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ITU-T L.1410 – Case study: The assessment of greenhouse gas emissions of a hybrid satellite broadband system over its life cycle

ITU-T L-series Recommendations – Supplement 26

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Supplement 26 to ITU-T L-series Recommendations

ITU-T L.1410 – Case study: The assessment of greenhouse gas emissions of a hybrid satellite broadband system over its life cycle

Summary

Supplement 26 to ITU-T L-series Recommendations presents a case study of the application of Recommendation ITU-T L.1410 to the assessment of the greenhouse gas (GHG) emissions of a hybrid satellite and terrestrial broadband system over its life cycle. The goal of this assessment was to calculate the additional emissions of a hybrid satellite system assuming that an existing broadband system is present, which does not meet the European Digital Agenda rate of 30 Mb/s. The GHG emissions model that was developed for the assessment was then used to identify those parts of the Broadband Access via integrated Terrestrial and Satellite (BATS) system that would contribute the most to the GHG emissions, so that attention could be focused on mitigating those emissions. The network is the subject of research and development and is aimed at providing 30 Mb/s broadband services to rural or remote households in Europe. The proposed system lifetime is 2020–2035. The work was funded under the European Union 7th Framework Programme. This study was completed in 2014 by BATS project partners.

History

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Supplement 26 to ITU-T L-series Recommendations

ITU-T L.1410 – Case Study: The assessment of greenhouse gas emissions of a hybrid satellite broadband system over its life cycle

1 Scope

This Supplement presents a case study of the assessment of greenhouse gas (GHG) emissions of a hybrid satellite and terrestrial broadband network over its life cycle. The goal of this assessment was to calculate the additional emissions of a hybrid satellite system, assuming that an existing broadband system is present which does not meet the European Digital Agenda rate of 30 Mb/s. This was therefore not a comparative assessment. The GHG emissions model that was developed for the assessment was then used to identify those parts of the network that would contribute the most to the GHG emissions, so that attention can be focused on mitigating those emissions. This analysis only applies to geostationary satellites rather than low-Earth orbit satellites. This Supplement does not compare GHG emissions of satellite systems with terrestrial systems. The network is the subject of research and development and is aimed at providing broadband services to rural or remote households in Europe (EU28 plus Turkey). The assumed system lifetime is 2020-2035. Only the first order effects, the GHG emissions of information and communication technology (ICT) are assessed according to [ITU-T L.1410].

2 References

[ITU-T L.1410] Recommendation ITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*.

3 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

ADSL	Asymmetric Digital Subscriber Line
BATS	Broadband Access via integrated Terrestrial and Satellite systems
CoC	Code of Conduct
EoLT	End-of-Life Treatment
GHG	Greenhouse Gas
GW	Gateway
HPA	High-Power Amplifier
ICT	Information and Communication Technology
ING	Intelligent Network Gateway
IUG	Intelligent User Gateway
LAN	Local Area Network
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment
P	Production
PA	Power Amplifier

RF	Radio Frequency
RMA	Raw Material Acquisition
U	Use
WAN	Wide Area Network
WEEE	Waste Electrical and Electronic Equipment
WLAN	Wireless Local Area Network

4 Background

This case study followed a process sum approach to the GHG assessment of a hybrid satellite/terrestrial network with the overall objective to minimize greenhouse gas (GHG) emissions and energy consumption. The processes are the installation and operation of a hybrid terrestrial/satellite network. The steps followed included:

- Setting the objectives within the scope of the European Union (EU) Broadband Access via integrated Terrestrial and Satellite (BATS) project
- Defining the network under study including the network elements
- Identifying the processes which are likely to have significant GHG emission within the operational life cycle of the network. The operational life cycle is assumed to span the years 2020–2035 inclusive. The assumption was made that a terrestrial broadband network already exists, which can carry broadband data, and the satellite system adds additional capacity. It is the additional GHG emissions due to the satellite system which are the subject of this assessment
- Obtaining data for the time-varying global parameters, such as the future addressable market, number of households served, the future emission factors of the electricity grid over the life cycle and trends in the future energy consumption of vehicles used for transport. This formed part of the inventory
- Obtaining data for the carbon factors which were given by the GHG emission by mass or by energy used. This formed part of the inventory
- Totaling the GHG emissions for the life cycle stages of the network elements for each year of operation. This formed part of the assessment
- Totaling the GHG emissions over the assumed 16 year life cycle. This produced a figure for the overall GHG emissions in gigatonnes. This formed part of the assessment
- Performing a sensitivity analysis on the overall emissions by varying input parameters of the network elements to establish possible ways of reducing the GHG emissions
- Reporting key findings

This life cycle analysis (LCA) partially complies with [ITU-T L.1410] with the exceptions transparently listed and justified. These are given in Appendix A. As such it serves as an example of the application of the methodology described in [ITU-T L.1410] and can therefore help practitioners and organizations in their approach to the assessment of future GHG emissions of products or services based on information and communication technology (ICT).

The approach to this assessment was dependent on there being publicly available conversion factors such as those published by the European Union Joint Research Centre [b-EU/JRC EDGAR, undated] and the Department for Environment Food and Rural Affairs in the UK [b-Defra, 2016]. These conversion factors provide the GHG emission in CO_2 equivalent (CO_2e) per unit mass (for production and waste disposal stages) or per unit energy (for use stage). In some cases, conversion factors were not available from tables, so these were estimated from first principles. One example is the GHG emitted during the production of fuel used by rockets that launch satellites. More information about how Defra derived its conversion factors can be obtained from [b-DECC, 2015], [b-UNU, 2007] and [b-U. Cambridge, 2014].

5 General description

5.1 General requirements: Overview of satellite-based telecommunications services

Satellite systems are one of several options to increase the coverage area of broadband communications to meet the target for next generation networks of 100% coverage at 30 Mb/s by 2020 [b-EC/DSM, 2016].

This case study reports a satellite-based system and does not make comparisons with terrestrial systems.

Figure 1 illustrates a conventional two-way satellite system. Geostationary satellites are characterized by round-trip signal delays of 240–280 ms that make them unsuitable for real time traffic for voice services or gaming.

