final.pdf

July 2013. The CoC, similar to the VA, sets maximal power requirements for electronic products but shows several differences to the VA. After a long period of discrepancies between both initiatives, it was agreed that the signing of the VA is a necessary condition for companies which are also signatories of the CoC. The extent to which consistency has been achieved has yet to be fully analysed.

Under the Swiss energy regulation (EnV (730.1) 1998 2015), CSTB are compliant if they fulfil the requirements of the CoC 2013. The only deviation of the EnV from the CoC 2013 is the TEC value calculation for headed equipment. The EnV sets clearer rules to calculate the periods of T_{on}, $T_{Standby}$ and T_{APD}:

- T_{On} = 4.5 h;
- $T_{Standby}$ = 3 × APD-Timeout;
- T_{APD} = 24 h – T_{On} – $T_{Standby}$.

For example: assuming the time to switch into APD is set to 5 hours, $T_{Standby}$ would be 15, T_{APD} 4.5 hours, exactly as defined in the VA (see Table 35 in the Annex). Any decrease in time to switch into APD, would increase the Auto Power Down period and vica verca. The T_{On} time remains untouched which is the main deviation of the EnV from the CoC.

Despite the above mentioned, the technological development has advanced further than the regulations actually depict. Today many complex set top boxes (CSTB) or multimedia gateways have their own hard disc drives which save data temporarily or permanently (movies, pictures, music or other data). In addition to this, many CSTB or multimedia gateways have an internet modem as well as a telephone unit and often serve as a wireless network access point. Another type of end-user equipment which became affordable for ordinary users is network attached storages (NAS), which offer large storage capacities intended to be combined with connecting devices such as modems, and CSTB. Such devices are constantly online and are categorised as network equipment with high network availability (HiNA). Many of the features of a modern multimedia gateway are not, however, appropriately depicted in the implementing measurers, the VA, or the CoC.

3 Methodologies

3.1 Life Cycle Assessment

The environmental impacts of telecom networks are quantified and interpreted using life cycle assessment (LCA) methodology. The expression life cycle assessment is a general term for an instrument which applies sound environmental principles to business practices. The essential characteristics of the life cycle assessment method are the calculation of substance and energy flows (in and outputs), in principle over their entire lifecycle within a system, and their evaluation against environmental criteria. Life cycle assessment is therefore a quantitative method for the assessment of the environmental impacts of human activities. A first step involves the calculation of goods, substances and energy flows. The effects on the environment from emissions are then determined on the basis of selected indicators. An assessment of these environmental impacts can then be made by means of suitable methods.

Specific LCA studies generally use a combination of data for the impact assessment calculations. Depending on the specific research question, inventory data of a specific product or service are collected, measured or calculated. Additional data on the substance and energy flows are taken from background data, which have been systematically collected and stored in life cycle inventory data bases. Typical background data of this kind are, for example, energy mixes of a specific region or the origin of a particular crop from a climatic zone. In this study, background data from the Life Cycle Inventory data base ecoinvent (ecoinvent 2010) was used. More details on LCA and the specific use of LCA evaluation methods in this study can be found in the Annex C.

3.2 Approach

The study was conducted in close cooperation with individual employees of upc cablecom, who provided essential data from their day-to-day experience and work. The data was collected and analysed according to the top down and bottom up approach in line with the classification of Coroama and Hilty (2013). Following data sources were used for the inventory of this LCA study

- Sustainability reporting and in house data collection
- Expert interviews
- Literature research
- Energy consumption measurements of CPEs
- LCA inventory database (ecoinvent 2010)

The network of the provider was systematically assessed, starting at the consumer end and moving on through the hierarchical network to data centres and head-ends (see also Figure 3, page 18). Interviews with experts of specific sections of the network were held. Workshops and specific site visits were conducted in order to brief experts on the data requirements of this study as well as to conduct specific measurements. In particular, the power consumption of the customer premises equipment (CPE) was measured with instruments of, and at, the premises of the university. The resulting energy consumptions of the CPEs were then calculated according to calculation standards as well as individual configurations of the end-user equipment.

The top down approach used energy data collected by the network provider from the metering bills of electricity companies. The top down data collection was gathered by the mother company *Liberty Global* of upc cablecom and will be used for the annual environmental reporting of Liberty Global.

An additional literature review was also conducted. Specific data was used to compensate evident data gaps and to compare key values.

In the case of the base line period, the provided services and the data volumes were additionally assessed, which enabled a calculation of specific energy consumption per transferred Gigabyte. These normalised environmental impacts were then used to extrapolate future scenarios.

The scope of the study describes the most important methodological choices, assumptions and limitations as described below.

4 Goal and Scope Definition

4.1 Goal

The goal of this study „Energy efficiency of telecommunication networks" is to assess the overall environmental impacts of telecommunication networks. As telecommunication is rapidly changing the study aims to detect the main causes for environmental impacts, extrapolating possible future developments and identifying potentials for improvements. The study also compares the environmental burden resulting from telecommunication networks to other daily activities requiring energy, and calculates the energy consumption of such networks per transmitted data volume. The research team is fully conscious of the uncertainty which come along such broad studies. According to Coroama and Hilty, two factors mainly influence the outcome: the point in time of such a study - the more recent the study the more efficient networks become - as well as the system border or scope of the research; - mainly by the decision to include or exclude end-user devices (Coroama and Hilty 2014). More recent studies recommend excluding end user devices but including consumer premises equipment (Coroama et al. 2015; Schien et al. 2015). This study used most recent data and included CPEs whereas end-user equipment was excluded. Scope

The study on hand analyses the environmental impacts of the use, maintenance and physical infrastructure of the upc cablecom telecommunication network within the physical borders of Switzerland. The impacts stem from the physical infrastructure as well as the energy consumption of the equipment used. The focus is on the evaluation of the entire life span of a specific functional unit by means of a life cycle assessment (LCA).

Only standardised services provided to private end consumers (Business to Consumers, B2C) are included, excluding tailor-made services for individual business customers as well as service bundles for business customers (Business to Business, B2B). Services to private end consumers, which are delivered by partner networks of upc cablecom, have been included in the study, as these are contracted by upc cablecom. Regional telecommunication networks originate from the federal structure of Switzerland and its tradition of building and maintaining regional infrastructure, including data networks. Excluded from the study are centralised services, drawn from data centres or platforms of upc cablecom's corporate group Liberty Global headquarters in Amsterdam.

In order to assess the environmental impacts of a telecommunication network in Switzerland, the entire physical electronic structure was accounted for. This includes centralised infrastructures, (data centres and head-ends), infrastructure for data distribution (Point of Presence and cable infrastructure) and electronic equipment for signal transformation, decoding and storing of private end consumers (consumer premises equipment, CPE). The entire environmental burden from the extraction, production and use of materials such as metals, minerals, plastics etc. is distributed over the entire life span of an individual product. Therefore, the annual share of the environmental burden of equipment is calculated by the total environmental burden, divided by the life span of the specific equipment. Accordingly the annual energy consumption of each piece of electronic equipment used in the network was accounted for, collected or measured.

It is known that the environmental impact of end user equipment (e.g. notebooks, tablet computers, mobile phones, televisions etc.) is one of the most prominent when assessing the impact of an entire telecommunication network. Malmodin et al. have calculated that end user equipment consume roughly 40 % of the entire networks energy demand. The authors also admit that energy demand of end user equipment has a large range due to large uncertainties of how end user equipment is used (Malmodin et al. 2014a/b). Hischier and Wäger compared environmental impacts of manufacturing, use and end-of-life treatment of PCs, notebooks and tablet computers and showed for each individual equipment that the smaller and more mobile a device is, the less energy is consumed while being used (Roland Hischier and Wäger 2015). While the impact of the use phase is decreasing they showed that the relative impact of the production phase gains importance, particularly if an increasing amount of equipment is produced (Roland Hischier et al. 2015.

Due to the above mentioned reasons, end-user equipment (such as televisions, PCs, laptops, mobile phones, game consoles etc.) is excluded from this study. The decision to exclude such devices was not only made because of the large uncertainty of how many devices are actually used with upc cablecom network, but also due to specific and variable user profiles of such devices. This stems from the large number and its resulting energy demand of appliances which are connected to a network). The focus of this study lies more in the details of the current network, the inclusion of end user equipment would have overwritten all other results. In addition to this, such devices are generally owned by the private consumer and consequently cannot be influenced by the telecommunication service provider directly.

Also buildings, offices and construction services - together with their associated energy demand- are not included, as they cannot be directly related to the functional units under observation. An explicit provision of mobile telecommunication has also not been considered, as upc cablecom did not provided such services during the year of investigation. A fair part of mobile communication is nevertheless included, e.g. mobile communication over a private wireless network access point or telephone services such as Voice over IP (VoIP).

In the future the telecommunication networks might connect more and more end user devices directly to cloud based services and make consumer premises equipment (which are included in this study) superfluous. Then, the direct control of energy efficient end user devices should be also considered by network providers.

4.1.1 Data collection proceeding

In order to collect, structure and evaluate the physical infrastructure and energy consumption, upc cable-com' s telecommunication network has been sectioned into four parts, briefly described below and also shown in Figure 3.

1a./b. Main Head-end and Data Centres

A head-end station in a cable network distributes and regulates TV and radio channels, video and online signals as well as interactive distribution services into a connected distribution network. Head-ends re-ceive signals from satellite receiver stations, video servers, public telecommunication networks as well as local or city networks. These demodulate and code signals, which are then distributed as digital video broadcasts or as interactive distribution services into the distribution network (Lipinski 2013). The main head-end of upc cablecom is located in Zurich-Leimbach.

A data centre is a location where centralised data processing occurs. Such services are either owned by telecommunication operating companies themselves or computing power is rented from an external data centre (Lipinski 2013). upc cablecom operates two data centres, one in Otelfingen and another in Zurich (Zollstrasse). A list of the physical infrastructure of main head-end and data centres can be found in the Annex Table 20 and Table 21. In 2015 a new data centre as well as offices will be opened in Glattbrugg near Zurich, which will eventually house the main offices of upc cablecom in Switzerland and replace the data centre location of Zurich/Zollstrasse.

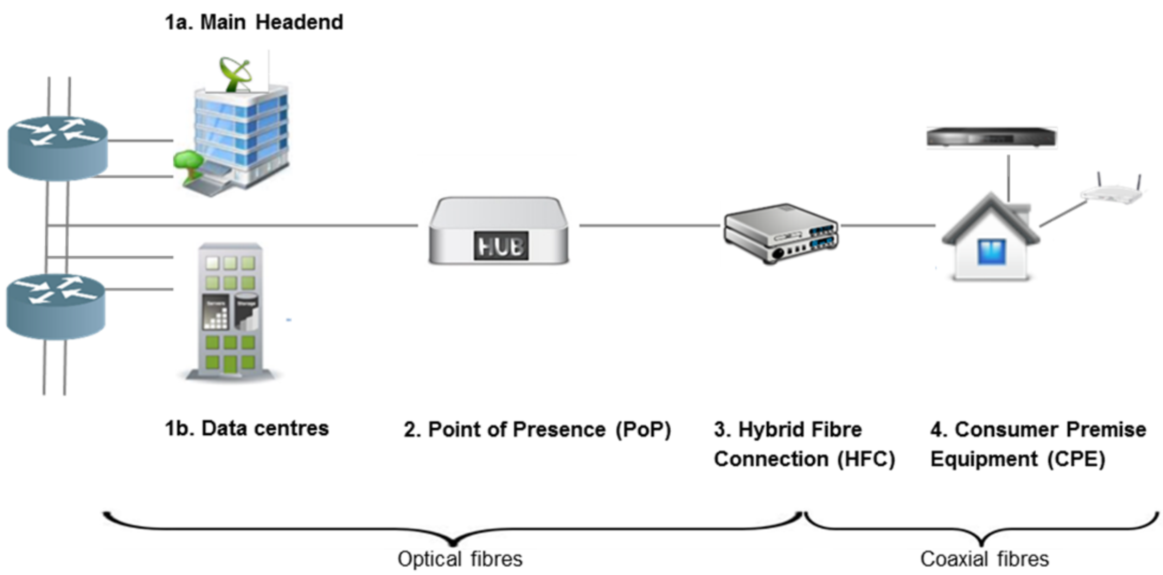


Figure 3 Four parts upc cablecom's telecommunication network

2. Point of Presence

Point of Presence (PoP) is a general description of a location where all signals (data and voice) from decentralised sources are drawn together and where modifications to the signals for a further transmission are executed. Depending on the transmission medium as well as the data transmission rates, the signals are modified and then passed on for both regional distribution or long distance transmission (Lipinski 2013). Such PoPs are owned and serviced by telecommunication operating companies. A cable telecommunication network distributes signals via TV broadcast signals or as individual, internet protocol (IP) based data transmission. According to the services provided (internet, telephone or television), PoPs can be distinguished into several categories. A PoP example for IP based traffic is a Cable Modem Termination System (CMTS). CMTS stations connect the provider signals delivered in DOCSIS standard (data over cable service interface specification) to IP-based traffic and finally to IP-routers (upstream). Vice versa, a CMTS station transforms the IP data packages and feeds it into the cable network as DOCSIS signals (downstream). A list of the physical infrastructure of PoPs can be found in the Annex Table 24.

3. Hybrid Fiber Coaxial

A Hybrid Fiber Coaxial (HFC) generally describes the transport medium which consist of a combination of optical fibers (glass fiber based) and coaxial cable (cooper or aluminium based) (Faulkner and Iarmer 1997). The study on hand includes in the HFC: nodes, network amplifiers as well as end consumer amplifiers into the HFC segment. A node can consist of a converter, which transforms optical signals into electronic signals (O/E converter with a photo cell), or vice versa (E/O converter, with a laser). The signals have to be amplified according to the transmission distance for both light signals via glass fiber cables as well as electronic signals via copper or aluminium cables. One of the main differences in optical data transmission is that the amplification of signals is much less frequently needed in comparison to coaxial cables. A house amplifier at the end consumer adjusts the transmission noise to the individual cabling of the household. A list of the physical infrastructure of HFC network can be found in the Annex Table 23.

4. Customer Premises Equipment

End consumers need customer premises equipment (CPE), which receives and supports the subscribed services. CPEs provide a specific interface for the input output equipment such as a telephone, personal computer, television set, handheld computer, mobile phone etc. (Lipinski 2013). CPE are differentiated in this study according to the type of services an end consumer receives; these are:

- Modems for internet and telephone services
- Complex Set-top boxes for television signals
- Multimedia gateways for internet, telephone and television services.

4.1.2 Technology employed

National authorities licence well defined frequencies to telecommunication providers generally for a limited time period. A telecommunication provider is free to use the frequencies for any type of service, provided that other radio services are not disturbed. Cable network providers from many areas of the world, including Europe, Australia, large parts of Asia, Africa and South America, adhere to the Phase Alternating Line (Norm Pal B/G) ("Phase Alternating Line" 2014). The Pal B/G is standardised and splits frequencies into transmit channels of 8 MHz and 265 QAM modulation. Each transmit channel has a data transmission rate of 50 Mbit/sec. Standard-definitions (SD) and high definition (HD) TV channels are distributed in a certain order over the entire bandwidth. By adjusting and rearranging the location of TV channels, the system provider optimizes bandwidth use according to local demand. Each quarter upc cablecom conducts a fine-tuning of the TV channel distribution. Approximately once a year, a larger redistribution is performed.

The cable network provider, upc cablecom, currently employs four different technologies simultaneously, three of which cover television demand.

1. IP based services: Data up- and downloads for internet and telephone services.
2. DTV broadcast television services: Broadcast signals up to the household socket with an entire range of regional or national televisions channels.
3. Analogue television services: Broadcast signals also available on the bandwidth of a certain frequency. One analogue channel occupies a transmission channel of 8 MHz bandwidth or 50Mbits/sec data volume, which is much higher than digitalised SD and HD signals[6] .
4. Video on Demand (VOD): VOD is a generic description of a linear video service. Depending on the transmission network, different technologies are employed. For cable networks a customer searches on the internet for a particular video, guided by the particular VOD programme on a CPE. The customer selects a video, an order is placed and a so called video pump provides a SD or HD version of the chosen video. The CPE is directed to a particular VOD frequency and receives details on how to decode the MPEG2/4 stream. Once these connections are set, the video pump receives the video per IP stream from a media server, modulates the signal into QAM signal (Quadrature Amplitude Modulation) and transmits it to the customer.

This mix of technologies is currently employed in many European countries but shows some specific regional differences. Some services might not be available in all regions or countries, or a specific technology is added (not mentioned above). The above mix describes the situation in Switzerland in 2012 and 2013; the technology mix is, however, evolving rapidly. The above mentioned redistribution of channels offers

[6] SD channels have a transmission rate between 3-5 Mbit/sec whereas HD channels demand 12-13 Mbit/sec . Hence, about ten SD channels and four HD channels can be transmitted over one transmit channel of 51.3 Mbps bitrate.

optimization strategies in day to day business. IP based signal distribution -between two well defined points in a network- is eventually expected to replace the existing broadcast signal distribution.

4.2 SYSTEM BOUNDARIES

4.2.1 Temporal boundaries

The analysis focuses on the situation in the years 2012 and 2013. All data used reflects current state-of-the-art technology. For scenarios representing future technologies, corresponding assumptions are given.

4.2.2 Geographic system boundaries

The network infrastructure studied is limited to Switzerland. For background and pre-chain processes (such as the production of printed wiring boards), global boundaries have been used, production processes being spread throughout the world. Where ecoinvent processes were used, the geographic system boundaries are defined according to the natural resource supply chosen (ecoinvent 2007; ecoinvent 2010).

4.2.3 Normalisation Factors

A large variety of consumption patterns as well as technical equipment are combined in this LCA study. Both the consumption patterns and the equipment are currently undergoing considerable transformation. Thus it is not always easy to distinguish cause from effect. As this study also investigates how future telecommunication networks might be designed, it is not only essential to consider technical equipment (and its life cycle) but also the actual volumes of transferred data. The inventory data was used to calculate the energy consumption per date volume transmitted -expressed in kWh/GB. Such a normalized key value allows the comparison of data transmission with other activities or products and is increasingly used in scientific literature.

4.2.4 Technical boundaries

Almost the entire operation of a cable network is powered by electricity, its production and distribution being one of the main contributors of environmental impacts caused by telecommunication. But as electricity production varies largely between countries and regions, the choice of a suitable electricity mix (e.g. for a specific country) is crucial to determine the potential environmental impacts. In this study it is assumed that any additional demand of electricity will be satisfied by the so-called marginal electricity mix.

The marginal electricity mix depicts the type of electricity provided to satisfy an additional demand of electricity and accordingly the power plants, which would be shut down in the case of a reduction in electricity demand. As Switzerland trades electricity with Europe, the European electricity mix UCTE is used as an approximation to the marginal electricity mix within this study. The Union for the Co-ordination of Transmission of Electricity (UCTE) was responsible for the coordination of the European electricity network. Members included all European countries except Ireland, Great Britain, the Nordic and Baltic states. Since 2009 all duties formerly fulfilled by the UCTE have been taken over by the superior organisation ENTSO-E (European Network of Transmission System Operators for Electricity), which encompasses all

European countries. As an approximation to the marginal electricity mix, UCTE is more appropriate than ENTSO-E as it better approximates theoretical marginal electricity use.

As sensitivity the influence of the different electricity mixes was calculated and the corresponding results can be found in annex C.I.

4.2.5 Functional Unit

The functional unit is the base upon which environmental impacts can be compared. It corresponds to the mathematical expression of the function of products or services enabling a comparison of two or more products or services by linking all environmental impacts to the same functional unit. The functional unit used for this LCA is:

The use of telecommunication services of a cable network provider by a typical household during one year.

As mentioned above the LCA results were also used to calculate the energy consumption per transferred data volume. The life cycle inventory already provided the energy consumption during one year; the life cycle assessment results produced key indicators, one of which is the CO_2 emission for the functional unit. In addition to these research results, it was also necessary to collect and calculate the transferred data volumes during the reference years and extrapolate the future development of trends by consulting expert knowledge.

The total amount of customers provided with telecommunication services was kept constant. This is an artificial assumption, as competition for market shares and customer subscription is not static. But in order to compare future scenarios to the base line, it is helpful to keep the total number of subscribers constant. An exception was made for the base line end of 2012 and end of 2013, where the actual subscriber numbers of the corresponding years were used.

The energy consumption for the individual scenarios was calculated by standardised proceeding and is summarised as follows:

1. Power consumption measurements or product specification data depending on the mode of activity. These can be -and are- specified according to the equipment type:
    a. On (operational or on&active): measured power consumption.
    b. Hot-standby: slightly reduced power consumption.
    c. Lukewarm: reduced power consumption.
    d. Cold standby: strongly reduced power consumption.
    e. Auto Power Down (APD): automatic standby (as specified in each case).
    f. Off: the equipment does not consume any power or is unplugged.
2. Definition of the usage period of the above mentioned individual modes within a year.
3. Stock of individual appliances employed during the year.

4.2.6 Choice of LCA valuation method

Preliminary calculations showed that the system investigated is strongly influenced by electricity demand. To determine the most suitable valuation method for the system in question, several methods taking into account energy consumption were evaluated. Aside from the midpoint indicator global warming potential in CO_2 equivalents, the following single score indicators were assessed:

- ReCiPe 2008
- Eco-Indicator 99
- Ecological Scarcity 2006.

All of the mentioned methods showed comparable results and it was decided to choose one main method to present the LCA calculation results. Because of its wide acceptance in Europe and throughout the world, the ReCiPe 2008 method was selected as main method, although it only partially incorporates the environmental impacts of nuclear power generation (See Figure 21 and Figure 22 in the annex). Due to the chosen electricity mix (see chapter 4.3.4, page 22) these effects are not very pronounced and still allow reliable result calculations. ReCiPe strongly emphasizes the effects of CO_2-emission; the produced results are hence often similar to those of the midpoint method global warming potential according to IPCC 2007. As a sensitivity assessment the other possible perspectives to aggregate the midpoint indicators within the ReCiPe-Method were also evaluated but showed similar results compared to the recommended and used perspective "Hierachist/Average, Europe". Eco-Indicator 99 was superseded by ReCiPe in 2008 and was subsequently only used for sensitivity analyses.

The ecological scarcity 2006 method better describes the environmental effects of nuclear power generation, namely the effects of radioactive waste repositories. Since the method only has limited recognition outside of Switzerland it was chosen as a supplementary method. When conducting sensitivity analyses and comparing evaluation results, it is nevertheless strongly recommended to include the ecological scarcity 2006 method, as electricity from nuclear power plants still contributes to the European electricity mix. To allow a comparison the results of the three different evaluation methods are shown in the Annex Figure 28 and Figure 29 on page 99. If not stated otherwise the main results will be shown with either the ReCiPe 2008 or the global warming potential according to IPCC 2007.

4.3 LIMITATION OF THE STUDY

The study has included Business-to-Consumer (B2C) connections of the upc cablecom Telecommunication Network. No data has been made accessible to which extend Business Customers (B2B connections) also use the network. Thus the environmental burden from B2B customers on the network might be included in the presented results and could be smaller if an allocation key would be applied.

The study does not allow to compare other transmission technologies directly (such as public switched telephone networks (PSTN) or pure digital subscriber lines (xDSL)), as the investigated network combines broadcast technology and IP based services, thus represents an own transmission technology.

4.3.1 Long term emissions

The calculation of long-term emissions for the chosen methods was disabled, the main reason being the considerable uncertainty of general toxicity calculations, particularly over long periods. Additionally, the main toxic effects within the systems investigated stem from heavy metal emissions into various environmental compartments. These emissions not only have large uncertainties for the toxic effect mechanisms but also for the actual amounts emitted into the corresponding system.

4.4 Baseline & Scenarios

4.4.1 Overview of scenarios

An overview of the base line and scenarios 1-3 can be found on Table 2. As a summary of the most important assumption the following list is provided:

- Base line 2012: actual data provided by upc cablecom
- Base line 2013: actual data provided by upc cablecom
- S1: Environmentally improved consumer base as 2013, most energy efficient CPEs
- S2: Moderate growth consumer base as 2013, CPEs compliant with EU regulation
- S3: Growth scenario consumer base extrapolated, TEC values of CPEs as of 2013
- S4: Data scenario extrapolation of transmitted data volumes and energy demand until 2016, scenario 4 has not been included in the LCA

Table 2 Overview of basline and scenarios

No		1	2	3	4	
Network part		Data Centres and Main Headend	Points of Presence (PoP)	Hybrid Fiber Connection (HFC)	CPE	GWh/a
Baseline 2012	# units	1'843	10'081	290'317	1'220'750	
	GWh/a	9'194	19'203	55'832	148'994	233'224
Baseline 2013	# units	1'843	10'081	290'317	1'239'198	
	GWh/a	8'618	20'739	59'159	184'554	273'070
Scenario 1: Environmentally improved	# units	1'843	10'081	290'317	1'239'198	
	GWh/a	8'618	20'739	59'159	139'309	227'825
Scenario 2: Moderate growth	# units	1'843	10'081	290'317	1'239'198	
	GWh/a	8'618	20'739	59'159	112'690	201'206
Scenario 3: Growth scenario	# units	1'843	10'081	290'317	1'342'000	
	GWh/a	8'618	20'739	59'159	209'369	297'885

Table 2 gives an overview of the data used in the baseline 2012 and 2013 as well as the scenarios. It becomes obvious that only the CPE data have been modelled in the scenarios but not the network infrastructure data. Only for the two baseline, sufficient network infrastructure data have been made available to calculate the annual change of network infrastructure equipment as well as energy demand.

In the following, the base line and different scenarios are described. Details of the scenarios can be found in Inventory Analysis in 5.1 (*Network infrastructure*) and 5.4 (C*onsumer premises equipment*) where the details of data used are explained. Details of the used inventory used in the scenario can be found, in the Annex B.I.i (*network infrastructure*) and B.I.ii (*Consumer premises equipment*). Annex B.II *Consumer premises equipment* sectioned into physical units (section B.II.i) and typical energy consumption of each CPE category (section B.II.iito B.II.v).

