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Full LCA (Life Cycle Assessment)**

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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

The Energy efficiency of a satellite broadband network is addressed by ETSI TR 103 352 [i.4] "Energy Efficiency of Satellite Broadband Network". The present document carries out a full Life Cycle Analysis (LCA) of a satellite broadband network considering all stages of the life cycle.

1 Scope

Satellite Broadband Networks allow broadband services to be delivered to approaching 100 % of the population, even in remote areas, and can therefore be used to fill gaps in the coverage of other broadband technologies. Satellite Broadband services can be offered to residential or business customers in a cost effective manner compared to other methods of services provision.

The present document reviews the assessment of GHG emissions over the lifecycle of satellite broadband networks, and identifies whether additions are required to the full life cycle assessment methodology developed in ETSI TS 103 199 [i.3].

2 References

2.1 Normative references

As informative publications shall not contain normative references this clause shall remain empty.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Greenhouse Gas Protocol (GHG Protocol).

NOTE: Available at http://www.ghgprotocol.org/.

[i.2] Recommendation ITU-T L.1420: "Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations".

[i.3] ETSI TS 103 199: "Environmental Engineering (EE); Life Cycle Assessment (LCA) of ICT equipment, networks and services".

[i.4] ETSI TR 103 352: "Satellite Earth Stations and Systems (SES); Energy Efficiency of Satellite broadband network".

[i.5] Guidelines to DEFRA/DECC's GHG Conversion Factors for Company Reporting.

NOTE: Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224437/pb13988-emission-factor-methodology-130719.pdf.

[i.6] ISO 14044:2006: "Environmental Management-Life Cycle Assessment - Requirements and Guidelines".

[i.7] "Energy Efficiency", EC FP7 Project BATS Broadband Access via Integrated Terrestrial and Satellite Systems Deliverable D5.3.

NOTE: Available at http://www.batsproject.eu.

[i.8] "Cost Benefit Analysis", EC FP7 Project BATS Broadband Access via Integrated Terrestrial and Satellite Systems Deliverable D5.2.

[i.9] Ariane 5 ECA technical data.

NOTE: Available at http://www.spacelaunchreport.com/ariane5.html.

[i.10] Number of private households in Europe.

NOTE: Available at http://www.pordata.pt/en/Europe/Private+households+total+and+by+number+of+children-1615.

[i.11] Number of households in Croatia.

NOTE: Available at http://www.dzs.hr/default_e.htm.

[i.12] Number of households in Turkey.

NOTE: See http://www.turkstat.gov.tr/PreHaberBultenleri.do?id=15843.

[i.13] "EU Energy Trends to 2030".

NOTE: Available at https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2030_update_2009.pdf.

[i.14] "Tracking Industrial Energy Efficiency and CO2 Emissions", details of the manufacture of liquid oxygen, IEA.

NOTE: Available at http://www.iea.org/publications/freepublications/publication/tracking_emissions.pdf.

[i.15] Liquid hydrogen manufacturing conversion factor, US EPA, "Technical Support Document for Hydrogen Production: Proposed Rule for Mandatory Reporting of Greenhouse Gases", page 2.

NOTE: Available at https://www.epa.gov/sites/production/files/2015-02/documents/subpartp-tsd_hydrogenproduction.pdf.

[i.16] Chemistry of the solid rocket booster propellant.

NOTE: Available at https://chlorine.americanchemistry.com/Chlorine_Site_Content/Science_Center/Chlorine_Compounds/Ammonium_Perchlorate__Helping_to_Launch_the_Space_Shuttle_Discovery.aspx.

[i.17] "Forecast emission factors for vehicles, Chapter 5: Reducing emissions from transport".

NOTE: Available at http://www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Chap5_1.pdf.

[i.18] EU Code of Conduct on Energy Consumption of Broadband Equipment Version 5.

NOTE: Available at http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/files/documents/ICT_CoC/cocv5-broadband_final.pdf.

[i.19] European Parliament COM(2009) 7604 2009/2228(INI): "Mobilising Information and Communication Technologies to facilitate the transition to an energy-efficient, low-carbon economy".

[i.20] Directive 2005/32/EC of the European Pariliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council.

[i.21] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (Text with EEA relevance).

[i.22] Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products (Text with EEA relevance).

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

baseline scenario: hypothetical reference case that best represents the conditions most likely to occur in the absence of any environmental impact reduction measures

cut-off: threshold below which part of a product, service or system can be considered insignificant and need not be considered by a LCA

Emission Factor (EF): mass of a specified pollutant (e.g. GHG or CO_2e) emitted divided by a unit mass, volume, distance, or duration of the activity emitting the pollutant

EXAMPLE: Number of kilograms of GHG emitted per kW of power generated or number of kilograms of CO_2e emitted per km travelled.

greenhouse gas: gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds

greenhouse gas emission: total mass of a GHG released to the atmosphere over a specified period of time

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADSL	Astmmetric Digital Subscriber Line
BATS	Broadband Access via Integrated Terrestrial and Satellite Systems
CO2	Carbon Dioxide
CO2e	CO2 equivalent (warming potential of other GHGs)
CPI	Communications and Power Industries
DEFRA	(UK) Department for Environment, Food & Rural Affairs
EF	Emission Factor
EoLT	End of Life Treatment
FP7	EU 7th R&D Framework Programme
GD Satcom	General Dynamics SATCOM Technologies
GHG	GreenHouse Gas
GTO	Gross Take Off
HPA	High Power Amplifier
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
ING	Intelligent Network Gateway
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organisations
IUG	Intelligent User Gateway
LAN	Local Area Network
LCA	Life Cycle Assessment
MW	Megawatt
PUE	Power Usage Effectiveness
QTY	Quantity
RF	Radio Frequency
UPS	Uninterruptible Power Supply
VDSL	Very-high-bit-rate Digital Subscriber Line
WAN	Wide Area Network
WBCSD	World Business Council on Sustainable Development
WEEE	Waste Electronic and Electrical Equipment
WRI	World Resources Institute

4 Requirements arising from relevant policies/legislation

European Member States have committed themselves to reducing greenhouse gas emissions (GHG) by 20 %, increasing the share of renewable in the EU's energy mix to 20 %, and achieving a 20 % energy efficiency target by 2020.