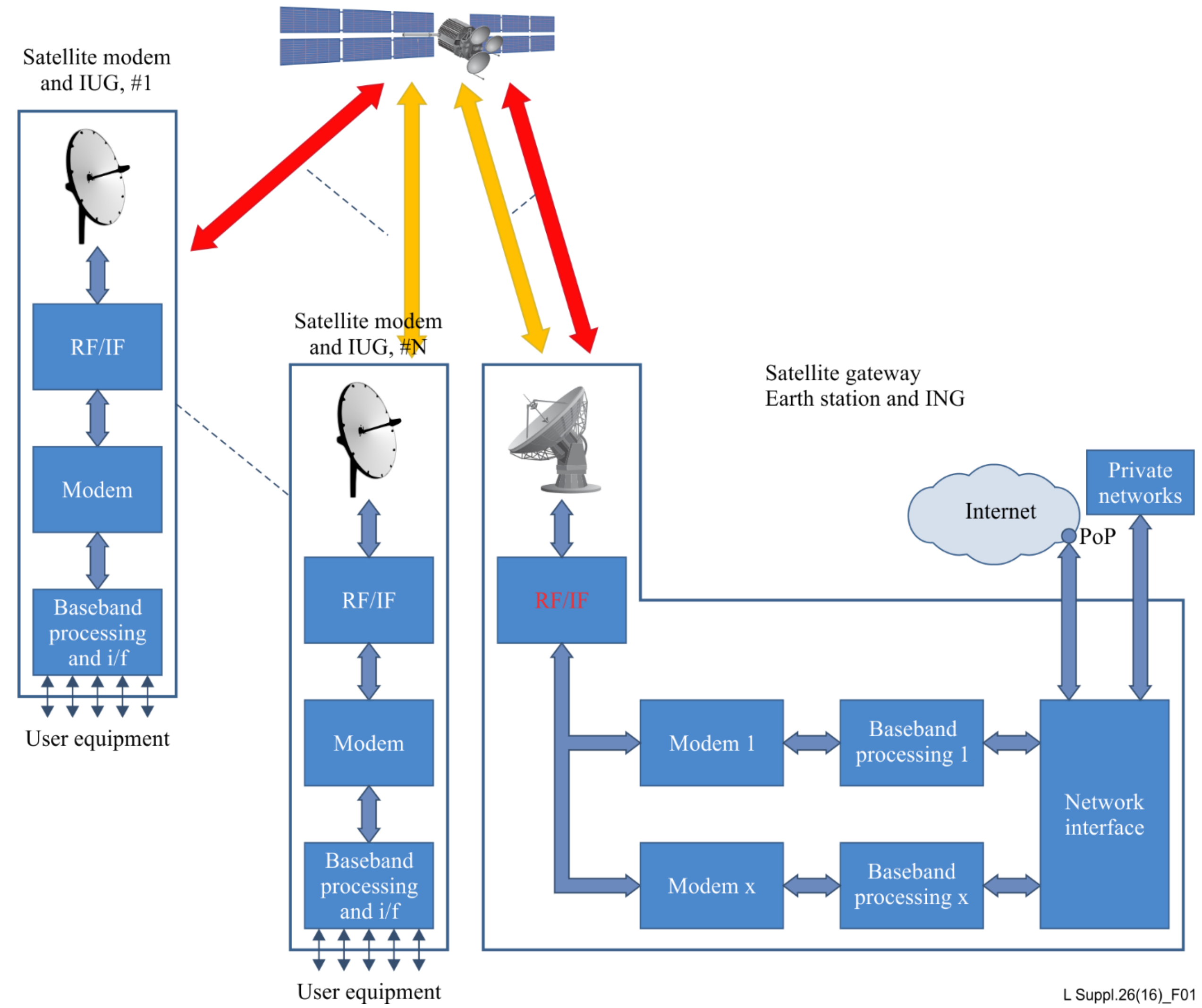


Figure 1 – Two way service satellite network architecture

A geostationary-based satellite access network is typically composed of the following parts:

- A space segment composed of one or more high-throughput satellites in geostationary orbit. The satellite relays bidirectional signals between the gateways (GWs) and user terminals.

- A ground segment, which includes a set of GWs that are in charge of transmitting and receiving data, control and management traffic to or from user terminals. This is part of the Earth station, which is assumed to be already operational serving existing satellite systems.
- A user segment that is composed of a set of user terminals.

Figure 2 illustrates a hybrid satellite system utilizing a combination of terrestrial and satellite paths to provide users with an interactive broadband service with an acceptable response time. Delay-sensitive traffic is routed via the terrestrial network whilst delay-insensitive traffic, often characterized by long packets, is routed via either network.

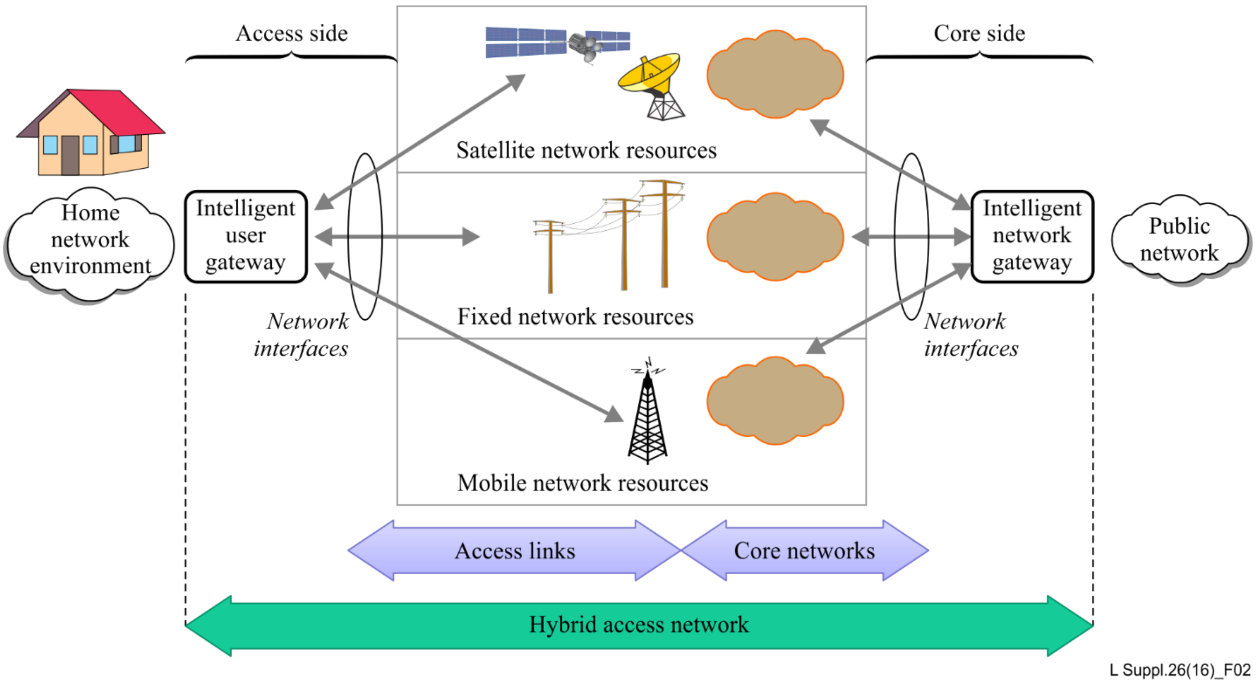


Figure 2 – Hybrid satellite/terrestrial system architecture

The routing of traffic is controlled by the intelligent network gateway (ING) shown at the right of Figure 2 and the intelligent user gateway (IUG) on the left. The energy challenge for this hybrid broadband access solution is to minimize the energy consumption and GHG emissions of a satellite system that supplements one or more terrestrial systems.

5.2 Low-power modes

At the outset of the BATS project, it was understood that the higher the energy efficiency of the network, the lower the GHG intensity is likely to be. An initial GHG assessment revealed that the in-use energy consumption of user satellite modems installed in possibly millions of household throughout Europe would make a strong contribution to the overall GHG emission of the network. Low-power modes were therefore considered for the user satellite modems.

Permanently installed two-way satellite systems are traditionally set to run at their full capacity at all times so that they are instantly available when required. However, with a hybrid system, the user satellite modem may be powered down to save energy according to the required duty cycle. The terrestrial network is assumed to be available to trigger the satellite into operation, e.g., when large quantities of data are to be transported.

The introduction of low-power modes provides a useful energy saving. The following operational modes are defined:

A. full-speed transmit;

B. idle, two-way ready;

C. idle with power amplifier (PA) in mute;

D. only receiving;

E. not receiving;

F. power-down [wake on local area network (LAN)].

Table 1 gives the time taken to return to full two-way operation from each mode, together with the power consumption in that mode. The current design does not use modes D, E and F.

Table 1 – Characteristics of satellite modem operational modes

Satellite communication modem mode	**Mode**	**Delay for forward link connectivity (receive)** s	**Delay for return link connectivity (transmit)** s	**Return link packet latency** s	**Power consumption** W
Full-speed transmit	A	0	0	~0	<22
Idle two-way ready	B	0	0	~0	<13
Idle with PA in mute	C	0	0	~0	<6
Only receiving	D	0	0	<5	<5
Not receiving	E	<10	0	<30	<4
Power-down (wake-on-LAN)	F	<70	<60	<30	<1

The amount of energy and the GHG emissions can be reduced by increasing the relative amount of time a satellite modem operates in states with the lowest power consumption. However, care must be taken, as use of the states with the lowest power consumption can affect the quality of service.

Figure 3 shows the state transitions that are required. The IUG will not normally have knowledge of the state of the satellite modem, nor will it be able to instruct the modem to change state. However, it may be required to manage power-up and power-down. The satellite modem determines which mode to adopt by responding to transmitted packets from the IUG. These packets will be buffered for the time taken to make the transition from the current mode to mode A.