4.4.2 Base line

The base line describes the state of the telecommunication network and the corresponding particular consumer mix in 2012 and 2013 (measured at the end of each year). The consumer mix consists of end-users subscribing to three services (television, internet **and** phone), two services (internet **and** phone) or only one service (television **or** internet **or** phone). It became apparent that service subscriptions of only internet or only phone are almost non-existent.

At the end of 2012 upc cablecom introduced the first multi-media gateway to its customers. The Samsung SMT-G7400 comprises an internet modem with WiFi router, six television tuners, a VoIP telephone unit as well as a hard disc drive, Samsung being the original equipment manufacturer, Intel the chipset provider and NDS the software provider. Hence it is one of the first CPEs to include all services (television, internet and phone) on offer from upc cablecom.

Table 3 summarises the base line data according to parts of the cable network shown in Figure 3 and as explained in detail in the following chapter. The introduction of a multimedia gateway triggered a change in the ratio of employed CPEs and subscribed services. Some of these changes which occurred between 2012 and 2013 are illustrated in Table 5 (page 34) (number of employed CPEs) and Table 6 (page 34) (number of subscribed services). For details please also consult Table 31 and Table 32 in the Annex which show details of the CPE stocks and energy consumption. For more details which CPEs were used to deliver a specific service see Table 33 in the Annex B.II on page 76.

It is evident that the environmental impact increases as more services are provided and used. This is especially the case if we assume that a customer is only subscribing to TV services at upc cablecom but receiving internet and phone services from other provides and networks. It is however of interest to compare the relative share of environmental impacts caused by one, two or all services, and to evaluate the potentials for improvements.

Table 3 Summary of base line data according to parts of the Cable network, energy consumption and phyical units end of 2012 and 2013

No	Part of the cable network	2012 [units]	2012 power consumption [kWh]	2013 [units]	2013 power consumption [kWh]
1	**Data centres and headend**				
	Data centres		7'929'226		7'256'553
	Headend		1'265'044		1'361'067
	Units	1'843		1'843	
2	**Points of Presence (PoP)**				
	Units	10'081	19'203'146	10'081	20'739'398
3	**Hybrid Fiber Connection (HFC)**				
	Units	290'317	55'832'216	290'317	59'159'456
	Cable (km length)	46'821		46'821	
4	**Consumer Premises Equipment**				
	Units	1'221'283	149'165'000	1'239'198	184'554'000
	Digicard	196'194		201'179	
	Subscribed service	2'464'400		2'538'700	
Sum			**233'394'632**		**273'070'474**

A differentiation of the usage of specific services and the according energy consumption was therefore made. According to the distribution of CPEs and the subscription to services, the impacts of the following three types of users were evaluated:

- Telephone and internet
- Only television services with a CSTB
- All services (telephone, internet and television)

Other combinations are also possible but have not been considered in the LCA evaluation. In order to evaluate the environmental burden, the relative impacts (impacts/service & households) as well as the total impacts at the end of 2013 (impacts/service) have been calculated. For more details which CPEs were used to deliver a specific service see Table 33 in the Annex B.II on page 76.

There are large numbers of customers who receive television services without a particular CPE or subscription with the Cable Network Provider. This is due to the fact that modern televisions are able to decode digital signals directly without a CSTB. Additionally upc cablecom decided to lift the coding of several basic TV programs in 2012, which allows customers to watch TV programs without a particular CPE. Finally, the option to buy a Common Interface Card (CI+)[7] increases the amount of TV channels, which can be directly received without an additional, externally powered CPE. The above categories only refer to customers who have an externally powered CPE and a TV service subscription.

[7] A CI+ card has to be purchased once by the end user and plugged into as specific CI+ slot. The device decodes a controlled number of channels which can be consumed without additional energy demand of financial obligations.

4.4.3 Scenario 1: environmentally improved base line

The scenario 1 "environmentally improved base line" assumes an optimal and minimized use of CPE equipment in order to

a. provide services to the same amount of household and customers as in the year 2012 and
b. minimise the environmental impact.

The main optimisation is the adjustment of roughly 40% of households being equipped with more than one CPE as well as the reduction of numbers of CPEs. It was assumed that all end-users have the most energy efficient phone and data modem available at the end of 2013, allowing data transfer of up to 150 Mbit per second. Additionally all TV users are equipped with either a digital video receiver, a digital TV recorder or with a multi-media gateway, depending on which services they subscribe to. All three types of equipment are currently the most energy efficient in their class. Environmentally improved base line (scenario 1) describes the actual state of the network with DOCSIS 3.0 standard. For details of how the energy consumption of modems was calculated see B.II.iii, for complex settop boxes B.II.iv and for multimedia gateways on B.II.v on page 78 and following.

4.4.4 Scenario 2: Moderate growth scenario

The moderate growth scenario applies a growth scenario until the end of year 2015. To calculate the saturation level of multi-media gateways in 2015, it was assumed that the current decreasing demand for data modems will be counterbalanced by an increased employment of multi-media gateways. Even though the demand for television services as well as the subscription of television services with a set-top box decreased slightly between 2012 and 2013, an increasing number of customers subscribed to television services with a multi-media gateway. Hence, the onus has shifted from television customers with set-top boxes to those who either do without television subscriptions or others who would like to have all services delivered by one CPE. This is certainly a result of successful marketing but also reflects an increasing demand for "all in one" solutions. The moderate growth scenario also assumes that the multimedia gateway complies with the tighter standby levels which are required by the EU legislation at the beginning of 2015.

4.4.5 Scenario 3: Growth scenario

The growth scenario extrapolated the business forecast of uPC marketing experts at the end of 2013 until 2015. This scenario assumed consequently an increase of the customer base and therefore cannot directly be compared with the other scenarios. Only the relative values of impact per household are comparable.

The growth scenario assumes that the multimedia gateway consumes the same amount of energy as at the end of 2013. The energy consumption values were kept at the measured values and were not adjusted to values which have to be complied with under EU regulation.

4.4.6 Scenario 4: Data scenario

Additionally to the data collection for the LCA, a data scenario has been designed. Experts agree that in the future the IP traffic will dominate the transmission no matter whether you telephone, what a video or surf on the internet. It is assumed that data transmission intensive services -such as non-linear TV consumption, cloud services etc. - will increase considerably. Such a forecast seems reasonable, as recent data would seem to verify this. Countries with less developed telecommunication infrastructures show annual data transmission growth rates above 50% per annum.

One of the key indicators of current literature is the ratio of transmitted data volumes per kWh (or per CO_2 emission). S4 Data scenario suggests a calculation method for the transmitted data volumes of a broadcast telecommunication network and collects data of transmitted data volumes of an IP based service. These data, -together with the energy consumption of the base line years - were extrapolated until 2016.

For S4: Data scenario a data driven approach different to the base line and the first two scenarios was chosen to evaluate the energy intensity per transferred data volumes as describes earlier. According to Coroama and Hilty 2013, a top down calculation was applied -using the overall energy consumption-, as well as a model-based approach -in order to calculate actual data transmission volumes.

This scenario is, of course, hypothetical as many factors can only be anticipated, not measured or calculated. Among these factors are: the lack of technical equipment, unknown regulative measures e.g. for minimal broadcast services, consumer behaviour and technological innovation.

A specific analysis how much of transmitted data volume of each service (telephone, internet and television) demands with part of the physical infrastructure as well as and analysis of which kind and duration of service was demanded by customers, was not possible to conduct under the current study.

5 Inventory Analysis

As outlined in chapter 4 the system analysed consists of the following main parts:

1. a.)Datacenter and b.) Main Head-end
2. Points of presence (PoP)
3. Hybrid fibre coaxial net (HFC)
4. Consumer Premises Equipment (CPEs), or end-user equipment

In the following paragraphs the sourcing of the inventory of data of hardware and energy consumption is explained. Most of the tables and figures in the following chapters adhere to the above categorisation and display the results within that context.

5.1 NETWORK INFRASTRUCTURE

5.1.1 Physical units of Network Infrastructure

upc Cablecom internal data lists have been used to calculate the network infrastructure of the Hybrid Fiber Connection (HFC) and Point of Presence (PoP) as well as the data centre in Otelfingen.

Physical inventory data are only available for the main data centre in Otelfingen. Other data centres or so called main headend are located in Zurich/Leimbach and Zurich/Center (Zollstrasse, a main headend which is due to be closed down). In order to estimate the physical infrastructure, literature data and the physical infrastructure of the main data centre have been used. A study conducted by the German Umweltbundesamt (Hintermann, Fichter, and Stobbe 2010), evaluated the physical infrastructure of data centres, categorising three types of data centres (big, medium, small) according to the number of employed servers, their size and the transmitting power of the installed ICT equipment. Additionally, data centres are categorised into server, storage and network data centres.

According to the typology of the above mentioned study, the datacentre Otelfingen is a medium sized data centre, despite being the biggest of the UPC telecommunication network in Switzerland. Accordingly, the data centre in Zurich/Zollstrasse and the main headend are categorised as small data centres. The average total numbers of servers of small data centres were taken from the study and used as a proxy for Zurich/Zollstrasse. In order to set the proportional share of the individual equipment employed (server type etc.), the distribution of the data centre Otelfingen was used and scaled down for Zurich/Zollstrasse and the main headend.

Several of the employed components within the network infrastructure of upc cablecom were modelled separately. Namely the following processes for the selected devices were created:

- *Server computers for data centres* consisting of:
    - Tower format

    - Rack format
    - Blade format (including enclosures)
- *Infrastructure for data transfer* consisting of:
    - Copper cables
    - Optical fibre cables
    - CMTS small (0.7 nominal power)
    - CMTS large (2.5 kWh nominal power)
    - Network amplifiers
    - Network routers

As upc cablecom offices will move to new premises in Glattbrugg in the year 2014, the entire offices and data centre in Zurich/Zollstrasse will be closed. Due to the move of data centre whilst in full operation, Glattbrugg appears in Table 4 as an energy consuming factor only in 2013.

The HFC comprises all coaxial cables and glass fiber connections in Switzerland, necessary for the upc cablecom telecommunication network. Nodes are connection points in the field, where cables are drawn together and data distribution occurs. In order to provide a consistent picture of the existing data lists, nodes have been described generically, in terms of amplifying and transmitting & receiving equipment. Nodes are included in the HFC category for both physical infrastructure as well as energy consumption.

To calculate the overall impact of the different components employed, ecoinvent background processes were utilised and modified and/or adapted accordingly to suit the current project. Other background processes such as transport from factories to Switzerland were estimated from other projects and own experience. For more detail see Annex B.I.i Inventory data collection of network infrastructure.

5.1.2 Energy consumption of Network Infrastructure

In 2012 Liberty Global announced, that it would be included in both the Dow Jones Sustainability World Index and North America Indexes Index. Since then all national dependencies of Liberty Global are requested to collect continuous energy consumption data as well as monitor overtime development. This includes upc cablecom as the Swiss daughter company of Liberty Global. With a tool called "Credit360", upc cablecom has collected comprehensive, annual data on its energy consumption and management.

The "Credit360" data is collected mainly by the evaluation of consumption data of electricity meters, which include all network equipment as well as the energy consumption of offices, lighting etc. The individual sectors of the network, offices, heating cooling ventilation etc. are then allocated according to technical specifications and the knowledge of individual experts. An internal audit checks the plausibility of the collected energy consumption data. Electricity consumption data for the data centres and main headends were mostly taken from the "Credit360" data of the year 2012, which were made available for this study.

Additional data on the energy consumption of the HFC and PoPs was calculated by the power consumption of individual appliances and the assumption of an all year round activity of such network components. The most relevant energy demand in these network sectors is created by in-house amplifiers and amplifiers in the nodes (HFC). In order to also include the losses of the HFC and PoPs equipment, the following assumption were made:

- 10% energy losses of the reactive power
- 92% effective power rate of the power supply units
- 1-2% replacement /annually of all amplifiers employed in the network

As upc cablecom has not invested in any particular energy efficiency measures for data centres, we have assumed a PUE of 2.0 in accordance with the client. The provided data from upc cablecom's data centres comprised the energy consumption of all equipment used including cooling, ventilation, uninterrupted power supply or lighting systems. The PoPs were the only network element which required a corrected energy consumption calculation with the above mentioned PUE factor (see Annex Table 22 and Table 24). The resulting energy consumptions in 2012 of relevant sectors of the telecommunication network, including the PoP calculations, are shown in Table 4.

The energy demands for the other elements of the telecommunication network have been calculated in a similar manner as those of the CPEs. The power demand of appliances multiplied with the average running times during one year results in the energy demand for PoPs, HFC network and main headend.

Table 4 lists the energy consumption in 2012 and 2013 of the relevant sectors of the telecommunication network, main headend and data centres. Because of the wide employment of in-house and network amplifiers these network components contribute 63% of the electricity consumption of network infrastructure, data centres and main headend. This is also the case for PoPs, as they have also been classified as amplifying and receiving /transmitting units. For more detail see Annex B.I.ii Energy consumption of network infrastructure.

Table 4 Electricity consumption of network infrastructure and Data centers/ Main headend of the year 2012 & 2013

Components	[kWh/a] in 2012	[kWh/a] in 2013
In-house amplifier	25'592'822	25'592'822
Network amplifier	30'239'394	33'566'634
Point of Presence (PoP)	19'203'146	20'739'398
Main headend	1'265'044	1'361'067
Data centre Zurich - Zollstrasse	1'264'486	994'353
Data centre Otelfingen	6'664'740	6'262'200
Data centre Glattbrugg	-	231'220
Total	**84'229'634**	**88'747'693**

5.2 Consumer premises Equipment (CPEs)

To assess the environmental impacts from manufacturing the consumer premises equipment, the provided data from upc cablecom as well as technical specifications for the different modems, receivers, recorders and multimedia gateway were used.

For the specific scenario calculations the specific end-user equipment was modelled according to the technical data provided, including plastic and metal amount, PWB weight and additional components such as hard disk drives or power supply units.

Other background processes such as transport from the factory to Switzerland were estimated from other projects and own experience.

5.2.1 Physical units of CPEs

Consumer premises Equipment (CPEs) of the upc cablecom network can be differentiated into three categories:

1. Cable television modems (CATV)
   Cable television modems (CATV) allow the internet to be accessed via broadband cable connection. CATV modems support DOCSIS 3.0 configurations; some of them also contain a WIFI unit (such as Technicolor TC7200 and Thomson TWG870). At the end of 2013 only one CATV model - based on DOCSIS 2.0 configuration- is still in use (Scientific Atlanta EPC2203). This modem has, however, been taken off the market and is soon to be entirely phased out.
2. Complex Set-top boxes (CSTB):
   In order to display digital television signals on a television, a digital analog converter is needed. Set-top boxes are such converters. Apart from decoding, Set-top boxes often have a return channel which allows a bidirectional communication, which is necessary for services such as Video on Demand. A return channel is the necessary condition for a STB to be called a Complex set-top box (CSTB). In the table below such CPE are called "CSTB receiver". CSTB which also contain a hard disc and are able to store data are named "CSTB recorder".
3. Mulitmedia gateways
   Multimedia Gateways are a combination of a Cable modem and a CSTB. Multimedia Gateways also require a return channel for bidirectional communication.

An overview of all employed CPEs in 2012 and 2013 in Switzerland can be found in Table 5 and shows an overall annual increase of 4%. Due to the introduction of multimedia gateways in 2013, it is not surprising that this category contributed most to the CPE increase. In contrast, Complex Set-top Boxes (CSTB) recorders decreased by 28% (~98'000 units), which might be due to the replacement of such CPEs by multimedia gateways. The stock of data modems has decreased by 5% (~30‘000 units). CSTB receivers increased slightly (3% or by ~7'000 units) and account -together with the CSTB recorders -for the larger proportion in comparison to multimedia gateways.

Thomson TWG870 and Scientific Atlanta EPC2203 constituted the largest proportion of the category modems. Cisco 8685 and Pace DCR7111 are the most frequently employed CSTB receivers and recorders (see Annex Table 32 for more details).

Table 5 Number of Customer Premises Equipment (CPE) employed at the end of 2012 and 2013. The category Complex Set-top Boxes (CSTB) was differentiated into CSTB receivers and recorders (see also Annex Table 32)

CPE Customer Premises Equipment (CPE)	2012	2013
Modem	626'423	596'614
CSTB receiver	346'067	247'824
CSTB recorder	248'260	255'419
Multimedia gateway	533	139'341
Total	**1'221'283**	**1'239'198**

Table 6 shows the number of subscriptions per service at the end of 2012 and 2013, officially published upc Cablecom. A slight decrease in service television but increase in internet and telephone service subscription can be seen.

Table 6 Number of subscribed services (source: upc cablecom official website)

	Subscriber amount in 2012	Subscriber amount in 2013
Television	1'448'500	1'416'400
Internet	594'500	663'800
Phone	421'400	458'500
Total	**2'464'400**	**2'538'700**

Customers can be clustered into: single-, double - or triple play users. Single-play households only subscribe to one service: internet, telephone or television. Double-play users consequently subscribe to two services, consisting of three possible combinations: internet & telephone, internet & television or telephone & television. Lastly, a triple-play subscribes to internet, telephone and television services. Therefore the numbers of subscribed services do not reveal the number of households because customers may subscribe to several services in a package. Thus some CPEs and customers are counted twice or three times in Table 6 (e.g. the 1'416'400 television customers in 2013 represent the entire sum of households with any one of the service combination television subscriptions mentioned above).

Numbers of CPEs (Table 5) and subscribed services (Table 6) were used to create the link between subscribed services and the employment of a particular CPE category. upc cablecom experts distributed the employed CPE to all customers' subscriptions.

Due to the large number of CPE combinations it became necessary to scale down the combination. As changes in the distribution of television services are of particular interest, it was decided to differentiate between three categories of households each of which receive the services:

- telephone and internet ,
- only television services with a CSTB,
- all services (telephone, internet and television) .

Table 7 Allocation of households according to quantity of CPEs (reference year 2013)

Services provided in 2013				# Households
Telephone, internet		**29.3%**	**250'252**	
	Only Modem	29.3%		250'252
Television		**22.0%**	**187'763**	
	one CSTB	20.5%		175'481
	more than one CSTB	1.4%		12'283
Telephone, internet, television		**48.8%**	**416'751**	
	one Multimedia Gateway	11.3%		96'338
	any CPE combination	37.5%		320'414
	Total	**100.0%**	**854'766**	

Table 7 shows household numbers according to the subscribed service as well as its total share of UPC customers. For both -internet and telephone- only a data modem is necessary. Therefore the amount of households with either an internet subscription, telephone subscription or both equals the numbers of "Households equipped with …only modem", for the respective years. The other categories were formed by compiling households which only have a CSTB and hence only subscribe to television services from upc cablecom. All other CPE combinations were assumed to be "triple play users". Modem and CSTB combinations certainly subscribe to two, if not three, services. With the introduction of the Multimedia Gateway, it becomes difficult to decide whether a household equipped with such a CPE is using one, two, or three services. But as the multimedia gateway is designed to process three services, it was assumed that during the year of introduction, all multimedia gateways were used to receive all three services.

Accordingly, the consumer mix in 2013 can be described as displayed in Table 7 (for details please also consult Table 32 and Table 33 in the Annex). The usage of multiple CPEs for one service has only been counted once.

Together with the total subscriber numbers for television services per year (Table 6), it was possible to calculate the number of customer base households consuming television services without CPE. By subtracting the *all TV households* in Table 7 from the amount of subscribed *television service* Table 6, the household numbers consuming television services without a set-top box or a multimedia gateway can be calculated; these were approximately 800'000 households in 2013.

Both figures, the serviced households and the number of employed CPEs, play a decisive role in this study. The number of customers measured in households, as well as the employed CPEs for telecommunication services, which are specifically installed for the subscribed services; make up the major parameters which are varied in the scenarios.

5.2.2 Energy consumption CPEs

a. Typical Electricity Consumption (TEC)

The Typical Electricity Consumption (TEC) is an established calculation method which enables the estimation of the energy consumption of energy relevant products within a year. It is used extensively for the labelling of electrical and electronic equipment, the typical A-G label uses a traffic colouring system (see section B.I.ii in the Annex). For each type of equipment, a typical user profile is determined, which describes the time that it runs in a certain mode, over a specified period (details of the choices made in this study can be found in the Annex in section B.III) Together with the power consumption in each mode, the energy consumption can be calculated. The main value of such TEC numbers is that they can be compared easily and give end-users a feeling which appliances use more than others.

Specific power consumption measurements for CPEs have been carried out in this study in cooperation with the Institute of Automation at the School of Engineering, University of Applied Sciences and Arts Northwestern Switzerland. TEC values have been calculated by taking the measured values of the experiments and the active and standby times suggested by the Voluntary Industry Agreement (Industry Group 2011).

Hence, TEC values combine objective data (power consumption) and subjective data (average usage time in a certain mode). It is therefore crucial to agree to a common set of data in order make TEC values comparable and an approximation to the reality at the same time. In this study we used the average usage time as prescribed by the legislative framework. See Table 34 for the duty cycles used in this study and Table 35 which shows the corresponding duty cycle defined in the Voluntary Agreement(Industry Group 2011). If such numbers are missing we have approached the average retention in a certain mode from other data sources e.g. such as the statistical office (see Table 34 and Table 37 in the Annex).

5.3 TRANSMITTED DATA VOLUMES

Additionally to the data collection for the LCA study, data of transmitted volumes have been collected as in current literature the ratio of transmitted data volumes per kWh or per CO_2 equivalent are two commonly agreed indicators.

In order to archive such data transmission rates, new technical equipment is required. Also new standards have to be implemented which means a substantial shift to IP based services, as well as the employment of a new DOCSIS standard for cable transmission (DOCSIS 3.1).

Data volumes in a cable network occur by the application of different transmitting technologies consisting of a large variety of data modulation and data compilation techniques and formats. In this study inter protocol (IP) based services and broadcast TV services were taken into account. The research team has made the following assumption in accordance with the experts from upc cablecom and in full awareness that the forecasts bare large uncertainties, because technologies, consumer behaviour and other factors are changing very rapidly.

Table 8 TV channel per transmission channel and transmission rates

	TV channels per transmission channels [#]	Data transmission rates [Mbit /sec*#channels]
51.3 Mbit/sec in a 8 MHz/256 QAM transmission channel		
Standard Definition (SD)	10.0	5.1
High Definition (HD)	4.0	12.8
Analog channel	1.0	51.3

For television broadcast services, theoretical data transmission rate for the three qualities of televisions channels standard definition (SD) high definition (HD) and analog channels were calculated. Assuming a data transmission rate of 51.3 Mbit/sec for 8 MHz broadband frequency with a 256-QAM modulation, the data transmission rate per SD, HD or analog channel can be calculated. With a transmission rate of 3-5 Mbit/sec more than ten SD channels can be transmitted over one transmit channel. Additional multiplexing can further lower a transmission rate per channel. It was estimated that four HD television channels occupy approximately one transmit channel, or roughly 12-13 Mbit/sec for each HD channel. These transmission rates and number of channels might differ from other regions but are currently the most plausible in central Europe. Table 8 summaries the transmission rates and TV channel capacity per transmission channel.

Additionally the average television consumption per day in Switzerland (average mean over different language regions, see also Table 37 in the Annex) was used to calculate the data transmission rate per serviced household or all households serviced by upc cablecom. To do this, shares of television consumption in SD, HD and analog quality were anticipated as shown in Table 9. It can be seen for example that in 2016 no analog services will be broadcasted any more. The changes of the proportion of SD and HD television channels as well as total television consumption per day have been forecasted by upc cablecom experts.

Table 9 Average televsion use in minutes per day

Average TV consumption		Comments	2012	2013	2014	2015	2016
Sum in CH in minutes/person	2	% reduction per year	150	147	144	141	138
Standard Definition (SD)	20	% reduction per year	50	39	31	24	19
High Definition (HD)			80	93	103	112	119
Analog		Phase out in 2016	20	15	10	5	-

For IP data transmission volumes, monthly measurements of the Liberty Global Group were taken into account. These volumes account for all IP based traffic (DOCSIS, up- and download) both residential and business, nevertheless the former being much larger than the later. The measured data volumes do not include local data traffic, which is managed from regional or national data centres, such as Video on Demand, or transmitted data volumes from service providers such as Google or Swisscom.

6 Results

6.1 Life Cycle Assessment Impact Assessment

The following chapters present the major findings of the life cycle assessment. The life cycle of the majority of the infrastructure can be divided into the parts:

- Manufacturing and end-of-life treatment
- Use stage

The production and use phases of telecommunication equipment are most relevant, while the disposal stage exercises a minimal influence on the whole life cycle. The results are presented first in tables with the relevant numbers of hardware for each scenario. This is then followed by the LCA results. Several LCA evaluation methods have been applied from which two have been chosen: ReCiPe 2008 or the global warming potential according to IPCC 2007.

6.1.1 Manufacturing

Expenses per device:

In Figure 4 the manufacturing expenses calculated with ReCiPe for the multimedia gateway SMT-G7400 are shown. It is evident that the major impacts derive from the printing wiring board (PWB) within the multimedia gateway. Other CPE types as well as other IT components of the network show similar results which leads to the conclusion that the amount of PWB used is a sensitive parameter within the system.

