The Effect of Revised Characterization Indices for N_2O and CO_2 in Life Cycle Assessment of Optical Fiber Networks – The Case of Ozone Depletion and Aquatic Acidification

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Abstract

The general trend for fixed broadband is that FTTx will overtake ADSL platforms and the number of FTTx subscribers is increasing exponentially. Moreover, it is likely that the ozone depletion potential (ODP) of dinitrogen oxide (N_2O) and the aquatic acidification potential (AAP) of CO_2 have been underestimated in LCA studies. The aim of this study is for the first time to assess the ODP and AAP of different FTTx network deployments in Italy adding the most recent characterization factors for N_2O and CO_2. An LCA case study was conducted covering three FTTx deployments (FTTC is compared to FTTB and FTTH) for 10,000 homes during one year in Italy. The focus is primarily on ODP and AP results in different life cycle phases. The ODP results suggest, using 0.017 kg/kg instead of 0 kg/kg as CFC-11e factor for N_2O, for the greenfield/high power customer premise equipment (CPE) scenario, that FTTB, FTTC, and FTTH all rises from around 80–100 gram to around 600–700 gram CFC-11e/year dominated by the use and deployment stages. For AAP, with 1.752 kg/kg as SO_2e factor for CO_2 instead of 0 kg/kg, the rise is from 5–6 tons to 1,500–1,800 tons SO_2e/year. The weight of the use stage is increasing with these new characterization indices. For FTTC

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controlling the power of the CPE is more important than the technique used for deployment. However, for FTTB and FTTH the deployment technique becomes almost as important as the power mode. Concerning FTTH, the main drivers for CFC-11e footprint are the electricity usage of the home gateways (HGWs), their manufacturing, and the use of diesel trucks in traditional civil works and mini-trench deployment. The inclusion of "average" bandwidth gives an advantage for FTTH as more data can be transferred more efficient and faster. For brownfield deployment in Italy (low power CPEs), FTTH architecture has the lowest amount of total CFC-11e emissions (appr. 130 grams). One of the most important criteria, from ozone depletion point of view, when choosing an FTTx network, is whether fiber has been deployed or not. Including the ODP factor for N_2O increases the ODP score by 430–660% for the present systems. The increase for AAP is dramatic and shall be interpreted as a suggestion to include CO_2 acidification in further LCIA research.

Keywords: aquatic acidification, CO_2, FTTx, FTTH, life cycle assessment, N_2O, optical fiber networks, ozone depletion.

Notation

AAP	Aquatic Acidification Potential
BF	Brownfield
FTTx	Fiber To The X
GF	Greenfield
ODP	Ozone Depletion Potential
RMA	Raw Material Acquisition

1 Introduction

Global communication based on ICT is rapidly increasing. The EU project "Energy Aware Radio and Networking Technologies" (EARTH) has predicted that the data traffic between 2010 to 2020 will rise by something like 1,700% and the number of ICT Equipment in use by around 100% [1]. The general trend for fixed broadband is that fiber to the X (FTTx, x = Cabinet, C, Home, H, Building, B) will overtake asymmetric digital subscriber line (ADSL) platforms as the number of FTTH subscribers is increasing exponentially [2]. Another trend is that carbon emissions caps or taxes probably

will be sooner or later introduced in a formal way. Moreover, within the ICT sector several standardization efforts have been finalized [3, 4]. Taking this into account, Telecom Italia and Huawei jointly performed a streamlined life cycle assessment (LCA) study in order to estimate the carbon footprint of the introduction of three different FTTx networks [5, 6]. Through the LCA study it was possible to propose an optimization the system under study by finding the energy usage and carbon emission "hot-spots". In life cycle simulations carbon dioxide emissions are rather straightforward to estimate compared to other footprints and the energy used is often fossil based. As the databases and LCA methodologies are improved, the introduction of other footprints will be trivial. As research produce more knowledge our understanding of LCIA indices are revised. Recently Lighthart et al. [7] showed that improved understanding of LCIA indices in the CML baseline 2000 LCIA method (CML) is highly relevant for LCA studies using zinc products. Here the ozone depletion potential (ODP by CML) of the FTTx networks is discussed in light of new facts about the underestimated CFC-11e footprint of N_2O [8]. In the same manner the aquatic acidification potential of CO_2 (AP by CML) is explored.

The problem to be addressed is: What are the implications for an LCA study of FTTx networks of adding characterization indices for N_2O for ODP and CO_2 for AAP in CML?