In COM(2009) 7604 [i.19] "*Mobilising Information and Communication Technologies to facilitate the transition to an energy-efficient, low-carbon economy"*, the EC notes that "The use of ICT equipment in the delivery of services represents about 1,75 % of carbon emissions in Europe; a further 0,25 % of carbon emissions come from the production of ICT and consumer electronic equipment. As the range and penetration of ICTs increase, their overall energy use is growing". The Communication went on to recommend the ICT sector set itself an energy reduction target.

In terms of carbon accounting, any organization (or indeed industry sector) is responsible for greenhouse gas (GHG) emissions in a number of ways, either directly by burning fuel or processing chemicals, through the purchase of energy from other sources, and indirectly through its supply chain the use of its products. The Greenhouse Gas Protocol is a collaboration between the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD) [i.1]. It differentiates between these three different categories of emissions and refers to them as Scopes 1, 2 and 3 respectively. Recommendation ITU-T L.1420 [i.2] explains how ICT companies can apply this to their own operations.

In line with this policy landscape, the European Union has issued a number of directives to foster energy efficient design of products:

- Directive 2005/32/EC on 6th July 2005 [i.20] establishing a framework for the setting of eco-design requirements for energy-using products
- Directive 2009/125/EC on 21st October 2009 [i.21] establishing a framework for the setting of eco-design requirements for energy-related products.
- Directive 2010/30/EU on 19th May 2010 [i.22] on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products

5 Life Cycle Assessment (LCA) Overview

5.1 Life Cycle Stages

ETSI TS 103 199 [i.3] specifies the following life cycle stages applying to ICT Equipment, Networks and Services:

a) Goods Raw material acquisition which is composed by:
  - Raw material extraction.
  - Raw material processing.

b) Production which is composed by:
  - ICT Goods production.
  - Support Goods production.

c) Use which is composed by:
  - ICT Goods Use.
  - Support Goods Use.
  - Operator support activities.
  - Service Provider support Activities.

d) Goods End of Life Treatment:

- Re-use.
- ICT specific EoLT.
- Other EoLT.

If all these life cycle stages are not assessed, this should be stated when reporting.

The LCA for a satellite broadband network is described in the following sections. For all stages, the design operational lifetime is considered to be 15 years.

5.2 Scope and Boundaries

Figure 1 (from ETSI TR 103 352 [i.4]) shows the main components of a 2 way service satellite network architecture suitable for providing broadband services. The boundary of the satellite system includes:

- The satellite composed of the payload and the platform.
- The satellite terminals composed of the antenna system (dish), the RF part (Power Amplifier, Low Noise Amplifier and filters) and the modem implementing the base band processing of the satellite radio interface.
- The Hub that includes both a Network Control Centre to manage the in orbit radio resources and a Gateway with its antenna system, the RF part, a set of modems.

The Network Control Centre is not shown here and the power consumption is ignored under cut-off rules.

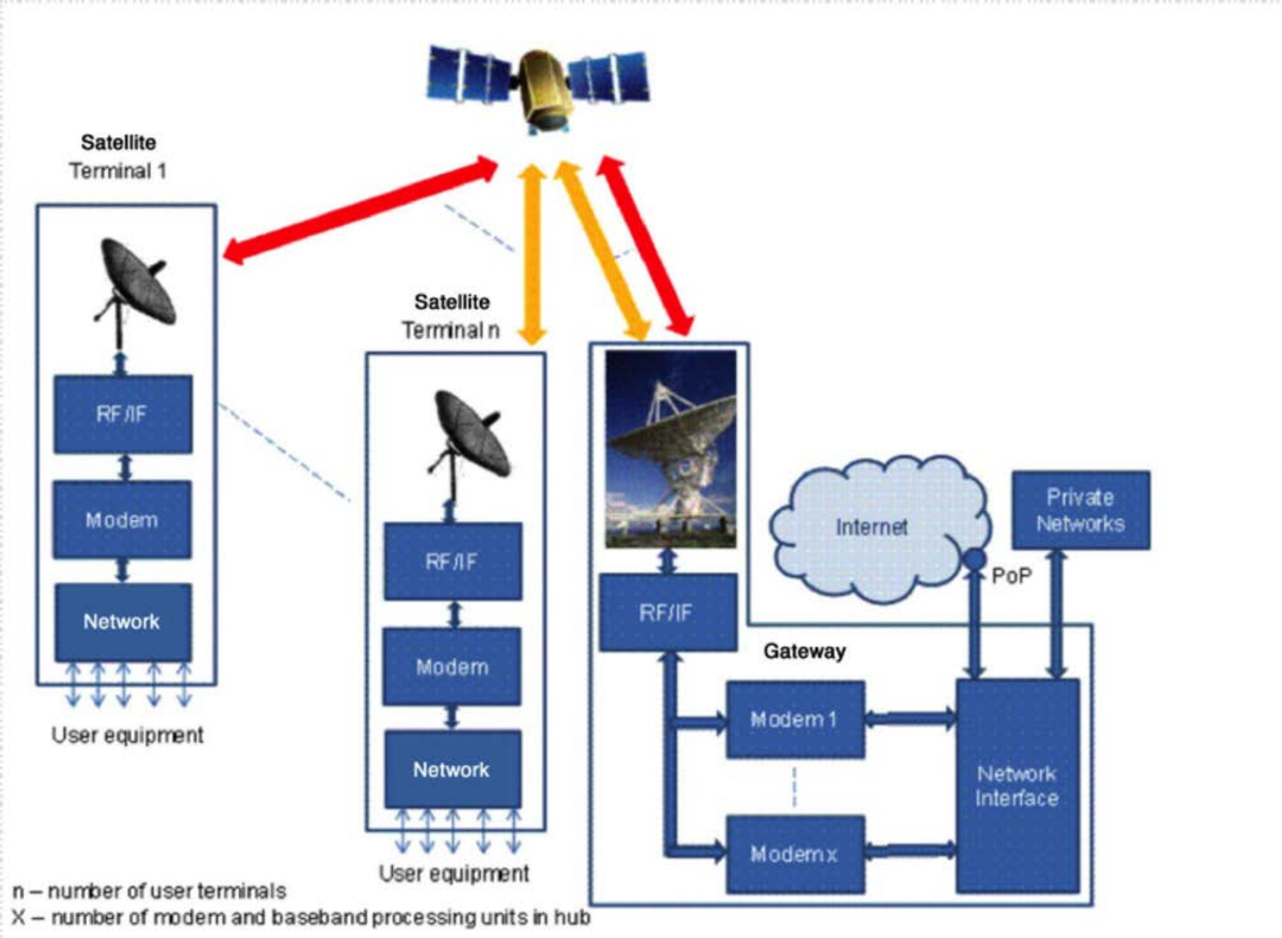

Figure 1: 2 way service satellite network architecture (e.g. Broadband)

The GHG emissions arising from a satellite network during all stages is the sum of the GHG emissions from all subsystems and equipment included within the boundary of the system under investigation. The GHG emissions per operator is the sum of the GHG emissions arising from the satellites, satellite control centres, gateways and terminals under the control of the operator that are used to provide the broadband service.

