Developing a Generic Approach for FTTH Solutions using Life Cycle Analysis Methodology to Determine the Environmental Benefits of FTTH Deployments in the USA

Results and Methodological Guide

October 2008

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Moreover, the results of the study should be considered in the aggregate with regard to the assumptions made and not taken individually. For all matters of interpretation, the original paper copy of our report takes precedence over any other version.

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Executive Summary of Analysis Results

As a main quantitative finding, the environmental impact of the deployment of a typical FTTH network in the United States will be positive within less than 6 years in average considering only benefits associated to telecommuting.

Further either existing or developing applications will emphasize these results.

Beyond their environmental-friendly aspects, FTTH solutions can offer considerable additional social and economical benefits.

If we admit the fact that we are in the middle of a new industrial era, FTTH solutions are a key sustainable utility driver in this context.

Goals and applications of the study

The mission of the FTTH Council, North America is to educate stakeholders and to promote and accelerate FTTH solutions. One opportunity to accomplish this goal is to quantify the quality of life enhancements provided via FTTH deployments. The Council would like to develop a standard approach for evaluating FTTH solutions using globally accepted Life Cycle Assessment (LCA) methodology. The goal is to assess FTTH network implementation scenarios using the LCA methodology.

The Council's key objectives are the following:

- Evaluate environmental impacts of FTTH technology deployment with the environmental benefits associated with the assumption that people will work at home more often as a result of using FTTH-enabled services. A simplified LCA approach is used here.
- Qualify the resulting quality of life enhancements (the societal aspect) from the point of view of sustainable development.

According to ISO 14040, the environmental assessment is based on consistent and relevant data quality requirements.

Scope of the study and boundaries of the systems

1 Description of the FTTH scenarios

The fiber access network is modeled in the system analysis. The local central office (CO) is the starting point for the infrastructure that is considered. The study incorporates the passive components of the outside plant fiber network (cable + hardware) from the CO to the end-user, as well as the active equipment components in the access network. The studied system does not consider the infrastructure associated with the metro or long haul portions of the network.

The system integrates the environmental impacts associated with the fiber networks over their estimated life span, from their construction to the end of their useful life, excluding maintenance. The end-of-life is modeled as “leave the network in place” (i.e. basically). End-of-life for cables and boxes are modeled.

The results are presented as one generic case study model for fiber network implementation in the United States (US). However, the data collected for the model represents approximately 75% of the total deployed FTTH networks in the US as of mid-2008 and can be regarded as statistically representative for reliable results to a very high confidence factor.

The fiber network topology is assessed through the amount and nature of fiber cable used, the number and nature of nodes (hardware and boxes), and the energy consumed during the network use phase.

The social changes associated with the deployment of FTTH networks are represented by telecommuting. Others associated “life enhancement” services are also potentially provided by an FTTH deployment. These include telemedicine, e-commerce, delimiting, etc. Previous study results in late 2007, related to the European FTTH network sustainability analysis, indicated that telecommuting represents the majority (circa 99% for all the main environmental indicators) of the total benefits associated with these known FTTH-enabled services. Therefore, the other services were not considered within the current study.

Telecommuting behavior of FTTH subscribers has been surveyed in the US by RVA LLC since 2006, and subscriber data from those surveys strongly supports the assumptions of increased telecommuting that result from FTTH subscribership.

While evidence exists that telecommuting increases the longer one is an FTTH subscriber, this analysis used a fixed amount of additional telecommuting per subscriber over the duration of the analysis.

The final results of the LCA presents an aggregation of both aspects (total network environmental impact and environmental savings) in order to evaluate if FTTH deployment in the US results in an overall environmental benefit.

2 Functional unit

The **functional unit** for the FTTH Network deployment LCA has been determined during the study and is as follows:

Allow a residential customer to use FTTH technologies during one year

The reference flow is the FTTH network user in the United States.

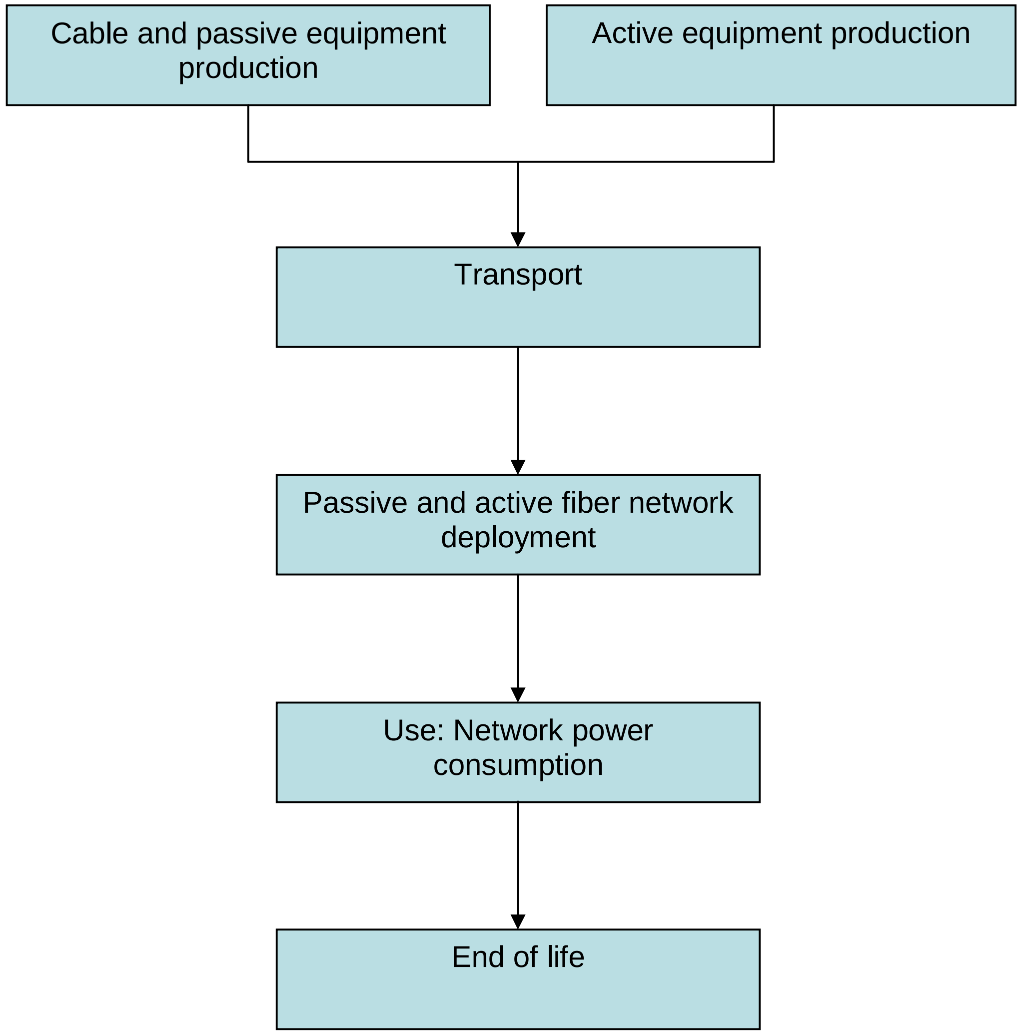
Nevertheless, in the following results, we chose the **number of years as a result,** in order to evaluate the depreciation of the network deployment, compared with the total savings due to usage of this network.