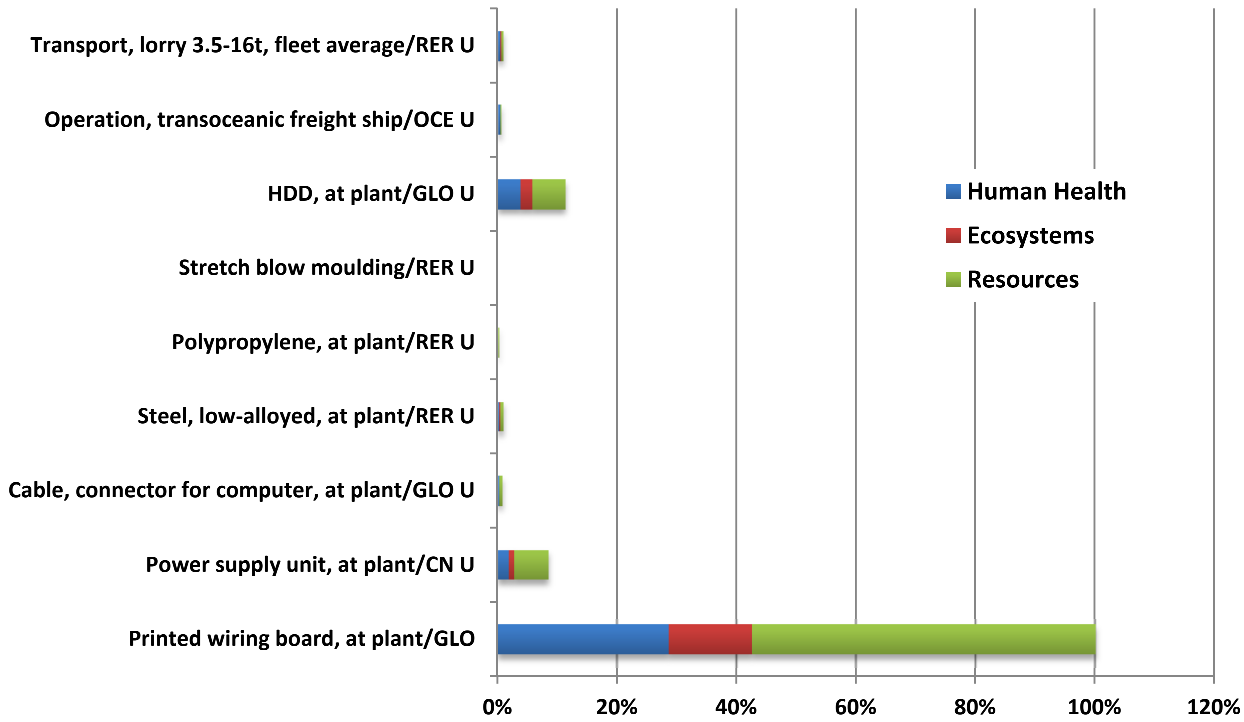


Figure 4 Environmental impacts according to ReCiPe 2008 for the manufacturing stage of SMT-G7400.

The complete network system concerning the manufacturing process based on the year 2012 is displayed in Figure 5. The sheer amount of end-user devices, which clearly dominates the results, makes the impacts of datacentre and head-end disappear in comparison.

The figure includes all expenses of all CPEs for the investigated manufacturing phase. These numbers are not yet adjusted for their expected useful lifetime or durability as this would introduce a new variable within the comparison. The so mean time between failure (MTBF) was taken into account accordingly for the complete life cycle calculations.

Detailed information on most of the components analysed in this study can be found in the Annex in section" B Inventory data collection " and on Table 20 and Table 21 starting on 71.

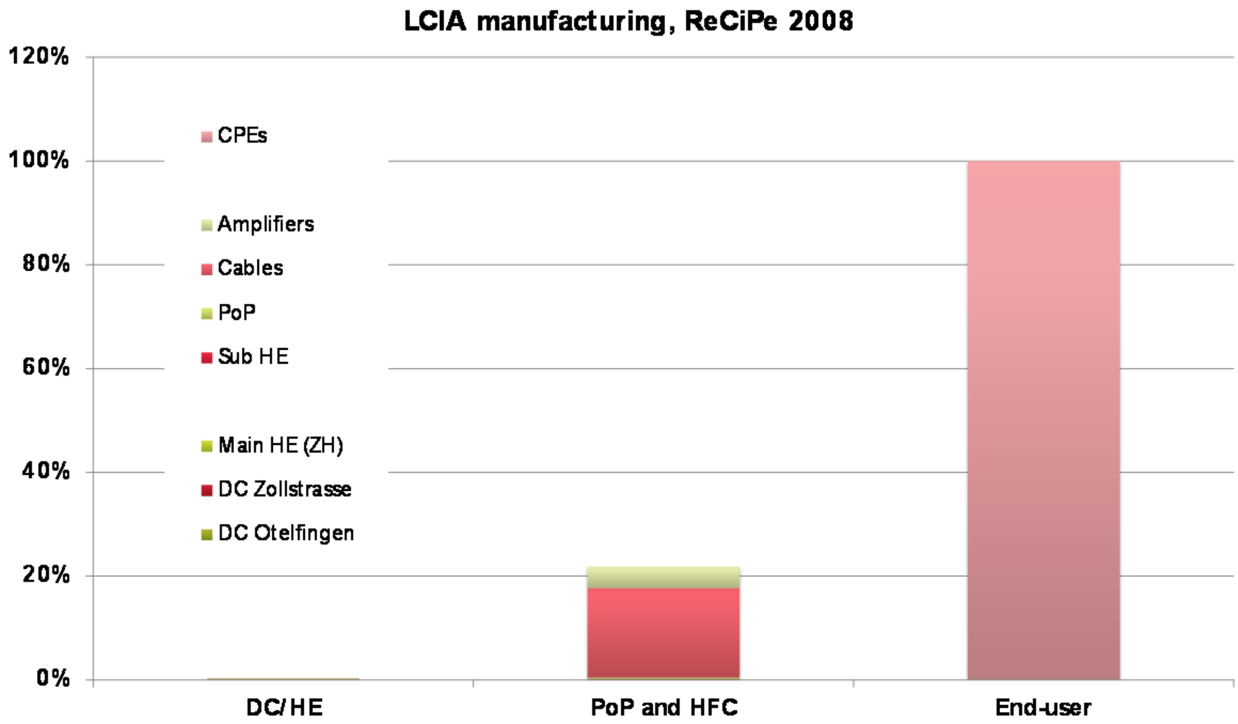


Figure 5 Life cycle impact assessment according to ReCiPe 2008, manufacturing phase, complete telecom network

6.1.2 Use phase

The use phase exclusively needs electricity to power all devices. As shown in Figure 6 the CPEs dominate the results again. However, network infrastructure and datacentres show larger impacts compared to the manufacturing stage.

While the CPEs have energy saving mechanisms implemented and activated, most of the network infrastructure runs at more or less the same power level 24 hours a day. Although the end-user equipment has a much smaller energy demand per device, the sheer number of devices still leads to the result observed in the figure above. The figure presented also shows that the electricity demand gradually increases as one follows the network from datacentre to the end-user equipment. This implies that the larger energy demand per device for the datacentre or PoPs is overcompensated by the number of devices further downstream in the network infrastructure.

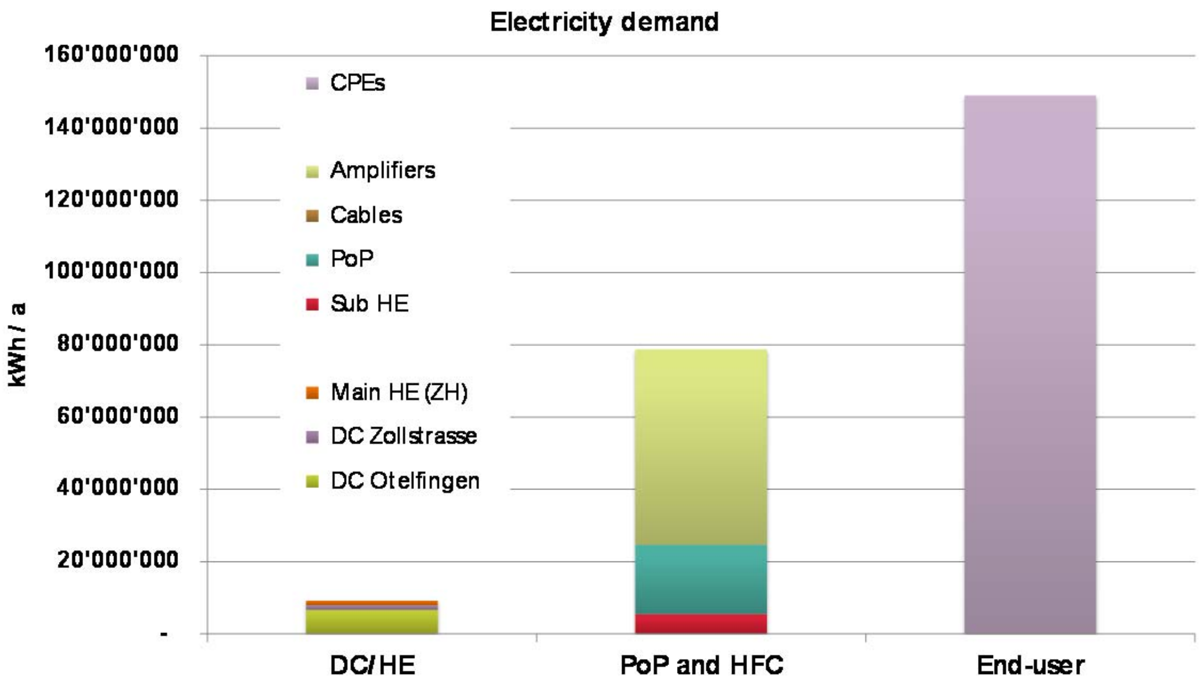


Figure 6 Electricity demand telecom network upc cablecom

6.2 BASE LINE: ENVIRONMENTAL IMPACTS OF UPC CABLECOM TELECOM NETWORKS

The results of the previous two chapters are now combined in the next four chapters to show the complete life cycle for the different components within the telecom network. Life expectancy or mean time between failure (MTBF) are accordingly taken into account to reflect the impacts for one year only.

All figures shown here are supplemented with everyday activities to put the numbers displayed into perspective.

6.2.1 Base line 2012

The following section represents the LCA calculation results according to the scenario described in chapter 4.4.2 on page 26. It mainly describes the state of the telecommunication network and the corresponding particular consumer mix at the end of 2012 (measured at the end of the year).

The consumer mix of CPEs and its energy consumption in 2012 is displayed in Table 10. Towards the end of 2012, upc cablecom started the subscription multimedia gateway SMT-G7400. In the beginning it was mainly distributed for testing purposes[8]. By the end of 2013 almost 140'000 multimedia gateways were employed (see Table 11). Please note that in order to compare two base line years, one without and one with multimedia gateways, 533 gateways as well as their corresponding typical energy consumption of 171'000 kWh were not considered in base line 2012. Multimedia Gateway numbers in Table 10 deviate therefore from Table 5 above and Table 32 and Table 33 in the Annex.

Table 10 Base line 2012: Typical Electricity Consumption (TEC) values, total amount of CPEs and energy consumption per year.

Base line 2012	Number CPE 2012	Sum (kWh/a)
Modem	626'423	47'259'000
Recorder (DVR)	346'067	51'990'000
Receiver (RCV)	248'260	49'745'000
Multimedia Gateway	-	-
Total	**1'220'750**	**148'994'000**

In Figure 7 the shares of electricity consumption of the different sectors of upc cablecom network are displayed. Data centres & main head-ends (DC & HE) as well as Point of Presence and Hybrid Fiber Connections, including amplifiers (PoP &

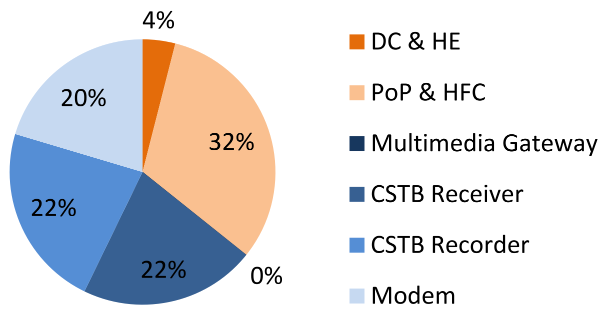


Figure 7 Base line 2013: shares of electricity consumption of the different sectors and CPE categories, multimedia gateway not present in 2012

[8] According to the marketing department, 533 multimedia gateways were delivered by the end of December 2012.

HFC) are shown in orange, the different types of CPEs in blue. The pie chart has been designed identically for each scenario and depicts the relative amount of electricity consumption of the different sectors. To illustrate the impacts of using and operating the upc cablecom network the following figures (Figure 8 to Figure 10) provides a comparison of some common activities requiring energy consumption. The Figures show representative travel activities for average capacity loadings (single occupation of car transport and fully booked airplane) compared to the LCA results. Train transport refers to an average regional train within Switzerland.

For the base line of 2012 not only the main valuation method ReCiPe is shown but also the ecological scarcity method. The choice of the presentation is to allow comparisons to be drawn. Additionally, the midpoint indicator *global warming potential* is presented as carbon dioxide emissions are commonly accepted as indicators for global warming.

Figure 8 clearly shows that effects of the data centres and headend are almost negligible compared to the network infrastructure and end-user equipment. It is also evident that consumer premises equipment dominates the complete life cycle calculation and has approximately twice the environmental impact compared to the PoP and HFC.

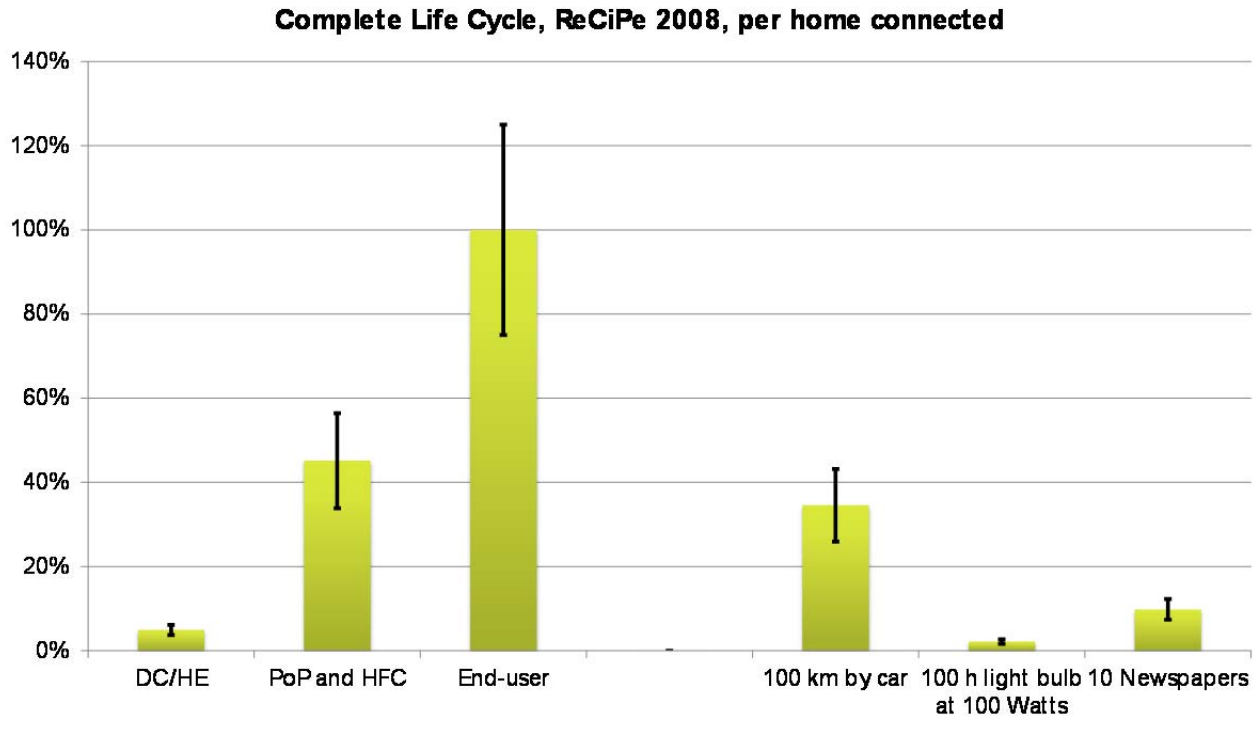


Figure 8 Life cycle impact assessment according to ReCiPe 2008, complete telecom network

The ecological scarcity method 2006, displayed Figure 9 shows quite similar results, although the method takes a completely different approach to calculate the potential environmental impacts. As stated before, the subsequent calculation results of the other scenarios are only presented for the main method ReCiPe

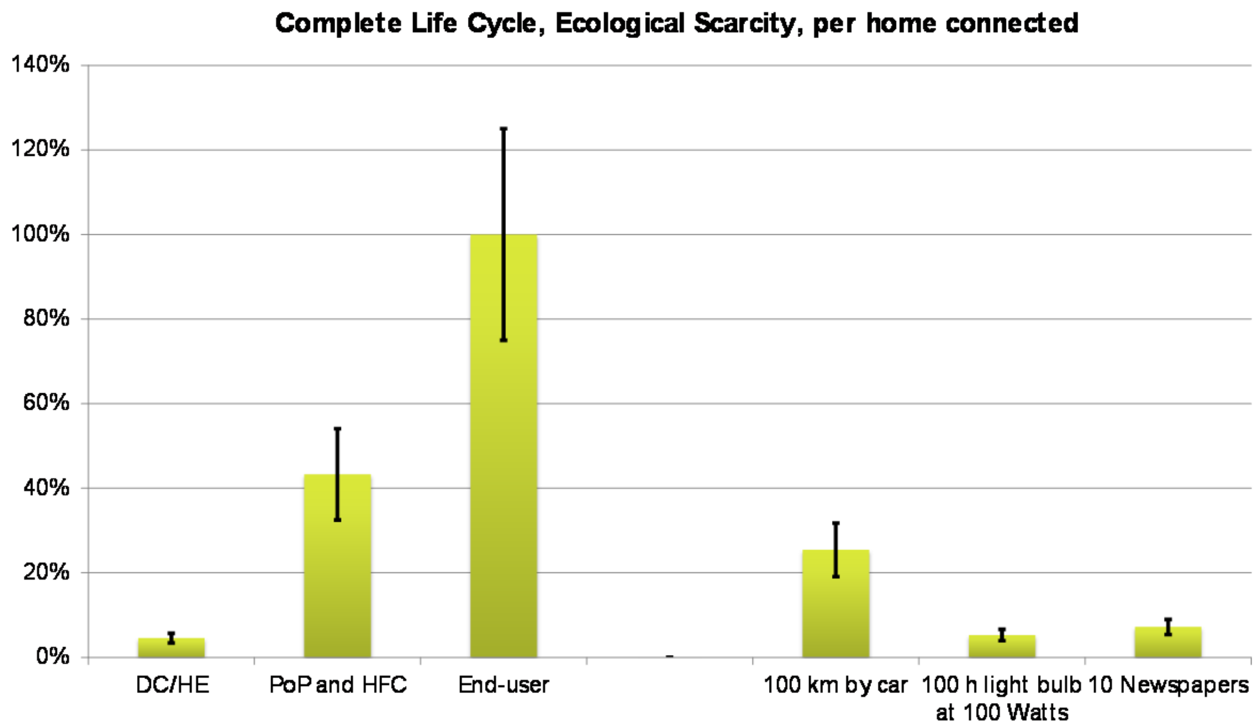


Figure 9 Life cycle impact assessment according to Ecological Scarcity, complete telecom network

The results calculated for the midpoint indicator global warming potential (Figure 10) again exhibit analogous numbers and underline the already shown results with the two single score methods. All presented charts clearly demonstrate the importance of end-user equipment and its use. About half of the determined impacts derive from the PoP and HFC network, while the results are only marginally influenced by the data centre and headend infrastructure. Depending on which method is selected, the entire impact of the energy consumed per home connected equals roughly 400-600 km by car.

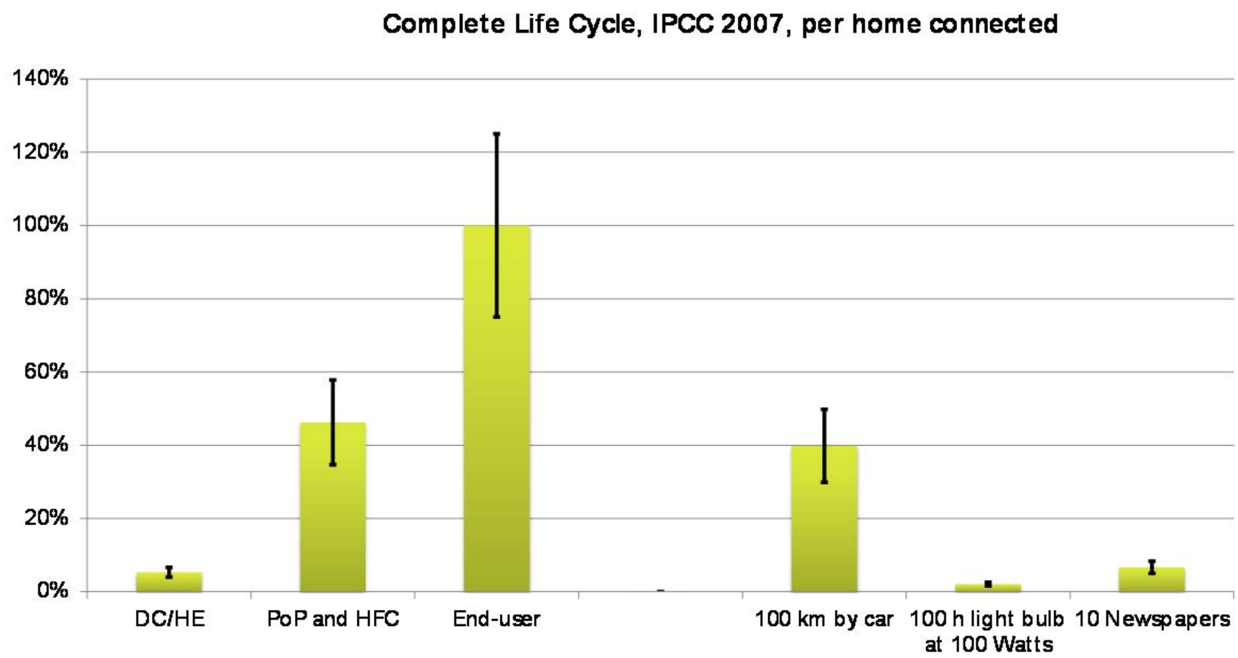


Figure 10 Life cycle impact assessment according to IPCC 2007, complete telecom network

6.2.2 Base line 2013

The following section shows the LCA calculation results according to the scenario described in chapter 4.4.2 on page 26. It focuses on the state of the telecommunication network and the corresponding particular consumer mix at the end of 2013 (measured at the end of the year).

The change of the consumer mix between year 2012 and 2013 can be seen by comparing Table 10 and Table 11 (for details please consult Table 32 and Table 33 in the Annex.

Table 11 Base line 2013: Typical Electricity Consumption (TEC) values, total amount of CPEs and energy consumption per year.

Base line 2013	Number CPE 2013	Sum (kWh/a)
Modem	596'614	46'603'000
Recorder (DVR)	247'824	37'651'000
Receiver (RCV)	255'419	55'652'000
Multimedia Gateway (hot standby)	139'341	44'648'000
Total	**1'239'198**	**184'554'000**

Table 11 and Figure 11 illustrate that the introduction of the multimedia gateway SMT-G7400 (1-1-60) altered the total and relative distribution of the energy consumption. 19 % of the overall electricity demand can be traced back to the use of multimedia gateway.

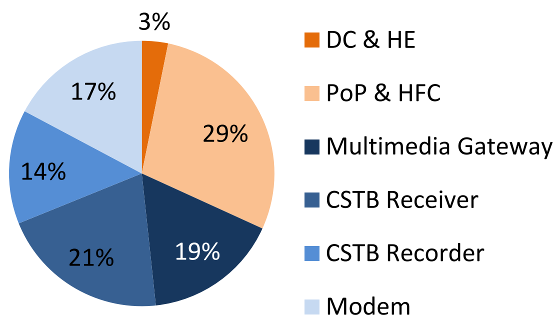


Figure 11 Base line 2013: shares of electricity consumption of the different sectors and CPE categories

The results presented in Table 12 make it clear that they don't differ significantly from the ones for the base line 2012. However, it can be seen from the representation that the use phase and its electricity consumption is larger than the corresponding manufacturing phase. This holds true for the CPEs and even more so for the infrastructure and data centres.

The next three chapters present the findings for the three chosen scenarios with adapted background data for the modelling of the upc cablecom network.

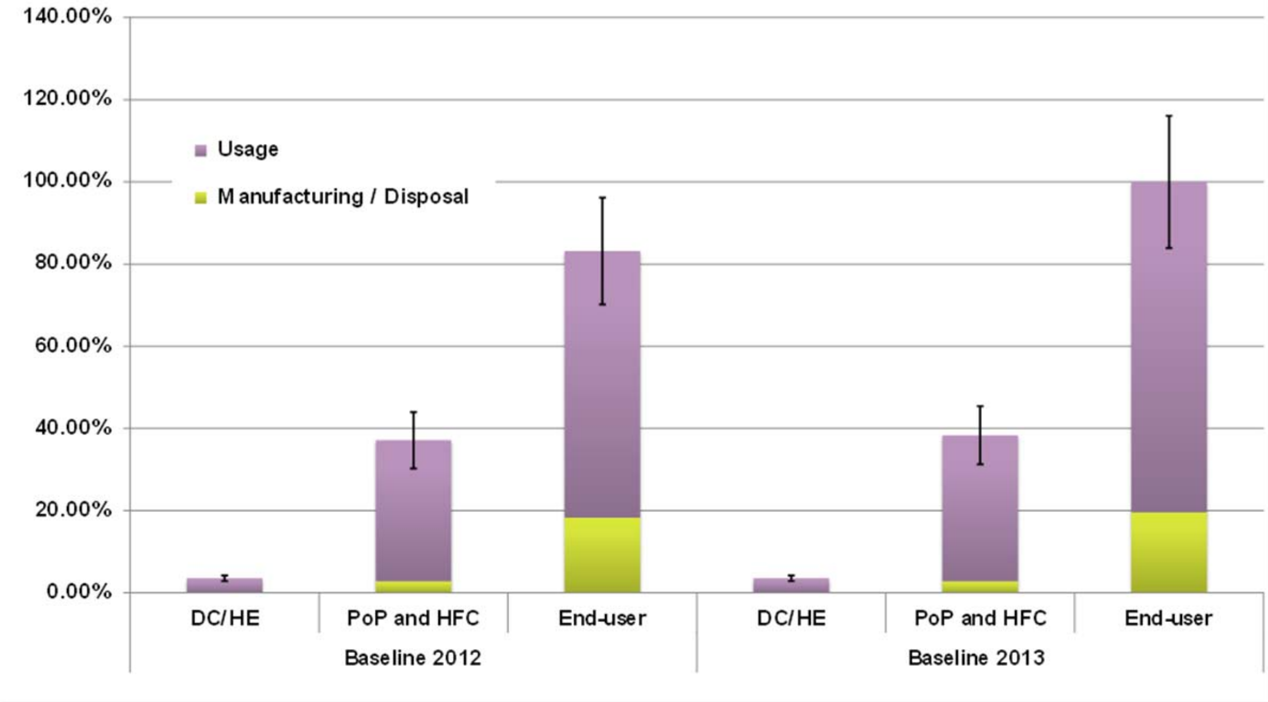


Figure 12 Life cycle impact assessment according to ReCiPe 2008, complete telecom network, base line 2012 and 2013

6.3 SCENARIO 1: ENVIRONMENTALLY IMPROVED BASE LINE

The following section represents the LCA calculation results according to the scenario 1 described in chapter 4.4.3 on page 28. The main optimisation is the adjustment of roughly 40% of households equipped with more than one CPE as well as the reduction of the numbers of CPEs.