2 Materials and Methods

The present research is based on a previously performed LCA [1, 5, 6] and an LCA from 2008 by FTTH Council Europe for an FTTH network where the functional unit was "allow a European citizen to use FTTH technologies during one year" [9]. The scope included production of passive equipment such as optical fiber cables and boxes and active equipment such as optical network terminals (ONT), optical line terminals (OLT) deployment of cables, use of network (ONTs and OLTs), and incineration/landfill of cables. The environmental benefits per year were also estimated and thereby the result is displayed as the number of years it would take to "pay" for the environmental loadings caused by the FTTH network. FTTH networks are usually deployed in a number of characteristic topographies. The amount of optical fiber cable and deployment technique will differ according to topography. For example, for "Urban Dense" topography FTTH Council Europe used 60% re-use of existing infrastructure, 20% traditional civil works, and 20% micro-trenching. "Urban Wide" and "Rural Deployment" use different shares of deployment techniques. Anyway, the depreciation for a scenario of 60% Urban Dense,

30% Urban Wide and 10% Rural Deployment was 9.6 years as far as ODP [9, section 7.1.1]. Assuming a service life of 5 years for active equipment and 30 years for the remainder, the FTTH network would generate 0.005 g CFC-11e (ODP) and 90 g SO2e (AAP) per subscriber per year and micro-trench deployment would be the main contributor. In this research for the deployment impacts per type and distance the impact assessment numbers of FTTH Council Europe were used.

The added value of the present paper is the first case study to our knowledge introducing a "new" LCIA factor for CO_2 for AAP. Also the N_2O (0.017 kg CFC-11e/kg) developed by Ravishankara et al. [8] within ODP has not been used much [10, 11].

The role of CO_2 in *lake/sea* acidification is not as clear as for *ocean* acidification [12, 13]. Eutrophication also enhances the CO_2 acidification [13].

2.1 LCA Basics

LCA is a standardized method [3, 4, 14, 15] for making model based estimations of the environmental exchanges associated with technology functions.

LCA studies are required to follow four main steps:

1. Goal & scope definition,
2. Inventory analysis,
3. Impact assessment of the inventory, and
4. Interpretation of the impact assessment.

The impact assessment is usually done with so called mid-point and/or end-point valuation.

This paper will highlight some advancement in impact assessment compared to a previous carbon footprint study [5, 6].

2.2 Goal & Scope

The *studied product system* (SPS) is shown in Figure 1 denoted by the dashed line. The architectural scope would be rather wide if all system nodes of a fixed network would be included and allocated to the specific network. The transport and core network equipment such as local area network (LAN) switches and routers are not parts of the SPS as well as the personal computers (PCs) and already installed copper cables. Included is the fixed access network from the OLT on the Central Office to the ONU/ONT on the user

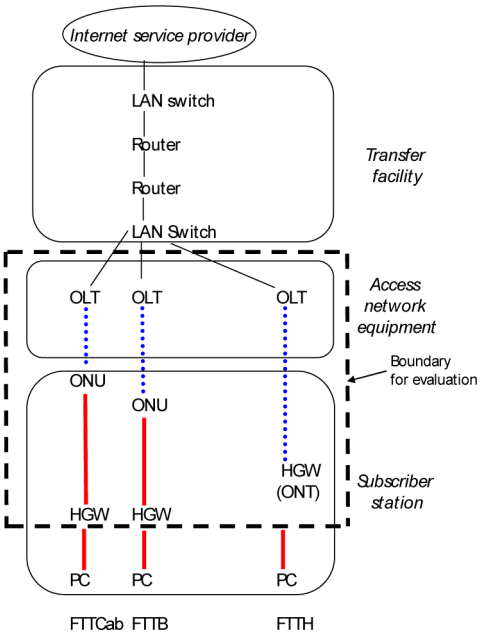


Figure 1 Studied product system of LCA study.

side as well as the optical distribution network (ODN) connecting them. The scope was chosen to highlight differences in between FTTx technologies. The dotted lines between OLT & ONU and OLT & HGW represent optical fiber calbes. The full lines between ONU & PC and HGW & PC, respectively, represent copper cables.

The LCA study performed has neither included the life cycles of internet service provider and the transfer facility, nor the PC. For the environmental LCA the functional unit (f.u.) is *broadband network in an Italian urban dense area for use by 10,000 homes during one year*, and the system boundaries are from cradle-to-grave.

Summary of SPS, cut-off and excluded building blocks:

- SPS: RMA+Production and Use of HGW, ONT, OLT, optical fiber, Deployment of optical fiber, End-of-life treatment of hardware and optical fibers.
- Cut-off from SPS: End-of-life treatment of hardware and optical fibers, cooling of central offices, support equipment RMA+Production+EoLT

Table 1 Assumptions for greenfield and brownfield deployment in Italy.

Deployment type	Network type		
	FTTC Brownfield scenario/Greenfield scenario (%)	FTTB Brownfield scenario/Greenfield scenario (%)	FTTH Brownfield scenario/Greenfield scenario (%)
Mini-trench	15/35	0/25	0/25
Traditional civil works	15/35	0/25	0/25
Existing deployment	70/30	100/50	100/50

- Excluded: End-user equipment such as PCs, C&C Network, Data centers, Service Provider activities.

Scenario development is unavoidable in LCA studies and here a greenfield and brownfield scenario for deployment was set according to Table 1.