For more robust results, future LCA studies should determine the number of years of life for the different equipment in the network (should be from 30 to 50 years for passive equipments and 5 to 10 years for active equipments).

In this study, the maintenance of the network and replacement of equipment has not been evaluated.

3 System and Life Cycle phases studied

This study is "**a cradle to grave**" screening LCA study: it covers the production steps, from the raw materials "in earth" (*the cradle*) to the FTTH network end of life (*the grave)*.



System boundaries description

Ecobilan has modeled the FTTH network impacts and associated services savings using a life-cycle approach with its proprietary LCA software tool TEAM^{TM}.

Reminder: the maintenance of the network and equipment has not been evaluated in the following assumptions and results.

4 Methodology

4.1 An overview of our approach

In this section, we describe the approach we have adopted in providing the consultancy support required. We recognize that this is a project with various stakeholders, i.e. members of the FTTH Council, North America, and have defined a structured and pragmatic approach, incorporating good business practice designed specifically to meet the requirements.

A critical success factor was the establishment of a close partnering between the participating companies and us. This ensures a shared project vision and objectives and facilitates the development of ownership of the Project and use of the results.

The following members of the FTTH Council, North America have contributed to the project:

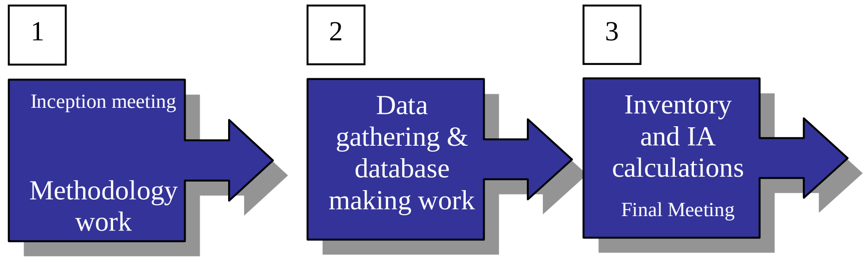
- Joe Savage – NA FTTH Council
- Peter Ballhaussen

4.2 Our methodology

We have followed the methodology defined by the ISO 14040 series of standards, to ensure a robust and defensible approach.

The objectives were to:

- define the methodology and data required
- focus on the data gathering,
- ensure that sensible conclusions can be drawn from the data,
- present the data in a user-friendly way adapted to their purpose,
- ensure a good know-how transfer to FTTH Council members.



5 Main assumptions and data sources

5.1 Optical Fiber life cycle

Data sources and modeling assumptions have been mainly provided by the FTTH Council, Europe SUDEFIB (Sustainable Development Fiber) Committee.

5.1.1 Production of cables

Data related to the cable production has been delivered by Acome, a European based cable producer through a questionnaire. We assume that cable production data do not differ in a significant way between cable producers globally. Details of raw materials and assumptions are given hereafter. Detailed data are confidential.

Outdoor cable

Two types of outdoor cable have been taken into account: 50% of LTA and 50% of CTC.

- The 72 optical fibers LTA cable is mainly made of HDPE (polyethylene) and Polyester,
- The 72 optical fibers CTC cable is mainly made of HDPE (polyethylene), PVC and glass fiber.

Aerial cable

The aerial cable is an outdoor cable consolidated with FRP (Polyester Resin) and additional polyethylene.

Buried cable

The buried cable is an outdoor cable armored with steel band.

Indoor cable

The 24 optical fibers H-Pace cable is mainly made of LSOH which has been considered as polypropylene.

Drop cable

Drop cable is represented by a mono-mode Optical Fiber is mainly made of photopolymerisable material (Acrylic Resin) and Silica which has been considered as Glass Fiber.