Calculating the energy demand of scenario 1 we assumed that the most energy efficient CPEs are distributed across the customers (see Table 12). The TEC values are calculated as in the base line taking the normative prescriptions of the Voluntary Agreement and the Code of Conducts as guidance (4.5h hours on and 19.5 hours standby) into account. The total amount of CPEs was kept constant in order to compare base line against the scenario 1.

Table 12 Typical Electricity Consumption (TEC) values, total amount of CPEs and energy consumption per year for scenario 1: Environmentally improved base line

Scenario 1 Environmentally improved base line, 2013			
	TEC (kWh/a)	Number CPE in 2013	Sum (kWh/a)
Motorola SVB6120E	58	596'614	34'604'000
Pace DCR7111 (Receiver)	84	255'419	21'455'000
Cisco 8685 (Recorder)	156	247'824	38'661'000
Multimedia Gateway	320	139'341	44'589'000
Total		**1'239'198**	**139'309'000**

Comparing the base line 2013 with scenario 1, about 45 million kWh or 17% of electricity could be saved by employing the most efficient CPEs throughout Switzerland. Figure 13 illustrates that a larger share is now consumed by the datacentres, headend, PoPs and HFC.

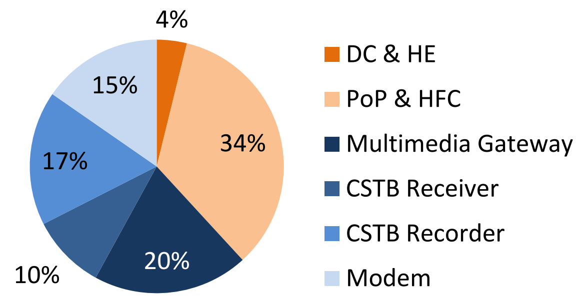


Figure 13 Scenario 1: shares of electricity consumption of the different sectors and CPE categories: environmentally improved base line

For the CSTB as well as the Multimedia Gateway a further optimization would be possible as all three CPEs allow a cold standby mode. In addition to this, the Multimedia Gateway offers a "lukewarm standby" with intermediate power consumption. Assuming that the boxes are operational only 4.5 hours a day, whilst being sent to the lowest power consumption mode (in the case of the free boxes: the cold standby) during 19.4 hours, a reduction of energy consumption of 43% compared to that of scenario 1, or 47 % compared to the base line 2013 would be possible. However, with the current settings of the CPEs, such daily profiles are unrealistic as no telephone calls or updates can be received in the cold standby mode. Particularly for Multimedia Gateways with an integrated telephone modem, cold standby during 19.5 hours is not an option, as additional appliances need to be installed for telephone services. It is also unrealistic to switch off CSTB immediately after use, even though this would not interfere with other services.

For the LCA calculations the above values in Table 12 were used. Compared with the results from base line 2012 and 2013 the differences observed are not very pronounced and hardly detectable in Table 12 above.

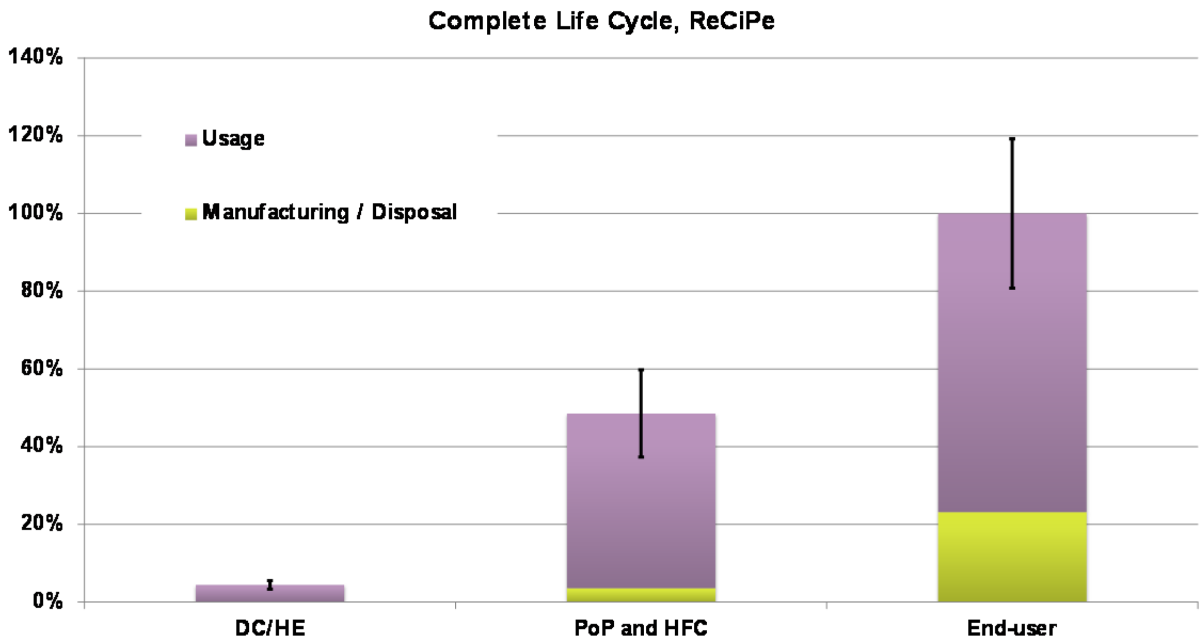


Figure 14 Life cycle impact assessment according to ReCiPe 2008, complete telecom network, improved base line

6.4 SCENARIO 2: MODERATE GROWTH SCENARIO

The following part represents the LCA calculation results according to the scenario 2 described in chapter 4.4.4, page 28. For scenario 2 the total amount of CPEs was again kept constant. This means that only a qualitative growth does occur with a shift towards more consumers being equipped with a multimedia gateway. Comparing scenario 1 with scenario 2 it becomes obvious that all number s of CPEs decrease, except for multimedia gateways, which increase in the same proportion. For all three CPE types -modem, CSTB recorder and CSTB receiver- a 5 % decrease per year of employed units was assumed. For multimedia gateways an annual increase of 10% was assumed. The "Number of CPE in 2015"was then scaled up to the same total amount as in 2013 as shown in Table 12.

Slight adjustments have been made in the TEC values of modems and CSTB receivers. The former due to the phase out of the most efficient model, the latter due to the advanced energy savings modes which can be activated for the CSTB. For more details of the CPE selection and TEC calculation see Table 27, Table 28 and Table 29.

Furthermore it is also assumed that multi-media gateways will become more efficient and will comply with the maximal power consumption target for HiNA products set in the EU regulation (EU, No 801/2013

2013) (see Table 1 on page 12). The TEC values have been adjusted to the values, which are obligatory as required by tier 3 (Voluntary Agreement) which will come into effect on 01.01.2015. This mainly affects the so-called networked standby mode.

Table 13 Scenario 2: Typical Electricity Consumption (TEC) values, total amount of CPEs and energy consumption per year for scenario 2: Moderate growth scenario

Scenario 2	TEC (kWh/a)	Number CPE in 2015	Sum (kWh/a)
Modem	61	576'446	35'163'000
CSTB Receiver	84	246'135	20'675'000
CSTB Recorder	124	237'611	29'464'000
Multimedia Gateway	153	179'007	27'388'000
Total		**1'239'198**	**112'690'000**

Comparing the base line 2013 and scenario 2, almost 72 million kWh or 27% of electricity could be saved by employing the most efficient CPEs throughout Switzerland. Figure 15 illustrates that even a larger share than in scenario 1 is now consumed by the network and (datacentres, PoP and HFC).

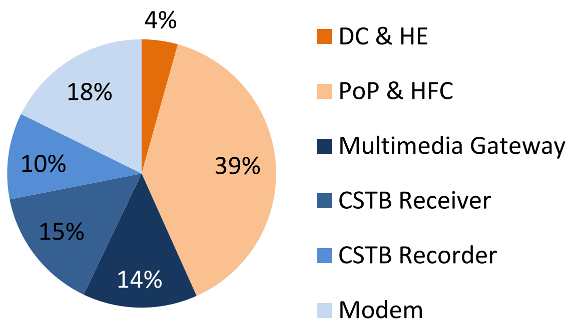


Figure 15 Scenario 2: shares of electricity consumption of the different sectors and CPE categories: moderate qualitiative growth scenario

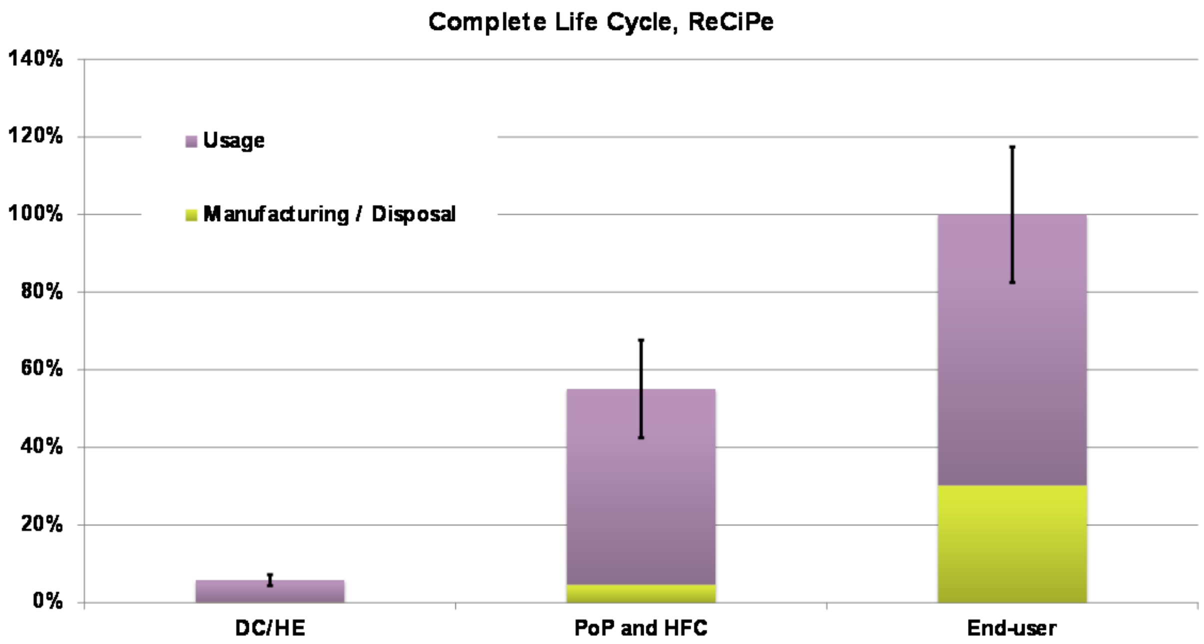


Figure 16 Life cycle impact assessment according to ReCiPe 2008, complete telecom network, moderate growth scenario2 (customer base as of 2013 and improvements with standby values compliant to legal requirement).

6.5 Scenario 3: Growth scenario

The following part represents the LCA calculation results according to the scenario 3 described in chapter 0, page 29. For scenario 3 the forecast of upc marketing experts and the growth rates in the years 2012 & 2013 were extrapolated until 2015. This means that a qualitative and a quantitative growth do occur with an increase of employed CPEs. The total number of CPEs is therefore higher than in the previous scenarios or in the baseline 2013.

For each category of CPEs the number increase, the number of multimedia gateway nevertheless grows the strongest. The TEC value of the multimedia gateway was keep at the level of 2013. With other words, this scenario describes the worst situation with the gateway being not compliant to EU regulation and no upgrade of the operating system with an improved energy management. The other TEC values were kept as in scenario 2. For more details of the CPE selection and TEC calculation see Table 27, Table 28 and Table 29.

Table 14 Scenario 3: Growth scenario

Scenario 3	TEC (kWh/a)	Number CPE in 2015	Sum (kWh/a)
Modem (Technicolor TC7200)	61	541'000	33'001'000
CSTB Receiver	84	127'000	10'668'000
CSTB Recorder	124	255'000	31'620'000
Multimedia Gateway (hot standby)	320	419'000	134'080'000
Sum		**1'342'000**	**209'369'000**

Comparing the base line 2013 and scenario 3, still 45 million kWh or 17% of electricity could be saved by employing CPEs throughout Switzerland, which comply with energy efficiency rules valid as of January 2015. While the total amount of multimedia gateway in service more the double (increase by 135% compared to scenario 2), the share of the energy consumption by multimedia gateways doubles to 28% of the overall electricity demand compared to scenario 2.

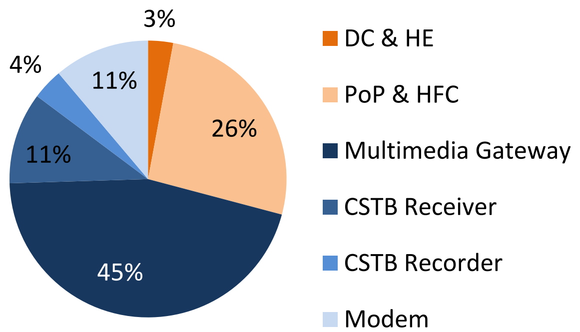


Figure 17 Scenario 3: shares of electrcity consumption of the different sectors and CPE categories: Growth scenario

For multimedia gateways an annual increase of 10% was assumed, whereas for the other services (and CPEs) the most modern and efficient equipment available in 2013 was employed for all subscriptions. Between the end of 2012 and 2013, the allocated employment of data modems decreased by 5 %, whereas set-top box recorders decreased by 28%. Only a slight increase in the amount of employed DTV receivers was noted (3%). As a consequence the total number of CPEs in service increases in scenario 2b by 8% or

102'802 units. The entire energy consumption in 2015 is consequently higher compared with the other scenarios and can be compared only in relative values.

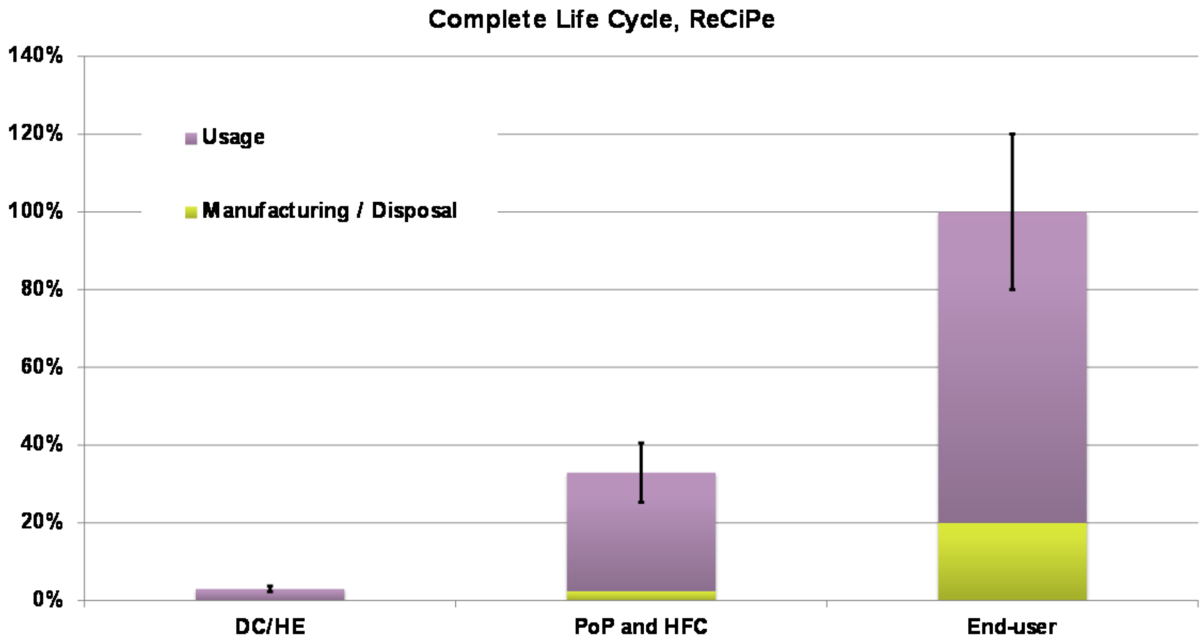


Figure 18 Life cycle impact assessment according to ReCiPe 2008, complete telecom network, growth scenario3 (increase in customer base and 2013 standby values)

In Figure 18 it can be seen from above that modified distribution of CPEs and energy demand leads to slightly different results than in the scenarios before. The effects of the end-user equipment are now even more distinct and the PoP and HFC influence has decreased even more.

6.6 Comparison of environmental impacts of the LCA

A comparison of the presented scenarios with the two baselines is shown in Figure 19 and Table 15. In Figure 19, each bar encompasses the complete life cycle respectively and consequently includes the production, use and disposal phase for each part and component of the upc cablecom network. The results are shown as relative values in contrast to Scenario 2: Moderate Growth, which was set as 100%.

It can be seen that the manufacturing and disposal processes remain almost unchanged along the different calculations, while the use phase differs between the models. The higher energy demand for the base line 2013 compared to base line 2012 clearly leads to a larger impact as shown in Figure 19. An equivalent effect is seen when comparing the two scenarios: base line 2013 and Moderate Growth. The scenario: *Environmentally improved base line 2013* demonstrates that a similar level of environmental impact as that seen in base line 2012 can be achieved when applying the mentioned measures (most energy efficient CPEs for all customers).

Although the differences between the scenarios in Figure 19 are visible, the results all lie within the margin of error and therefore are not significant, implying that all calculated outcomes have similar environmental impacts.

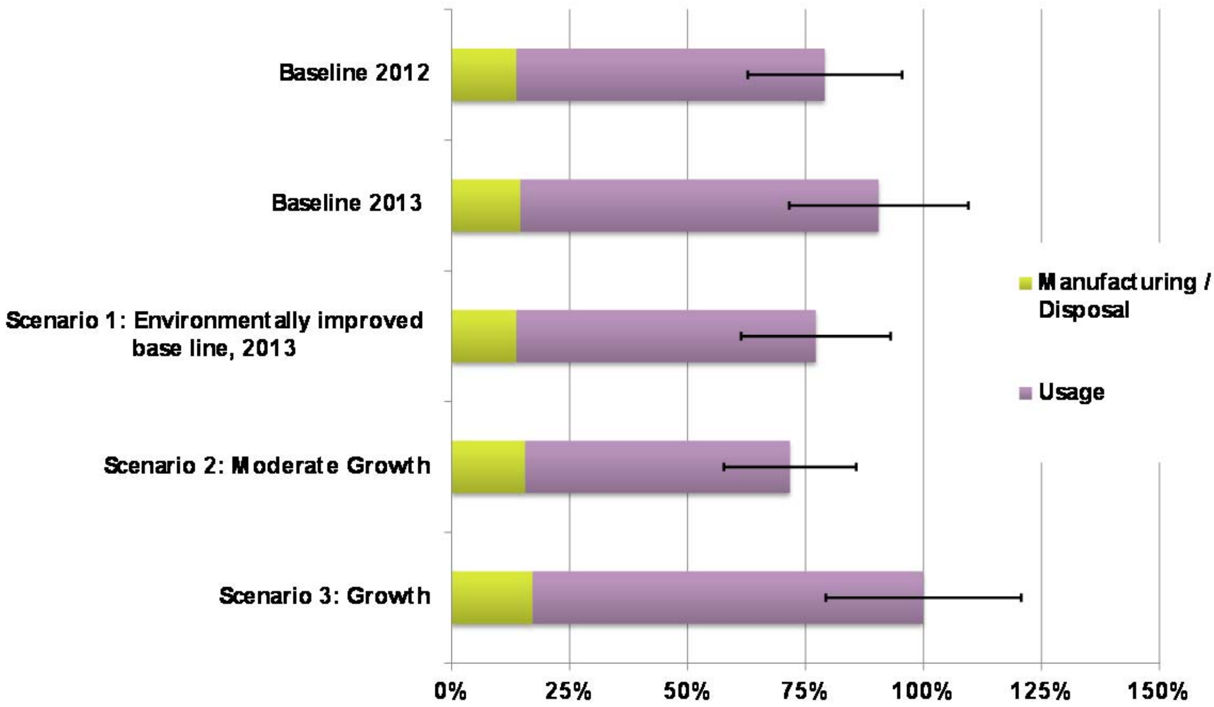


Figure 19 Comparison of the life cycle impact assessment according to ReCiPe 2008, base line and all scenarios

Table 15 shows the total number of employed CPEs, the connected households and the total energy consumption of each scenario. The exact number of connected households was only made available for the baseline 2013. The values of the other scenarios are derived from the ratio of households per employed CPE, assuming that the ration household/CPE stays constant. Therefore the last column of Table 15, "Energy consumption per house-hold [kWh/a*HH]", has to be handled with the limitation in mind, that the used household numbers are only derived numbers and might vary in the future considerably. This might be particularly influenced by the introduction of cloud based services and an increasing number of directly connected end-user equipment which do not need a CPE.

Table 15 Comparison of Total energy consumption and energy consumption per connected household and year[9]

	Number CPEs	Connected households	Total energy consumption [GWh/a]	Energy consumption per household [kWh/a*HH]
Baseline 2012	1'220'750	842'041	148'994	174
Baseline 2013	1'239'198	854'766	184'554	216
S1: Environmental improvement		854'766	139'309	163
S2: Moderate Growth		854'766	112'690	132
S3: Growth	1'342'000	925'676	209'369	245

[9] Please note that in order to compare two base line years, one without and one with multimedia gateways, 533 gateways as well as their corresponding typical energy consumption of 171'000 kWh in 2012 were not considered in base line 2012.

6.7 Scenario 4: Data scenario

6.7.1 Transmitted data volumes

Transmitted data volumes have been extrapolated from historical data. It is assumed that the demand for data intensive services -such as non-linear TV consumption- and the increasing demand for cloud services will grow moderately and will require an increase of bandwidth.

In chapter 5.3, page 36, the methodology for the calculation of the transmitted data volumes of a broadcast service was introduced. Data volumes are calculated by multiplying the average television use in minutes (Table 9, page 37) with the channel and transmission rates of a specific television channel (Table 8, page 37). Gigabytes per day are received by dividing the results with the factor 8000 (megabits to gigabytes). In Table 16 the actual data volumes of year 2012 transmitted to a connected household as well as the prognosis until 2016 are displayed. The prognosis was carried out by consulting upc cablecom experts as well as by taking business decisions into account, e.g. such as phasing out analog broadcast services in Switzerland by 2016.

Table 16 Average data volumes download for TV consumption

Average data volumes download for TV consumption	2012	2013	2014	2015	2016
			[GB/day]		
Standard Definition (SD)	1.92	1.51	1.18	0.93	0.73
High Definition (HD)	7.69	8.92	9.94	10.78	11.49
Analog	7.69	5.77	3.85	1.92	-

The total data volumes transmitted comprise the broadcast volumes as described above as well as IP based traffic mainly caused by internet and telephone services. Whereas telephone services do not add substantially to the data volumes, video streaming and time shifted consumption of television services are some of the internet services which causes large data volumes. During large events (Baliga et al. 2011)e.g. Olympic Games and football championships) video streaming platforms (such as Zattoo, Teleboy, Wilmaa and others), account temporarily for an increase of up to 50% of access to their websites (Fischer 2014).

Table 17 Data volumes transmitted, total and per household

		2012	2013	2014	2015	2016
				[TB/year]		
Connected households in Switzerland	Internet & Phone	220'721	417'913	626'870	940'305	1'410'457
	Television (broadcast)	9'152'039	8'376'471	8'123'971	7'768'352	7'310'663
	Sum	**9'372'759**	**8'794'385**	**8'750'841**	**8'708'657**	**8'721'120**
Per connected household	Internet & Phone	0.15	0.30	0.42	0.60	0.86
	Television (broadcast)	6.32	5.91	5.46	4.97	4.46
	Sum	**6.47**	**6.21**	**5.88**	**5.58**	**5.32**
				#		
	Total households connected	1'448'500	1'416'400	1'543'500	1'620'675	1'701'709

In order to balance out services which are not accounted for (local data traffic, video on demand, transmitted data volumes from services providers) 20 % of the measured volumes were added. This estimation is based on expert knowledge of upc cablecom employees.

In Table 17 both the data volumes of telephone and internet services and the use of television broadcast signals for all upc cablecom customer households is summarized. The volumes are shown in Terabytes/year for each household and as the sum of all connected households. Similar to the prognosis of the broadcast services, expert knowledge of upc cablecom employees was consulted to forecast the increase in internet up- and down-load volumes until 2016.

It can be seen that the data volumes transmitted by broadcast service are one magnitude higher than the current data volumes of internet and telephone services. Looking at the prognosis made until 2016, it is expected that, due to the above mentioned shift to an increased use of IP based services, the importance of broadcast services will diminish, although this process might take a decade or more to show full effects.

6.7.2 Energy intensity of data transmission

Table 18 shows the energy intensity of one Gigabyte data transmission, which can be consequently calculated. For 2012, 0.025 kWh/GB are necessary; whereas an increase to 0.031 kWh/GB can be measured for the year 2013. During 2013 the total energy demand of all upc cablecom activities in Switzerland increased by 17% compared to the 2012 demand (see Table 3 on page 27). The future energy demand was assumed to increase yearly by the same amount. Such an increase in energy demand divided by the above illustrated trend of transmitted data volumes results in an increase of energy intensity per data transmitted to the level of 0.049 kWh/GB by 2016.