5.3 Key Input Parameters

For the purposes of the LCA, the key input parameters are:

- The total energy consumption (covered in ETSI TR 103 352 [i.4]).
- The weight of a component or subsystem.
- The lifetime of the satellite broadband system.
- The number of terminals in operation per year.
- The GHGe emission factor of the electricity supply (either for locally generated electricity if this is all that is used for the system, or the emission factor per country).
- The embodied carbon during manufacture, installation and EoLT.
- The annual change in value of the inputs over the period of the study.

5.4 Assumptions and Approximations during the LCA

The approximations made during the environmental assessment will depend on the budget available and the purpose of the assessment, and a balance should be struck between these. Often a quick provisional assessment will provide 80 % of the value from an assessment at (perhaps) 20 % of the costs. The benefits of doing this often make results available which can be acted on sooner, to improve energy efficiency of a subsystem for example, which may outweigh the value of carrying out a full LCA. A faster assessment can point to the equipment or subsystem whose environmental impact or energy efficiency should be improved without going to the expense of a full LCA, and generally a more accurate model need only be developed if there is doubt about the validity of the application of a cut off rule.

During the raw material extraction, production and EoLT stages, assumptions can be made as follows:

- The lifetime of the system in use.
  The design operational lifetime of a satellite broadband network is considered to be 15 years. This cannot be known accurately in advance but could have a significant impact on the resulting GHG emissions per annum, particularly when compared with the calculation of the embodied carbon in the other stages. If the lifetime of the system is less than predicted then the impact of the embodied carbon arising from the other stages will be higher than calculated and may therefore become more significant according to the cut-off rules.
- The use of weight or price as a predictor of the embodied carbon in a component or subsystem. In the DEFRA tables [i.5] a single figure is given to cover the raw material acquisition, proportion of recycled material and production stages. It is uncertain how accurate an assessment this provides, but does offer a way forward to what otherwise would be a very wide ranging assessment. Reference to a more detailed embodied carbon database for electronic products and recycling would be preferable if this becomes available.
- For the purposes of calculating emissions from the production stage, the satellite launch vehicle needs to be taken into account. In one example it was assumed to be the Ariane 5.
- The fuel for the delivery vehicles should be taken into account over the lifecycle. In one example it was assumed that all road transport delivery vehicles will continue to use diesel fuel rather than adopt renewable technologies such as hydrogen fuel cells.

5.5 Cut-off Rules

Cut-off is the process for the exclusion of insignificant items and activities from the LCA ETSI TS 103 199 [i.3]. Invoking cut-off can simplify the assessment and reduce the cost by excluding items and activities that will not significantly change the overall conclusions of the study. This is valid as long as the intended purpose of the assessment is still met. Cut-offs should be avoided if possible, and are only acceptable if allowed according to guidance given in ISO 14044 [i.6] and an alternative to cut-off can be to model unavailable data based on known data.

The cut-off criteria include a specified proportion of the total mass, energy or environmental significance of the system. Irrespective of the cut-off method applied, the accumulated effects need careful consideration to prevent the sum of cut-offs exceeding the targeted share of the total impact which is acceptable for cut-off.

If a preliminary assessment indicates that one of the stages of the LCA will be responsible for less than 1 % of the total GHG emissions, then it can be ignored under cut-off rules. In practice, depending on the purposes of the assessment, if one of the stages of the LCA is responsible for less than 10 % of the GHG emissions, then it can be ignored in some circumstances, provided that this is stated in the assessment report and that cumulatively the number of stages ignored under the cut-off rules do not add up to a more significant proportion of the GHG emissions.

Cut-offs that are applied should be stated in the assumptions.

6 Life Cycle Assessment Method applied to Satellite Network

6.1 Variables and Assumptions

For a given satellite network, the data listed below is required. The assumptions on these are taken from ETSI TR 103 352 [i.4] with additional information on Hybrid Satellite networks taken from Annex A of [i.7]. As described in ETSI TR 103 352 [i.4], the number of satellite terminals that can be supported by a given satellite network can be derived from the average bandwidth required by each satellite terminal during the busy hour.

LT_{SN} Expected satellite network life time in years.

T_{SN} Satellite network throughput in Tbps.

T_{max} Max Service rate per terminal in Mbps.

T_{av} Average throughput rate per terminal during the busy hour in Mbps.

N_{SN} Number of terminals that can be supported by a satellite network in average throughput mode.

N_{SG} Number of satellite gateways required to support the number of terminals served [i.8].

N_S Number of satellites launched.

N_{SL} Number of separate satellite launches.

EF_{av} Average emission factor of the electricity supply over the lifetime of the satellite network.

6.2 Raw material acquisition stage

GHG emissions arising from the goods raw material acquisition stage should be assessed in accordance with ETSI TS 103 199 [i.3].

Tables such as those published by DEFRA for the United Kingdom [i.5] can be used to calculate the GHG emissions from the raw material acquisition stage. These specify conversion factors to estimate the GHG emissions according to the weight of a component or subsystem. For electronic products, 'weight' is a 'catch all' estimate for the materials used. This serves where a more detailed inventory is not available which could, for example, include emissions from the extraction of all the raw materials. Such details are considered to be below the cut-off of the LCA.

It is acceptable under cut off rules to include raw material acquisition as part of the GHG emissions from the Production stage, provided the tables used include this. This is assumed in the present document and so the raw material acquisition stage is not accounted for separately.

6.3 Production stage

GHG emissions arising from the production stage should be assessed in accordance with ETSI TS 103 199 [i.3].

Production is considered to include:

- Component manufacture
- Subsystem construction and assembly
- Transport of materials to site
- Installation process

ETSI TS 103 199 [i.3] specifies a range of metrics including power, weight, volume and cost according to the information available. Where possible, primary data should be used as follows:

- Scope 1 emissions are the GHG emissions from the burning of fossil fuels directly by the reporting entity. These are easily measured.
- Scope 2 (electricity) emissions are reported on a national basis and the only complication is which electricity emission factor is used.
- Scope 3 (other companies) emissions are more difficult to determine because the boundary is harder to determine. For example, should employees working at home have their additional electricity consumption measured and included as Scope 3?