Typical for ICT networks is that the lifetime of system parts vary and this has to be handled when expressing the result annually as required by the recent ETSI and ITU LCA standards [3, 4]. The lifetime of the studied FTTx networks was assumed to be 30 years and therefore the amounts of different hardware and cables is proportional to their lifetime. For example, 26 tons of fiber cables are deployed for FTTH, but per year only 0.87 ton is used as the fiber cables can be in the ground for 30 years. Per year only 2,000 home gateways (HGW (ONT), Figure 3) are used as their lifetime was assumed to be 5 years.

The purifying and drawing of optical fiber in its production were excluded. Other excluded parts are splitters and distribution boxes. These parts were excluded as they likely are a small share of the total score. These omitted parts constitute the so called “cut-off” from the SPS. Anyway, the greenfield scenario is a kind of “worst-case” scenario regarding power usage, running of digging machines and amount of deployed optical fiber cable. The detailed architecture and parameters of FTTx solutions are also defined. FTTH case is shown in Figure 2 as an example.

2.3 Inventory Analysis

Starting from the power usage measurements of three different networks [16], the scope was expanded in order to include manufacturing of hardware, transport of hardware from China to Italy, deployment of each network, and end-of-life. Maintenance & repair during the use phase are excluded.

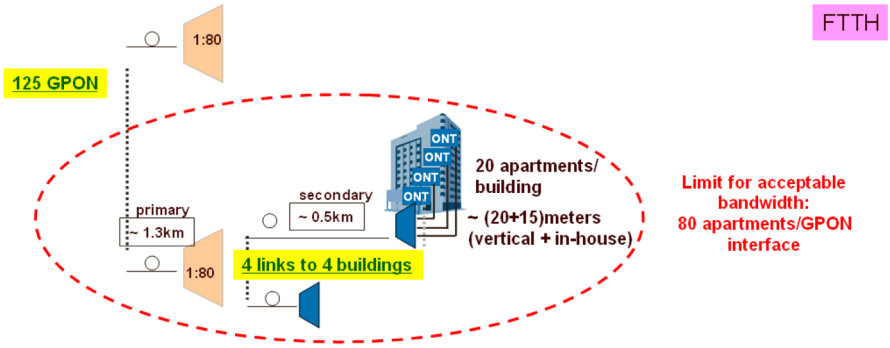


Figure 2 Architecture for FTTH.



Figure 3 One piece of HGW (ONT) (EchoLife HG863).

The assembly of the hardware is assumed to be entirely in China. Huawei provide the OLTs (Huawei product name *MA5600T*), ONUs (*MA5603* and *MA5606*), outdoor cabinets for ONU (*B01D200* and *F01E100*), HGW (ONT) equipment (*EchoLife HG863*, Figure 3) for FTTH as well as HGW very-high-bitrate DSL (VDSL) modems (*EchoLife HG520v*) used by FTTC and FTTB.

The cradle-to-gate analysis of optical fiber cables is likely underestimating the purification and drawing processes. The model is based on Unger and Gough material content [17] and appropriate processes from the LCA tool SimaPro 7.3.2.

Concerning the digging methods in deployment, three different solutions have been considered: mini-trench, traditional civil works and usage of existing channels. For FTTH, FTTB, and FTTC, 412.5, 315 and 65 km optical fiber cable is deployed, respectively. For example the distance deployed cable

Table 2 Summary of life cycle inventory for FTTH networks per functional unit.

Substance	Unit	Indicative Uncertainty	FTTC	FTTB	FTTH
CO_2	kg	±30%	880,000	1,000,000	810,000
CFC-11	kg	±16%	0.01	0.04	0.05
Halon 1211	kg	±88%	0.007	0.008	0.007
Halon 1301	kg	±74%	0.002	0.002	0.002
CH_4	kg	±76%	38	90	48
N_2O	kg	±50%	31	35	28
SO_2	kg	±21%	3,600	4,100	3,400
NH_3	kg	±57%	28	31	21
NO_2	kg	±54%	1	3	14
NO_x	kg	±54%	2,600	2,800	1,700

for FTTH is calculated as:

$$G \times (D_P \times R_P + D_S \times R_S \times L) \tag{1}$$

where G is the number of (gigabit capable passive optical networks) GPONs ($= 125$); R_P is the average reduction coefficient for primary network, between 0.5 (best) and 1 (worst) ($= 1$); R_S is the average reduction coefficient for secondary network ($= 1$); D_P is the primary distance optic fiber [km] ($= 1.3$); D_S is the secondary distance optic fiber [km] ($= 0.5$); L is the number of links ($= 4$) (see Figure 2).

The average reduction coefficient, R, reflects the share of links which are included under the same digging.

In Table 2 a summary of the inventory analysis for Greenfield/High power scenario is shown.

The CO_2 values in Table 2 are lower than the ones in [5, 6] due to lower contribution per km from deployment.