6.7.1 Comparison of energy intensity of data transmission

Comparing characteristic data published in literature reviews, these values are at the lower end of the scale. They are near the values of 0.037 kWh/GB calculated by Coroama and Hilty (2014) or 0.057 kWh/GB (Schien et al. 2012; Schien et al. 2013). Nevertheless they are above the lowest value published of 0.006 kWh/GB (Baliga et al. 2011).

Table 18 Energy intensity of 1 GB data tranmission

		2012	2013	2014	2015	2016
Total volumes of data transmitted	[TB/year]	9'372'759	8'794'385	8'750'841	8'708'657	8'721'120
Total energy consumption	[kWh/year]	233'394'632	273'070'474	319'490'998	369'248'147	430'599'461
Energy intensity of 1GB data transmission	**[kWh/GB]**	**0.025**	**0.031**	**0.036**	**0.042**	**0.049**

Coroma et al (2015) and Schien et al. (2015) conducted separate studies, first of the CPE and access network and secondly of the edge and core network. The first study assessed a large range of studies which partly included also end-user equipment. Their own case study an energy consumption < 0.2kWh/GB was calculated. They strongly recommend to exclude end-user devices but include CPE and access network as they are part of the telecommunication network (Coroama et al. 2013; Coroama et al. 2015). The second study presents a bottom up approach with data collection on energy demand of specific devices and transmitted data volumes. They derive an energy consumption of 0.052 kWh/GB for the edge and core devices of a telecommunication network (Schien et al. 2015). Taking these two studies together an energy consumption of 0.252 kWh/GB can be deducted, from with roughly 80% is caused by CPEs and access network and 20% caused by edge and core networks.

Comparing the values of this study shown in Table 18 with the literature values, they are considerably lower. One of the main reasons are the calculation of transmitted data volume for the broadcast service of upc cablecom as introduced in Scenario in chapter 4 5.3 on page 36 and chapter 0 on page 53. This calculation method should be reviewed and, if necessary, adjusted. The presented key indicators, such as typical energy consumption TEC [kWh/year] value and energy demand per data transmission [kWh/GB], are used frequently in literature. But these indicators are mainly applied to unicast - in contrast to multicast or broadcast systems. This underlines the necessity to also develop metrics and standards for the efficiency valuation of a broadcast telecommunication system.

7 Interpretation and Conclusions

7.1 Interpretation

The main environmental impact of a telecommunication system stems from energy consumption during the use phase. Telecommunication systems are built very hierarchically, in order to connect and reach end users at private homes and businesses. Looking at the entire environmental impact it is not surprising that all the equipment which stands at the end users but are an integral part of the network (in this study called CPEs) consumes the largest share of electricity and hence contributes the most to the overall environmental impacts. CPEs cannot be used as standalone devices in contrast to end-user devices, such as TV, PC, notebooks and tablet computers. Estimates of the electricity demand on end-user devices (not CPEs) are far larger than the electricity demand of CPEs or the network. Due to several reason from which the large variability of use of end-user devices weight the most, such devices have been excluded from the LCA evaluation.

The scenario variation has shown that there exists an improvement potential if most efficient appliances of CPEs are employed. On the other side, new appliances which supply an "all in one solutions" (VOIP, modem and CSTB in one CPE) do not diminish the overall environmental impact; they actually do the contrary and increase the impact. As multimedia gateways have to be operational mainly for receiving and outgoing telephone calls, such appliances stay continually on an activity mode which consumes considerably more electricity than single device or even a combination of single devices. They are not (yet) capable to enter a lower and selective power saving mode which sends all unwanted parts of the device to an energy saving mode while leaving essential services - such as the telephone unit- active all the time. Such "selective power saving modes" have been announced but have not been made available during the period of this study.

The scenario variation did not show significant differences (see Figure 19 on page 54). Nevertheless the additional impacts caused by the introduction of a CPE which serves a single CPE for all services, seems disproportionate to the added value of services of data transmission. The variation of environmental impacts shown in Figure 19, mainly stem from the employment of CPEs with a higher energy demand or TEC value. Only the employment of energy efficient CPEs allow a reduction of environmental impact by more than 20 percent. It might be the case that the CPE has been employed and distributed at an immature stage with no or little concern for the energy consumption. But at the current situation a further employment and wide replacement of CPEs by the multimedia gateway would increase the energy consumption significantly.

The effects observed originate to a major extent from the electricity demand and the large degree of employment of the corresponding devices. The results indicate that electricity consumption of end users devices should be carefully monitored by telecommunication network providers. Although the payment of energy costs are generally not paid by telecommunication network providers but appear on the customers electricity bill, energy efficient CPEs should be high on the priority list of telecommunication network providers.

These potential for improvements are only indicative as

- the results have been calculated for a constant amount of customers and
- the different results vary only within the error margins and are, hence, statistically not significant.

The "real world" saving potential can only be calculated on effective customer data as well as effective capacity load of the transmitting devices.

The results of this study correspond with other life cycle assessment studies e.g. of mobile telecommunication networks: in comparison to centralised and strictly hierarchical systems which run and support the system, dispersed employments of a large number of end-user equipment -running up to 24 hours, 7 days a week- consume one magnitude more electricity. The results of this current study correspond to that of the IEA report, which analysed a large data set (International Energy Agency; 2014). Figure 20 below shows the ICT energy footprint, which is similar to the distribution shown in the previous chapter. The IEA report revealed that in 2013 more than 40% of ICT electricity consumption was caused by user premise network equipment[10] and edge devices[11]. In our study the data centres play a minor role. Reasons for this might be electricity consumption of outsourced services and centralised services (e.g. in The Netherlands) which are not accounted for. Only by tackling the nitty-gritty details of billions of widely spread end-user equipment, can improvements of the energy efficiency of telecommunication networks be achieved.

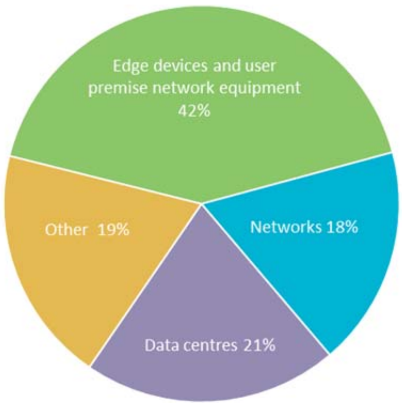


Figure 20 The global energy footprint of information and communication technologies in 2013 (International Energy Agency; 2014)

[10] *Equipment that is located in buildings and offices as opposed to equipment that is located in telecommunication or Internet service provider sites.*

[11] *End-user devices that are connected to networks; two main types of edge devices exist:*

- *Electronic edge device comprises those for which the primary function is data storage or use; e.g. networked devices, network-enabled devices, and networked end-user devices (which include entertainment and communication type devices, such as smart TVs).*
- *Other edge device comprises those for which the primary function is not data-related; i.e. all appliances and equipment other than electronic devices. These includes kitchen and laundry appliances, cooking equipment, heating and cooling equipment, lighting, and all manner of commercial and industrial equipment.*

(International Energy Agency; 2014).

Directly connected to the degree of the caused environmental impact is the choice of the electricity mix of a specific country or region. Malmodin has shown this drastic effect comparing the LCA results of Swedish telecommunication system, first using the average European and then the Swedish electricity mix. As Sweden produces electricity almost entirely from hydropower stations the impacts are reduced by more than 50% (Malmodin et al. 2014a; Malmodin et al. 2014b). Partly such circumstances are also apparent in Switzerland as a large share of electricity in produced by hydropower (see Figure 21 on page 88 in the Annex a comparison of the LCA results with Swiss and European electricity mixes). For economic reasons the hydropower potential is generally used at peak energy demand while being "recharged" at low cost electricity periods. The latter consumes excess energy e.g. from atomic power stations. It is therefore impossible to exactly pin down the consumed electricity. A conservative choice, to use the European average electricity mix (UCTE), was selected as the most appropriate to the upc cablecom network in Switzerland.

upc network's energy intensity of data transmission stands at a very low value compared to current literature studies. This is partly understandable as one of the main drivers of energy efficiency is time(Coroama and Hilty 2014). Over time the devices become more energy efficient and, hence, relative values such as kWh/GB transmitted decrease. As literature studies date back to the turn of the century, this study which focuses on 2012/2013 is expected to be less energy intensive. On the other hand, the very efficient data transmission technology of broadcast television signals allows the delivery of large amounts of data to an almost unlimited number of users. This study applied a conservative data volume calculation based on the actual consumer behaviour of Swiss television customers. It has to be considered that broadcast signals are not specifically designed for an individual customer demand and do not allow a return channel for interactive communication. Additionally, the calculation of data transmission volumes applied in the study might overrate the volumes of broadcast technology. The method should be revised and cross-checked with other calculation methods in order to come to a standardised way of calculation. But putting all this limitations aside, the energy intensity of data transmission of the upc cablecom network ranges at the lowest end of all studies consulted.

Starting at relatively low values might bare a certain danger. With an increasing customer base, changes in transmitting technologies and increased data transmission rates can lead to a rise rather than a decrease of indicators. In scenario 4 such increases in the energy intensity in *kWh/GB transferred* are already visible. Without doubt, data transmission per IP traffic will continue to increase in the next decade. To a certain extent, IP services providing television services will replace traditional broadcasting services. This tendency might be even stronger in Switzerland as the average TV consumption lies below European average values and IP based television offers might encourage the avoidance of television subscription via broadcast signals.

The fact is that the transmission of moving pictures generates the lion's share of internet traffic. One second of high definition video, for example, generates more than 2 000 times as many bytes as required to store a single page of text (McKinsey Global Institute; 2011). On average the global volume of data collected, transmitted and stored has doubled every 18 months (see Table 19). Other predictions assume that in 2017 the IP based video traffic will rise from 57% in 2012 to almost 70% of all internet traffic (or that the sum of all forms of IP based video (non-linear television, VoD, video conferencing, peer -to peer etc.) will account for 80% to 90% of the entire global consumer internet traffic (Cisco Systems, Inc.; 2012). All numbers indicate that the efficient management of very fast growing data volumes will play a competitive role in the telecommunication market.

Table 19 Growth of global internet traffic (Cisco Systems, Inc.; 2013; Cisco Systems, Inc.; 2014)

Year	Global Internet Traffic	
1992	100	GB per day
1997	100	GB per hour
2002	100	GB per seconds
2007	2'000	GBps
2013	28'875	GBps
2018	50'000	GBps

7.2 CONCLUSIONS

In order to reduce the environmental impacts of a telecommunication system the focus should lie on employing consumer devices which consume less energy. In fact the study has shown that

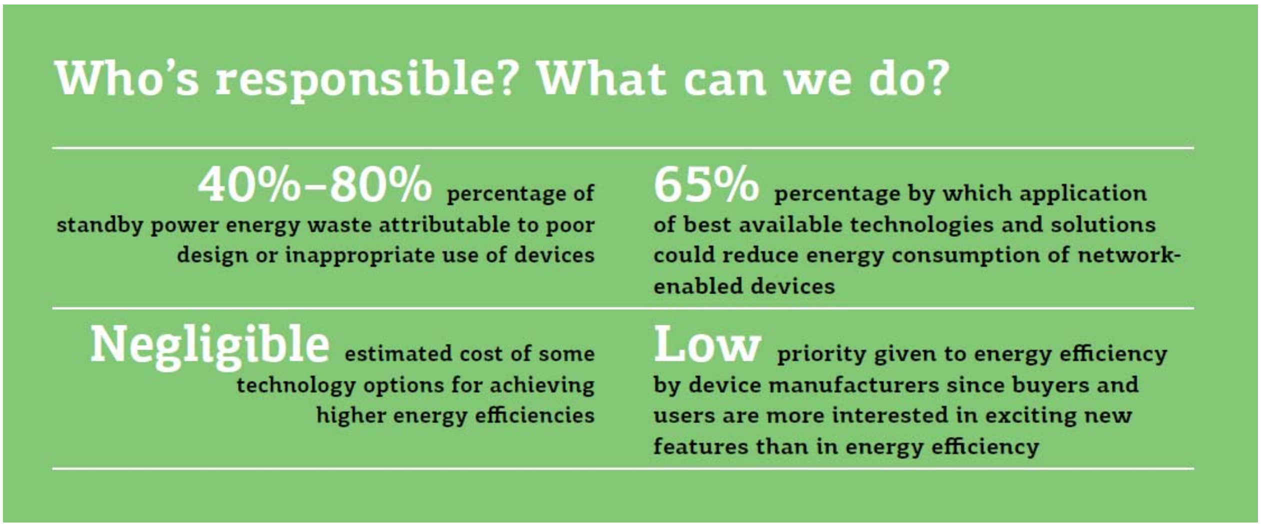
- electricity consumption of CPEs create by far the largest environmental impact,
- the closer an electronic device is installed to the end user, the larger the number of employed devices and -consequently- the greater the energy consumption and also the total environmental impact, and
- the design and mass employment of energy saving end user equipment can lead to a large reduction of environmental impacts.

This, however, is easier said than done, as generally it is assumed that customers expect three services (television, internet and telephone) to be available round the clock. This point might be misleading or create wrong incentives. To be part time "offline" is perhaps a state which an increasing number of users might appreciate -depending on their individual work & life balance. Marketing departments might have overseen such a demand for "offline" periods.

How to design CPEs which allow such individual scheduling have been explored in a study for the design of a very efficient data modem consuming less than 2 Watts on average. The prototype model was designed for a VDSL2 connection. The energy consumption was optimised by selecting the most energy efficient hard ware and by equipping the modem with a GSM module. The modem was then programmed to switch off during low usage periods (night time) and deviate telephone calls to the GSM module in order to receive calls 24 hours a day (Zielinski and Martschitsch 2013). Only with the aid of these technical modifications and by exploiting the user off-periods, was an average value of 2 Watts achieved. This equals a TEC value of approximately 17 kWh/a. Such modification and preprogramed user profiles are not at all standard in commercial modems. Nevertheless, the example shows that typical energy consumption values of CPEs have one order of magnitude as a range.

Admittedly, the validity of such a comparison could be questioned, as technological differences of VDSL and cable network -such as reach per line and geographical range- are excluded. But the approach of designing an utmost energy efficient CPE with very efficient components and with modules which are sent to a low energy consuming "sleep mode" when not being used, would be, from the researcher's and policy makers' point of view, an innovative approach which would satisfy customer demand.

The international Energy Study published (International Energy Agency; 2014) summarises the responsibilities of all stakeholders involved in the telecommunication business. The study leaves little or no doubt that currently employed technology is poorly designed and that already existing best available technology (BAT) can help to bring about energy efficient telecommunication networks an. Furthermore, the study concludes that research costs for BAT is negligible but that the priority for developing, purchasing and implementing BAT for energy efficient telecommunication networks is not yet on the agenda of many of the stakeholders involved. . A telecommunication network provider which would like to be distinguished from his competitors by its energy efficient network structure and reduced cost for his customers should find easy ways to implement such a strategy.



Source: International Energy Agency; More Data, Less Energy: Making Network Standby More Efficient in Billions of Connected Devices. 2014, page 24

7.3 RECOMMENDATIONS

From this study a number of *ready to apply* recommendations as well as longer term and hypothetical recommendations can be put forward. The causes of current practices and the immediate measurements which can be applied are shown in the following:

Cause		Measurement
❖ Multiple use of CPEs	➔	Call back of unnecessary CPEs and avoid use of multiple CPEs
❖ Main environmental impact from CPEs and their electricity consumption	➔	Demanding energy efficient CPEs from original equipment manufacturers. Establishment of energy efficiency for CPEs as key indicator.
❖ Energy consumption of home and network amplifier	➔	Continuous improvement. Establishment of energy efficiency for home & network amplifiers as key indicator.
❖ Decreasing television use	➔	Promotion of CI+ as energy efficient and low cost television option
❖ Energy demand of data centre and head end	➔	Clear strategy for free cooling or low energy data centres (PUE improvement) and continuous improvement of headend infrastructure

Medium term improvements could be achieved by a clear commitment to an entirely "non-CPE solution" combined with cloud services. Such a service might include recommendations and a customer support service how to include e.g. a Network Attached Storage (NAS) with the cloud services offered. NAS might be used as a backup and to store data such as private pictures, but will be owned (and paid) by the end user. Additionally the potential of smart television appliances which allow linear television consumption (broadcast), non-linear TV use (IP based) as well as internet browsing should be exploited in such a scenario.

An entire switch to internet protocol (IP) based services might be another scenario which could bring about substantial decrease of the environmental impacts of telecommunication services. Many experts involved in this study agree that in the future the distribution and exchange of information via IP channels will dominate over broadcast television and radio signals. Crucial for a telecommunication provider is the velocity that such a system change would bring about and the resulting demand for having to simultaneously run two systems parallel. Further research would be necessary to explore the potentials of such a scenario but would require a subtle inventory of the infrastructure as well as a thorough knowledge and anticipation of any anticipated near future technology changes.

It might be of interest to develop Switzerland or some of its regions into high performance and energy efficient large scale telecommunication regions. With its first class infrastructure, consumer sensitivity and willingness to pay, Switzerland might be the perfect candidate to carry out such an experiment.

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Annexes

A Lists of Tables and Figures

A.I List of Tables

A.II List of Figures

B Inventory data collection

B.I Network Infrastructure

B.I.i Physical units of Network Infrastructure

Following ecoinvent inventory data have been used to calculate the environmental impacts of manufacturing

- *Server computers for data centres* consisting of:
    - Tower format (modelled HP ProLiant ML350p Gen8 (“QuickSpecs HP ProLiant ML350p Generation 8 (Gen8)” 2012, 350), based on ecoinvent process “Desktop computer, without screen, at plant/GLO”)
    - Rack format (modelled HP ProLiant DL360p Gen8 (“QuickSpecs HP ProLiant DL360p Generation 8 (Gen8)” 2013, 360) , based on ecoinvent process “Desktop computer, without screen, at plant/GLO”)
    - Blade format (including enclosures) (modelled HP ProLiant BL460c Gen8 (“QuickSpecs HP ProLiant BL460c Generation 8 (Gen8) Server Blade” 2013), based on ecoinvent process “Desktop computer, without screen, at plant/GLO” the enclosure was modelled as a separate process based on HP c7000 (“QuickSpecs HP BladeSystem c7000 Enclosure” 2013))
    - Rack format (modelled HP ProLiant DL360p Gen8 (“QuickSpecs HP ProLiant DL360p Generation 8 (Gen8)” 2013, 360) , based on ecoinvent process “Desktop computer, without screen, at plant/GLO”)
    - Blade format (including enclosures) (modelled HP ProLiant BL460c Gen8 (“QuickSpecs HP ProLiant BL460c Generation 8 (Gen8) Server Blade” 2013), based on ecoinvent process “Desktop computer, without screen, at plant/GLO” the enclosure was modelled as a separate process based on HP c7000 (“QuickSpecs HP BladeSystem c7000 Enclosure” 2013))
- *Infrastructure for data transfer* consisting of:
    - Copper cables (own process, based on ecoinvent-Process: “cable, data cable in infrastructure, at plant/m/GLO”)
    - Optical fibre cables (own process, based on ecoinvent-Process: “cable, data cable in infrastructure, at plant/m/GLO”)
    - CMTS small (0.7 nominal power), own process based on ecoinvent process "router, IP network, at server", used device: CMTS Casa C3200
    - CMTS large (2.5 kWh nominal power), own process based on ecoinvent process "router, IP network, at server”, used device: CMTS 4 ARRIS Rel. 8.1.5
    - Network amplifiers: small network device, newly modelled process
    - Network routers: based on ecoinvent process "router, IP network, at server"

Where available the exact technical specifications were used to generate the corresponding processes for the devices listed in Table 21.

The main background processes, which were used as proxies are as follows:

- printed wiring board, mixed mounted, unspec., solder mix, at plant/kg/GLO
- Integrated circuit, IC, logic type, at plant/GLO
- Integrated circuit, IC, memory type, at plant/GLO
- Steel, low-alloyed, at plant/RER
- Power supply unit, at plant/CN
- HDD, desktop computer, at plant/GLO
- Copper, at regional storage/RER
- Glass fibre, at plant/RER U

Table 20 and Table 21 list the physical infrastructure of main headend and data centres. The energy consumption is shown in the next Annex chapter.

Table 20 2012 inventory of the data centers and the main headend.

Type and site	Main headend Zurich Leimbach	Data centres Zurich Zollstrasse	Otelfingen
	#	#	#
Server	37	37	463
Blade Server	45	45	78
Rack-Server	68	68	-
Storage (shelfs or controller)	40	40	149
Tape-Library	1	1	2
Enclosure	3	3	12
VG: Cluster	2	2	8
Switches	79	79	291
Router	24	24	90
Encoder	10	10	36
Decoder	2	2	8
DWDM Multiplexer	3	3	10
CWDM Multiplexer	5	5	20
SDH	4	4	14
Terminal-Server	-	-	15
VG: Load balancer	-	-	1
2012 energy consumption out of the C360-list [kWh]	1'265'044	1'264'46	6'664'740

Table 21 Datacentre components

		Server type:								
		Tower	***comment***	**Rack**	***comment***	**Blade**	***comment***	**Blade enclo-sure**	***comment***	**unit**
		HP ProLiant ML350p Gen8		**HP ProLiant DL360p Gen8**		**HP ProLiant BL460c Gen8 Server Blade**		**HP BladeSystem c7000**		
enclosure	aluminium	1'864	assumptions based on datasheet	852	assumptions based on datasheet	320	assumptions based on datasheet	6'391	assumptions based on datasheet	g
enclosure	steel	32'101	assumptions based on datasheet	14'675	assumptions based on datasheet	5'503	assumptions based on datasheet	110'059	assumptions based on datasheet	g
enclosure	plastic	1'036	assumptions based on datasheet	473	assumptions based on datasheet	178	assumptions based on datasheet	3'550	assumptions based on datasheet	g
PSU		1'360	one PSU	1'360	one PSU	0	from datasheet	3'390	3 2400W PSUs, half popu-lated enclosure assumed	g
CD-ROM		900	from ecoinvent	900	from ecoinvent	0	from datasheet			g
HDD		1'400	assumption: at least RAID5 ➔ 5 HDDs (2.5", SAS); RAID1 System disk (2.5", SAS); 200g per drive	1'000	assumption: at least RAID5 ➔ 3 HDDs (2.5", SAS); RAID1 System disk (2.5", SAS); 200g per drive	400	assumption: 2 HDDs (2.5", SAS); 200g per drive			g
Mainboard		1'800	assumption based on tyan and supermicro boards	1'400	assumption based on tyan and supermicro boards	1'000	assumption based on tyan and supermicro boards	200	own assumptions	g
RAM		80	32 GB: 4*8GB DIMM ➔ 4*20g (own weighing)	80	32 GB: 4*8GB DIMM ➔ 4*20g (own weighing)	80	32 GB: 4*8GB DIMM ➔ 4*20g (own weighing)			g
CPU		3	1 CPU, several cores	43	1 CPU, several cores	43	1 CPU, several cores			g
mezzanine boards			none		none		none	7'000	one Gb-Ethernet Board assumed	g
fans		4	from datasheet	8		0	from datasheet	10	from datasheet	p
cables		260	own assumptions	260	own assumptions	260	own assumptions	390	own assumptions	g

B.I.ii Energy consumption of Network Infrastructure

The power usage effectiveness (PUE) is a commonly accepted method to calculate the energy efficiency of a centre developed by a non-profit industry consortium[12]. Cooling, ventilation, uninterrupted power supply (UPS) and lighting systems accounting for the "Total Facility Energy" of a data centre. This value is divided by the energy used by the IT equipment (see Equation 1). Cooling and ventilation systems are essential for many data centres and were traditionally carried out by electrical coolers or ventilators. Very efficient data centres do not need extra energy for cooling but can provide heat or energy for other purposes. The lower the value of PUE, the more energy efficient the data centre. A PUE of one describes a very efficient data centre, which utilizes all consumed energy for the IC equipment itself, without any additional cooling or ventilation, as each IT equipment already provides this. The relevant literature shows, that the average PUE of a data centre lies between 1.8 and 1.9 (Coroama et al. 2013). According to Green Grid, the average PUE is 2.03 (Bednar et al. 2009), which means that roughly the same amount that is used for IT equipment is used for additional cooling, ventilation, uninterrupted power supply or lighting systems. Older data centres nevertheless might have a PUE of 2.5 and higher.

$$PUE = \frac{Total\ Facility\ Energy}{IT\ Equipment\ Energy} \quad \text{Equation 1}$$

Table 22 shows the energy consumption of data centers and main headend in 2012 and 2013 using the above mentioned calculation method and a PUE of 2.0.For 2013 a 8% growth was assumed as measured by the C360 assessment . Table 22 Power usage effectiveness (PUE) of data centers

Power usage effectiveness	[kWh] in 2012	[kWh] in 2013
A: power consumption by the conform PoP - sites/ year without PUE	**9'601'573**	**10'369'699***
B: power consumption by the conform PoP - sites/ year with PUE	**19'203'146**	**20'739'398***
(PUE= $\frac{Total\ Facility\ Energy}{IT\ Equipment\ Energy}$,)	2.0	

[12] http://www.thegreengrid.org/

Table 23 lists the physical infrastructure and energy consumption of the Hybrid Fiber Cable (HFC). The data of 2012 were also used for the year 2013 as no additional data were avalable.

Table 23 Components of Hybrid Fiber Cable (HFC)

Type of components of the network HFC	Physical units Status Dec. 2012	Power consumption [kWh] (C360, LG) Stand 2012	Comments
Amplifier & transmitting equipment		28'423'088	
In-house amplifier	286'427	25'592'822	
Copper cable (km)	34'865		plus 1500 km per year
Fibre optic cable (km)	11'956		plus 700 km per year
Node	3'890		

Table 24 lists the physical infrastructure and energy consumption of the Points of Presence (PoP) caculated with the relevant number of equipment and power consumption.