Where primary data is not available, weight can be used as a predictor of GHG emissions. A process tree showing the interconnectivity among parts and various items in each life cycle of ICT goods should be developed using the product composition information. By arranging parts in descending order of weight and by calculating the cumulative weight of each part, a basis is given for a cut-off of insignificant parts from the product subsystem.

Many suppliers of ICT equipment now quote a weight of the packaging as well as the equipment itself. This can be included in the overall weight of the product.

The subsystems are considered to be:

- Satellite.
- Satellite launch vehicle including fuel used.
- Satellite gateways.
- Satellite terminal equipment including the satellite modem and any associated terminal equipment necessary for communication (e.g. IUG).

Other activities that should be considered during the Production stage include:

- Installation of the Satellite gateways.
- Installation of the Satellite terminal equipment.

The total GHG (CO2e) emissions arising from the satellite network during the Production stage are calculated by summing the GHG emissions arising from the individual subsystems:

$$GHG_{Prod} = Prod_S + Prod_{SL} + Prod_{SG} + Prod_{ST}$$

where: GHG_{Prod} is the emissions arising from the whole satellite network and its subsystems during the Production stage.

$Prod_S$ is the emissions arising from production of the satellite(s).

$Prod_{SL}$ is the emissions arising from production of the satellite launch vehicle(s).

$Prod_{SG}$ is the emissions arising from production of the satellite gateways.

$Prod_{ST}$ is the emissions arising from production of the satellite terminals (including any associated terminal equipment necessary for communication).

For the emissions arising from production of the satellite(s):

$$Prod_S = W_S \times N_S \times CF_{Prod}$$

where: W_S is the weight of the satellite.

N_S is the number of satellites.

CF_{Prod} is the conversion factor for the emissions arising from production of the satellite(s).

For the emissions arising from production of the satellite launch vehicle(s):

$$Prod_{SL} = W_{SL} \times N_{SL} \times CF_{Prod}$$

where: W_{SL} is the weight of the satellite launch vehicle.

N_{SL} is the number of satellite launches.

CF_{Prod} is the conversion factor for the emissions arising from production of the satellite launch vehicles.

For the emissions arising from production of the satellite gateways:

$$Prod_{SG} = W_{SG} \times N_{SG} \times CF_{Prod}$$

where: W_{SG} is the weight of the satellite gateway.

N_{SG} is the number of satellite gateways deployed.

CF_{Prod} is the conversion factor for the emissions arising from production of the satellite gateways.

For the emissions arising from production of the satellite terminals:

$$Prod_{ST} = W_{ST} \times N_{ST} \times CF_{Prod}$$

where: W_{ST} is the weight of a satellite terminal (including any associated terminal equipment) necessary for communication.

N_{ST} is the number of satellite terminals deployed.

CF_{Prod} is the conversion factor for the emissions arising from production of the satellite terminal.

6.4 Use (Operation)

The key input parameter during the Use stage is the average power consumed by the satellite network and equipment. This is covered in ETSI TR 103 352 [i.4]. If the GHG emissions arising from the Use stage are to be compared with those from other stages, then it should be assessed over the lifetime of the system and not simply as an average in the first year of operation. This should take into account the growth in the number of terminals over the lifetime of the system and the expected or actual changes in emission factor of the electricity supply.

For satellite terminal equipment which is capable of moving from a full operational state to a low power (standby) state, an important consideration in assessing the power consumption during the Use stage is the proportion of time that the terminal equipment spends in each low power state. A typical duty cycle between the time spent in full operational mode and low power states should be assumed and this used as a multiplier on the annual energy consumption. It was assumed in ETSI TR 103 352 [i.4] that the proportion of time the terminal spends in full transmit/receive mode is 15 %. At other times it is assumed to be in a lower power state.

From ETSI TR 103 352 [i.4], the total instantaneous power consumed by the satellite network P_{SN} (in kW) is:

$$P_{SN} = (P_{SG} \times N_{SG}) + (P_{ST} \times N_{ST})$$

where: P_{SG} is the average power consumed by a satellite gateway,

N_{SG} is the number of satellite gateways.

P_{ST} is the average power consumed by a satellite terminal (including any associated terminal equipment necessary for communication).

N_{ST} is the number of satellite terminals supported.

The total power consumed by the satellite network over the lifetime of the satellite network (in kWh) is:

$$P_{total} = P_{SN} \times LT_{SN} \times 365{,}25 \times 24$$

The total GHG emissions over the lifetime of the satellite network during the Use stage can be then calculated by multiplying the total power consumed by the satellite network P_{total} by the average emission factor (EF_{av}) over the lifetime of the satellite network of the power supply in the country or region being considered:

$$GHG_{use} = P_{total} \times EF_{av}$$

6.5 End of Life Treatment

GHG emissions arising from EoLT should be assessed in accordance with ETSI TS 103 199 [i.3]. In tables such as those used by DEFRA [i.5], the weight of the component or subsystem includes values for both Production and EoLT. Production includes a proportion of recycled material. The emissions arising from EoLT are therefore significantly less than for Production.

Open-loop recycling is assumed to be part of the manufacturing process. If separate conversion factors for waste disposal cannot be obtained, it is acceptable under cut off rules to include emissions from EoLT as part of the emissions from the Production stage, provided the tables used include this.

If separate conversion factors for waste disposal are available, the total GHG (CO2e) emissions arising from the satellite network during the EoLT stage are calculated by summing the GHG emissions arising from the individual subsystems:

$$GHG_{EoLT} = EoLT_S + EoLT_{SL} + EoLT_{SG} + EoLT_{ST}$$

where: GHG_{EoLT} is the emissions arising from the whole satellite network and its subsystems during the EoLT stage.

$EoLT_S$ is the emissions arising from the satellite(s) EoLT.

$EoLT_{SL}$ is the emissions arising from the satellite launch vehicle(s) EoLT.

$EoLT_{SG}$ is the emissions arising from the satellite gateway(s) EoLT.

$EoLT_{ST}$ is the emissions arising from the satellite terminals (including any associated terminal equipment necessary for communication) EoLT.

Normally emissions arising from the satellite(s) EoLT do not have to be considered because a satellite will either eventually burn up in the atmosphere and be destroyed or will enter a graveyard orbit. It is unlikely that this will create significant emissions which need to be taken into account under cut-off rules.