On a high level, the LCA model for FTTH network consists of 14 main modules (Tables 3 and 4). The amount needed of each LCA module is decided by each individual FTTH deployment. Concerning the digging methods in deployment, three different solutions have been considered: mini-trench, traditional civil works and usage of existing ducts.

Perhaps the most interesting observation from Table 3 is the 690% increase for Italian (average retrospective) electricity production. This is of general relevance as electricity is used in most LCA studies.

Table 4 strongly suggests that the role of CO_2 in LCIA calculations which involve aquatic acidification needs to be clarified further.

Table 3 Summary of life cycle CFC-11e emissions of main LCA modules for FTTH network.

Name	Unit	g CFC-11e (N_2O = 0) per unit	g CFC-11e (N_2O = 0.017 kg/kg) per unit	% increase due to N_2O new ODP index
1. Optical fiber production	km (1km weighs appr. 34 kg)	0.14	0.16	14
2. Transport model from China to Italy	ton×km	0.36	0.64	78
3. Existing infrastructure deployment	km	∼0	1	not applicable
4. Mini-trench deployment	km	10	21	110
5. Traditional civil works deployment	km	4	8.3	110
6. Electricity, Italy (average retrospective)	kWh	5.2×10^{-5}	4.1×10^{-4}	690
7. HGW (ONT) production	kg	1.9×10^{-3}	2.7×10^{-2}	1,360
8. OLT production	kg	1.8×10^{-3}	1.4×10^{-2}	680

3 Results

3.1 Impact Assessment

Figures 4 and 5 show some ODP results for the greenfield and brownfield scenarios, respectively. The production includes manufacturing of network equipment and transport from China to Italy. Deployment includes manufacturing of site materials (e.g., concrete) and deployment operations.

For FTTH, when adding the CFC-11e factor for N_2O, the relative weight of Deployment (GF) decreases from 44 to 18% and the ICT Equipment Use increases from 48 to 72%.

For all networks, the production, deployment and use phases are more important than others. The use stage is doubtlessly the main contributor to CFC-11e footprint for the greenfield deployment scenario.

As shown in Figure 5 for the greenfield deployment, the CFC-11e results for calculated by LCA are (on average) 40% higher than results calculated by multiplying the electricity usage by a CFC-11e emission factor.

Table 4 Summary of life cycle SO_2e emissions of main LCA modules for FTTH network.

Name	Unit	kg SO_2e (CO_2 = 0) per unit	kg CFC-11e (CO_2 = 1.752 kg/kg) per unit	% increase due to new CO_2 AP index
1. Optical fiber production	km (1 km weighs 34 kg)	0.91	213	23,300
2. Transport model from China to Italy	ton	9.7	1,800	18,400
3. Existing infrastructure deployment	km	1.6	346	21,500
4. Mini-trench deployment	km	88	33,200	37,600
5. Traditional civil works deployment	km	62	12,800	20,500
6. Electricity, Italy (retrospective)	kWh	0.003	1.1	36,600
7. HGW (ONT) production	kg	0.96	66	6,800
8. OLT production	kg	0.23	32	13,800

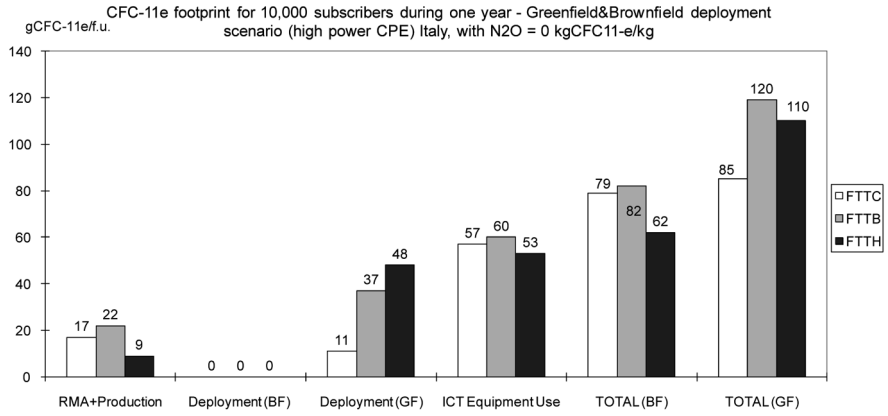


Figure 4 CFC-11e footprint with N_2O = 0 CFC11-e kg/kg for the greenfield and brownfield deployment in Italy.