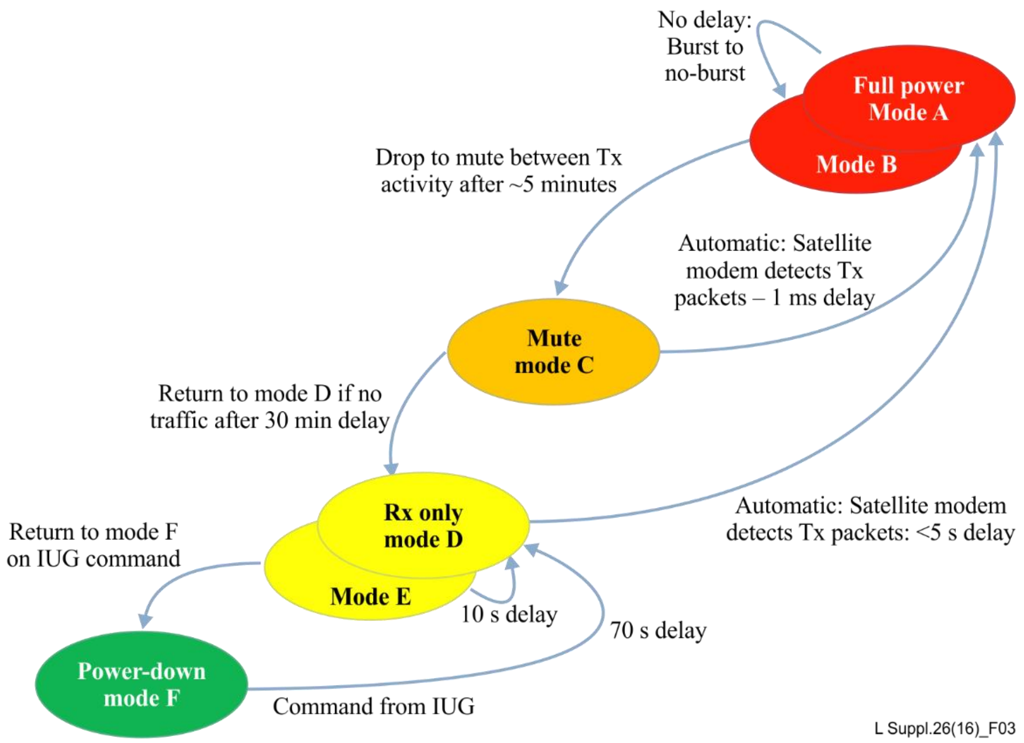


Figure 3 – Satellite modem mode transitions

Under typical usage patterns, it may be possible to reduce the average power consumption of the satellite modem by up to 70% without the user experiencing significant delays in the responsiveness of the system. This is because the IUG will send data traffic via the terrestrial communications channel until the satellite modem is returned to fully operational transmission mode. In the intervening time any packets passed to the satellite modem for transmission will be stored in the buffer. The worst case delay is 5 s, but the system will subsequently run with no further delay.

Table 2 introduces different power plans according to the amount of time that the satellite modem spends in each mode; from which the average duty cycle may be deduced. This ranges from 22 W when on full to 3.2 W under low usage.

Table 2 – Average power consumption using different power plans

Power plan	**Satellite modem mode**	**F**	**D**	**C**	**B**	**A**		
		Power-down	**Rx only**	**Mute**	**Ready**	**Full**	**Average** W	**GHG CO_2e EU** Mt
	power (W)	***1***	***5***	***6***	***13***	***22***		
0	PA always on					100%	22.0	5.39
1	Always on, with idle				90%	10%	13.9	3.71
2	Includes the use of muted mode			80%	10%	10%	8.3	2.54
3	Including Rx-only state,		78%	2%	10%	10%	7.5	2.37
3L	Low usage with plan 3		88%	2%	5%	5%	6.3	2.12
4	Including state F	63%	15%	2%	10%	10%	5.0	1.85
4L	Low usage with plan 4	78%	10%	2%	5%	5%	3.2	1.48

6 Methodological framework

6.1 General requirements

6.1.1 Handling of software

The network elements will contain software to ensure that the network can be managed remotely. This has yet to be designed in the form of a product. It was assumed that the GHG impact of this software is negligible compared with the traffic handled by the hardware, since it will not be required to change state rapidly. However, there will be hardware and software that control the routing of packets via the terrestrial or the satellite links. This is the primary function of the ING and IUG and these were therefore included in the GHG emissions model, including representative use cases. A sensitivity analysis was conducted to demonstrate the GHG impact of various use cases.

6.1.2 Operating lifetime

The operating lifetime of the system was estimated to be the lifetime of a geostationary satellite, which in this case is 16 years from 2020 to 2035. It is assumed that services are migrated on to other system platforms after the satellite service ceases.

6.2 Goal and scope definition

6.2.1 Goal and scope of the study

The goal of the assessment was to calculate the additional emissions of a hybrid satellite system, assuming that an existing broadband system is present that does not meet the European Digital Agenda rate of 30 Mb/s. The subject of this study is an ICT network which can provide ICT services. The GHG emissions model that was developed for the assessment was then used to identify those parts of the BATS system that would contribute the most to the GHG emission, so that attention could be focused on mitigating those emissions.

6.2.2 Functional unit

The function experienced by a user is the ability to send and receive data at up to 30 Mb/s in a rural or remote household, given that there is an existing broadband service operating at rates below 2 Mb/s.

The corresponding functional unit is the use of a broadband satellite system to provide an additional path to carry delay-insensitive information at rates of up to 30 Mb/s to a market peaking at 6.4 million households in Europe (EU28 plus Turkey) over an assumed life cycle of 16 years (2020–2035 inclusive).

The GHG emission of the network was estimated for each year of operation and summed to provide the life cycle GHG emission of the system.

6.2.3 System boundary

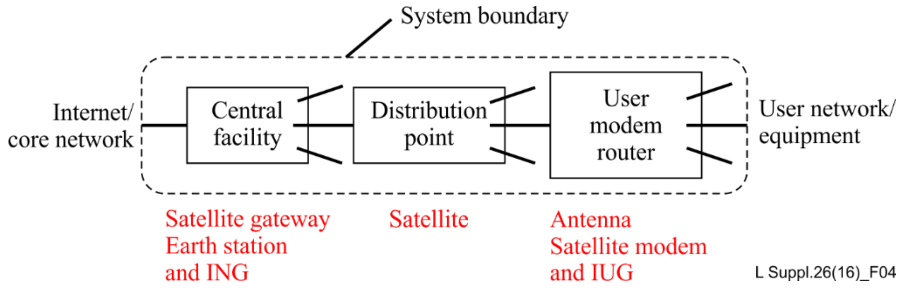


Figure 4 – System boundary

The boundary of the hybrid broadband satellite system is shown in Figure 4. Network elements for the satellite system include the following.

- The central facilities, also known as satellite GWs comprising: antenna, Earth station and ING.
- The distribution point, a geostationary satellite. Note that the launch vehicle and its fuel were included in the analysis.
- The user satellite modem, consisting of the antenna (dish), the radio frequency (RF) part consisting of a high-power amplifier (HPA) and a low-noise amplifier, baseband processor and the IUG.

The core network, data centres, user network and user equipment were assumed to be already present and are outside the scope of this assessment.

6.2.4 System boundary – Checklist of eight items

1) ICT hardware

This checklist item refers to the life cycle impact of ICT hardware. The hardware items were:

- IUG;
- Earth station GW upgrade for hybrid satellite;
- satellite (and launch vehicle plus fuel);
- user satellite modem;
- ING.

For each of these network elements, data values were gathered for the following life cycle stages included in the assessment:

- production: including raw material extraction and transport to installation site;
- use: including electricity or fuel;
- end of life treatment (EoLT): including disposal of network elements;

2) ICT software.

Only pre-production software was available at this stage of the project. More significant will be the software used to activate the expected use cases, which will vary dynamically according to the traffic presented. Handling of the future software needed to control this functionality and network configuration and management was not assessed. A sensitivity analysis was performed on a user satellite modem to highlight the GHG emission of various use cases as described later.

3) Consumables and other supportive products

Packaging was included in the calculation of production emissions of the user equipment.

4) Site infrastructure

The Earth station buildings and customer premises were assumed to be already in place, including air-conditioning units.

5) Transport (movement of goods)

Transportation of the ICT hardware to the location of installation was included.

6) Travel (movement of people)

This was considered to be out-of-scope for a calculation of the impact of ICT alone. Only first order effects were included.

7) Storage of goods

This was not accounted for.

8) Working environment

This was not accounted for.

6.3 Cut-offs

The following cut-offs were applied.