Similarly, emissions arising from the satellite launch vehicle(s) EoLT do not have to be considered because these will also be destroyed as part of the launch procedure. It is unlikely that this process will create significant emissions which need to be taken into account under cut-off rules.

For the emissions arising from the satellite gateways EoLT:

$$EoLT_{SG} = W_{SG} \times N_{SG} \times CF_{EoLT}$$

where: W_{SG} is the weight of the satellite gateway.

N_{SG} is the number of satellite gateways.

CF_{EoLT} is the conversion factor for the emissions arising from the satellite gateway EoLT.

For the emissions arising from the satellite terminals EoLT:

$$EoLT_{ST} = W_{ST} \times N_{ST} \times CF_{EoLT}$$

where: W_{ST} is the weight of a satellite terminal (including any associated terminal equipment necessary for communication).

N_{ST} is the number of satellite terminals deployed.

CF_{EoLT} is the conversion factor for the emissions arising from the satellite terminal EoLT.

6.6 LCA for complete Satellite Network

From clauses 6.1 to 6.5, the total GHG (CO2e) emissions arising from the satellite network over the lifetime of the satellite network are:

$$GHG_{total} = GHG_{Prod} + GHG_{use} + GHG_{EoLT}$$

An analysis of the GHG emissions arising from a satellite broadband network taking into account all subsystems over all life cycle stages is shown in annex A.

7 Results/Conclusions

A method of assessing the GHG emissions over the full life cycle of a satellite broadband network, including the satellite terminals, has been provided. This covers the raw material acquisition, production, use and end of life stages. The present document can represent the basis for further detailed assessment procedures leading to a Technical Specification on the assessment of the full environmental impact (including GHG emissions) of a satellite network.

In annex A, the results of a case study on the assessment of the GHG emissions from a Hybrid Satellite Broadband network are given.

Annex A: Case Study on Hybrid Satellite broadband

A.1 General

The LCA for a High Throughput Satellite System considering a Hybrid broadband access scheme described here is based on the work done in the EU FP7 BATS *Broadband Access via Integrated Terrestrial and Satellite Systems* project [i.7]. The carbon footprint arising from all stages of the LCA was assessed in accordance with ETSI TS 103 199 [i.3]. The life cycle under consideration was the period of operation projected for the years 2020 to 3035.

The Operational (Use) stage was addressed in ETSI TR 103 352 [i.4]. The figures for energy consumption in W calculated there should be converted into GHG emissions using the average emission factor of the electricity supply over the lifetime of the system. During the other stages, assumptions were made as follows:

- The lifetime of the system in use. This cannot be known accurately in advance but could have a significant impact on the resulting GHG emissions per annum, particularly when compared with the calculation of the embodied carbon in the other stages. If the lifetime of the system is less than predicted then the impact of the embodied carbon arising from the other stages will be higher than calculated and may therefore become more significant according to the cut-off rules. Emissions due to maintenance were not included in this study.
- The use of weight for the embodied carbon in a component or subsystem was adopted, as previously discussed. For example, in the DEFRA tables, a single figure is given to cover the raw material acquisition, proportion of recycled material and production stages. It is uncertain how accurate an assessment this provides, but it does offer a way forward to what otherwise would be a very wide ranging assessment. Reference to a more detailed embodied carbon database for electronic products and recycling would be preferable if this was available.
- It is assumed that all road transport delivery vehicles will continue to use diesel fuel rather than adopt renewable technologies such as hydrogen fuel cells.
- It is assumed that there is no significant increase in operational power because of increased traffic carried over the life of the system.

The number of satellite terminals that can be supported by a given satellite network can be derived from the average bandwidth required by each satellite terminal during the busy hour. In this case, a High Throughput Satellite with a capacity of 0,5 Tbps could support around 250 000 separate equivalent 30 Mbps links (in combination with the terrestrial link) with a peak average busy hour requirement of 2 Mbps via satellite in 2020 [i.8]. This is complemented by 0,2 Mbps that is carried terrestrially. The figure of 250 000 terminals supplied is considered to be easily attainable, as the total addressable market for hybrid satellite broadband systems should be much larger than this, with the peak number of households taking the service calculated to be 6,4 M households in year 2029 ([i.10], [i.11] and [i.12]).

The satellite launch vehicle was assumed to be the Ariane 5 [i.8]. The GHG impact of some of its propellants in the troposphere is the subject of ongoing research. Note that other launch vehicles may use other propellants which may have much larger GHG footprints.

LT_{SN} Satellite network life time - assumed to be 15 years.

T_{SN} Satellite network throughput - assumed to be 0,5 Tbps.

T_{max} Max Service rate per terminal - assumed to be 30 Mbps.

T_{av} Average throughput rate per terminal during the busy hour - assumed to be 2 Mbps.

N_{SN} Number of terminals that can be supported by a satellite network - assumed to be 250 000 in average throughput mode.

N_{SG} Number of satellite gateways - assumed to be 26 to support the number of terminals above [i.8].

N_S Number of satellites - assumed to be 1.

N_{SL} Number of satellite launches - assumed to be the same as the number of satellites as satellites will be launched in line with the growth in use of the service.

EF_{av} Average emission factor of the electricity supply over the lifetime of the satellite network.

A.2 Emission factors

Emissions factors are parameters normally provided by tables which, when multiplied by a value attributable to a network element such as energy in kWh, weight in kg or distance travelled in km, produce a value of carbon dioxide equivalent (CO2e) emitted in kg. In some cases no emission factor could be found in tables or other references, e.g. the manufacture and combustion of butadiene which is used as a binder in the solid fuel booster. In that case, estimates were made from first principles.

A key emission factor is that of electricity. The GHG emission factor of electricity supply each year for the EU will vary over the period 2020 to 2035. The report "EU Energy Trends to 2030" provides a perspective of the energy source mix [i.13] over the life cycle of the system.