Distances of cables (Source FTTH meeting)

	Case Study	Source
Total distance of home cable (in feet) per user	81.75	USA Case Study, Questionnaire
Total distance of indoor cable in the FTTH network (in feet) per user	16.35	USA Case Study, Questionnaire
Total distance of outdoor cable in the FTTH network (in feet) per user	294.2	USA Case Study, Questionnaire

5.1.2 Production of active equipments

Active equipments considered in this study are:

- ONT (Optical Network Terminal)

- OLT (Optical Line Terminal)

- Network Nodes

Details of data and calculations are in the following:

- The weight of one ONT is 780 g (Source: CREDO). ONT is supposed to be a 50/50 mix of Steel and HDPE.
- Dimensions of OLT rack have been delivered by the FTTH council (Source: Cisco). OLT rack is supposed to be a 50/50 mix of Steel and HDPE.
- One OLT is made of 2 OLT racks in PON configuration (Source: Europe FTTH council).
- Network Nodes correspond to the different nodes of the network: the different splitters and the distribution boxes.
    - The estimated weight for one splitter is 500 g and is supposed to be made of HDPE.
    - The estimated weight for one box is 3 kg and is supposed to be made of HDPE.

5.1.3 Production of raw materials

Bibliographical data has been used to the modeling of the production of raw materials (Appendix II).

5.1.4 Repartition by FTTH user

We consider that 1 OLT deserves 410 users (Source: USA Case Study).

There is 1 ONT per user.

For the Network Nodes:

- We have modeled a 1-to-32 split ratio.
- 1 distribution box is used per 24 home passed (average value) (Source: CREDO).

5.1.5 Transport of raw materials

We consider that a truck covers an average distance of 621 miles and there are 89.5 miles of cable per truck (Source: Acome).

5.1.6 Optical Fiber deployment

- **Created ducts deployment**

Civil engineering holes are supposed to be 3.2 feet wide.

Diesel oil consumption is 20 gallons for a 66,000-gallon excavation hole. (Source: civil works company).

We suppose that 85% of holes are made in grass, the others 15% are supposed to be made into concrete (street and sidewalks).

The duct created cable are made of High Density Polyethylene (Source: CREDO); Here are its main characteristics:

- External diameter: 2.5 inches

- Internal diameter: 2 inches

- **Poles deployment**

All poles are considered to be wood made. We also consider that 10 new poles are required per mile (Source: NA FTTH Council).

Data concerning wood poles come from the internet website of a pole producer.

Cables used for this deployment technique are aerial cables (cf. 5.1.1).

- **Plowed Direct Buried deployment**

The width of the trench is 60 cm (Source: Fiber Optic Cable Placing Direct Buried, Corning).

We suppose that 85% of holes are made in grass, the others 15% are supposed to be made into concrete (street and sidewalks).

Cable plowing machine are supposed to be fuel driven with light fuel oil with a power of 225 horsepower. (Source: Fiber Optic Cable Placing Direct Buried, Corning).

Cables plow deployment speed has been estimated to 1.19 miles per hour. (Source: United States Department of Agriculture)

The Multi-fiber Services Terminal Hand-hole enclosure is supposed to be made of PVC (17.7 kg)

Average distance between two manholes has been estimated to 0.6 miles (Source: cable laying professional).

Cables used for this deployment technique are buried cables (cf. 5.1.1).

- **Existing deployment**

Average distance between 2 manholes has been provided by FTTH case study questionnaire.

We suppose that 85% of holes are made in grass, the others 15% are supposed to be concrete (street and sidewalks).

Diesel oil consumption is 20 gallons for a 66,000-gallon excavation hole. Assumption on hole features are as follows:

- Length= 1m,

- Depth= 2 m,

- Width= 2 m.

Protection boxes are supposed to be made of Polyester Resin (Source: CREDO).

We consider 160 protection boxes for 1000 FTTH users.

- **Horizontal Drilling deployment**

The Horizontal Drilling machine is powered by a 261 horsepower diesel engine (Source: drilling and the fiber optic cable laying industry website)

Support machines fuel consumption has also be taken into account.

Cables used for this deployment technique are buried cables (cf. 5.1.1).

5.1.7 Repartition of deployment technologies

The following repartition has been provided by questionnaire:

	Case Study
Percentage of **Existing Ducts** for the FTTH deployment	8%
Percentage of **Created Ducts** for the FTTH deployment	0%
Percentage of **Plowed Direct Buried** for the FTTH deployment	33%
Percentage of **Horizontal Drilling** for the FTTH deployment	1%
Percentage of **Poles** for the FTTH deployment	59%

5.1.8 Use: active equipments power consumption

In the use phase, only electrical consumption has been considered. The calculations have been made for 1 entire year of FTTH utilization.

Concerning ONT:

Activity mode and sleeping mode have been distinguished.

- 10 h of activity (12 W);

- 14h in sleeping mode (2 W).

Concerning OLT:

0.6 W/User for PON technology during 24 hours/day.

Data about consumption has been provided by Credo and by FTTH Council Europe.

5.1.9 Optical Fiber end of life

The reference case for the end of life model is the CCU 72OF cable.
Demolition impacts are not taken into account (vehicles and energy used for demolition)

End of Life assumptions:
Polyethylene end of life is considered to be 50% incinerated and 50% landfilled.
Glass fiber has been considered as silica and is 100% incinerated.

5.2 Environmental benefits of FTTH deployment

Telecommuting has been assessed. Transportation assumptions for all cases:

-Average of gas consumption: 24.5 miles a gallon (Source: US department of transportation, Summary of fuel economy performance, mars 2004);

- Repartition of USA fleet of cars (Source: R.L. Polk & Co. report)

  - 97% of cars are gasoline-powered.
  - 3% of cars in USA are diesel-powered.
  - No alternative fuels have been considered.