- Second order and other effects were not included (e.g., changes in user behaviour).
- The system boundary (see Figure 4) was assumed to be the IUG and ING in the case of hybrid broadband satellite technology. End user devices, such as television sets and personal computers, were not included because these were assumed to be existing devices. The core network was not included.
- The Earth station buildings and customer premises were assumed to be already in place, including air-conditioning units. Changes in building structure required for the upgrade of Earth stations, etc. were not included.
- Emissions from maintenance work was not included.
- Support activities were not included,
- Storage, disassembly, dismantling and shredding were not included.

6.4 Data collection and quality

Wherever possible, referenced sources of data were used, thus reducing the need for estimates by the project team. Secondary data used in the assessment was for the future network.

Global parameters, such as: the future addressable market, the number of households served and the future emission factors of the electricity grid are described in clause 8.

Clause 8 also describes how the network element parameters, such as the GHG emission by mass or by energy, were obtained.

For the European model, priority was given to emission factors obtained from the *Emissions database for global atmospheric research* [b-EU/JRC EDGAR, undated]. This database includes values for chemicals emitted, including CO_2 per unit mass. However, some tables date from 2006. When no figure was available, the most recent Defra spreadsheet was used [b-Defra, 2016]. It is not known what the trends will be in the future. Defra tables of carbon factors are updated annually. The most recent set of tables were used at the time of assessment (2014). No attempt was made to predict future values for these tables.

In some cases, no conversion factor was available from tables, so estimates were made from first principles. One example is the GHG emitted during the production of the fuel used by the rockets that launch satellites.

Where a parameter was considered to be important and could be estimated well into the future, publications were used to provide forward estimates. These included the number of households in a country, the emission factor for electricity (dependent on the energy mix), the addressable market and market share and the emissions of delivery vehicles. Future values for the power of broadband equipment were available from [b-EU/JRC CoC, 2013] up to 2016. More information on this is given in clause 8.

The data quality is difficult to assess for this case study, which requires parameters to be estimated for the future time period 2020–2035. In some cases, e.g., electricity and transport, future estimates were made from publications from the best available sources.

The JRC database [b-EU/JRC EDGAR, undated] is relevant to Europe, the geographical area of the study, but this is incomplete, as it focuses on chemical and materials rather than products (such as electrical goods). The data is older data than that of Defra [b-Defra, 2016], which is updated annually.

Whilst the Defra database is up-to-date, and includes the production (material use) of electrical goods by mass, it is focused on the UK. The estimate required for this case study should be an average for the whole of Europe, but in many cases only the Defra figure was available.

For waste electrical and electronic equipment (WEEE) the tables of [b-Defra, 2016] employed assume that raw materials rather than open loop recycling is used. However, recycling is being introduced in the UK for WEEE. Therefore the materials use for WEEE products may be an overestimate.

7 Life cycle stages

7.1 Raw material acquisition stage

Figures for the launch vehicle (rocket) and its fuel were derived from first principles using published data from [b-EU/JRC EDGAR, undated]. The derivation included values for elements such as iron, aluminium and hydrogen.

7.2 Production stage

Tables, such as those published for the UK [b-Defra, 2016], were used to provide carbon factors by mass for network elements that were used to construct the network. These are categorized as: WEEE – large; WEEE – mixed; and WEEE – small. (The same classification is used for EoLT. See clause 7.4). The generic tables available from [b-Defra, 2016] for electronic goods were used as a detailed inventory of the raw materials used in electronic products, such as a satellite modem. The proportions of raw materials in electronic products are not declared by Defra.

The production stage included the following processes:

- production of network elements and interconnections;
- transport of products to site;
- installation process.

The mass of a network element and its packaging was obtained from representative products already available.

7.3 Use stage

The energy consumption of a hybrid broadband satellite network during the use (operational) stage is the sum of the energy consumption of all subsystems and equipment included within the boundary of the network under investigation.

The energy consumption was assessed in kilowatt hours over the period of the assessment, including all subsystems. The energy consumption was estimated with reference to the EU JRC codes of conduct [b-EU/JRC CoC, 2013] or, if not available there, from representative products.

To convert in-use electricity into GHG emissions, the emission factor for the electricity supply was estimated, as described in clause 8. This will vary from year to year over the period 2020–2035. The variation of conversion factors for electricity in the EU can be found in [b-EC/DGE Energy, 2010]. It should be noted that the CO_2e conversion factor is expected to drop from 0.357 kg/kWh in 2020 to 0.275 kg/kWh in 2035.

A first approximation of the energy consumption of a hybrid broadband satellite network was derived from a typical satellite broadband network operating in the Ka band via a state-of-the-art geostationary high-throughput satellite, addressing both Earth station (GW) and user terminals. The satellite itself was not considered to consume any energy from sources on Earth while in orbit and therefore does not need to be accounted for in the use stage. However, the embodied carbon arising from the production of the satellite (including any electricity-generating sources, such as solar panels) was included.

It is understood that, if low duty cycle modes are implemented, the energy used by the user satellite modems will vary according to the traffic carried. No statistics were available to predict traffic usage patterns. A sensitivity analysis was therefore made according to the possible use cases (power plans) shown in Table 2. For this case study, the satellite modem power ranges from on full at 22 W to low usage at 3.2 W and the total GHG emission of the network varies accordingly. Since much of the traffic will be handled by the terrestrial network, a typical value of 7.5 W was assumed and used for the results shown in Table 5 and Figure 9.

7.4 End-of-life treatment stage

In tables, such as those available from [b-Defra, 2016], there are separate sheets relating to conversion factors for material use and waste disposal. Open-loop recycling is generally included as part of the production process under material use. For WEEE (electronic products), the tables of [b-Defra, 2016] assume that raw materials rather than open-loop recycling is used in the manufacturing phase. The EoLT emissions factors are therefore one or two orders of magnitude lower than those for production and could, for example, be representative of the transportation of waste material to the disposal point.

8 Life cycle inventory

8.1 Key input parameters

For the purposes of the LCA, the key input parameters are considered to be as follows.

- The total energy consumption of the subsystems.
- The mass of a component or subsystem.
- The lifetime of the system – assumed to be 16 years (for a period of study from 2020 to 2035 inclusive).
- The number of terminals in operation per year (see Figure 5).
- The GHG emission factor of the electricity supply (see 8.4).
- Embodied carbon during production, installation and EoLT (see Figure 8).
- The annual values of the parameters, as they are expected to change, over the period of the study.
- These parameters are discussed in more detail in clauses 8.2 to 8.9 and in [b-GHG EU, 2015].

8.2 Estimating the number of terminals in operation

The number of terminals added and in operation each year is the product of four variables: the number of households, the take-up rate, the market share for satellite services and the market annual profile.

An internal deliverable within the BATS consortium that includes an estimate for the addressable market for rural services in Europe is shown in Figure 5.