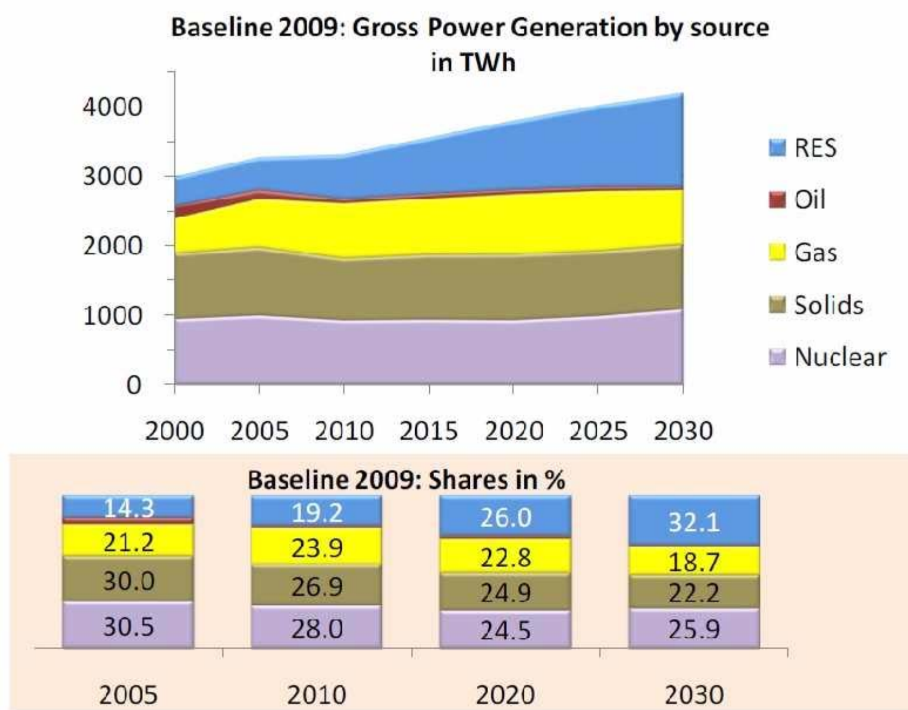

Figure A.1: Gross Power Generation by Source (Europe) [i.13]

From figure A.1 the annualized decrease in fossil fuel is 0,75 % between 2020 and 2030. This trend is assumed to continue until 2035. The average GHG conversion factor for the EU in 2013 is given as 0,34723 kg CO2 per kWh [i.5]. This was treated as the base year from which subsequent conversion factors are derived. In 2020 figure A.1 shows that the proportion of fossil fuel is predicted to have fallen from 51,8 % to 49,5 %. The emission factor will then have fallen pro-rata to $0{,}34723 \times 49{,}5/51{,}8 = 0{,}33181$. To this was added a transmission and distribution loss of 0,025 kg CO^2 per kWh [i.5]. Linear interpolation was used to derive the emission factors for each year over the period 2020 to 2035.

A.3 Satellite payload and launch vehicle

The manufacture of the satellite system includes all the physical components including the launch vehicle and its payload. In addition the emissions arising from combustion of the fuel used to take the satellite into geostationary orbit should be accounted for. This should be accounted for under the Transport stage of the life cycle.

To estimate the emissions due to manufacturing, tables [i.5] were used to obtain a carbon factor. In this case the weight (mass) was multiplied by the emission factor to arrive at a CO2e value in kg.

The Ariane 5 launch vehicle has a Gross Take Off (GTO) launch capacity of 10 000 kg (22 000 lb.) for dual payloads or 10 500 kg (23 100 lb.) for a single payload [i.9]. The emissions of the launch vehicle were therefore scaled according to the actual payload (6 400 kg) assuming a second load is carried.

The launch vehicle mass includes the main stage the upper stage, the solid fuel boosters, the payloads and the propellants.

Hydrogen and oxygen are the two chemicals used in the cryogenic main engine. The masses are 133 and 26 tonnes respectively. These react to produce water which is not classified as a GHG. No account is taken of the impact of water emission into the stratosphere. Note that this reaction would be in the transport stage of the life cycle as the satellite is transported to its geostationary orbit. Account is taken of the emissions incurred during manufacture of propellants. Details of the manufacture of liquid oxygen are given in Reference [i.14]. The conversion factor is 0,310 kWh/kg. Details of the manufacture of hydrogen are given in [i.15]. The conversion factor is 8,5 CO2e kg/kg.

The emission due to the manufacturing and transport of the solid fuel booster was calculated from the mix of its chemical constituents which include a propellant mix of 68 % ammonium perchlorate (oxidizer), 18 % aluminium (fuel), and 14 % polybutadiene (binder) is used in the solid rocket motors. [i.16] states: "The chemistry of the solid rocket booster propellant can be summed up in this reaction:

$$10\ Al + 6NH_4ClO_4 \Rightarrow 4Al_2O_3 + 2AlCl_3 + 12H_2O + 3N_2$$

The CO2e emission arising from the manufacturing of solid fuel boosters was estimated by consideration of the detailed manufacturing processes of each chemical multiplied by their molecular weights. The chemicals included: aluminium (both as a fuel and in the tank casings), ammonium perchlorate, hydroxyl-terminated polybutadiene (binder). Boosters are fabricated from 62 tonnes steel.

The CO2e emissions arising from the launch of Ariane 5 may be considered as the transport stage of the lifecycle. The reactant products are not classified as greenhouse gases by the Intergovernmental Panel on Climate Change (IPCC). They are emitted as a white powder. In the stratosphere they are likely to reflect direct sunlight and so may have an overall cooling effect. However they may trap infrared radiation and have a warming effect. More research is being carried out to measure the overall impact on surface temperature.

The second reaction arising from the solid fuel booster may be estimated from the combustion of 1-3 Butadiene (C4H6) binder. It is assumed this short chain dominates but longer chains exist in the binder.

$$C_4H_6 + 11O_2 \Rightarrow 4CO_2 + 3H_2O$$

The mass of polybutadiene was calculated to be 66,6 tonnes. From consideration of the molecular weights the mass of CO2 ejected is 217 tonnes per launch assuming all the binder is consumed.

No account was taken of the waste treatment as no parts of the Ariane 5 are recovered. The environmental impact of steel in seawater was assumed to be negligible.

A.4 Satellite gateway

The satellite gateway includes: Antenna, High Power Amplifier (HPA), frequency convertors, electronics for control and management and air-conditioning.

Table A.1: Breakdown of Parameters for Satellite Gateway

ID	Component	Wt (kg)	Pwr (W)	QTY	Tot wt	Tot pwr	Source
1	Antenna	2 500	15	1	2 500	15	Comsat Systems data
2	HPA	25	821	3	75	2 463	CPI data sheet
3	Frequency convertors	7	60	21	147	1 260	GD Satcom data sheets
4	Other electronics	50	500	1	50	500	Estimate
5	Air conditioning	150	8 000	-	-	381	In existing room with other services, 30 % duty cycle assumed at PUE=1.3
	Total				**2 772**	**4 605**	

The breakdown of parameters for the satellite gateway is given in table A.1. 26 satellite gateways are required throughout Europe.