Table 24 Components Point of Presence (PoP)

Type of equipment of PoPs	Power con-sumption (kW)	Number	Energy consumption of the site (kW)	power consumption per year (kWh) without PUE
CMTSen CASA 10G	2.7	10	27	236'520
CMTSen CASA 3200	0.7	223	156.1	1'367'436
CMTSen ARRIS 4C	2.5	29	72.5	635'100
RF Gateways	0.3	614	184.2	1'613'592
ApearTV Chassis	0.33	80	26.4	231'264
Transmode Chassis	0.55	424	233.2	2'042'832
TM CWDM Chassis	0.2	39	7.8	68'328
ONS Chassis (HE = 12)	0.6	44	26.4	231'264
CMP Chassis	1.5	0	0	0
760X Router	3.2	47	150.4	1'317'504
ASR 9k	3	12	36	315'360
HFC optics	0.025	6032	150.8	1'321'008
Active HFC equipment	0.01	2527	25.27	221'365
Total			**1'096**	**9'601'573**

B.II Consumer Premises Equipment

B.II.i Physical unties of Consumer Premises Equipment

For the base line years 2012 and 2013 as well as for the scenarios, the following parameters were aggregated with a weighted average over all used devices and divided into three corresponding groups of: modems, set top boxes and multimedia gateways (described below):

- Overall weight of device (plastic and metal parts)
- Weight of printed wiring board PWB)
- Weight of included hard disk drives (average weight was used to calculate the number of harddisk drives)
- Weight of included external cables
- Type and weight of power supply units

The following Table 25 list the key values used for the calculation of the different CPE types. The entire list of component and material distribution of the CPEs can be found in Table 26.

Table 25 Key values for Customer Premises Equipment modelling

CPE Type	PWB [g]	Metals [g]	Plastics [g]
Modem	189	7	240
STB	492	799	218
Multimedia gateway	572	345	912

Table 26 Components of the CPEs

Typ	Model	Weight, total	Power-supply unit	Printed Wiring Board	Hard-disk	Cable	Ventila-tor	Metal	Plastic
				All values in [g]					
Modem									
	Thomson TWG870	519	153	223	-	136	-	3	294
	Scientific Atlanta EPC2203	284	224	131	-	102	-	2	151
	UBEE EVM3206	380	104	175	-	199	-	2	203
	UBEE EVM3236	381	104	158	-	200	-	2	198
	Technicolor TC7200	534	109	220	-	134	-	30	285
CSTB									
	Philips DCR7101/03	1860	-	629	-	251	-	1096	100
	Philips DCR8111/03	3060	-	705	564	251	36	1188	564
	Thomson DC152	1840	-	600	-	358	-	105	145
	Cisco 8485	2726	-	629	551	251	-	1423	88
	Pace DCR7111	711	121	295		174	-	41	367
	Cisco 8685	2686	-	650	546	251	-	1408	86
Multimedia Gateway	Samsung SMT-G7400	2328	376	572	400	235	58	345	912
Remote		112	-	19	-	-	-	0.4	92

To calculate the overall impact for the different components, ecoinvent background processes were used and modified and/or adapted accordingly to suit the current project. The main background processes, which were used as are as follows:

- printed wiring board, mixed mounted, unspecified solder mix, at plant/kg/GLO
- Steel, low-alloyed, at plant/RER
- Power supply unit, at plant/CN
- HDD, desktop computer, at plant/GLO

B.II.ii Typical Energy Consumption (TEC) of CPE

The Typical Electricity Consumption (TEC) is an established calculation method which enables the estimation of the energy consumption of energy relevant products within a year. TEC values are generally given in kWh/year. As described in chapter 2 *Legal background*, the typical energy consumption of a CSTB is based on two agreements:

- *Voluntary Industry Agreement to improve the energy consumption of CSTB* (Industry Group 2011)
- *Code of Conduct on Energy Efficiency of Digital TV Service Version 9.0* (CoC; 2013).

In this study the measured TEC values are calculated as defined in the Voluntary Industry Agreement and do not differ from the Code of Conduct requirements. The power consumption (in Watt) and the individual usage period (in hours) allow the calculation of the energy consumption (TEC values in kWh/year) according to Equation 2 or 3. The daily values are adjusted by the constant ***c*** = 0.365, in order to calculate the energy consumption in kilo-Watt hours per year.

$$TEC\ [kWh/a] = c * [T_{on} * P_{on} + T_{standby} * P_{standby}]$$ **Equation 2**

$$TEC\ [kWh/a] = c * [T_{on} * P_{on} + T_{standby} * P_{standby} + T_{APD} * P_{APD}]$$ **Equation 3**

T_{on}	=	Hours, active mode enabled during one day
P_{on}	=	Watt, power consumption in active mode
$T_{standby}$	=	Hours, standby mode enabled during one day
$P_{standby}$	=	Watt, power consumption in standby mode
T_{APD}	=	Hours, APD mode enabled during one day
P_{APD}	=	Watt, power consumption in APD mode
c	=	0.365, constant, scaling factor in order to adjust energy consumption for one year

Specific power consumption measurements for CPEs have been carried out in this study in cooperation with the Institute of Automation at the School of Engineering, University of Applied Sciences and Arts

Northwestern Switzerland. In order to minimize measurement uncertainties, two identical appliances were measured.

For each appliance, a measurement protocol was designed, including all power modes of the respective model. The power consumption in the active mode was measured whilst loading an internet side (data modems) or receiving a television programme (CSTB or multimedia gateway). The measurements were carried out with a Power Analyser (Voltech, Typ PM 1000).

B.II.iii Typical Electricity Consumption of modems

Table 29 shows the power demand of modems without a connected device and with a connected device as well as the resulting TEC values of one year energy consumption. The given values in Table 27 are the arithmetic means of the two individual measurements. Whether a modem is "on & active" or only "on" does not make much of a difference concerning power demand, whereas the TEC values of the different CPEs differ from 44 kWh/a to 105 kWh/a (see Table 27) . The most efficient CPE modem is the Scientific Atlanta EPC2203; in contrast the two modems Ubee EVM3206 (without WiFi) and Thomson TWG 870 (with WiFi) consume the most.

Table 27 Power demand and emergy consumption of modem in the working condition on & aktiv and on, based on the equations given in the Volunatry Agreement.

Modem	Specification	On & Active [W] LAN interface occu-pied / 150 Mbit/s IP transport	On [W] test object without connected device in the operational state	TEC [kWh/a]
Scientific Atlanta EPC2203	ED[13] 2	5.04	5.06	44
Motorola Surfboard	ED 3	7.55	6.08	58
Ubee EVM3236	ED 3	7.1	6.87	61
Technicolor TC7200	ED 3, WiFi	8.55	7.9	71
Ubee EVM3206	ED 3	8.95	8.62	77
Thomson TWG870	ED 3, WiFi	12.21	11.8	105

B.II.iv Typical Electricity Consumption of CSTB

Almost all CSTB are equipped with a so called "hot standby". During hot standby the basic functions can be reactivated in a very short period. As the television is controlled by the CSTB, a "hot standby" reduces the time it takes to show a picture on the television after being switched on. Television channels in High Definition (HD) require a higher data transmission rate, therefore the "hot standby" mode also requires higher power levels than Standard Definition (SD).

[13] ED: EuroDocsis, Docsis: Data Over Cable Service Interface Specification

The hot standby modes only marginally reduce the power demand compared to the on modes. But some CSTB are equipped with a "cold standby" mode. As of today such a standby has to be below 1Watt power demand, required by EU legislation for a variety of electronic equipment. "Cold standby" is generally an off mode with only a light diode still glowing. CSTB cannot perform any basic functions in the "cold standby" and have to be booted. Only the CSTB Pace DCR7111 and Cisco 8485 have "cold standby" modes. Assuming that these CSTB switch into the "cold standby" for the entire standby time, a substantial reduction (factor 3.5) of the energy consumption can be achieved (see last column of Table 29). This could well be a realistic scenario as the relevant CSTB are not essential for any internet or telephone services and can therefore remain in cold standby when not used.

Table 28 Active power demand of Set-top-box

Complex set–top-box	Philips DCR7101	PACE DCR7111[14]	Thomson DC152	Cisco 8485[13]	Cisco 8685[13]	Philips DCR8111
Operation modes	Digital Video Receiver, power demand in [W]			Digital Video Recorder, power demand in [W]		
a. operational plus one record	n.a	n.a	n.a	24.4	41.0	33.0
b. operational plus two records	n.a	n.a	n.a	n.a	n.a	33.3
c. operational plus one record and one playing	n.a	n.a	n.a	24.1	41.1	33.2
d. operational plus two record and one playing	n.a	n.a	n.a	n.a	n.a	33.3
Standby modes						
Operational	18.0	10.6	14.8	24.1	23.6	31.4
Hot standby	16.9	9.4	14.7	16.5	16.4	24.4
Cold standby	-	0.7	-	0.8	0.7	-

The Auto Power Down Mode (APD) is the "*mandatory capability of Headless or Headed Equipment with Networked Standby functionality to automatically switch from the Active(Headless) or (user-)APD (Headed) mode to the lowest-power Standby mode the Service Provider deems to be appropriate after a period of time without service request."* (CoC 2103, page 18).

Headed equipment's have the following capabilities:

- Audio-Video programs decoding.
- Graphic composition especially for user interface.
- Mixing the corresponding content and convert to Audio-Video signal.
- Directly feeding an external TV with Audio-Video signal.
- Capability to be controlled by mean of local control or remote control.

Headless equipment is CSTB not being Headed Equipment (which is generally an appliance which only possesses a light diode in the machine without any local control buttons).

[14] Equipped with Auto Power Down (APD) mode

APD functionalities have been taken into account for the models which are equipped with such a mode. Apart from the multimedia gateway, the CPEs Pace DCR7111, Cisco 8485 and Cisco 8685 have an APD mode installed.

These tendencies are shown below in Table 29, even though differences of the brand prevail over the HD or SD readiness. The TEC values vary by a factor 2.8. Taking the functionalities (HD or SD readiness) into account, the CSTB Pace DCR7111 is the most efficient HD receiver, Cisco 8685 the most efficient HD recorder.

Table 29 Power demand and energy consumption of set-top-box in the working condition operational, hot and cold standby, based on the equations given in the Volunatry Agreement.

Complex set-top-boxes						
	Specification	operational [W]	hot standby [W]	cold standby [W]	TEC hot standby [kWh/a]	TEC cold standby [kWh/a]
Pace DCR7111	Receiver, HD	10.6	9.4	0.7	84	22
ADB[15] CCM 3000	Receiver, SD	29.6	10.0		117	
Thomson DC152	Receiver, SD	14.8	14.7		129	
Philips DCR7101	Receiver, HD	18.0	16.9		151	
ADB CCM 7100	Recorder, SD	15.5	12.0		152	
Cisco 8685	Recorder, HD	23.6	16.4	0.7	156	
Cisco 8485	Recorder, HD	24.1	16.5	0.8	157	45
Philips DCR8111	Recorder, HD	31.4	24.4		236	

B.II.v Typical Electricity Consumption of multimedia gateways

The investigated multimedia gateway (SMT-G7400 1-1-60) provides an extra standby mode: "lukewarm standby" during which several functions are still active or can be reactivated within a reduced time period. An additional operational mode is foreseen for a future update of the software operating system. Switched to the "cold standby", the multimedia gateway does not allow any functions to be reactivated or carried out. But it fulfils the (non-networked) standby legal requirements of below 1 Watt. In this mode the multimedia gateways cannot receive telephone calls or any data (see also Annex E, SMT-G7400 1-1-60 manual guide, power management on page 105).

Currently (end of 2014) SMT-G7400 1-1-60 is put on the market with the following settings: automatic switch to the preselected standby mode after 20 minutes of being inactive. When the multimedia gateway is initially started and installed, either "hot standby" or "lukewarm standby" must be set by the user as the preselected standby mode. The installation will not continue unless the user has selected one of the two

[15] Advanced Digital Broadcast

modes. Only if "lukewarm standby" is selected can the additional option "cold standby" be selected as standby mode. This option was also not available for the first commissioning of the gateway, but was only introduced (by software update) for a later version.

Table 30 shows the power demand data (active power in Watt and reactive power in Voltampere) of operation modes and the different standby modes. Differences of the power demand while the gateway is processing data, e.g. for recording or playing a HV video, do not differ substantially from the values given in Table 30. In the operational mode the current Gateway Samsung SMT-G7400 version demands between 40.2 and 43.5 Watts.

Table 30 Power demand of Multimedia Gateway in the oeration modes andstandby modes[16]

Multimedia Gateway Samsung SMT-G7400 (1-1-60)	Active power demand [W]	Reactive power demand [VA]
Operation modes		
a. test object without connected device in the operational state	40.2	73.8
b. one LAN interface occupied / 150 Mbit/s IP data traffic	40.9	75.1
c. WIFI on	41.1	76.0
d. all four LAN interfaces occupied	42.2	77.8
e. operational plus two recording	43.5	81.1
g. operational plus two records and one playing	43.4	79.6
Standby modes		
a. Operational	41.3	75.9
b. Hot standby	35.5	70.0
c. Lukewarm standby	18.7	39.8
d. Cold standby / low power standby	0.81	7.9

The calculation of a specific TEC value of multimedia gateways is neither specified in the Voluntary Industry agreement nor in the Code of Conduct. Both regulations focus on either CSTB or data modems. One of the difficulties is that modern multimedia equipment has to be online -at least on a low level -all the time (because they offer all services). At the same time they allow users to set the duty cycle almost free of choice. In order to calculate the TEC values of the multimedia gateway SMT-G7400 1-1-60 as close as possible to reality, we have applied different duty cycles, each of which matches with the regulatory framework (VA, CoC and Swiss energy ordinance). All calculations are carried out according to Equation 2 and Equation 3 (page 77).

According to an annual report in 2012 of Mediapulse (Mediapulse 2012) and the statistical office in Switzerland (Bundesamt für Statistik 2012) an average usage period of television services of 2.5-3.0 hours / day was assumed. This is below the average time used in Europe (4-4.5 hours /day) but was considered a more realistic value. The average use of the data modem was assumed to last 1.0-3.0 hour/day for both,

[16] Own measurements, and technical information

telephone and internet (Latzer et al. 2012). Hence, for the calculation of TEC values, the multimedia gateway was assumed to be in the operational mode for a period of 4.5 -9.0 hours /day.

For the remaining time, it had to be decided which of the different standby modes in which the multimedia gateway is conditioned, are applied. Several options have been calculated as shown in Table 31.

The resulting TEC values are at their highest if the gateway remains during the residual period in hot standby; in contrast, TEC values are at their lowest if cold standby is chosen. Table 31 shows the 24 hour distribution of all modes as well as the TEC values (in kWh/year) calculated with the power demand of Table 30. See also the following comments to the below mentioned duty cycles and TEC values as well as the duty cycles of the VA (Table 35) and the CoC (Table 36) in the Annex.

Table 31 Duty cycles (in hours) of total energy consumption (TEC in kWh) calculated with the corresponding standby modes (stby)

	Multimedia Gateway SMT-G7400 (1-1-60)	$T_{on\ telephony}$	$T_{on\ internet}$	$T_{on\ TV}$	$T_{hot\ stb}$	$T_{lukewarm\ stb}$	$T_{cold\ stb}$	TEC calculated [kWh/a]
I	4.5h on and 19.5h hot stby	1.0	1.0	2.5	19.5			320
II	**9h on and 15h lukewarm stby**	**3.0**	**3.0**	**3.0**		**15.0**		**238**
III	4.5h on, 20min (APD-timeout), 18.5h stby	1.0	1.0	2.5	1	18.5		207
IV	4.5h on and 19.5h lukewarm stby	1.0	1.0	2.5		19.5		201
V	4.5h on and 19.5h cold stby	1.0	1.0	2.5			19.5	74

I. This duty cycle describes a setup of the Multimedia Gateway for maximal availability. It might be chosen by users which constantly up and download data or a household with a large number of connected users.

II. This TEC value of 238 kWh/year can be calculated by using measured values of this study and the duty cycle of the Voluntary Agreement (Industry Group 2011) for a CSTB without APD function (see also Table 35). Under the Code of Conduct (CoC; 2013) this would mean a that the appliance remains in same mode (lukewarm standby) for both, the standby and the APD mode. According to information given from upc, this duty cycle corresponds with the settings of the SMT-G7400 as currently put on the market. Consequently it was used during this study to calculate the life cycle impacts.

III. This TEC value corresponds with a duty cycle as prescribed under the Swiss energy ordinance (EnV (730.1) 1998 2015). It was assumed that the APD to timeout period is 20 minutes which produces a 1.0 hour $T_{Standby}$ period, an 18.5 hours T_{APD} period and the fixed 4.5 hours T_{On} period.

IV. A lower TEC value of 201 kWh/year can be calculated with a 4.5h T_{On} period and 19.5h T_{APD} period. Such a duty cycle corresponds to the Code of Conduct for a headless CSTB with networked standby functionality (see also Table 36).

V. This duty cycle describes a use period of 4.5 hours per day and 19.5 hours cold standby during which no data can be received or send. This is a theoretical mode which describes the use of the gateway only a video (and data) receiver and recorder but not as telephone modem. These values were not used for further analysis.

Simultaneous multiple operations (e.g. recording and telephoning and internet surfing) was not differentiated. The measurements have shown that multiple operations only have a minor effect on the power demand (as shown in Table 30) [17].

The legislative framework, no matter whether it is a formal regulation or an industry self-regulation, cannot foresee all the differentiations and variation of the energy modes mentioned above. This showcases the fact that technical innovation sometimes leapfrogs formal legislation or regulation. In this study we have intended to depict the current situation appropriately and to forecast possible development realistically.

[17] Oral communication with UPC experts of multimedia gateways

B.II.vi Base Line 2012 & 2013

Table 32 CPE stocks [18]

CPE	Specifications	Dec 2012	Dec 2013
Modem		**626'423**	**596'614**
Motorola Surfboard	ED 3, eMTA[19]	915	30
Ubee EVM3206	ED 3, eMTA	103'776	80'467
Technicolor TC7200	ED 3, WiFi, eMTA	0	93'106
Ubee EVM3236	ED 3, eMTA	103'421	95'038
Scientific Atlanta EPC2203	ED 2, eMTA	179'357	104'802
Thomson TWG870	ED 3, WiFi, eMTA	238'954	223'171
Set-top-Box		**594'327**	**503'243**
Total Receiver		**248'260**	**255'419**
ADB	Receiver, SD	6'165	4'772
Philips DCR7101	Receiver, HD	25'412	17'175
Thomson DC152upc	Receiver, SD	57'949	26'374
Pace DCR7111	Receiver, HD	158'734	207'098
Total Recorder		**346'067**	**247'824**
ADB	Recorder, SD[20]	1'389	195
Philips DCR8111	Recorder, HD[21]	27'605	14'277
Cisco 8485	Recorder, HD	139'016	96'514
Cisco 8685	Recorder, HD	178'057	136'838
Multimedia Gateway		**533**	**139'341**
SMT-G7400	ED 3, WiFi, Recorder	533	139'341

[18] All data are based on information given from upc cablecom Switzerland at the beginning of the years 2013 and 2014

[19] ED 3, eMTA: Euro Docsis 3, Embedded Multimedia Terminal Adapter,

[20] SD: Standard Definition

[21] HD: High Definition

Table 33 Detailed CPE stocks and electricity consumption for the year 2012 and 2013[22]

Typ	Model	Status	Physical units Dec 2012	Power consumption [kWh] 2012	Physical units Dec 2013	Power consumption [kWh] 2013
Modem (total)			**626'423**	**47'259'000**	**596'614**	**46'603'000**
	Scientific Atlanta EPC2203	Phase out	179'357	7'933'000	104'802	4'636'000
	Motorola Surfboard	Phase out	915	53'000	30	2'000
	Thomson TWG870	Deployment	238'954	25'022'000	223'171	23'369'000
	UBEE EVM3206	Deployment	103'776	7'949'000	80'467	6'163'000
	UBEE EVM3236	Deployment	103'421	6'302'000	95'038	5'791'000
	Technicolor TC7200	Deployment	0	0	93'106	6'642'000
CSTB (total)			**594'327**	**101'735'000**	**503'243**	**93'303'000**
	Thomson DC152upc	Phase Out	57'949	7'456'000	26'374	3'393'000
	Philips DCR8111	Phase Out	27'605	2'319'000	14'277	1'199'000
	ADB digital TV	Phase Out	1'389	162'000	195	23'000
	Philips DCR7101	Phase Out	25'412	3'843'000	17'175	2'597'000
	Pace DCR7111	Deployment	158'734	37'509'000	207'098	48'937'000
	Cisco 8485	Deployment	139'016	21'813'000	96'514	15'144'000
	Cisco 8685	Deployment	178'057	27'696'000	136'838	21'285'000
	ADB digital TV	Deployment	6'165	937'000	4'772	725'000
Multimedia Gateway			**533**	**171'000**	**139'341**	**44'648'000**
	Samsung GATEWAY	Deployment	533	171'000	139'341	44'648'000
Digicard	CI+	Deployment	**196'194**	**-**	**201'179**	**-**
Total CPE (without CI+)			**1'221'283**	**149'165'000**	**1'239'198**	**184'554'000**

[22] All data are based on country specific information given from upc cablecom Switzerland at the beginning of the years 2013 and 2014; personal communication with Rolf Ochsenbein 27.01.14, Hien van Dijk 14.02.2014. Measured power consumption values were used for calculation of energy consumption

B.III Additional data used for inventory data collection

Table 34 Average duty cycle for CPEs assumed for the TEC caculation

CPE	Typ	Average time active (CSTB), On & active (modem) [h]	Average time standby (CSTB), On (modem) [h]
Modem			
	Thomson TWG870	9	15
	Scientific Atlanta EPC2203		
	UBEE EVM3236 (ED 3.0)		
	UBEE EVM3206 (ED 3.0)		
	Motorola Surfboard (ED 3.0)		
	Technicolor TC7200		
CSTB			
	ADB digital TV (Receiver)	9	15
	Philips DCR7101 (Receiver)		
	Thomson DC152upc(Receiver)		
	PACE DCR7111 (Receiver)		
	ADB digital TV (Recorder)		
	Philips DCR8111 (Recorder)		
	Cisco 8485 (Recorder with APD)	4.5	19.5
	Cisco 8685 (Recorder with APD)		
Multimedia Gateway			
	Samsung SMT-G7400	4.5	19.5

Table 35 Duty Cycle according to the Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU (Industry Group 2011)

CSTB with no APD	On	Standby	
Daily time duration in this mode	T_{On}= 9h	$T_{Standby}$=15h	
CSTB with APD	**On**	**Standby**	**Standby from APD**
Daily time duration in this mode	T_{On}= 4.5h	$T_{Standby}$=15h	T_{APD}= 4.5h

Table 36 Duty Cycle according to the CoC 2013 for Total Energy Consumption calculation (CoC; 2013)

Daily time duration in this mode	Equipment without Networked Standby functionality [hours/day]		Equipment with Networked Standby functionality [hours/day]	
	Headed	Headless	Headed	Headless
T_{On}	4.5	24	4.5	4.5
$T_{Standby}$	15	0	4.5	0
T_{APD}	4.5	0	15	19.5

Table 37 Linear televsion service: using time

User data of television	Mon – Sun (average value 2009 - 2012 in minutes)	population 2010 Switzerland in %	average value calculated in consideration of population distribution, in minutes
German-speaking Switzerland	140.25	68%	95.0
French-speaking Switzerland	157	24%	37.0
Italian-speaking Switzerland	178	9%	15.5
Total	144	100%	147.5

C Life Cycle Assessment

C.I Electricity mix

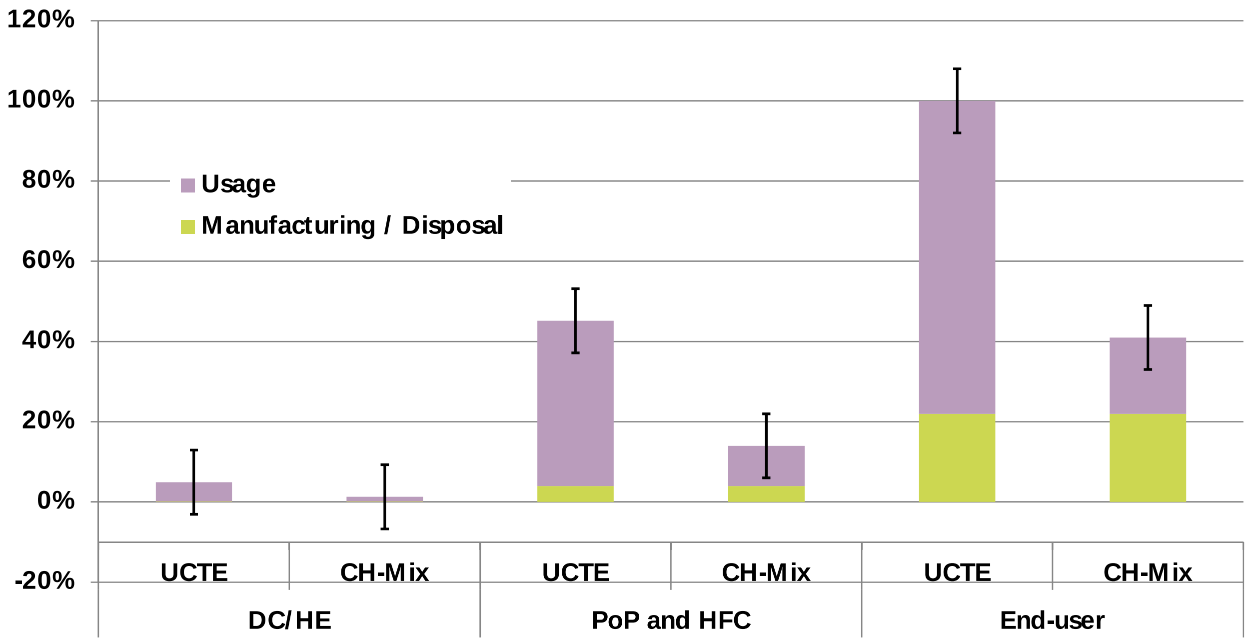


Figure 21 Base line 2012 according to UCTE and Swiss electricity mix

C.I.i LCA Background Information electricity mix (UCTE)