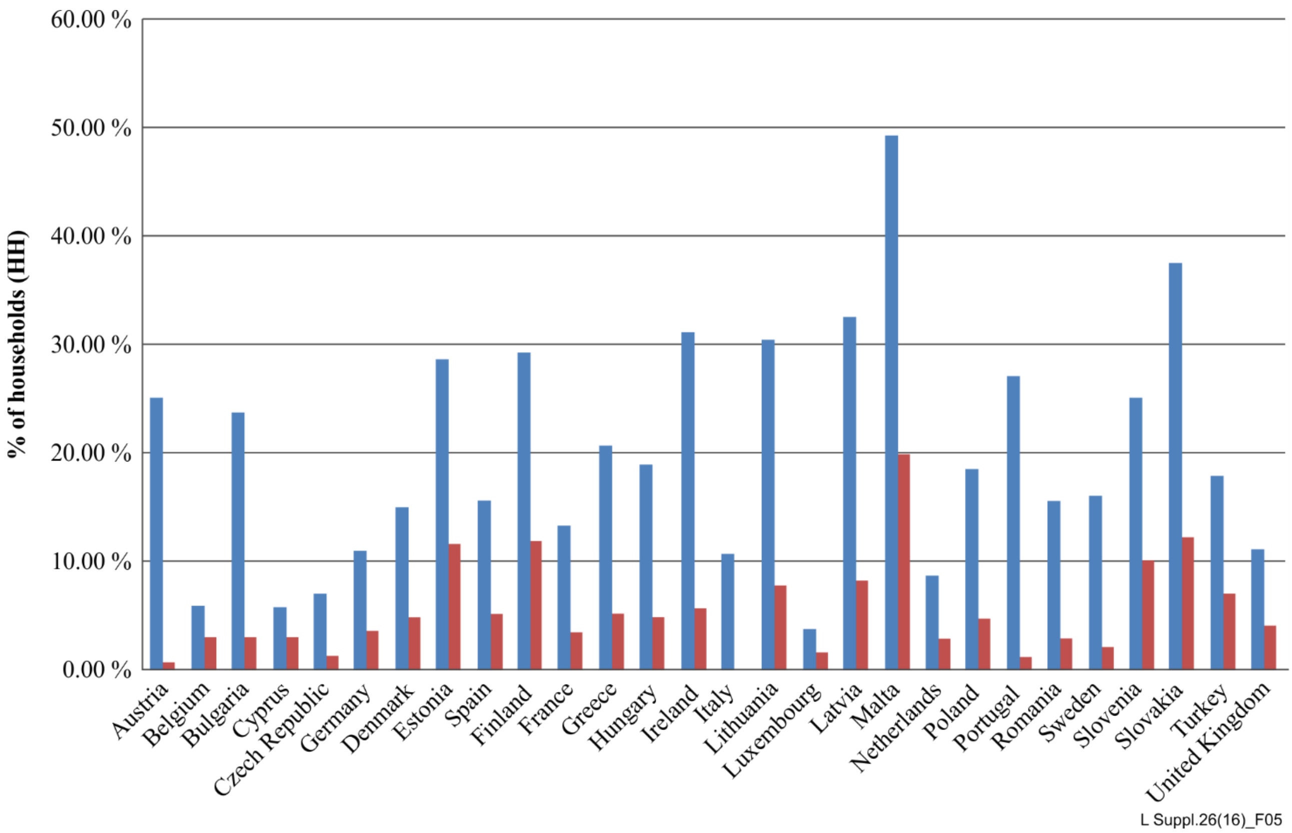


Figure 5 – Addressable market for 30 Mb/s services in year 2020 (Source: [b-GHG EU, 2015])

Figure 5 shows the addressable market (blue bars) and take-up percentage (red bars) by 2020. On average, 14.4% of households in the EU27 (Croatia excluded) countries plus Turkey will have satellite as the only available technology for supplying broadband services at 30 Mb/s or more. Note that these data are reused from another study. The average percentage of total households that will take up a satellite broadband connection is 3.72% (averaging the red bars), which are mostly located in remote areas.

The number of households in Europe (E28 plus Turkey) over the period 2020–2035 was estimated using [b-households EU, 2016], [b-households HR, 2015] and [b-households TR, undated]. An analysis of these references showed that the projected number of households in year 2020 is 245.5 million and a growth rate of 0.41% per annum is forecast.

The take-up rate annual profile (timeline) assumed is shown in Figure 6. Only the red (remote) profile was used for this assessment. It was assumed that, at its peak, only 50% of the addressable market will opt for a BATS solution.

The peak number of households taking hybrid satellite service was calculated to be 6.4 million households in the year 2029.

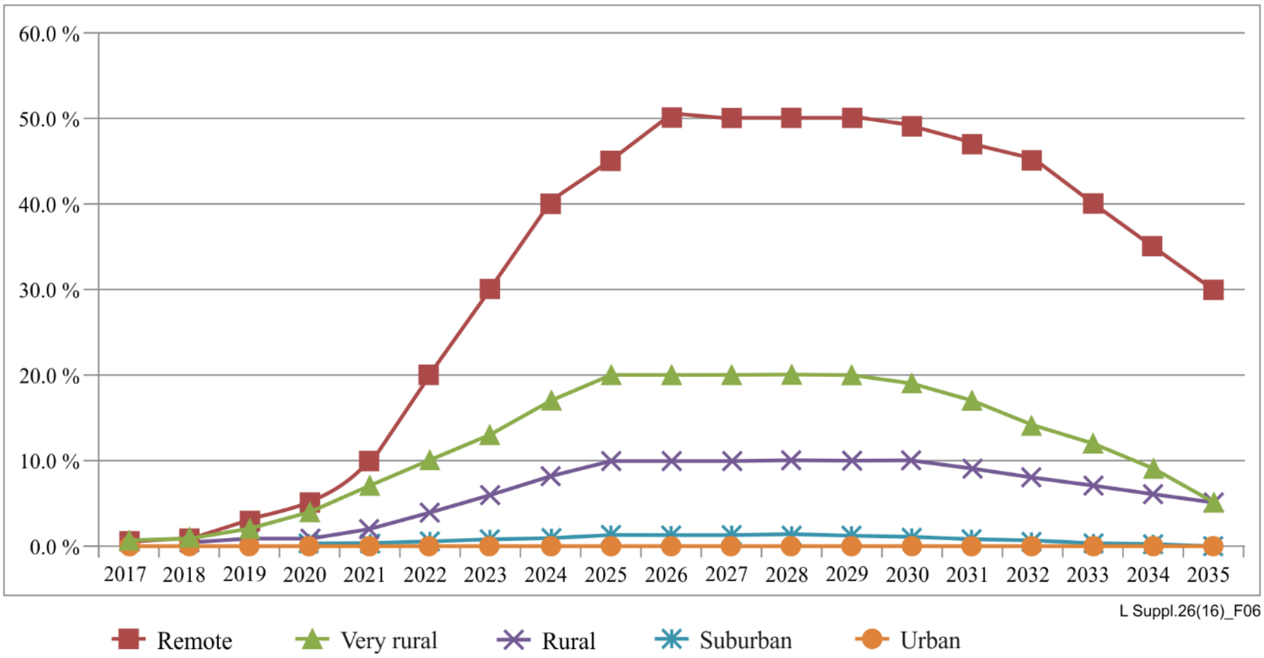


Figure 6 – Take-up annual profile for satellite-based broadband services

8.3 Delivery vehicles and their emissions trend

Emissions factors for delivery vehicles are expected to change over the period 2020–2035. The expected values by year were calculated from published references as detailed in [b-GHG EU, 2015], [b-GHG UK, 2015] and [b-GHG FR, 2015]. Light commercial vehicles and heavy goods vehicles were considered. No allowance was made for the proportion of commercial vehicles that will use electricity or hydrogen as a fuel as no data were available.

8.4 On grid electricity and emissions trends

The GHG emission factor for electricity supply each year for the EU will vary over the period 2020–2035. [b-EC/DGE Energy, 2010] provides a perspective on the energy source mix over the life cycle of the satellite service deployment.

The annualized decrease in fossil fuel is estimated from Figure 7 to be 0.75% between 2020 and 2030 and this trend is assumed to continue until 2035. The average GHG CO_2 conversion factor for the EU in 2013 is given as 0.347 23 kg/kWh [b-Defra, 2016]. This was treated as the base year from which subsequent conversion factors were derived. In 2020, Figure 7 shows that the proportion of fossil fuel is predicted to fall from 51.8% to 49.5%. The CO_2 emission factor will then have fallen pro-rata to 0.347 23 × 49.5/51.8 = 0.331 81 kg/kWh. To this was added a CO_2 transmission and distribution loss of 0.025 kg/kWh [b-Defra, 2016]. Linear interpolation was used to derive the emission factors for each year over the period 2020–2035.