It was assumed that the buildings already exist and that there is sufficient existing HVAC, UPS and standby generator capacity is sufficient.

The Earth Station manufacturing emissions were estimated from the incremental weight of 2 772 kg multiplied by a carbon factor of 0,537 kg CO2e per kg for WEEE - large [i.5]. The 2014 figure was used.

It is assumed that the equipment and antenna are made mostly from aluminium.

Incremental installation activities include: site survey, installation of equipment racks, installation of equipment and commissioning. Transport was assumed to be approximately 400 km. This would be via 10 visits per gateway in a light commercial van with a 40 km round trip. The emission factor of a light commercial van was estimated to be 0,164 kg CO2e in year 2020 falling to 0,12 kg CO2e in year 2035 [i.17].

The manufacturing emissions were estimated from the incremental weight of 10 kg (including modem cable and antenna) in kg multiplied by a carbon factor of 0,537 kg CO2e per kg for WEEE - large [i.5]. The 2014 figure was used as the latest available.

The delivery vehicle for installation is assumed to be a light commercial van. 40 km was assumed initially (as for VDSL and fibre examples). However 15 % of users are assumed to adopt self-install. Therefore a nominal 40 km reduces to 34 km plus 2 km round trip for mail van delivery of the modem and IUG (final proportion of trip).

The waste treatment was calculated from the mass of the components multiplied by the conversion factor for WEEE [i.5]. The 2014 figure was used as the latest available. This was 2 772 kg multiplied 0,021 kg CO2e per kg.

A.5 Intelligent Network gateway lifecycle parameters

A virtualized Intelligent Network Gateway (ING) is envisaged in Year 2020. The power consumption was estimated by taking the power consumption of a server of today and scaling it according to Moore's Law to year 2020. This produced a value of 650 W as if the whole ING function is handled by a single server of 650 W power consumption. The power consumption was then apportioned to the number of Intelligent User Gateways (IUGs) it can serve according to its maximum fan-out which is 94 081 in year 2020. The power consumption was therefore entered into the GHG accounting model 650/94 081 Watts per satellite terminal.

The manufacturing weight was assumed to be 27 kg and the transport to the site assumed to be 120 km by light commercial van. These were nominal figures as the future system will be virtualized in an existing data centre.

The waste treatment was calculated from the mass of the units multiplied by the conversion factor for WEEE [i.5].

A.6 User modem lifecycle parameters

An average satellite modem power of 7,5 W was considered to be representative of hybrid satellite systems over the period 2020 to 2035 based upon a modem of peak power 22 W and the existence of standby modes which reduce the duty-cycle to around 30 %. The majority of the upstream traffic would be carried by the ADSL2 modem. Whereas downstream traffic will increase over the period, the upstream traffic is not expected to increase significantly. This is because illegal file sharing via peer to peer networking is changing to favour legitimate downloads using paid-for services.

The manufacturing emissions were estimated from the incremental weight 10 kg (including modem cable and antenna) in kg multiplied by a carbon factor of 1,149 kg CO2e per kg for WEEE -mixed [i.5]. The 2014 figure was used as the latest available.

It is assumed that satellite terminals are not replaced during the life of the hybrid satellite system and the waste is disposed of during the final year 2035. The conversion factor used was 0,021 kgCO2e/kg, from the DEFRA 2014 sheet on 'waste treatment' [i.5].

A.7 Intelligent user gateway

The Intelligent User Gateway (IUG) is assumed to be functionally similar to a home gateway as described in section C1 of the EU CoC for broadband equipment [i.18].

The power consumption target for 2015 - 2016 may be estimated by summing the power consumption of the WAN interfaces (including the central processor and data storage) plus the LAN interface(s). The average power consumption with cache was estimated to be 5,7 W.

It is assumed that the manufacturing weight is similar to that of an ADSL modem. This was estimated to be 0,47 kg including power supply.

The IUG was assumed installed along with satellite modem as described above.

It is assumed that IUGs (and satellite modems) are not replaced during the life of the hybrid satellite system and the waste is disposed of during the final year 2035. The conversion factor used was 0,021 kgCO2e/kg, from the DEFRA 2014 sheet on 'waste treatment' [i.5].

A.8 Results

An analysis of the GHG (CO2e) emissions arising from all stages of the life cycle of the subsystems of a satellite broadband network are listed in table A.2.

Table A.2: GHG (CO_2e) emissions arising from all stages of the life cycle of a satellite broadband network

Subsystem	Primary Factor (weight / distance)	No.	Total weight / distance of subsystems	Conversion factor (initial)	GHG (CO2e) emissions over lifetime	% of Satellite Network Emissions
Satellite	6,400 kg	1	6,400 kg	2,865 kg CO2e/kg	18,3 tCO2e	0,01 %
Satellite launch vehicle manufacture	21,417 kg	1	21,417 kg	2,865 kg CO2e/kg	61,4 tCO2e	0,04 %
Solid fuel booster casing manufacture	39,680 kg	1	39,680 kg	0,8623 kg CO2e/kg	34,2 tCO2e	0,02 %
Launch fuel manufacture and emission	Various				0,79 ktCO2e	0,5 %
Satellite gateway manufacture	2,722 kg	26	70,772 kg	0,537 kg CO2e/kg	38 tCO2e	0,02 %
Satellite gateway installation	400 km	26	10,400 km	0,164 kg CO2e/km	1,71 tCO2e	0,001 %
Satellite gateway power consumption	4,605 kW	26	120 kW	0,35681 kg CO2e/kWh	5,31 ktCO2e	3,3 %
Satellite gateway EoLT	2,722 kg	26	70,772 kg	0,021 kg CO2e/kg	57,2 kgCO2e	0,00004 %
ING manufacture	27 kg	1	27 kg	0,537 kg CO2e/kg	14,5 kg CO2e	0,13 %
ING installation	120 km	1	120 km	0,164 kg CO2e/km	19,7 kg CO2e	0,00001 %
ING power consumption	42 kW	1	42 kW	0,35681 kg CO2e/kWh	1,86 ktCO2e	1,17 %
ING EoLT	27 kg	1	27 kg	0,021 kg CO2e/kg	21,5 kg CO2e	0,00001 %
Satellite modem manufacture	10 kg	250 000	2,27 kt	1,149 kg CO2e/kg	2,87 ktCO2e	1,81 %
Satellite modem power consumption	7,5 W	250 000	1,70 MW	0,35681 kg CO2e/kWh	83,2 ktCO2e	52,3 %
IUG manufacture	0,466 kg	250 000	106 kg	1,761 kg CO2e/kg	205 tCO2e	0,13 %
IUG power consumption	5,7 W	250 000	1,29 MW	0,35681 kg CO2e/kWh	63,2 ktCO2e	39,7 %
User equipment Installation	34,3 km	250 000	7,79m km	0,164 kg CO2e/km	1,41 ktCO2e	0,88 %
User equipment EoLT	10,466 kg	250 000	2,38 kt	0,021 kg CO2e/kg	54,9 tCO2e	0,035 %
				Total	159 ktCO2e	100 %