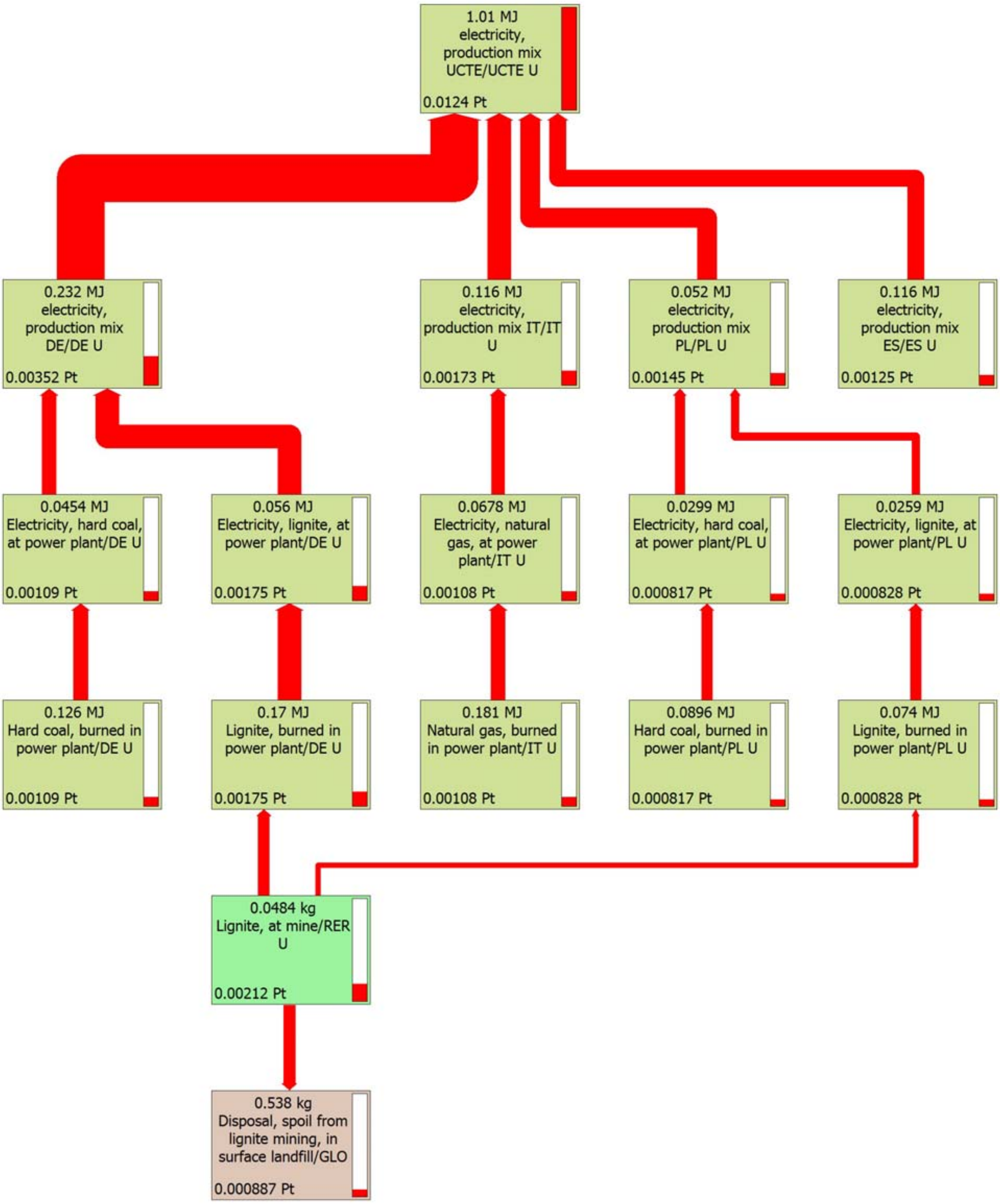


Figure 22 1 MJ of electricity, UCTE, effects calculated with ReCiPe 2008

Above Figure 22 shows that the effects from nuclear power generation are not visible, the main impacts stem from coal and gas power plants for electricity generation. Figure 23 in contrast, where the effects are calculated with the ecological scarcity method, clearly shows the effects of nuclear power generation. The largest fraction of all impacts originates from nuclear power, which is responsible for more than a fourth of all potential environmental impacts.

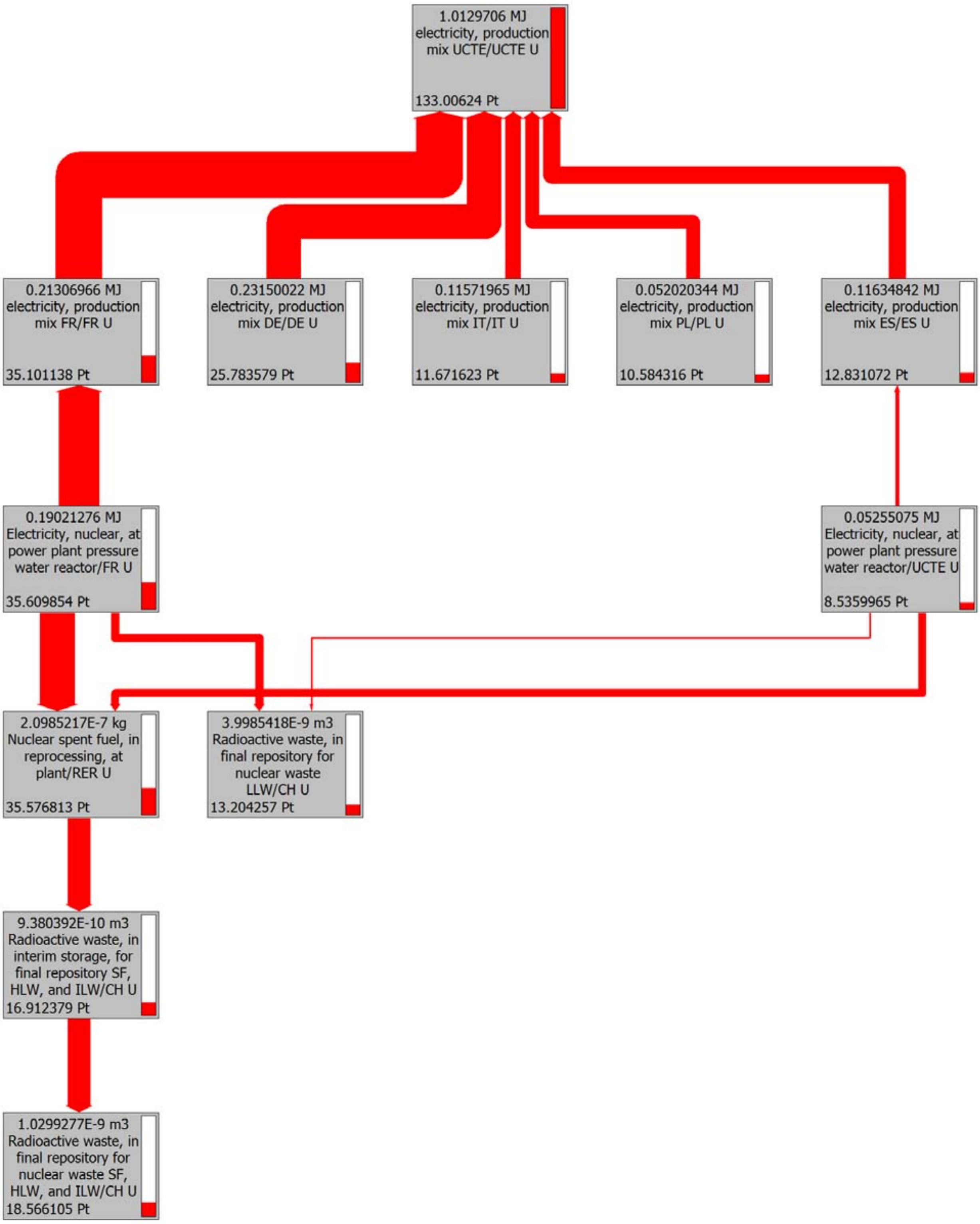


Figure 23 1 MJ of electricity, UCTE, effects calculated with Ecological Scarcity 2006

C.II LCA Methodology

There are the following ISO standards specifically designed for LCA application:

- ISO 14040: Principles and framework (E. ISO 2006)
- ISO 14044: Goal and Scope definition, inventory (LCI), Life Cycle Impact assessment (LCIA) and Interpretation (D. ISO 2006)

The most important factor when aiming to adhere to an ISO standard is the need for careful documentation of goal, scope and interpretation issues. A second factor is the possible necessity of having to include a peer review by independent experts, as described in ISO 14040.

Some years ago, the standards were revised and reconfigured, resulting in the current two standards, ISO 14040 and ISO 14044. The revision had no major impact on how LCAs are executed (see www.iso.org, search for TC205/SC5).

A life cycle assessment (LCA) determines the potential environmental impacts of all relevant materials and energy flows over the entire period from introduction into the anthropogenic system until final disposal.

According to ISO 14040, an LCA study consists of the following four steps:

1. Defining the goal and scope of the study.
2. Establishing a model of the product life cycle with all the environmental inflows and outflows. This data collection effort is usually referred to as the life cycle inventory (LCI) stage.
3. Understanding the environmental relevance of all the inflows and outflows; this is referred to as the life cycle impact assessment (LCIA) phase.
4. The interpretation of the study. This is often complemented by a critical review of the whole LCA exercise.

The main technique used in LCA is modelling. In the inventory phase, a model is made of the complex technical system, which makes up the production, transport, use and disposal of a product. This results in a graphical flow sheet or process tree with all the relevant processes. For each process, all the relevant inflows and outflows are enumerated and quantified. The result is usually a very long list of inflows and outflows that is often difficult to interpret.

In the life cycle impact assessment phase, a completely different model is used to describe the relevance of inflows and outflows. For this, a model of an environmental mechanism is used. For example, emissions of SO_2 could increase the acidity of soils, which can cause changes in these soils, causing certain species of trees to die out etc. By using several environmental mechanisms, the LCI result can then be translated into a number of impact categories such as acidification, climate change and so on.

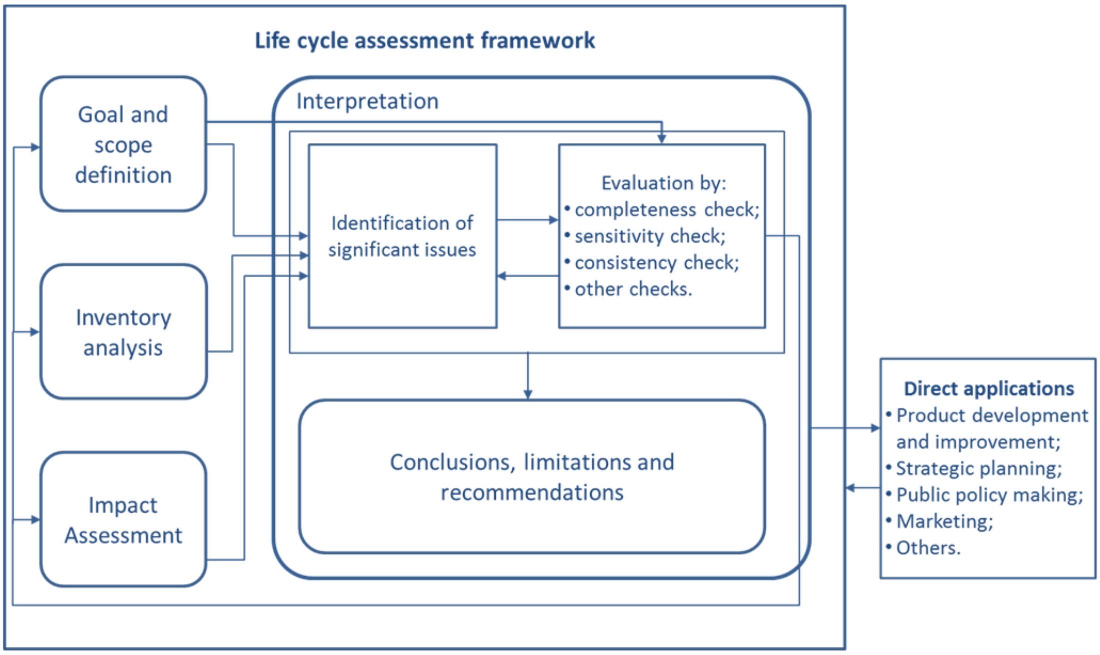


Figure 24 LCA phases according to the ISO technical standard 14'040

C.II.i Supporting Modelling Tools

Within this particular study, the LCI and the LCIA analyses are carried out using the LCA software system SimaPro, version 7.3.3 (PRé Consultants 2011) with ecoinvent data (ecoinvent 2010) for background processes.

C.II.ii Inventory Analysis

Details of the procedure can be found in the chapter Goal and Scope Definition

C.II.iii Impact assessment and valuation method

Even when the analysis is limited to the "major" substances, the resulting tables of figures are nevertheless difficult to interpret. It is therefore essential to group and then summarise substance emissions according to their impact on the environment (characterisation). For the purposes of this project, the following impacts were calculated:

- **Global warming potential (IPCC 2007)**
  The rising of the average temperature of the Earth as a result of the release of gases such as CO_2, methane and nitrous oxide
- **Energy resources** (R. Hischier et al. 2010)
  This refers to the energy content of fuel primary products required to produce the corresponding quantity of usable or end energy. These are usually divided into renewable and non-renewable resources.
- **Ozone generation potential** (Guinée et al. 2002)

Increase in ozone levels (summer smog) as a result of emissions of substances such as organic solvents and nitrogen oxides (NO_x)

- **Acidification potential** (Guinée et al. 2002)
  Acidification of soil and the related damages to plants through the emissions of substances such as nitrogen oxides (NO_x) and sulphur dioxide (SO_2)
- **Air toxicity** (Guinée et al. 2002)
  Impact on the health of people and animals through poisonous substances in the air being breathed, such as organic compounds, nitrogen oxides (NO_x)
- **Water toxicity** (Guinée et al. 2002)
  Damage to plants and animals in water through poisonous substances such as nitrites, oil
- **Eutrophication** (Guinée et al. 2002)
  Disturbance to the nutritional content of bodies of water and soils by substances which are sources of plant nutrients, such as nitrates, phosphates, ammonium, etc.
- **Landfilled wastes:**
  Wastes classified as inert substances, wastes destined for biological reactor deposits, and hazardous wastes
- **Effects on plants:**
  Effects on biodiversity, total quantities of biomass, the occurrence of rare species, and stages of development, are assessed.

It should be noted, that although the individual impacts are not explicitly represented in the figures shown, they having no direct bearing on the decision-making process, they do form, in conjunction with the assessment method (see chapter C.II.iii)

Within this study, the following impact assessment methods were evaluated:

a) ReCiPe 2008 (designated successor of Eco-Indicator 99, used for sensitivity analyses only)
b) Eco-Indicator 99 (Hierachist Average / Europe)
c) Climate Change (Intergovernmental Panel on Climate Change)
d) Ecological Scarcity 2006 (method developed in Switzerland, based on Swiss environmental policy)

a) **ReCiPe**

The primary objective of the ReCiPe method (Goedkoop et al. 2009), is to transform the long list of Life Cycle Inventory results, into a limited number of indicator scores. These indicator scores express the relative severity on an environmental impact category. In ReCiPe indicators are determined at two levels:

1. Eighteen midpoint indicators
2. Three endpoint indicators

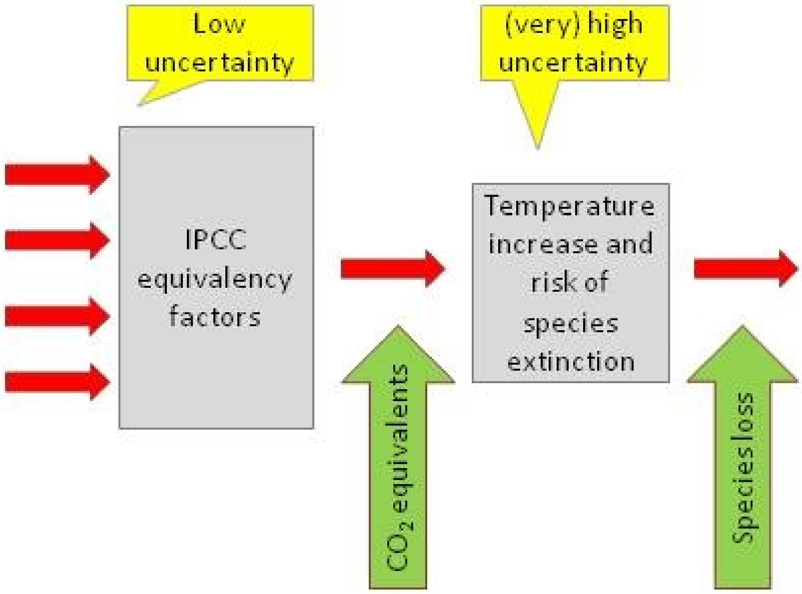


Figure 25 Example of a harmonised midpoint-endpoint model for climate change, linking to human health and ecosystem damage.

ReCiPe uses an environmental mechanism as the basis for the modelling. An environmental mechanism can be seen as a series of effects that together can create a certain level of damage to for instance, human health or ecosystems. For instance, for climate change it is known that a number of substances, increases the radiative forcing, which means heat is prevented from being radiated from the earth to space. As a result, more energy is trapped on earth, and overall temperature increases. As a result of this we can expect changes in habitats for living organisms, and as a result of this species may go extinct.

From this example it is clear that the longer one makes this environmental mechanism the higher the uncertainties get. The radiative forcing is a physical parameter which can be relatively easily measured in a laboratory. The resulting temperature increase is less easy to determine, as there are many parallel positive and negative feedbacks.

Combining mid- and endpoints

In ReCiPe eighteen of such midpoint indicators are calculated, but also three much more uncertain endpoint indicators. The motivation to calculate the endpoint indicators is that the large number of midpoint indicators is very difficult to interpret, partially as there are too many, partially because they have a very abstract meaning. How to compare radiative forcing with base saturation numbers that express acidification? The indicators at the endpoint level are intended to facilitate easier interpretation, as there are only three, and they have a more understandable meaning. The idea is that each user can choose at which level it wants to have the result:

- Eighteen robust midpoints, that are relatively robust, but not easy to interpret

- Three easy to understand, but more uncertain endpoints:
  - Damage to human health
  - Damage to ecosystems
  - Damage to resource availability

The user can thus choose between uncertainty in the indicators, and uncertainty on the correct interpretation of indicators. The figure below provides the overall structure of the method:

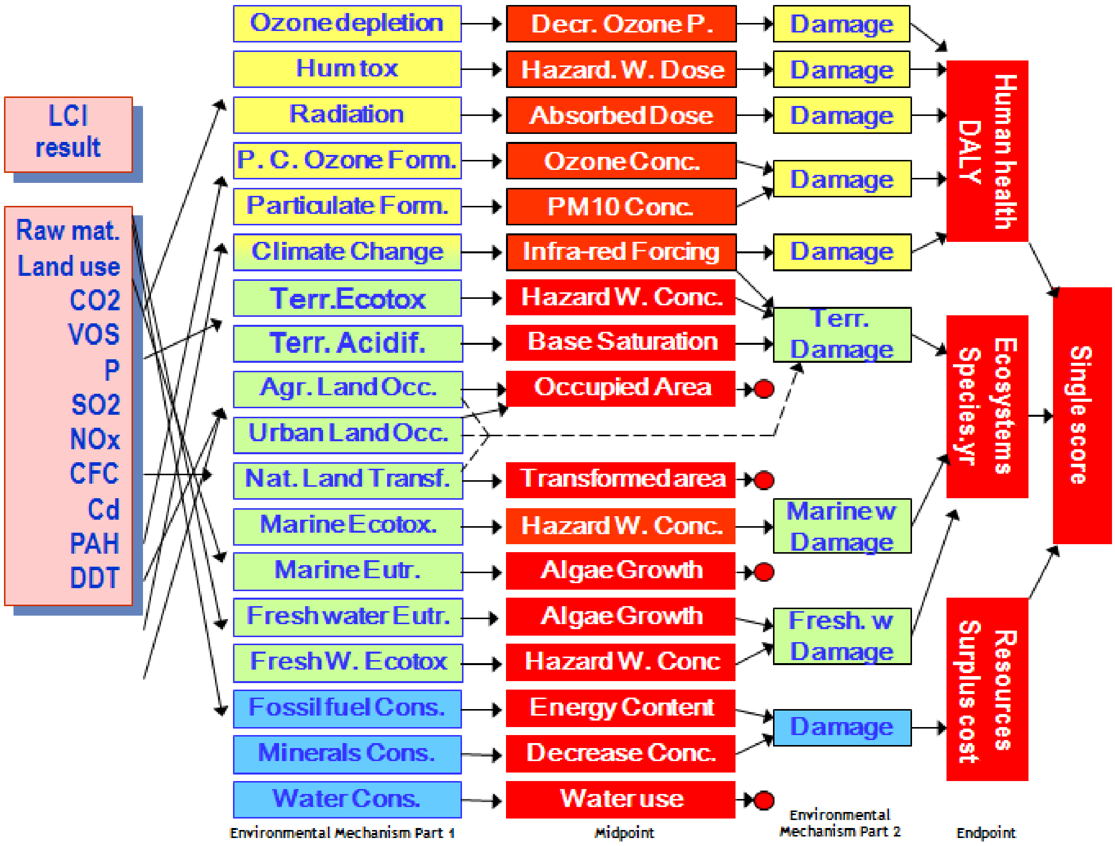


Figure 26 Relationship between LCI parameters (left), midpoint indicator (middle) and endpoint indicator (right) in ReCiPe

b) Eco-Indicator 99

In the Eco-indicator 99 method (Goedkoop, Effting, and Collignon 2000) the impact analysis categories analysed are climate change (or global warming), resource consumption (including minerals and fossil fuels), respiratory effects, acidification & eutrophication, land use, carcinogens and ecotoxicity. Within this methodology, these categories are associated with three types of environmental damages:

1. Human Health (unit: DALY= Disability adjusted life years; this means different disability caused by diseases are weighted);
2. Ecosystem Quality (unit: PDF*m^2*a; PDF= Potentially Disappeared Fraction of plant species);
3. Resources (unit: MJ surplus energy; Additional energy requirement to compensate lower future ore grade).

Normalisation and weighting are performed at this damage category level (end-point level in ISO terminology). The figure below shows an overview of these various steps within the Eco-Indicator 99 method. The whole method is an example of a damage-oriented approach, referring to European conditions.

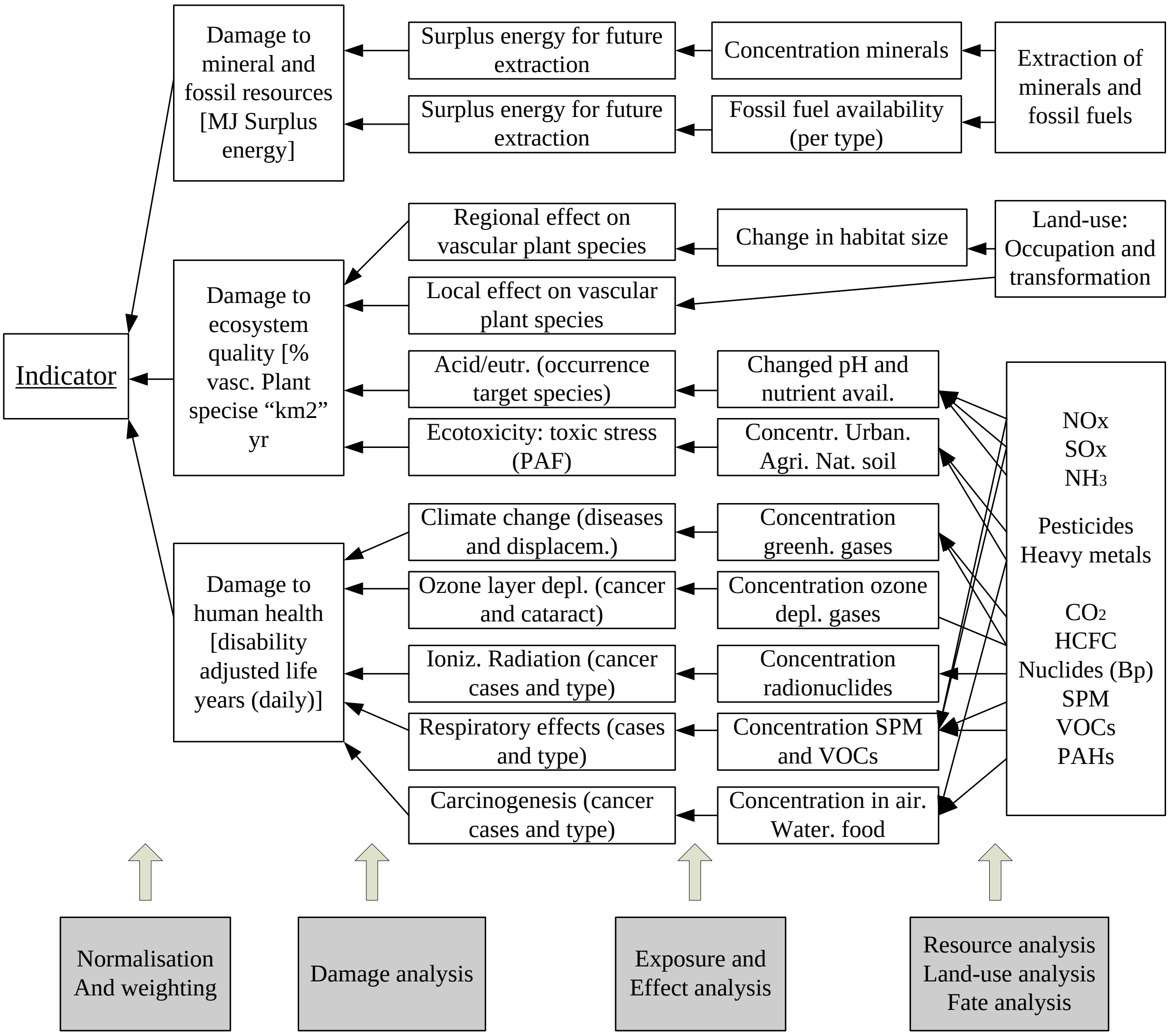


Figure 27 General Representation of the Methodology. The white boxes above refer to intermediate results; the other boxes below refer to procedures (for more, see at: http://www.pre.nl/eco-indicator99/eco-indicator_99_introduction.htm)

c) Climate Change (Intergovernmental Panel on Climate Change)

The change of the average temperature of the Earth as a result of the release of gases such as CO_2, methane and nitrous oxide is described by means of the global warming potential as an indicator. The predictions used here encompass a period of 100 years (IPCC 2007). The most widely known greenhouse gas is CO_2 which is generated e.g. through the burning of fossil raw materials. Beside CO_2 many other greenhouse gases are emitted during processes, such as CH_2 or N_2O. To quantify the so-called greenhouse gas effect (global warming effect) these gases can be expressed in a CO_2 equivalent amount. The climate impact is therefore generally stated in the unit "kg CO_2e", which means "kilogram CO_2-Equivalent", within which the effect of all greenhouse gases over a 100 year period is added.

d) **Ecological Scarcity method 2006**

Aside from the Eco-Indicator 99 method, the ecological scarcity method (Frischknecht, Steiner, and Jungbluth 2008) was used as a second end-point evaluation method in order to describe an environmental footprint (expressed as eco points). The Swiss method Ecological Scarcity was first introduced in 1990. The method was developed with the aim of aggregating all environmental indicators to one single score. The greater the environment impacts of a product, the more environmental impact points are allocated in its evaluation. For companies, the main advantage of using this method is that it measures the ecological performance of a company with reference to the political agenda of the country or region. This method is often used by Swiss companies but also currently enjoys a considerable degree of international acceptance.