From the current trends (2010-2011 and beyond) in FTTH networks use, we have chosen the following assumptions:

<u>Assumptions on Telecommuting:</u>

	Telecommuting assumptions in USA for 1 year	Sources
Population		
% of active population in USA	50% of the total population	North American Transportation Statistics Database, donneés 2006
% of prospective telecommuters in active population	10% of American working population telecommute 3 days per week	RVA LLC Study provided by FTTH NA
Number of working weeks per year	47	
American average Home-Work Distance round trip (km)	35 miles	Poll: Traffic in the United States: A Look Under the Hood of a Nation on Wheels, 2005
Floor space reduction		
Number of m² / employee in an office building	10 m² / employee	Assumptions chosen for the present study
Energy consumption for heating system	532.3kWh/m²/year	Etude Manicore from CEREN
Required Total primary Energy to produce 1 electric MJ	3 MJ	Bibliographical data of Electricity LCA

Production of energies and transport:

Details of bibliographical data used for the production of energies and transport are in Appendix II.

6 Impact categories

Ecobilan selected a list of impact categories presented in this section.

The fourteen following impact categories are usually used by Ecobilan to perform life cycle impact assessment:

Indicator	Environment	Calculation method
Total Primary Energy	RESOURCE	Sum of feedstock + fuel energy = sum of non renewable + renewable energy
Feedstock Energy	RESOURCE	Sum of feedstock energy consumption
Fuel Energy	RESOURCE	Sum of fuel energy consumption
Non renewable Energy consumption	RESOURCE	Sum of non renewable energy consumption
Renewable Energy	RESOURCE	Sum of renewable energy consumption
Depletion of abiotic resources: "Abiotic resources" are natural resources (including energy resources) such as iron ore, crude oil and wind energy, which are regarded as non-living. The characterization factor of abiotic depletion potential (ADP) for each extraction of minerals and fossil fuels is expressed in kg antimony equivalents.	RESOURCE	CML2000[1]
Greenhouse gas effect: The "greenhouse effect" refers to the ability of some atmospheric gases to retain heat which is radiating from the earth, and the Global Warming Potential (GWP) is the impact category measuring this effect, based on different time span. The Intergovernmental Panel on Climate Change developed the characterization method used by Ecobilan. The category indicator is in gram equivalent CO2. Ecobilan selected the direct impact at a span of 100 years	AIR	IPCC[2], 2001

[1] CML : University of Leiden (Netherlands).

[2] IPCC : International Panel on Climate Change.

Air acidification: The air acidification impact category represents an increase in the atmosphere of acid compounds such as nitrogen oxides and sulphur oxides. The characterization factor of a substance is calculated on the basis of the number of H+ ions, which can be produced per mole. The air acidification indicator is the sum of the inventory flows, which contributes to the air acidification multiplied by their characterization factors. ETH developed the characterization method used by Ecobilan.	AIR	CML2000
Depletion of the stratospheric ozone The ozone layer is present in the stratosphere and acts as a filter absorbing harmful short wave ultraviolet light whilst allowing longer wavelengths to pass through. This "hole" over the Antarctic is created due to the unique chemistry present over the Poles. Most chlorine and bromine (from CFCs and other sources) in the atmosphere is bound in reservoir compounds which render them inert and unable to affect ozone. However, in the presence of the PSCs, complex reactions occur which release active chlorine and bromine from the reservoir compounds.	AIR	CML2000
Photochemical oxidant formation: Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level, where they react with sunlight to produce photochemical smog. One of the components of smog is ozone, which is not emitted directly, but rather produced through the interactions of volatile organic compounds (VOCs) and oxides of nitrogen (NOx). The photochemical oxidant formation index is expressed in g. eq. ethylene.	AIR	CML2000
Water eutrophication: Eutrophication is defined as the enrichment in nutritive elements of waters when referring to human intervention. Oxygen depletion is the possible consequence of such enrichment. The characterization method used by Ecobilan is based on the method developed by the Centre of Environmental Science (CML), Leiden University, taking into account only the water compartment. It is based on the capacity of a substance to contribute to algae profusion. This contribution is translated into oxygen depletion taking into account the quantity of oxygen consumed when algae decompose. Characterization factors are given in gram equivalent phosphate.	WATER	CML2000
Toxicity (3 impacts): It is important to consider the potential impact of the FTTH deployment on **human life**, **aquatic life** and **terrestrial life**. However, the toxicity indices that are generated may not necessarily be reported as part of the impact results, but may be tested to compare the results of existing methods. The USES method, used by CML to derive a LCA characterization method, is considered as an improvement over previous methods. All emissions may participate through all compartments (air to water etc.). Eco-toxicity impacts should be handled with care (see below).	WATER HUMAN	CML2000

7 Comparison of Inventory and Environmental Impact Assessment

7.1 Results and Contribution Analysis

7.1.1 Synthesis of total results

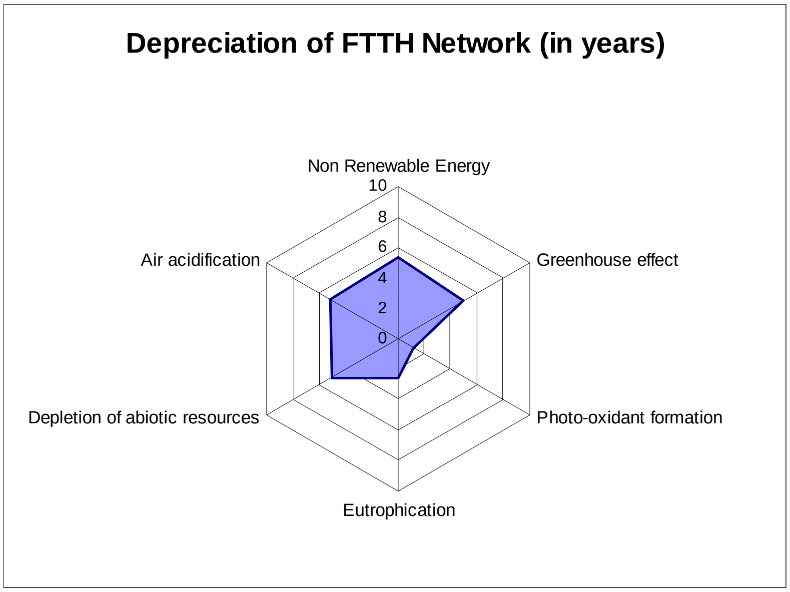
The full inventory and impact assessment results are presented in the following table. These results take into account all the above-mentioned assumptions.