NOTE: The ING is assumed to be located on a server in the Cloud and so this is only the additional emissions. The launch vehicle and fuel manufacture are apportioned according to the payload carried.

The conversion factors used to obtain GHG emissions are shown in Column 5.

The GHG emissions for a hybrid satellite broadband system are shown in more detail in tabular form in figure A.2. These are shown on a logarithmic scale because, on a linear scale, only the two largest emissions would be shown.

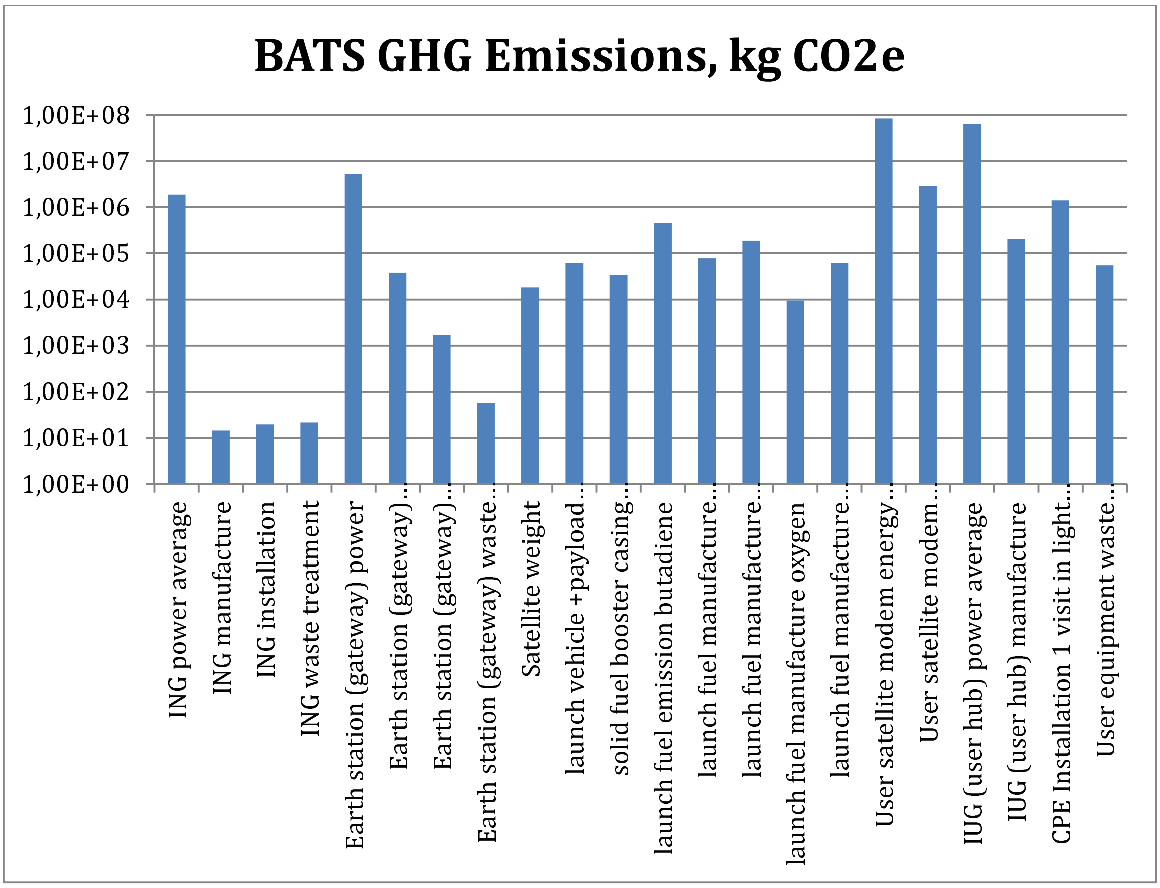

Figure A.2: GHG Emissions over the full lifecycle of a typical Hybrid Satellite broadband network

In total, the GHG emissions arising from the hybrid satellite broadband system over the project lifetime were 159 kt CO2e:

- The power consumed by the satellite modems was the largest contributor to overall emissions with 83,2 kt CO_2e (52,3 % of the total) over the satellite network lifetime.
- The power consumed by the IUGs was also significant at 63,2 kt CO_2e (39,7 % of the total) over the project lifetime.
- The GHG emissions arising from the embodied carbon in the satellite and the launch vehicle including fuel were 0,9 kt CO_2e, which is much less than the emissions during operation.
- The embodied carbon arising from the manufacture and installation of the IUG and satellite modems was 3,08 kt CO_2e, which is also much less than the emissions from power consumed by the subsystems during the lifetime of the satellite network.

The GHG emissions arising from each stage of the life cycle are shown in table A.3. The emissions from the satellite launch stage are shown separately although the manufacture of the satellite itself is included in the production stage.

Table A.3: GHG (CO2e) emissions arising from each stage of the life cycle of a satellite broadband network

Life cycle Stage	GHG (CO2e) emissions	% of Satellite Network Emissions
Production (inc Raw Material Acquisition and Installation)	4,5 ktCO2e	2,9
Satellite Launch	0,9 ktCO_2e	0,56
Use (Operation)	153,6 ktCO2e	96,6
End of Life Treatment	55,0 tCO2e	0,03
Total	159 ktCO2e	100

It can be seen that emissions from the Use Stage dominate the life cycle with 96,6 % of total emissions from the Hybrid Satellite broadband network. The emissions from the other stages have much less impact on the overall emissions. In particular, the satellite launch stage only contributes 0,56 % of total emissions.

History

Document history		
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