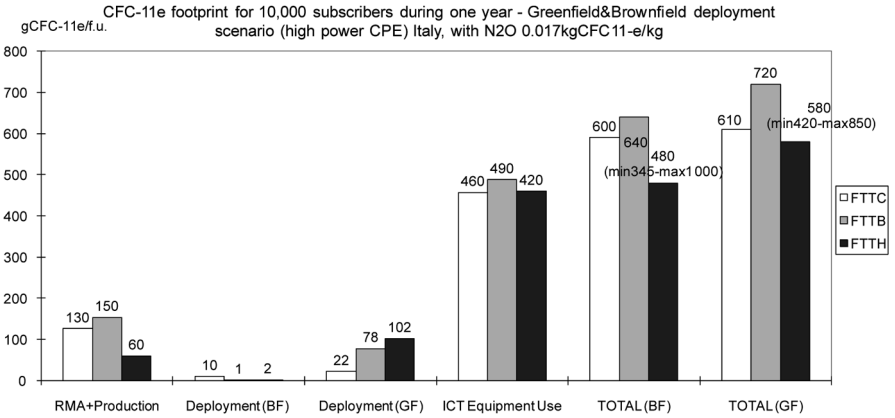


Figure 5 CFC-11e footprint with N_2O = 0.017 kg CFC11-e/kg for the greenfield and brownfield deployment in Italy.

3.2 Aquatic Acidification of CO_2

Potentially acidifying emissions are particularly SO_2 and NO_2 which in LCIA are aggregated based on their H^+ formation potential.

$$SO_2 + H_2O \rightarrow 2H^+ + SO_4^2 \tag{2}$$

$$NO_2 + \frac{1}{2}H_2O \rightarrow H^+ + NO_3^- \tag{3}$$

SO_2 is commonly the basis for acidification in LCIA and other compounds are expressed in SO_2-equivalents (SO_2e).

Acidification potential of SO_2 = two moles H^+/molecular mass of SO_2 = 2/64.0644 = 0.031 H^+/g SO_2 which corresponds to 1 g SO_2e/g in LCIA methods.

Acidification potential of NO_2 = 1 mole H^+/molecular mass of NO_2 = 1/46 = 0.021 H^+/g NO_2. 0.021/0.031 = 0.7 g SO_2e/g.

$$CO_2 + H_2O \rightarrow 2H^+ + CO_3^{2-} \tag{4}$$

One mole of CO_2 produces two moles of H^+. Acidification potential of CO_2 = two moles H^+/molecular mass of CO_2 = 2/44 = 0.0454 H^+/g CO_2. 0.0454/0.031 = 1.46 g SO_2e/g.

The characterization factor for SO_2 in AAP in CML is 1.2, hence CO_2 could have a factor of 1.752.

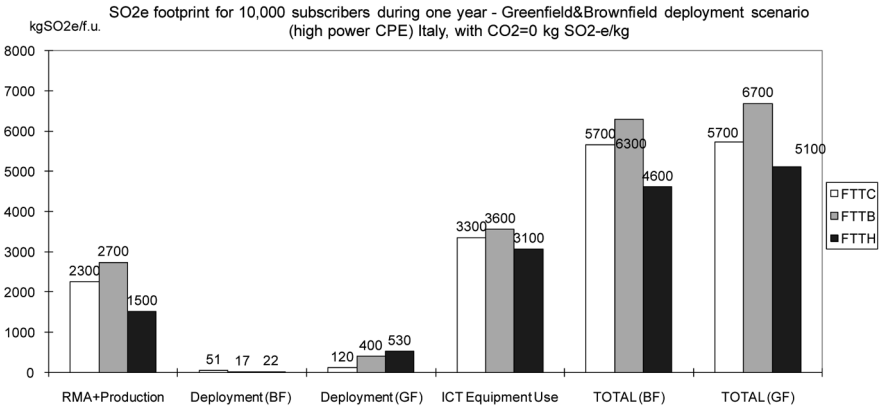


Figure 6 SO_2e footprint with $CO_2 = 0$ SO_2e/kg for the greenfield and brownfield deployment in Italy.

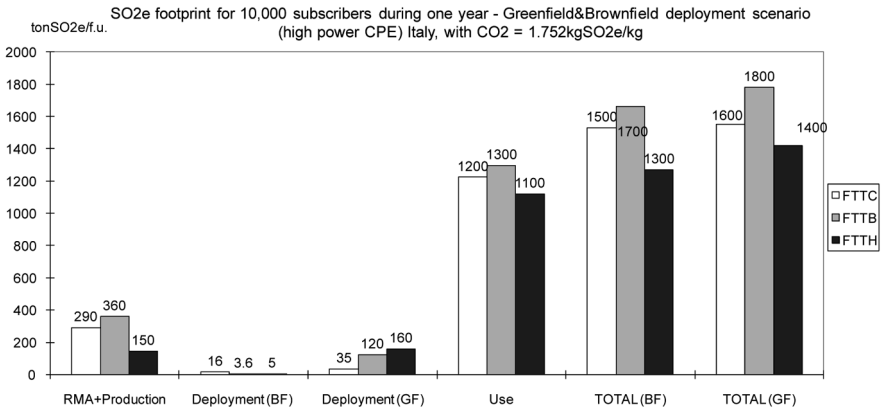


Figure 7 SO_2e footprint with $CO_2 = 1.752$ kg SO_2e/kg for the greenfield and brownfield deployment in Italy.