The number of years represents the depreciation of the FTTH network. The impact of FTTH network deployment takes into account the following stages: production of passive and active equipment, transportation, deployment, and end of life. The environment savings are computed as the difference between the benefits drawn from the use of the FTTH network and the energy required to power the network. Environmental savings are represented by one study case of telecommuting.

On the last column, years represent the depreciation of FTTH network. The numbers of years are obtained by dividing FTTH network impact by Total savings.

Comparative results	units	FTTH network impact / user	Total savings / user / year	Depreciation of FTTH network (in years)
Resources				
E Total Primary Energy	MJ	14859.50	1532.47	9.70
E Feedstock Energy	MJ	11168.20	0.09	117694.61
E Fuel Energy	MJ	3690.31	1532.38	2.41
E Non Renewable Energy	MJ	8168.07	1522.56	5.36
E Renewable Energy	MJ	6691.42	9.90	675.68
CML2000-Depletion of abiotic resources	kg eq. Sb	3.67	0.72	5.07
Air impact				
IPCC-Greenhouse effect (direct, 100 years)	g eq. CO2	540310.60	111035.36	4.87
CML2000-Air Acidification	g eq. SO2	1965.62	379.37	5.18
CML2000-Depletion of the strastosphic ozone	g eq.CFC-11	0.02	0.00	6.31
CML2000-Photo-oxidant formation	g eq.ethylene	38.64	32.40	1.19
Water impact				
CML2000-Eutrophication	g eq.PO43-	107.43	40.85	2.63
Toxicity				
CML2000-Aquatic Toxicity	g eq.1,4-DCB	8637.12	149.37	57.82
CML2000-Human Toxicity	g eq.1,4-DCB	45577.97	3102.61	14.69
CML2000-Terrestrial Toxicity	g eq.1,4-DCB	1696.52	36.74	46.18

We can summarize these results on a radar graph which only shows the 7 main representative impacts.

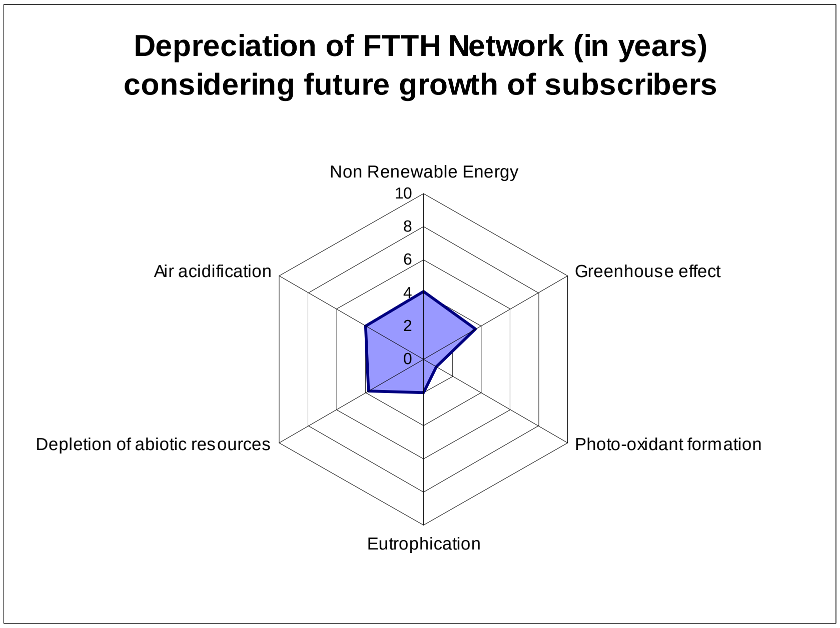


As a main quantitative finding, the environmental impact of the deployment of a typical FTTH network will be positive in less than 6 years considering only the telecommuting services.

7.1.2 Sensitivity analysis

According to the ISO 14044, sensitivity analysis is the study of how the variation in the output of the model can be apportioned quantitatively to different sources of variation in the input of the model.

In our context, we have quantified the future growth of subscribers. For purposes of this analysis, this growth does not require additional cable and equipment implementation, since the existing passive infrastructure is able to support the additional service subscribers. Only active equipment (OLT and ONT consumptions) and drop cable production were modified to account for the future growth of subscribers. The next graph represents the depreciation of FTTH Network considering a 25% growth from today's level:



As a main finding, we can see that the deployment of a FTTH network will be positive in less than 4 years when considering future growth of subscribers.