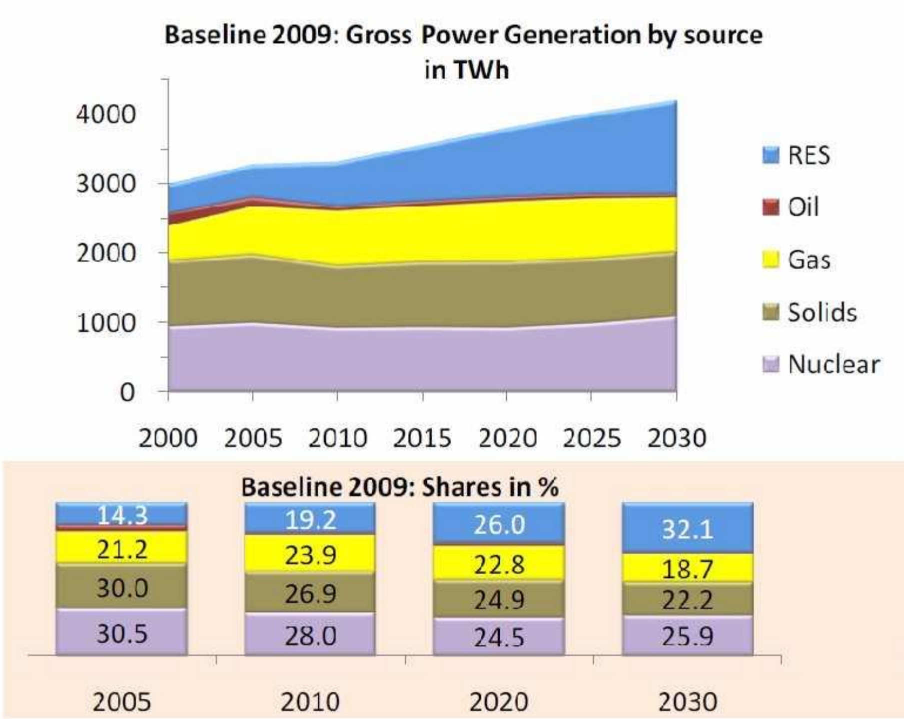


Figure 7 – Gross power generation by source (Europe) [b-EC/DGE Energy, 2010]

8.5 Satellite launch vehicle and payload

GHG emissions arising from the production of the satellite system include all the physical components including the launch vehicle and its payload. In addition, the emissions arising from combustion of the fuel supply used to take the satellite into geostationary orbit were accounted for.

Where available, tables of [b-EU/JRC EDGAR, undated] and [b-Defra, 2016] were used to obtain carbon factors for production emissions. The mass of a component (such as a rocket stage or the fuel in that stage) was multiplied by the emission factor to arrive at a CO_2e value in kilograms. Details are given in the following paragraphs.

The Ariane 5 launch vehicle has a gross take off launch capacity of 10.0t for dual payloads or 10.5 t for a single payload [b-Ariane, 2016]. The emissions of the launch vehicle were therefore scaled according to the actual payload (6.4 t) assuming a second satellite 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 t and 26 t, respectively. These react to produce water, which is not classified as a GHG. No account is therefore taken of the impact of water emission into the stratosphere. However, account is taken of the emissions incurred during production of the propellants. Details of the production of liquid oxygen are given on p. 82 of [b-IEA, 2007]. The conversion factor is 0.310 kWh/kg. Details of the production of hydrogen are given on p. 2 of [b-US EPA, 2008]. The CO_2e conversion factor given is 8.5 kg/kg.

The emission due to the production of the solid fuel booster was calculated from the propellant mix, namely 68 kg/100 kg ammonium perchlorate (oxidizer), 18 kg/100 kg aluminium (fuel), and 14 kg/100 kg polybutadiene (binder), used in solid rocket motors. [b-ACC, 2005] gives the chemistry of the solid rocket booster propellant in the reaction:

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

The CO_2e emission arising from the production of solid fuel boosters was estimated by consideration of the detailed production 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 t steel.

The CO_2e emissions arising from the launch of Ariane 5 were considered in the production phase of the life cycle. The reactant products are not classified as GHGs by the Intergovernmental Panel on Climate Change (IPCC). They are emitted as a white powder. The net radiative forcing has been shown to be positive. More research is needed by the IPCC to classify emissions and to enable an assessment of the CO_2e [b-Ross, 2014].

The second reaction arising from the solid fuel booster may be estimated from the combustion of 1,3-butadiene (C_4H_6) binder as shown in the reaction:

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

The mass of polybutadiene was calculated to be 66.6 t. From consideration of the molecular weights, the mass of CO_2 ejected is 217 t per launch, assuming all the binder is consumed.

It was assumed that no part of the launch vehicle or payload reached escape velocity meaning that the GHGs arising from the combustion process remained in Earth orbit and so contributed to the global warming potential.

No account was taken of waste treatment as no parts of the Ariane 5 are recovered.

8.6 Satellite gateway (ground segment) life cycle parameters

The satellite GW includes: antenna, HPA, frequency convertors, electronics for control and management and air-conditioning.

Table 3 shows the breakdown of parameters for the satellite GW. For European coverage, 38 of these are required.

Table 3 – Breakdown of parameters for satellite gateway

ID	Component	**Mass** kg	**Power** W	QTY	**Total mass** kg	**Total power** W	Source
1	Antenna	2,500	15	1	2,500	15	6.3 M Earth Station Antenna
2	High-power amplifier	25	821	3	75	2 463	250W CW outdoor TWT power amplifier for satellite communication [viewed 2016-09-13]s
3	Frequency convertors	7	60	21	147	1 260	GD Satcom, 10 uc 10 dc tc
4	Other BATS electronics	50	500	1	50	500	Estimate
5	Air conditioning	150	8 000	0	0	381	In existing room with other services: 30% duty cycle assumed at PUE=1.3
	Total				**2 772**	**4 605**	

The Earth station production emissions were estimated from the incremental mass of 2 772 kg from Table 3 multiplied by a carbon factor of 0.537 kg for (WEEE) – large [b-Defra, 2016]

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

Incremental installation activities include: site survey, installation of equipment racks, installation of equipment and commissioning. Transport distance was assumed to be approximately 400 km, consisting of 10 visits per GW 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 CO_2e in year 2020 falling to 0.12 kg CO_2e in year 2035 [b-CCC, 2013], [b-Defra, 2016].

The production emissions were estimated from the incremental mass of 10 kg (including modem cable and antenna) in kilograms multiplied by a carbon as CO_2e conversion factor of 0.537 kg/kg for WEEE – large [b-Defra, 2016].

The scenario for a household requiring service is a remote location 10 km from the nearest village and 10 km from the nearest city where there is a depot for the network provider. The delivery vehicle for installation is assumed to be a light commercial van. For the round-trip to a household in a remote location, 40 km was assumed. The waste treatment was calculated from the mass of the components multiplied by the CO_2e conversion factor for WEEE [b-2], i.e., 2 772 kg multiplied by 0.021 kg/kg.

8.7 Life cycle parameters for the intelligent network gateway

A virtualized ING is envisaged in the year 2020. It is assumed to be located on servers in data centres. No figures were available to cover the proportion of data centres that would be used to facilitate the ING functionality. An alternative estimate was therefore made based upon the use of discrete servers to provide this functionality.

The additional power consumption was estimated by taking the power consumption of a server of today and scaling it according to Moore's law to the year 2020. This produced a value of 650 W for a maximum calculated fan-out of 94 081 to the IUGs that are located in each household. The number of servers was calculated by dividing the maximum number of households served by the fan-out. The mass of a server is estimated to be 27 kg.

Transportation of a server to a satellite GW was assumed to require a 20 km round trip in a light commercial vehicle.

It is assumed that servers in a virtualized ING are not replaced during the life of the hybrid satellite system and that the waste is disposed of during the final year, 2035. The CO_2e conversion factor used was 0.021 kg/kg, from [b-Defra, 2016].

8.8 Life cycle parameters for the user modem

A satellite modem power of 7.5 W average was considered to be representative of hybrid satellite systems over the period 2020–2035. This is 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 an asymmetric digital subscriber line 2 (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.

Production emissions were estimated from the incremental mass of 10 kg (including modem cable and antenna) multiplied by a carbon as CO_2e conversion factor of 1.149 kg/kg under the materials use tab for WEEE – mixed [b-Defra, 2016]. The 2014 figure was used as the latest then available.

It is assumed that user satellite modems are not replaced during the life of the hybrid satellite system and that the waste is disposed of during the final year, 2035. The CO_2e conversion factor used was 0.021 kg/kg, from [b-Defra, 2016].

8.9 Life cycle parameters for the intelligent user gateway

The IUG is functionally similar to a home GW as described in Section C1 of [b-EU/JRC CoC, 2013], the EU code of conduct for broadband equipment.

The power consumption target for 2015–16 may therefore be estimated by summing the power consumption of the wide area network (WAN) interfaces (including the central processor and data storage) plus the local area network interface(s) as shown in Table 4. The average power consumption of the IUG, assuming average traffic loading with cache was estimated to be 5.7 W including an ADSL interface for the WAN.

Table 4 – Breakdown of parameters for an intelligent user gateway

	Load W	**Idle** W
IUG central processor unit plus ADSL2 WAN interface	2.8	2.2
Additional WAN interface, gigabit Ethernet	1	0.6
Wi-Fi interface, IEEE 802.11n	2	0.8
Server signal degrade (SSD)	1.4	0.6
IUG Total	7.2	4.2

Since the ADSL system is assumed to be already in place before the hybrid satellite system is installed only the incremental power consumption of the hybrid satellite system is calculated in this example. The ADSL WAN interface average power consumption is 2.4 W according to [b-EU/JRC CoC, 2013]. The incremental power consumption of the IUG is therefore 3.3 W.