From this the simplification is done that CO_2 has 1.46 times the aquatic acidification of SO_2 in LCIA methods. The implications for acidification in CML baseline 2000 are shown in Figures 6 and 7.

For FTTH, when adding the SO_2e factor for CO_2, the relative weight of Deployment (GF) is about the same 10%, but the RMA+Production share decreases from 30 to 10% and the ICT Equipment Use increases from 60 to 78%.

4 Discussion

The most important part of an LCA is the interpretation which includes contribution, uncertainty, and sensitivity analyses in which the robustness of the results is tested.

According to contribution analysis (Figures 4–7) the most important phase is Use followed by RMA+Production, and Deployment. Specifically for FTTH the most contributing processes are Italy electricity production and diesel burnt in building machines.

4.1 Interpretation – Uncertainty

The uncertainty analysis in LCA investigates how the precision of used data influence the spread of the final score. The difference between the systems was shown to be enough to draw conclusions as the LCA tool SimaPro quantifies the process correlation. However, the uncertainties of ODP and AAP indices were not included here.

4.2 Interpretation – Sensitivity

To further exemplify the sensitivity analysis, below the greenfield deployment/high power CPE scenario is compared to a more realistic brownfield deployment/low power CPE scenario. For the alternative brownfield deployment assumption, FTTB and FTTH use 100% and FTTC uses 70% of existing infrastructure (Table 1). The realistic low power hypothesis is that the HGWs are on full mode for four hours and in low power mode for 20. This reduced the electricity usage by more than 80% for these HGWs. For ODP LCIA score of FTTH, the brownfield deployment/low power scenario is 77% better than the greenfield deployment/high power CPE scenario. Figure 8 shows the combined effect of deployment technique and power mode for CPEs.

For FTTC controlling the power of the CPEs is more important than the technique used for deployment.

For FTTB and FTTH the deployment technique becomes more important. Moreover, for the brownfield deployment/high power CPE scenario, i.e., when optical fibers have already been deployed, FTTH is better (480 g) than FTTC (600 g) and FTTB (640 g). This means that an important criteria from CFC-11e point of view, when choosing an FTTx network, is whether fiber has been deployed or not.

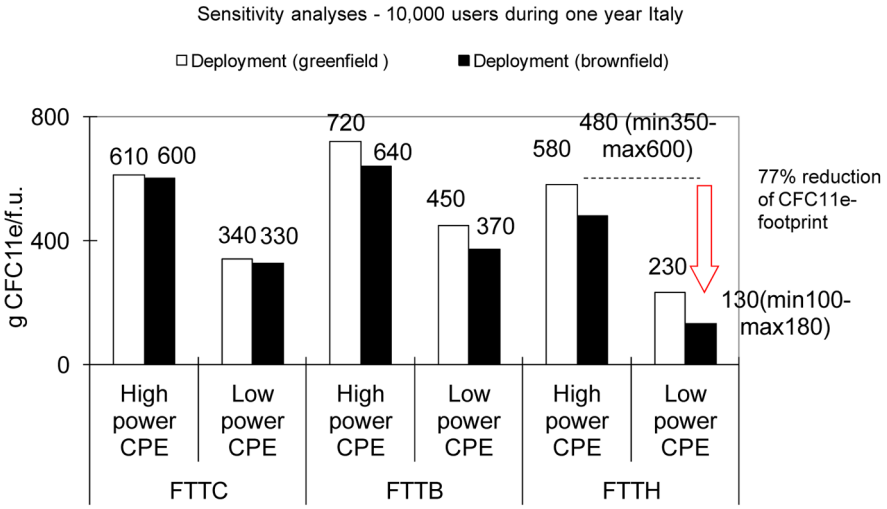


Figure 8 Combined effect of deployment technique and power mode for all networks in Italy.

The brownfield deployment/low power scenario also highlights FTTH as the winning architecture (130 gram compared to 370 for FTTB and 330 for FTTC).

To move into the key message for LCA, Figure 9 shows the effect of using the revised characterization index for N_2O within the ODP category in CML baseline 2000 LCIA method. Furthermore, Figure 9 shows a strong indication of how CO_2 acidification is underestimated in LCIA calculations. The acidification of oceans caused partly by anthropogenic CO_2 emissions to lakes/sea is a strong reason for reductions of global CO_2 [12, 13].

The result for FTTH is of comparable magnitude (per user) as FTTH Council Europe [9]. From Figures 9 and 10 it is clear that 0.011 g CFC-11e and 500 g SO_2e per user per year are the values to be compared to 0.005 and 90 g, respectively, from FTTH Council Europe [9].

A further indication of the effect on end-point methods of including CO_2 index for AAP and N_2O index for ODP is shown in Figure 11.

For the end-point method Eco-Indictator'99 (H) [18] with no modifications of Ozone depletion and Acidification indices they are together around less than 1% of the total scores in Figure 11 (left-hand side).