7.1.3 Detailed results of FTTH network impact per user (excluding use)

<u>Contribution of different FTTH network life cycle phases</u>

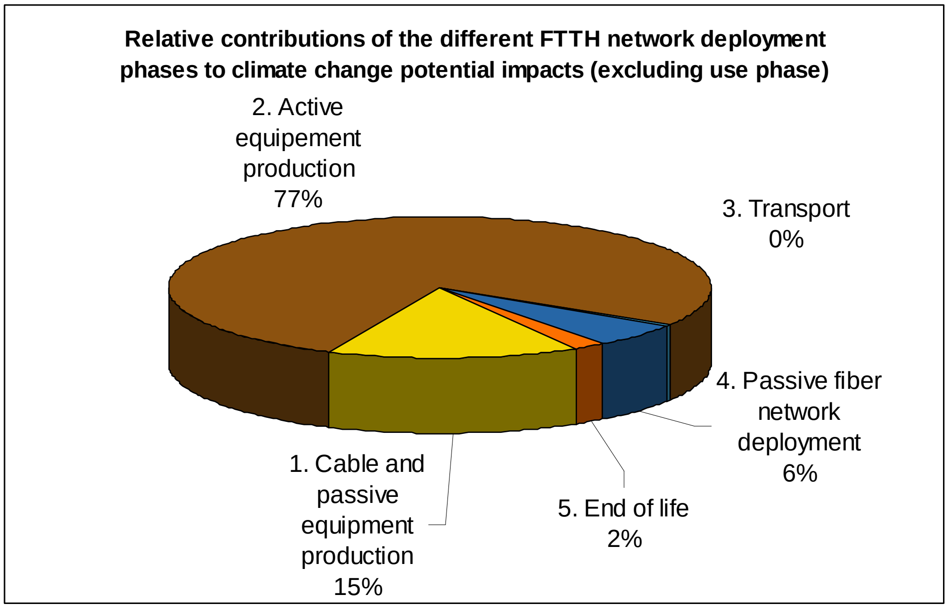
The full life cycle of an FTTH network is described on the following table. It has been divided into 5 phases. This table allows understanding the most impacting phases of the full life cycle.

Comparative results	units	FTTH network impact / user	1. Cable and passive equipment production	2. Active equipments production	3. Transport	4. Passive fiber network deployment	5. End of life
Resources							
E Total Primary Energy	MJ	14859.50	1751.81	5465.60	17.70	7616.98	7.39
E Feedstock Energy	MJ	11168.20	503.04	3490.04	0.00	7175.06	0.10
E Fuel Energy	MJ	3690.31	1248.76	1975.10	17.70	441.56	7.19
E Non Renewable Energy	MJ	8168.07	1712.82	5419.81	17.69	1010.65	7.10
E Renewable Energy	MJ	6691.42	38.98	45.77	0.01	6606.37	0.29
CML2000-Depletion of abiotic resources	kg eq. Sb	3.67	0.77	2.42	0.01	0.47	0.00
Air impact							
IPCC-Greenhouse effect (direct, 100 years)	G eq. CO2	540310.60	81790.62	416731.52	1418.83	30069.65	10300.46
CML2000-Air Acidification	G eq. SO2	1965.62	622.32	1106.27	8.55	225.22	3.27
CML2000-Depletion of the strastosphic ozone	G eq.CFC-11	0.02	0.01	0.00	0.00	0.01	0.00
CML2000-Photo-oxidant formation	G eq.ethylene	38.64	11.88	21.34	0.16	4.97	0.29
Water impact							
CML2000-Eutrophication	G eq.PO43-	107.43	31.86	48.51	2.05	23.76	1.24

Toxicity							
CML2000-Aquatic Toxicity	G eq.1,4-DCB	8637.12	1004.88	6407.48	27.90	613.19	583.69
CML2000-Human Toxicity	G eq.1,4-DCB	45577.97	14492.66	26411.13	130.99	4257.42	285.78
CML2000-Terrestrial Toxicity	G eq.1,4-DCB	1696.52	271.52	1059.30	1.51	123.93	240.26

Active equipment production is predominant and represents, for each impact, nearly 80% of the total impact of FTTH network.

The next graph focuses on the impact of greenhouse gas emissions during the life cycle. It allows understanding better the relative contribution of each phase.



As shown, active fiber network deployment represents 77% of the total impact. In particular, the key impacting parameter over the carbon emissions is the production of the OLT.

7.1.4 Detailed results of use associated to FTTH network

The total use for 1 year is presented in the following table. It represents the savings associated to telecommuting during 1 year minus the network power consumption for 1 year.

Comparative results	units	Total savings for 1 year	Telecommute one-year savings (3 days a week) including floor space reduction	Network power consumption for 1 year
Resources				
E Total Primary Energy	MJ	1532.47	2325.14	792.67
E Feedstock Energy	MJ	0.09	0.43	0.33
E Fuel Energy	MJ	1532.38	2324.71	792.34
E Non Renewable Energy	MJ	1522.56	2284.48	761.91
E Renewable Energy	MJ	9.90	40.65	30.75
CML2000-Depletion of abiotic resources	kg eq. Sb	0.72	1.11	0.39

Air impact				
IPCC-Greenhouse effect (direct, 100 years)	g eq. CO2	111035.36	160323.56	49288.20
CML2000-Air Acidification	g eq. SO2	379.37	685.43	306.06
CML2000-Depletion of the strastosphic ozone	g eq.CFC-11	0.00	0.00	0.00
CML2000-Photo-oxidant formation	g eq.ethylene	32.40	41.80	9.40
Water impact				
CML2000-Eutrophication	g eq.PO43-	40.85	53.61	12.76
Toxicity				
CML2000-Aquatic Toxicity	g eq.1,4-DCB	149.37	423.12	273.75
CML2000-Human Toxicity	g eq.1,4-DCB	3102.61	11393.09	8290.48
CML2000-Terrestrial Toxicity	g eq.1,4-DCB	36.74	146.84	110.11

7.1.5 Other benefits

Beyond its environmental-friendly aspects, FTTH solutions can offer additional social and economical benefits.

Moreover, FTTH networks can contribute to other fields not assessed in the present study (see also DG JRC report "The future impact of ICTs on environmental sustainability"):

- Telemedicine such as:

  - Imaging transfer savings
  - Teledialysis savings
  - Telestaff savings
  - Home-medical support savings

- Energy demand;

- Supply chain management;

- E-commerce (see also appendix IV);

- Tele-meetings;

- Intelligent Transport Systems;

- Facility management;

- Production progress management;

- Improved service and product utilization.