It is assumed that the production mass is similar to that of an ADSL modem. This was estimated to be 0.47 kg including power supply.

The IUG was assumed to be installed at the same time as the 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 CO_2e conversion factor used was 0.021 kg/kg [b-Defra, 2016].

9 Life cycle impact assessment

9.1 Description of the model

A process sum approach was adopted. The model was implemented by using a spreadsheet that sums GHG emissions annually over the life cycle.

Key global parameters are entered in cells A4–A14 of Figure 8, together with their base value (e.g., for year 2014) in cells B4–B14. Years (of hybrid satellite implementation) are shown in cells E2 and J2, etc. Values for each year are separated by purple columns such as D and I. Annualized parameters, such as number of households and conversion factors for electricity change and delivery vehicle emissions, have been estimated according to the best available published estimates and entered into the spreadsheet for each of the years 2020–2035. Extensive use was made of the comments field to show the source reference of a parameter value.

	A	B	C	D	E	F	G	H
1								
2	**Year >>**				2020			
3	**Calculation of market size**	value	Unit					
4	Growth rate of households	0.41	%		245500000			
5	Addressable market	14.4	%		35352000			
6	Take rate peak	35	%					
7	Addressable market annual profile % relative to peak at 100%	See>>	%		10			
8	Number of households with satellite broadband				1237320			
9	Number of BATS units operating based upon share of available sa	50	%		618660			
10	Number of Units added (or removed) in year				618660			
11	**Conversion Factors**							
12	Conversion factor-electricity	0.35681	kg CO2e per kWh				0.35681	
13	Conversion Factor - delivery vehicle (light commercial-van)	0.181	kg CO2e per km				0.164	
14	Conversion Factor - truck of capacity 3.5-7 tonnes	0.642	kg CO2e per km				0.6309524	
15								
16	**Network Elements and Processes**				Number	Number	Conversior	GHGe
17					added	Operational	factor	kgCO2e
18	**BATS network elements and processes**							
19	ING power average	0.65	kW		38	38	0.35681	7.73E+04
20	ING production	27	kg		38		0.53724	5.51E+02
21	ING installation	20	km		38		0.164	1.25E+02
22	ING waste treatment	27	kg		38	38		
23	Earth station (gateway) power	4.605	kW		19	19	0.35681	2.74E+05
24	Earth station (gateway) production	2722	kg		19		0.53724	2.78E+04
25	Earth station (gateway) installation	400	km		19		0.164	1.25E+03
26	Earth station (gateway) waste treatment	2722	kg		19			
27	Satellite weight	6400	kg		1		2.865	1.83E+04
28	launch vehicle +payload production	21417	kg		1		2.865	6.14E+04
29	solid fuel booster casing production	39680	kg		1		0.8623	3.42E+04
30	launch fuel emission butadiene	138880	kg		1		3.26	4.53E+05
31	launch fuel production aluminium	27392	kg		1		2.865	7.85E+04
32	launch fuel production hydrogen	22016	kg		1		8.5	1.87E+05
33	launch fuel production oxygen	26387	kWh		1		0.35681	9.42E+03
34	launch fuel production chlorine	172848	kWh		1		0.35681	6.17E+04
35	User satellite modem energy and power amplifier energy	0.0075	kW		618660	618660	0.35681	1.45E+07
36	User satellite modem production	10	kg		618660		1.149	7.11E+06
37	IUG (user hub) power average	0.0033	kW		618660	618660	0.35681	6.39E+06
38	IUG (user hub) production	0.466	kg		618660		1.761	5.08E+05
39	CPE Installation 1 visit in light commercial van	34.3	km		618660		0.164	3.48E+06
40	User equipment waste treatment	10.466	kg					
41	Total BATS							3.33E+07

Figure 8 – Screen shot of the EU GHG emissions model showing key input parameters

The hybrid satellite network elements and processes are listed in Column A. Column B shows the parameter, in kilowatts, kilograms or kilometres, which is associated with carbon emissions for the network. The number added in year 2020 is shown in column E. The conversion factor to kilograms of CO_2e is in Column H. These are obtained from tables or deduced from them according to the year of the emissions.

This shot shows details for year 2020. Each following year is calculated similarly and is then totalized over the life cycle.

10 Life cycle interpretation

10.1 Results of the life cycle impact assessment for a hybrid satellite system

The embodied carbon (shown as GHG emissions) arising from production, installation and waste disposal (or recycling) of the subsystems of a hybrid broadband satellite system for European deployment to a market peaking at 6.4 million users over the 16 year project lifetime are shown in Table 5.

Table 5 – Summary of embodied carbon in hybrid broadband satellite network

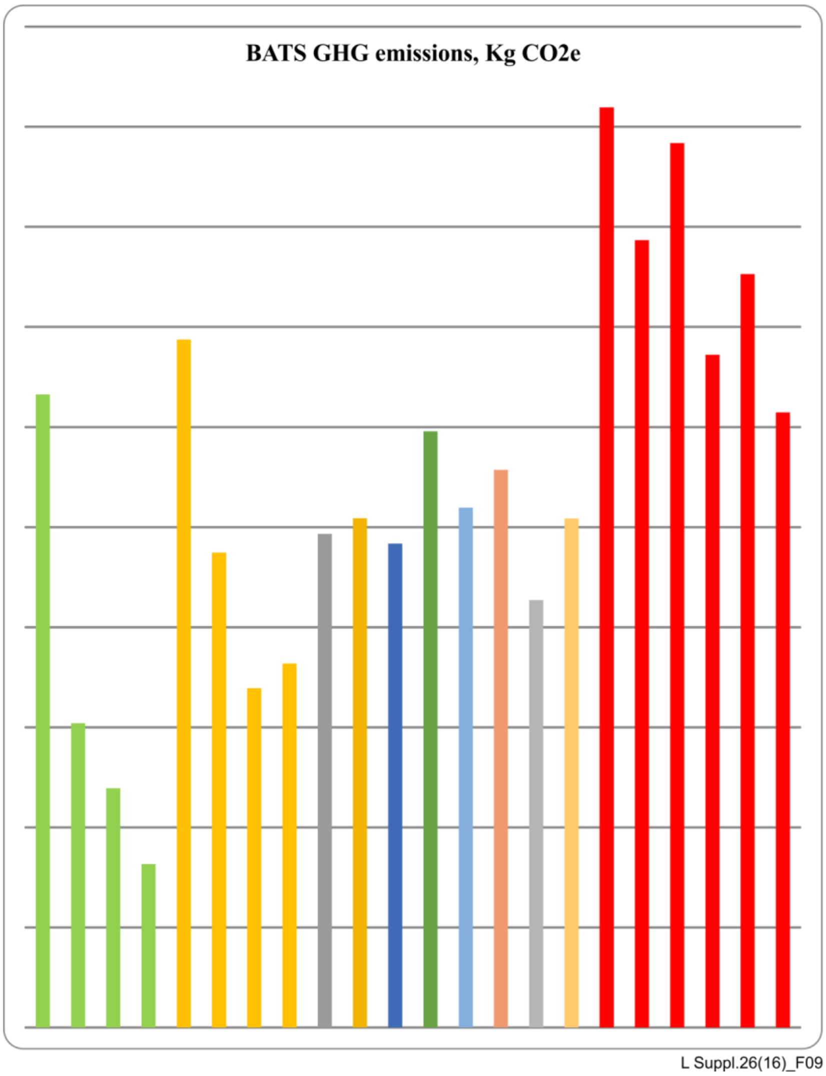
Subsystems of the satellite broadband network	Number of units	GHG emissions (CO_2e) t
Satellite gateways	38	62.4
Satellite terminals (intelligent user gateways, modems, antenna)	6 141 885	114 000
Launch vehicle production	2	191
Launch (fuel production and use)	2	1 577

The additional GHG emissions for the hybrid satellite system are shown in more detail in a bar chart on a logarithmic scale in Figure 9. In total, the additional GHG as CO_2e emissions arising from the hybrid broadband satellite system over the project lifetime is predicted to be 2.37 Mt over the life cycle.