This method is built on the assumption that a well-established environmental policy framework (including international treaties or national environmental legislation) may be used as a reference framework for the optimization and improvement of individual products and processes. Hence, for each aspect of the environmental policy, e.g. toxic airborne emissions, soil contamination or energy use, a goal is set. From these goals a critical flow is derived for every emission or for the consumption of resources, meaning that if the actual flow in a certain region is below the defined critical flow level, no damage is expected. If the actual flow is, however, above the critical flow level, the damage may occur. The valuation of the different impacts is achieved by applying the ratio of the actual flow to the critical flow, giving the distance-to-target. The following formula shows how the eco factors can be derived. The flow generated by the product system can then be multiplied with the eco factors to obtain the environmental impact points or shorter eco points (EP), in Germanso called "Umweltbelastungspunkte" (UBP)

$$\text{Eco factor} = \underbrace{C}_{\substack{\text{Characterization} \\ \text{(optional)}}} \cdot \underbrace{\frac{1 \cdot \text{UBP}}{F_n}}_{\text{Normalizing}} \cdot \underbrace{\left(\frac{F}{F_c}\right)^2}_{\text{Valuation}} \cdot \underbrace{c}_{\text{Constant}}$$

with: **C** = **Characterization factor** of a substance, respectively a resource

F_n = **Normalizing flow**: Actual annual flow, applied to Switzerland

F = **Actual flow**: Actual annual flow, applied to the reference region

F_k = **Critical flow**: critical annual flow, applied to the reference region

c = **Constant (10^{12}/a)**

UBP = **eco point** (from the German word Umweltbelastungspunkt): unit of the result

To conduct a sensitivity analyses of the chosen methods, the main calculations were also made by means of further commonly used methods (such as ReCiPe (Goedkoop et al. 2009), CML (Heijungs, Guinée, and voor Milieukunde 1992) or IPCC 2006 (IPCC 2006)).

C.II.iv Comparison of environmental impacts with different LCIA methods

The following three figures display the results for the complete life cycle calculated with two different single point methods and the global warming potential according to IPCC 2007. Both single score methods show that the major environmental impacts stem from the use phase within the upc cablecom network (Figure 28).

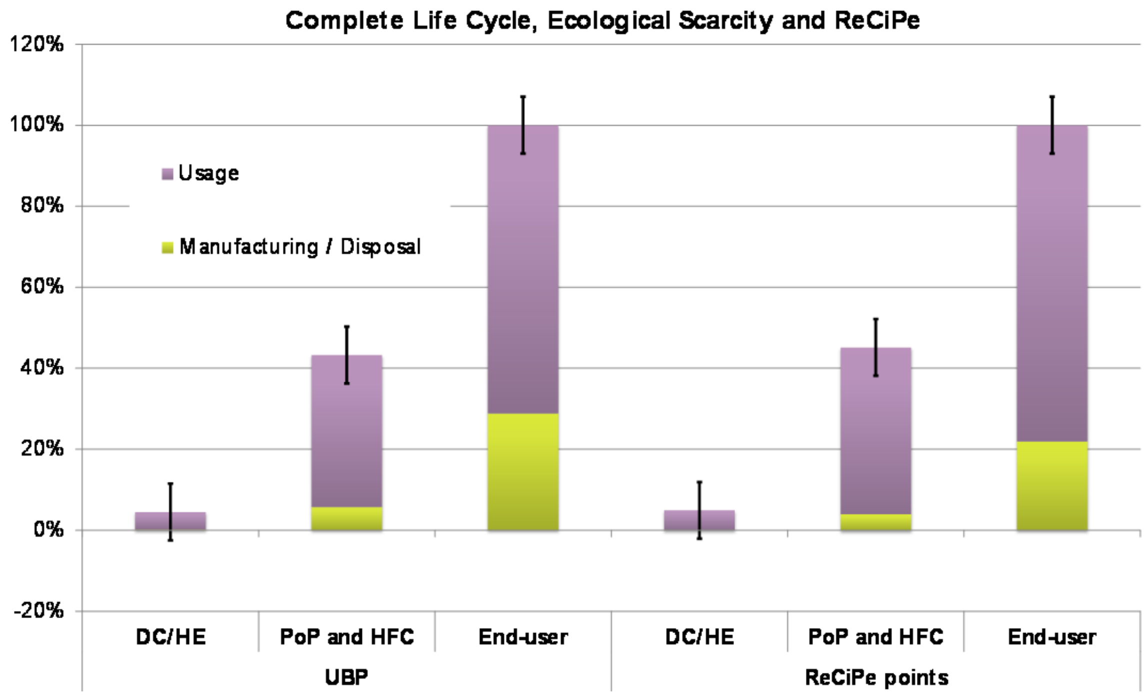


Figure 28 Life cycle impact assessment according to the ecological scarcity method and the ReCiPe method, complete telecom network

For datacentres and the distribution network, the manufacturing phase ranges from negligible to very small compared to the use phase whereas the end user equipment shows a larger impact from production the needed devices. As the completely different approaches of ReCiPe and ecological scarcity still display very similar results, the calculated numbers are assumed to be stable.

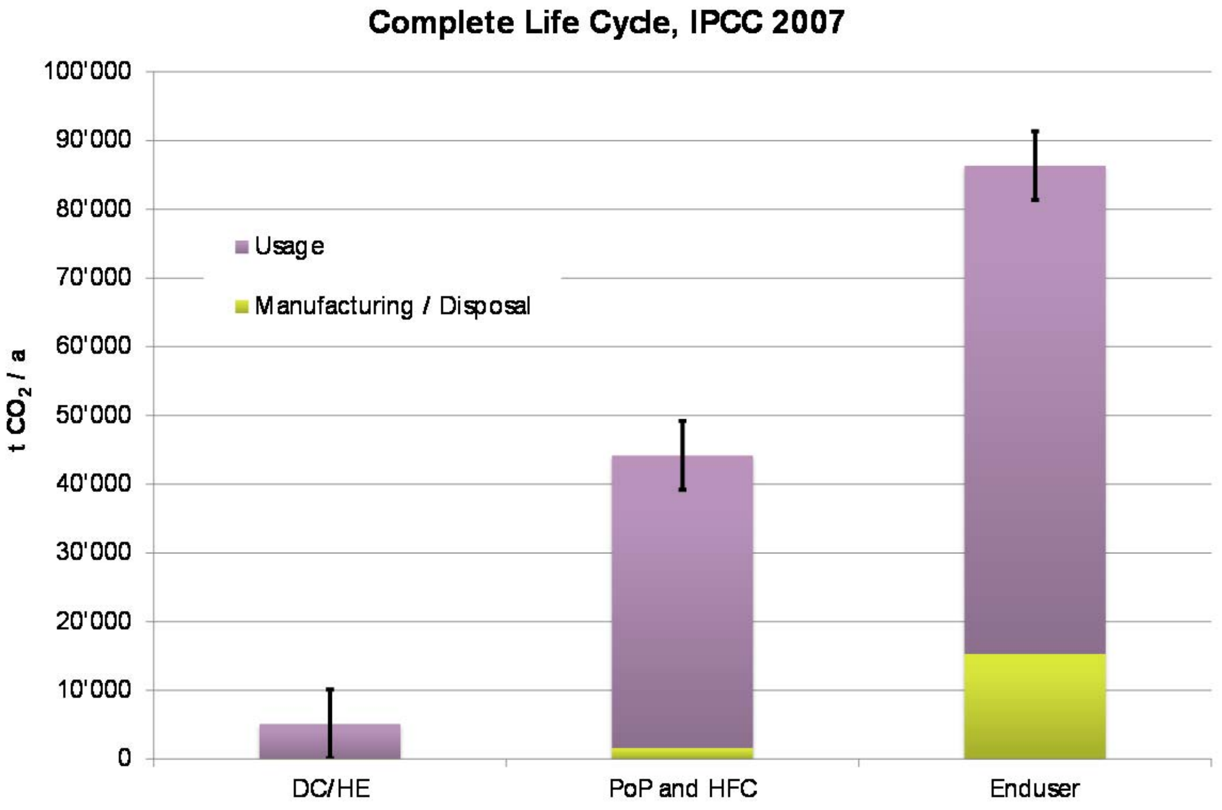


Figure 29 Life cycle impact assessment according to IPCC 2007, complete telecom network

Figure 29 shows the results for CO_2 equivalent emissions only, but for the same complete life cycle calculation as presented in the previous two figures. Although the impact from the use phase becomes even more pronounced compared to the other two methods, the main outcome remains the same. Enduser equipment still has the largest impact while the effects from network components are about half as high and the impact from datacentres remains at about roughly 6% of the impact from endusers.

D Details CPE

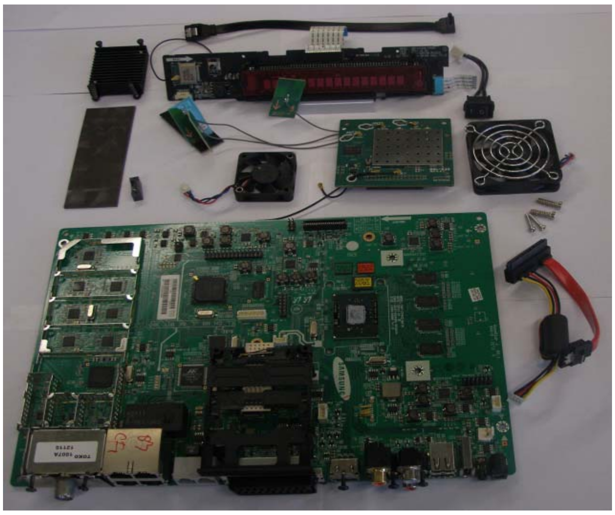
Table 38 Description Samsung SMT-G7400

Samsung SMT-G7400

- Hard drive
- Six tuner
- EuroDocsis 3
- WiFi
- VOD
- Possible to record four several shipments (65 hours HD)
- Internet, Telephony and TV
- Three standby modi

Delivery content

- External power supply
- Remote
- Scart cable
- HDMI cable
- RJ II cable



Components	Weight[g]
Horizon (total)	2328.2
Power-supply unit	375.6
Printed Wiring Board	572
Hard disk	399.51
Cable	234.5
Metal	344.77
Plastic	911.61
Ventilator	58.36

Table 39 Description Cisco 8685

Cisco 8685

- Recorder (30 hours HD)
- VoD
- Hard drive
- Two tuner
- One standby mode
- Internal power supply

Delivery content

- Remote
- Scart cable
- HDMI cable
- Cable Kit Mediabox

Components	Weight [g]
Cisco 8685 (total)	2685.8
Power-supply unit	-
Printed Wiring Board	649.53
Hard disk	545.74
Cable	251.4
Metal	1407.7
Plastic	86

Table 40 Description Pace DCR7111

Pace DCR7111

- Receiver
- No hard drive
- HDMI
- two standby modes
- VOD

Delivery content

- External power supply
- Remote
- Scart cable
- HDMI cable
- Cable Kit Mediabox

Components	Weight [g]
Pace (total)	711
Power-supply unit	120.6
Printed Wiring Board	295.41
Hard disk	-
Cable	173.9
Metal	41.03
Plastic	367.38

Table 41 Description Scientific Atlanta EPC2203

Scientific Atlanta EPC2203

- eTMA
- EuroDocsis 2
- Two RJ II-telephone ports for VoIP

Delivery content

- External power supply
- broadband cable (3m)

Components	Weight [g]
Scientific Atlanta	283.91
Power-supply unit	224
Printed Wiring Board	131
Hard disk	-
Cable	-
Metal [g]	2
Plastic [g]	151

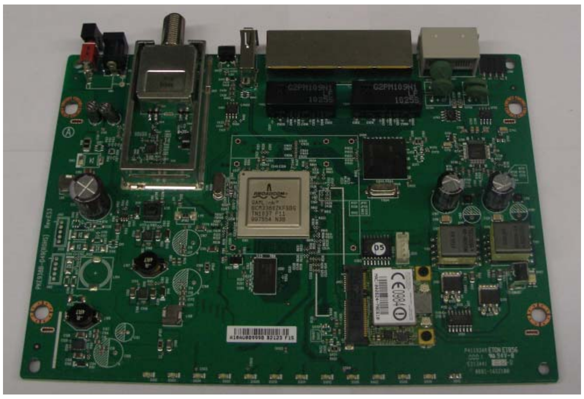
Table 42 Description Thomson TWG870

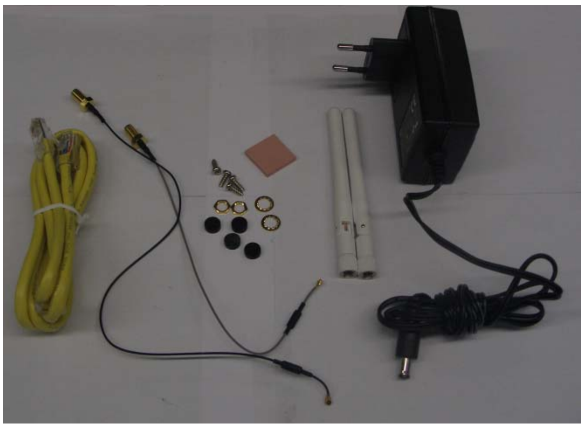
Thomson TWG870

- WiFi
- EuroDocsis 3
- Two RJ II-telephone ports for VoIP
- External antenna
- Possible to disconnect receipt

Delivery content

- RJ II- cable
- External power supply
- Broadband cable (3m)





Components	Weight [g]
Thomson (total)	519.3
Power-supply unit	151.6
Printed Wiring Board	222.48
Hard disk	-
Cable	135.98
Metal	3
Plastic	293.66

E User manual Guide: Samsung SMT-G7400, Horizon Box, power management

HORIZON BOX

The HORIZON BOX option enables you to set and adjust basic functions of the Horizon box.

POWER MANAGEMENT

The options available in POWER MANAGEMENT enable you to set the level of standby power and define standby usage:

STANDBY POWER USAGE Enables you to set the power level used when the Horizon box is in standby mode. The options are HIGH, MEDIUM, or LOW.

> Please note that when the power usage is set to LOW, your Phone and Internet connection will be deactivated.

AUTO STANDBY Enables you to define when the Horizon box automatically switches to standby.

AUTOMATIC
The Horizon box switches to standby at the time set by you or after a set period of time.

OFF
AUTO STANDBY not in use.

AT NIGHT
The Horizon box switches to standby at the default time of 23:00. AT NIGHT standby finishes at a default time of 5:00. These times can be set using DEFINE AUTO STANDBY TIME.

DEFINE AUTO STANDBY TIME Enables you to set the start and end time of AUTO STANDBY.

ACTIVATE STANDBY AFTER enables you to set the period of time after which the Horizon box switches to standby. The time is set in increments of 30 minutes, from 30 minutes to a maximum of 240 minutes. The default is 210 minutes.

SOFTWARE

Enables you to update the Horizon box system with the newest software and checks the version information of the currently installed system software.

DIAGNOSTICS

The options available in DIAGNOSTICS enable you to review the status of various features of the Horizon box

FACTORY RESET

Enables you to reset the Horizon box to the factory default settings with the possibility to keep or delete the recordings stored on the Horizon box disk.

FRONT PANEL BRIGHTNESS

This option enables you to set the brightness of the Horizon box front panel display. The available setting levels are 25 %, 50 %, 75 % and 100 %, where 100 % is the maximum brightness.

F Critical review

Comment: Roland Hischier original Critical Review included 8 points which were recommended to be revised for the final version. All recommendations have been implemented for this version, except the second part of recommendation 6: revision of the name of the scenario 2.

“Energy efficient telecom networks“

Critical Review Report

by

Roland Hischier

for

UPC Cablecom

Zürich (Switzerland)

Date

October 30, 2014

Status

Final Version

Final version ‚critical review' of the study

Energy efficient telecom networks

1 Origination and Course of Action

The herein described critical review process, commissioned by UPC Cablecom (Zürich, Switzerland), has been established in the timeframe of June 2013 to October 2014. Although the examined study is not a traditional life cycle assessment (LCA) study according to the ISO EN DIN 14040 series [1a+b], a critical review process in the spirit of the terms of ISO series [1a] has been established. This on hand critical review report is based on the **final report, version 0.998, dated from October 2014**. Its final version will be integrated in the very final version of the report of this study.

The study has been established by collaborators of the Center for Resource Efficiency of the Department of Renewable Energies and Resource Efficiency (IBRE) at University of Applied Sciences and Arts Northwestern Switzerland, Brugg-Windisch, together with the Zürich office of the company Carbotech Ltd, Basel. The review was done by Dr. Roland Hischier, Empa St. Gallen (Switzerland).

The critical review was established as a so-called accompanying survey, i.e. the reviewer was involved already in a rather early stage of the study, and thus had possibilities to influence the further development of the whole study from that moment on. Hence, besides the above mentioned report, the reviewers got multiple draft versions, and had several oral discussions with the involved people, especially from the company Carbotech Ltd, that did the actual LCA calculations.

The work of the reviewer took place in an open, friendly ambiance; requested documents and information were always delivered in time by either of the two authors. The commissioner of the study (UPC Cablecom) was directly involved in the very end of this review process only; the technical arbitrations took place between the authors and the commissioner only, without any involvement of the reviewer. Nevertheless, the reviewer judges the complete process as well as the dependency triangle between commissioner, authors of the study and reviewer still as sufficient.

Within the framework of the complete review process, the following meetings took place:

- 1st meeting: May 31, 2013, in Zürich (with Carbotech Ltd only) ;
- 2nd meeting: April 24, 2014, in Zürich (with Carbotech Ltd only) ;
- 3rd meeting: September 22, 2014, in Zürich.

2 Comments about the report

2.1 Criteria

Life Cycle Assessment studies follow the requirements of the ISO 14040 / 14044 standards; ISO standards that are used for the review process here as well. According to chapter 7.2 of the ISO standard 14040, a critical review may facilitate the understanding and enhance the credibility of such a study. Therefore, the following criteria have been examined here:

- the acceptability of the methodology and assumptions used, their consistency with the goal and scope of the project [-> see chapter 2.2 “Methodology”];
- the **acceptability of the data** used in the study and their consistency with the goal [-> see chapter 2.3 “Data”];
- the **transparency and the consistency** of the study **report** [-> see chapter 2.4 “Report”];
- the **compatibility of the conclusions with the goal**, method, data and assumptions used [-> see chapter 2.5 “Results & Conclusions”]

2.2 Methodology

Goal and scope of the study are clearly stipulated; there is a complete chapter dealing with the goal and scope. It can be seen from this chapter that the entire physical infrastructure of UPC Cablecom, without any kind of end-user devices (i.e. television, computer, …), is the middle of all investigations – taking into account the complete life cycle of this infrastructure – from the extraction of the used raw materials to the final disposal / the recycling of the various elements.

The functional unit – one-year use of telecommunication services of a cable network provider – is a reasonable choice and makes sense in the context of this study (and its goals) here. Its practical implementation, as well as the limitations coming from this choice, is documented in a clear and transparent manner in the study report.

The chosen system boundaries – taking into account the entire infrastructure of UPC Cablecom over its complete life-cycle – make sense in relation to the objectives of the study.

The End-of-Life phase of the various devices is included – however, the report is not giving any transparent information about the way, how this last life-stage has been modelled. As various studies in the past have shown that the disposal/recycling step of electronic components is of minor relevance (compared to the production and the use stage of such devices), this lack of transparency has no negative influence on the overall validity of this study here.

Hence, it can be concluded that all in all the method and assumptions used in the framework of this project here are logic and scientifically correct. They are in accordance with the goal and the scope of this study here, but also with the ISO 14040 standard.

2.3 Data

The requirements and the actual data collection process are described in an open and comprehensive manner in the project report. They are all in accordance with the goal and scope of the study. Composition data for the actual CPEs (i.e. the end-user equipment to access the UPC Cablecom network), being the most relevant part of the examined system here, are obtained directly from the commissioners of this study. Energy consumption values of these devices have been measured in the framework of this study here – representing real first-hand information. For the remaining data (especially the further equipment), exemplary devices have been chosen and their modelling has been done, based on producer data sheets as well as expert assumptions. The whole process is documented in details in Annex B.

In the background, the public database ecoinvent (version v2.2, as stipulated in Annex C.II.i) has been used. The database ecoinvent is currently one of the most comprehensive and most up-to-date background databases, used by several thousands of customers all over the world.

All in all it can be concluded that the used data are adequate and in accordance with the goal and scope of this study here.

Between the 2nd and the 3rd meeting, the reviewer visited Carbotech Ltd in order to get a more detailed and in-depth view of the calculation models used for this study here. This examination of the calculation model allowed to the reviewer to verify, by random samples, the calculation work done within this study and to see that the material and energy flows (as far as verified during this visit) are linked in a logical and correct way.

2.4 Report

The report (for the review, version v0.998 has been available) is in its large parts in a clear and logic way structured, most of time easy understandable and properly designed (exceptions – see list below). More detailed input data and calculation spreadsheets are summarized in the Annex of the report, allowing to the interested reader a very detailed insight into the data used in for this study.

There are however still some points where the reviewer is convinced that the transparency as well as the clarity of understanding of the report could be easily improved. These points are the following (see below).

2.5 Results and Conclusions

The conclusion chapter summarizes in a comprehensive and adequate manner the results of this project – and thus the content of the report. The authors have integrated in all the result figures error bars for the various values – showing like this in a very easy and clear manner the influence of the “uncertainty” on the overall evaluation of the results.

All the recommendations mentioned are in accordance with the calculation results.

2.6 Final Remarks

The complete study has been established in a transparent and logic way; its present report is complete. The requirements concerning a sound and adequate Life Cycle Assessment study in relation to the initially formulated goal and scope are fulfilled; conclusions and recommendations mentioned in the report are in accordance with the goal of the study.

The entire review process has been established in a very constructive atmosphere, especially between Carbotech Ltd (executing the actual LCA calculations) and the reviewer – for which the reviewer would thank. Actually, this review procedure will make the complete report more valuable for the commissioner as well.

3 References

[1a] International Standard (ISO): Environmental management - Life cycle assessment - Principles and framework. Standard ISO 14040:2006 (2006).

[1b] International Standard (ISO): Environmental management - Life cycle assessment – Requirements and Guidelines. Standard ISO 14044:2006 (2006).

St. Gallen, End of October, 2014

Dr. Roland Hischier

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Chapter	Comments / Questions
1 (p.12)	In the very last paragraph, the reference to the results chapter is wrong – it should be “chapter 6” and not (as written) “chapter 5”.
3.1, 3.2	You are referring to three different versions of the LCI database ecoinvent for the background data here – while according to Annex C.II.i the version 2.2 only has been used. Hence the correct (and unique) reference for the used background LCI data is “ecoinvent, 2010” (point that needs to be corrected also in Annex C.II.i).
4.1	The whole text is formatted as title, instead of being formatted as text.
4.2.1	I suggest moving Figure 3 after the first paragraph here (where you refer to this figure for the first time). This makes the whole chapter 4.2.1 much easier to read. Please check furthermore the references to the tables in the Annex – according to my understanding, references in point 2 (“point of presence”) should be to table 24 (not 23) and in point 3 (“hybrid fiber coaxial”) it should be table 23 (not 22).
4.5	The title here should rather be “Baseline & Scenarios” (as you describe both). Furthermore, I suggest revising the introducing paragraph, as this text is rather difficult to understand.
4.5.2 ff	The various scenarios are still rather difficult to understand – especially as part of the information is not in chapter 4.5, but later in the report. Here I suggest to revise the description of the various scenarios once more …e.g. by starting with the overview of the scenarios as a first sub-chapter (i.e. the existing chapter 4.5.6), including table 7 into this chapter. Objective of this overview has to make clear the differences between the various scenarios examined. Furthermore, I suggest to revise the name of the scenario 2 – as this scenario is (similar as scenario 1) assuming no change in the number of CPE (opposite to the scenario 3), but rather a change in the actual type (and use pattern) of CPE.
Table 4 (p.35)	This table shows a different number of CPEs for 2012 than Table 10 and Table 15; however, Tables 32 & 33 (in Annex B.II) show than again the same value as Table 4. This is confusing for the reader - please correct this point (e.g. by highlighting in the three tables that the reported Multimedia Gateways are not taken into account for the calculations due to ….).
Table 6 (p.38)	I would move this table before the second-last paragraph on page 36 (i.e. before the paragraph starting with “Table 6 shows household numbers …”), making the report more easily understandable.