8 Conclusion

As a main quantitative finding, the environmental impact of the deployment of a typical FTTH network in the United States will be positive within less than 6 years in average considering only benefits associated to telecommuting.

Further either existing or developing applications will emphasize these results.

Beyond their environmental-friendly aspects, FTTH solutions can offer considerable additional social and economical benefits.

If we admit the fact that we are in the middle of a new industrial era, FTTH solutions are a key sustainable utility driver in this context.

The sustainability of FTTH solutions will be clearly demonstrated when:

> Users' experience grows

> Bottlenecks such as network vertical and horizontal accesses are removed.

In the present study we consider an overall approach of FTTH alternative networks and associated services.

FTTH network solutions represent a responsible investment for:

- Operators
- Public bodies
- Shareholders
- Utilities

… and provide decisive leverage to policy makers.

Appendices

Appendix I: Bibliographical data used (Raw materials)

Appendix II: Bibliographical data used (Energy and transport)

Appendix III: Electricity model used

Appendix IV: Bibliographical elements on the environmental impact of E-commerce

Appendix I: Bibliographical data used (raw materials)

Name	Sources
_241I Silicone Rubber: Production	Confidential : SRI report160, June 1983
_261 Glass Drop (White): Production	BUWAL (Bundesamt für Umwelt, Wald und Landschaft) n°250 Bern, 1996 Page 102-103
_900 SILICA: Incineration	WISARD module 2007
_BPE: Production (m3)	SNBPE 2007
_road 1 m2	Bitumen production: Eurobitume Mise en oeuvre: European civil works company
020I Wood (55% dry): Supply	Ecobilan data
141I Limestone (CaCO3): Quarrying	Buwal 250 (Bundesamt für Umwelt, Wald und landschaft) Ökoinventare in Verpackungen Band II Bern, 1996 page: 463
142I Kaolin (Al2O3.2SiO2.2H2O): Mining	BUWAL 250 (office federal de l'environnement des forets et du paysage) Volume II: inventaires ecologiques relatifs aux emballages Berne, 1996 page 447
145I Perlite (SiO2, ore): Mining	Data from one European site.
211 Cardboard (Recycled, Grey Board): Production	BUWAL (Bundesamt für Umwelt, Wald und Landschaft) n°250 Band II: Ökoinventare für Verpackungen Bern, 1996 Page 254-255.
241 Carbon Dioxide (CO2): Production	Confidential data aggregated with upstream processes in order to preserve confidentiality
241 High Density Polyethylene (HDPE, Europe, 2005): Production	Ecoprofiles of the European plastics industry Polyolefins p19-25 I.Boustead PlasticsEurope, Brussels, March 2005 available on web site: http://www.PlasticsEurope.org
241 Hydrochloric Acid (HCl, 100%): Production	ELF ATOCHEM expertise, Mr. Lecouls' letter of 25 July 1997
241 Polypropylene (PP, Moulded by Injection): Production	Ecoprofiles of plastics and related intermediates I.Boustead APME, Brussels, 1999 available on web site: http://www.apme.org
241 Polyvinyl Chloride (PVC, Moulded by Injection): Production	Ecoprofiles of the European plastics industry PVC Conversion Processes Pages 34 to 41 I.Boustead APME, Brussels, October 2002 available on web site: http://www.apme.org
241 Sodium Hydroxide (NaOH, 100%): Production	Eco-profiles of the European plastics industry (APME) Polyvinyl Chloride I.Boustead Brussels, September 2002 Page: 50 à 55
241I Acrylic Resin: Production	BUWAL n°232 Comparative environmental evaluation of construction paints and varnishes Volume 2: data Bern , 1994 Page: 84-85
241I Argon (Ar): Production	Laboratorium für Energiesysteme ETH (Eidgenössische Technische Hochschule Zurich) Zurïch, 1996 Page 106
241I Boric Acid (H3BO3): Production	Confidential site data (1992)
241I Nitrogen (N2): Production	Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) Environmental Series No. 132 Bern, February 1991 page A59

241I Oxygen (O_2): Production	Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) Environmental Series No. 132 Bern, February 1991 page A59
241I Polyester Resin: Production	Confidential data - SRI
241I Sodium Sulphate (Na_2SO_4): Production	BUWAL 250 (office federal de l'environnement des forets et du paysage) Volume II: inventaires ecologiques relatifs aux emballages page 458 Primary source: Sodium sulfates. Ullmann's Encyclopedia of Industrial Chemistry. A24, 1993:355-368
241S Polyester Resin: Production	Confidential data - SRI
241S Silica (SiO_2): Production	Data from one European site.
261S Glass Fiber (Continous Wire Mast): Production	Confidentiel site data (1992)
266I Concrete: Production	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Teil 3, Basismaterialieren Page 51 Primary source: T.Weibel, \' Vergleichende Umweltrelevanz des Einsatzes alternativer Kältemittel in Kompressions-Wärmepumpen und Kälteanlagen\' , Bundesamt für Energiewirtschaft, Bern 1996
271I Steel Slab (Secondary): Production	Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) - derived from U.S. sources.
900 Polyethylene (PE): Incineration	Buwal 250 (Bundesamt für Umwelt, Wald und Landschaft) Ökoinventare für Verpackung: Band II Bern, 1996 page 433 primary source: Doka G., Huber F., Labhardt A., Menard M., Zimmermann P., Ökoinventare von Entsorgungprozessen-Grundlagen zur Integration der Entsorgung in Ökobilanzen, ESU-Reihe 1/96; Institut für Energietecknik, Gruppe Energie-Stoffe-Umwelt, ETH Zürich, 1996.
900 Polyethylene (PE): Landfill	Buwal 250 (Bundesamt für Umwelt, Wald und Landschaft) Ökoinventare für Verpackung: Band II Bern, 1996 page 433 primary source: Doka G., Huber F., Labhardt A., Menard M., Zimmermann P., Ökoinventare von Entsorgungprozessen-Grundlagen zur Integration der Entsorgung in Ökobilanzen, ESU-Reihe 1/96; Institut für Energietecknik, Gruppe Energie-Stoffe-Umwelt, ETH Zürich, 1996.