When adding new proportional values modifying the Eco-Indicator'99, 1.51986 PDF$*$m^{2}yr/kg, for CO_2 in "Acidification/Eutrophication" and

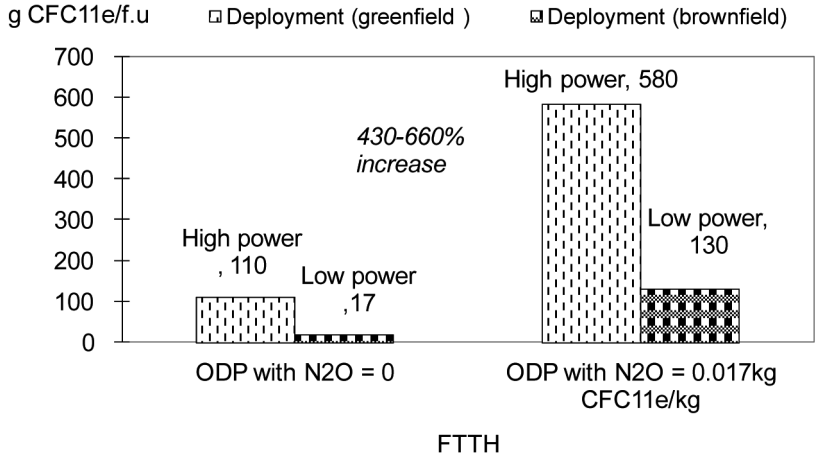


Figure 9 Effect of including N_2O index for FTTH scenarios.

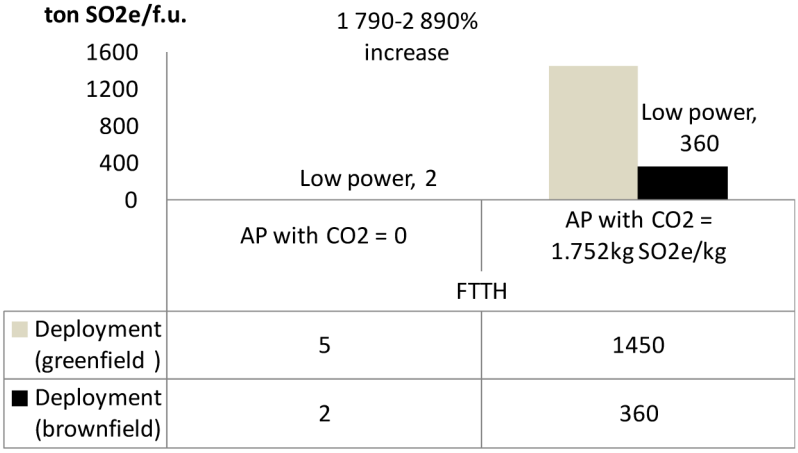


Figure 10 Effect of including CO_2 index for mid-point AAP for FTTH scenarios.

1.785×10^{-5} DALY/kg for N_2O in "Ozone layer", "Acidification/ Eutrophication" increases from 1.1 to 37.5%, whereas "Ozone layer" remains insignificant. This shows that these environmental effects are valued differently in Eco-Indicator'99 (H). The uncertainties of end-point Eco-indicator scores in Figure 11 are not modelled here, however, they are higher than mid-point uncertainties.

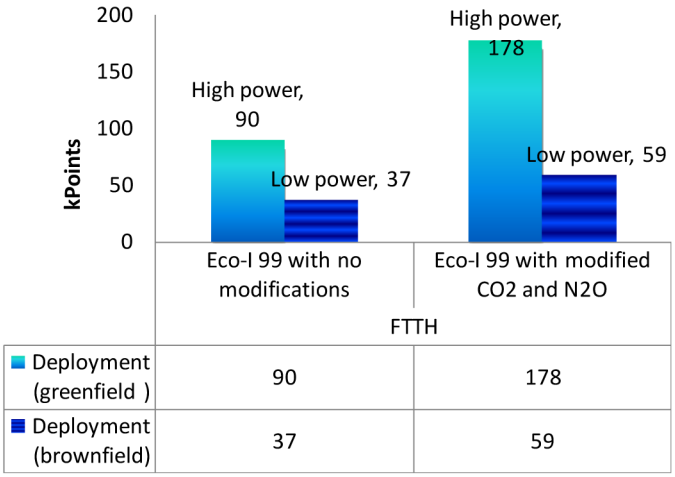


Figure 11 Effect of including N_2O and CO_2 indices for end-point method Eco-Indicator'99 (H) for FTTH scenarios.

4.2.1 CFC-11e-Efficiency Analysis

CFC-11e-efficiency is defined here as "average" bandwidth provided by each FTTx network divided by CFC-11e emissions for each annual FTTx network user. As shown in Figure 12, FTTH is considerably more efficient ("more output than input") than especially FTTC. FTTH is by far the best option even when the starting point is the greenfield deployment/high power CPE scenario. Concerning FTTH, the main drivers for CFC-11e footprint are the electricity usage of the HGWs, their manufacturing, and the use of diesel trucks in mini-trench and traditional civil works deployment. The inclusion of "average" bandwidth expressed as megabit per second (Mb/s) gives an advantage for FTTH as more data can be transferred more efficient and faster.