Appendix II: Bibliographical data used (Energy and transport)

Name	Sources
Road Transport (Gasoline, litre)	1) Gasoline production Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) Environmental Series No. 132 Bern, February 1991, page A9 2) Gasoline combustion European Car Manufacturer
Diesel Oil: Engine Combustion	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Teil 3, Anhang B: Transport und Bauprozesse Page 56 primary source: 1) Bundesamt für Umwelt , Wald und landschaft, \'Schadstoffemissionen und Treibstoffverbrauch von Baumaschinen\', Synthesebericht, Umwelt-Materialieren Nr 23 Luft, Bern 1994. 2) Bundesamt für Strassenbau , \'Infromation Schweizerische Nationalstrassen\', Bern 1992
Road Transport (Diesel Oil, litre)	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Anhang B: Strassengutertransport Page 22. Primary source: M.Maïbach, D.Peter, B.Seilen \'Okoinventar Transport; Grundlagen fûr den ôjologischen Vergleich von Transportsystem und fûr den Einbezug von Transportsystem in ökobilanzen\', SPP Umwelt, Modul 5, Infras Zurîch, 1995.
Diesel Oil: Engine Combustion	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Teil 3, Anhang B: Transport und Bauprozesse Page 56 primary source: 1) Bundesamt für Umwelt , Wald und landschaft, \'Schadstoffemissionen und Treibstoffverbrauch von Baumaschinen\', Synthesebericht, Umwelt-Materialieren Nr 23 Luft, Bern 1994. 2) Bundesamt für Strassenbau , \'Infromation Schweizerische Nationalstrassen\', Bern 1992
Sea Transport (Freighter, kg.km)	Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) Environmental Series No. 32 Bern, February 1991. pages A16, A8 (precombustion) Adaptation covers CO_2, methane, N_2O emissions (Ecobilan Data).
Diesel Oil: Production	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Teil 1, Erdol Page 173-174 Primary source: 1) Schmidt K.H, Romey I, \'Kohle, Erdöl, Erdgas; Chemie und Technik\', Würzburg 1981. 2) Concawe (Hrsg.), \'quality of aquous effluents from oil refineries in western europe\', Concawe report n°84/53, Brussels 1984 3) Concawe (Hrsg.), \'oil refineries waste survey -disposal methods, quantities and costs\', Concawe report n° 5/89, Brussels 1989. 4) Concawe (Hrsg), \'Performance of Oil Industry Pipeline in Western Europe Statistical Summary of Reported Spillages-1994\', Concawe report n° 4/95, Brussels 1995 5) <Raffoil 1991> Vertrauliche Informationen einer modernen, westeuropaischen Raffinerie, 1991.
Electricity (USA, 2003): Production	1) Combustion of coal, lignite, heavy fuel oil, natural gas in accordance with the AFNOR Fascicule, NF P 01-010, Mai 2005 Process gas: Laboratorium für Energiesysteme ETH, Zurich, 1996 2) For breakdown efficiencies: International energy agency publication "Electricity Information 2005" Web site : www.iea.org 3) For transport losses International energy agency publication "Electricity Information 2005" Web site : www.iea.org
Heavy Fuel Oil: Combustion	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Teil 1, Erdol Page 219-220
Natural Gas: Combustion	Laboratorium fur Energiesysteme ETH, Zurich, 1996 Teil 1, Erdgas Page 66-67

Appendix III: Assumptions on electricity production in the United States

The electricity production grid for USA is based on the International Energy Agency "Electricity information" report of 2005 and corresponds to 2003 data.

The data for USA are representative of the average production in USA.

Table 1 - Electricity grid for USA in 2003

	USA (2005)
Coal	48.56%
Process gaz	0.07%
Fuel oil	3.37%
Natural gas	16.42%
Nuclear	19.30%
Hydro	7.49%
Free Electricity*	2.11%

* Free Electricty: renewable fuels, solar, wind, tide, etc.

Appendix IV: Bibliographical elements on E-commerce

Three studies (Gay et al. 2005, Matthews and Hendrickson 2001, Williams and Tagami 2003) suggest that there is no clear difference between the energy and CO_2 emissions associated with the sale of tangible goods via traditional and e-commerce methods:

Traditional sales consume less energy when:

- Population density is high: consumers live close to stores
- Consumer transport is minimal: mass transportation more often used to shop
- Distribution:
    - E-commerce would involve air transportation
    - Traditional distribution to retail store is very efficient (high load factor and energy efficient vehicles)
- Packaging: E-commerce would require heavy external and substantial internal packaging
- Retail inventory is low: the floor space dedicated to the storage and display of the products is low

E-commerce sales consume less energy when:

- Population density is low: consumers live far from stores
- Consumer transport is significant: the consumer drives the car to the store
- Distribution:
    - E-commerce would involve ground transportation only
    - Traditional distribution to retail store is inefficient (low load factor and standard vehicles)
- Packaging: E-commerce requires only light packaging (e.g. light corrugate or Tyvek bag)
- Retail inventory is high: significant floor space is dedicated to the storage

The high majority of E-commerce sales are of tangible goods.