End-of-life processes seem to be irrelevant from a CFC-11e emission point of view and have therefore not been shown explicitly.

Robust LCA studies support two major benefits. The first is Benefit Maximization (most environmental reduction for least economic cost) and the second Continuous Improvement. In the first case the LCA shows where most environmental loadings occur and then the decision makers can find the most cost efficient solution to reduce these environmental loadings. In the second case, the first study helps to clarify the goals for the next product generation.

This analysis has highlighted that it is not enough to base the CFC-11e footprint on electricity usage measurements alone.

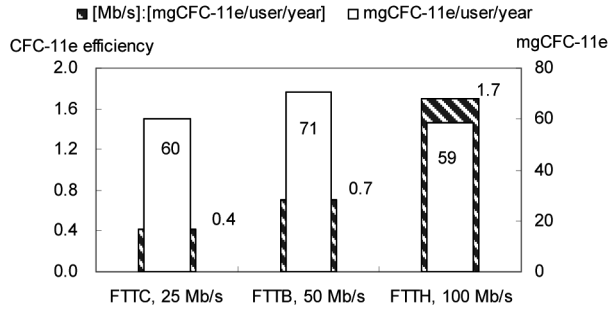


Figure 12 CFC-11e efficiency analysis of FTTx networks in Italy for Greenfield/high power CPE scenario.

Moreover, this study has shown that it is also not enough to compare the life cycles for the hardware systems alone, even though that is a necessary starting point for further research.

5 Conclusions

For the first time FTTC, FTTB and FTTH broadband networks have been simultaneously compared focusing of ODP and AAP by using LCA with a functional unit of *broadband network in an Italian urban dense area for use by 10,000 homes during one year*. The results of this analysis show that, for brownfield deployment in Italy (low power CPEs), FTTH architecture has the lowest amount of total CFC-11e emissions (appr. 130 g). One of the most important criteria, from ozone depletion point of view, when choosing an FTTx network, is whether fiber has been deployed or not. FTTH is more CFC-11e-efficient than FTTC and FTTB. Including the ozone depletion potential factor increases the ODP score by 430–660% for the present systems.

6 Recommendations and Perspectives

In order to get a more comprehensive understanding of the environmental implications of the present networks, water impact categories could be analysed. As the databases and LCA methodologies are improved, the introduction of other footprints (such as water footprint) will be trivial. This will on the other hand demand more primary data collection than CFC-11e footprint estimations. Naturally all LCAs including mid-point ODP analyses should include the "new" index for N_2O [8].

The LCIA field is challenging as new insights about environmental mechanisms are constantly appearing in other research fields than strict LCA.

For global warming likely the current understanding of which are the relevant contributing gases and land usages is correct. Global Warming Potential (GWP) results are therefore rather reliable emphasized by recent integration of the temporal dynamics of global warming was integrated with LCA [19].

Here the two previously *known* effects, N_2O ozone depletion and CO_2 aquatic acidification, are explored and an attempt was done to show how LCA results for ODP and AAP will be affected. The inclusion of N_2O in mid-point ODP is obviously necessary, however the CO_2 influence on AAP scores is probably not as strong as examined here. Likely instead in LCIA a new mid-point impact category for *oceanic acidification potential* is needed.

Still many challenges for LCIA modelling lies ahead of which these are just a few:

1. the indirect ozone depletion potential of water vapour driven by CO_2 and CH_4 emissions [20],
2. the global dimming (mitigating global warming) of particulates [21],
3. the ozone (O_3) creating potential (of black carbon and NO_x) which causes global warming [22], and
4. the influence of the above on environmental damage cost calculations [23].

From a Service LCA perspective, it was beyond the scope of the case study to find out if FTTH is also more effective (accomplished work compared to planned target) in specific working situations than FTTB and FTTC. To investigate such issues LCAs of ICT Services are needed. These can be performed with ETSI [3], ITU [4] and Greenhouse Gas Protocol [24].

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Biography

Anders S.G. Andrae received the M.Sc. degree in chemical engineering from the Royal Institute of Technology, Stockholm, Sweden, in 1997, and the Ph.D. degree in electronics production from Chalmers University of Technology, Gothenburg, Sweden, in 2005. He worked for Ericsson with LCA between 1997 and 2001. Between 2006 and 2008 he carried out post-doctoral studies at the National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan. His specialty is the application of sustainability assessment methodologies to ICT solutions from cradle-to-grave. Dr. Andrae was recently the Editor of European Telecommunications Standards Institute (ETSI) first LCA standard for ICT. He has previously published three books, three theses, 19 conference papers, and 13 peer-reviewed journal papers. Since 2008 Dr. Andrae is with Huawei Technologies in Sweden as Senior Expert of Emission Reduction/Ecodesign/Sustainability/LCA.