The additional power consumed by the satellite modems as part of the customer premises equipment was the largest contributor to overall CO_2e emissions, with 1.56 Mt over the life cycle.

The GHG as CO_2e emissions arising from the embodied carbon in the satellite and the launch vehicle including fuel were 863 t, which can be considered to be insignificant under cut-off rules compared with the emissions during the operational lifetime.

The embodied carbon as CO_2e arising from the production and installation of the IUG and satellite modems was 114 kt, which can also be considered to be insignificant under a 1% cut off rule when compared to the emissions during the operational lifetime of the subsystems.



Key – Green: ING, Orange: Earth station, Blue: Satellite, Red: User equipment

Figure 9 – GHG Emissions over the life cycle of a hybrid broadband satellite system
Note that the vertical scale is logarithmic

NOTE – This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal.

Emissions from production, transport and waste treatment represented only 4.9% of total emissions, relatively small in comparison to the overall assessment. Production, transport, and waste treatment emissions include those from the production of the satellite launch vehicle and the transport of the satellite into geostationary orbit.

10.2 Sensitivity analysis of major assumptions

Parameters were changed in the GHG emissions model to find out the overall impact on GHG emissions. The largest contributor is the power consumption of the satellite modem. This depends on the power plans shown in Table 2. If there are significant periods when traffic is low, good use can be made of low-power modes. The sensitivity analysis is shown in the rightmost column of Table 2. Here it can be seen that overall emissions as CO_2e from the satellite network range from 1.48 to 5.39 Mt over the life cycle according to the duty cycle of user satellite modems.

10.3 Discussion

The network as described is for future deployment. More development work is needed to provide a commercial hybrid satellite system with the power plans outlined in this case study.

10.4 Compliance with [ITU-T L.1410]

This LCA partially complies with [ITU-T L.1410], with the exceptions transparently listed and justified. These are given in Appendix I.

10.5 Review

The general methodology and case study was reviewed by members of the BATS consortium. A full review regarding compliance with [ITU-T L.1410] was performed by self-assessment. The case study was not reviewed externally for compliance with [ITU-T L.1410]. Discussions with ITU-T members were very helpful at the review stage.

Appendix I

Compliance with [ITU-T L.1410]

Table I.1 summarizes the fulfilment of requirements.

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
Introduction	Deviation(s) from the requirements shall be clearly motivated and reported.	YES		
5.2	Full compliance with [ITU-T L.1410] can be claimed if all mandatory requirements are fulfilled.	YES		
5.3	A third-party review is also needed if the comparison result is to be externally communicated.	YES		
5.3	In case of comparative assessment between ICT goods LCAs the operating lifetime shall be set to equal.	N.A.		This was not a comparative assessment
6.1	[b-ISO 14040], [b-ISO 14044] and [ITU-T L.1410] have to be taken into account.	YES	X	
6.1.1	The following four high-level life cycle stages [RMA, production (P), use (U), EoLT] shall apply to ICT goods, networks and services and shall be assessed as applicable in LCAs based on [ITU-T L.1410] in accordance with the goal and scope.	YES		[b-Defra, 2016] tables include RMA in 'materials use'
6.1.1	Table 2 of [ITU-T L.1410] defines the detailed life cycle stages that further define the system boundary and which are to be considered when assessing the life cycle impact of ICT goods, networks and services. In particular, it is important to cover all processes whose relevance is marked as mandatory in that table.		X	Storage/ disassembly/ dismantling/ shredding were not specified in BATS
6.1	Transport and energy supplies shall be included in all life cycle stages.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.1	At the time of publication, to collect appropriate data related to raw materials transport and to separate data related to raw material acquisition stage and production stage is considered challenging due to LCA tool limitations, lack of data, limitations in data granularity and the nature of ICT supply chains. Deviation(s) from this requirement shall be clearly motivated and reported.	YES		Defra tables include RMA in 'materials use'
6.1	Instances of the transportation of goods between production and use stages shall be taken into account.	YES		
6.1.2	The ICT goods, networks and services product system to be assessed shall be clearly described as well as relevant functions and characteristics.	YES		
6.1.2.1	For the ICT good under study, applicable types of parts, as well as amounts of these, shall be defined.	YES		
6.1.2.2	In the goal and scope phase it shall be outlined which network building blocks are covered.	YES		
6.1.2.2	For the ICT network under study, applicable types of nodes and infrastructure, as well as amounts of these, shall be defined.	YES		
6.1.2.3	For the ICT service under study, applicable types of ICT network elements and infrastructure, as well as amounts of these, shall be defined.	YES		
6.1.3.1	Software shall be considered as well as hardware.		X	Software for future roll-out not yet defined
6.1.3.1	For specific software applications, such as music distribution applications, the software is to be seen as an ICT service and shall be assessed according to the requirements outlined for services.	N.A.		
6.1.3.1	In these cases, the hardware needed to operate the software shall be considered as well.	YES		
6.1.3.1	For users of generic operating systems embedded in products, the life cycle impact of usage of this software may be considered as negligible. However, for the developer of this software the impact of the usage of this software shall be taken into account.		XX	Software for future roll-out not yet defined
6.1.3	Operating lifetime is critical for the interpretation of the results of LCAs and shall therefore always be reported when presenting LCA results.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.1.3	Operating lifetime estimates and assumptions shall also be clearly described in the reporting.	YES		
6.2.1	During the LCA scoping phase the building blocks of the ICT goods, networks or services shall be identified.		X	Future services have yet to be defined
6.2.2.1	The functional unit shall be chosen in accordance with the goal and scope of the LCA.	YES		
6.2.2.1	The functional unit requires inclusion of the relevant quantifiable properties and the technical/functional performance of the system. This means that the operating lifetime of all included ICT goods shall be specified.	YES		
6.2.2.1	The number of users/subscribers supported by the network and the traffic profile shall be included where applicable.	YES		
6.2.2.1	The functional unit shall be clearly defined and measurable.	YES		
6.2.2.1	The reference flow shall reflect the functional unit chosen.	YES		
6.2.2.2	The functional unit shall be chosen in the context of goal and scope of the LCA and shall be further clarified by system boundary and cut-off rules.	YES		
6.2.2.2	To comply with [ITU-T L.1410], the following functional units shall be applied where applicable: annual ICT goods use (per one year of ICT good use), or total ICT good use per lifetime of ICT good.	YES		Both were needed
6.2.2.2	For relevant LCA results, realistic use scenarios shall be captured.	YES		
6.2.2.3	ICT networks can be seen as a system composed of different types of ICT goods. For the purposes of [ITU-T L.1410], the following functional unit shall be applied where applicable for ICT networks used during at least 1 year: • annual network use.	YES		
6.2.2.3	For relevant LCA results, realistic use scenarios shall be captured.	YES		
6.2.2.4	For the purposes of [ITU-T L.1410], the following functional unit shall be applied where applicable: annual service use.		X	Future services have yet to be defined
6.2.2.4	For relevant LCA results, realistic use scenarios shall be captured.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.2.2.4	Corresponding realistic use scenarios shall be defined.	YES		
6.2.2.4	The annual service use shall be defined with respect to the usage scenario to make it possible to define the reference flow.	YES		
6.2.3.1	The selection of the system boundary shall be consistent with the goal of the study.	YES		
6.2.3.1	Consequently, the system boundaries here define the life cycle stages and the unit processes that shall be taken into account in an LCA of an ICT product system.	YES		
6.2.3.1	Table 2 of [ITU-T L.1410] includes further details of the life cycle stages to be included in LCAs of ICT goods, networks and services. The different life cycle stages are further described in clauses 6.2.3.4.2 to 6.2.3.4.5 of [ITU-T L.1410]. Mandatory in Table 2 of [ITU-T L.1410] means that the life cycle stage shall be included.	YES		
6.2.3.1	Mandatory life cycle stages or unit processes shall not be cut-off before considered for inclusion by using alternative data.	YES		
6.2.3.1	In Table 2 of [ITU-T L.1410], "Mandatory" means that the life cycle stage, if applicable to the studied product system, shall always be taken into account in an LCA for ICT.	YES		
6.2.3.3.1	In order to set the system boundary of ICT goods, the life cycle stages listed in clause 6.1.1 of [ITU-T L.1410] shall be detailed.	YES		
6.2.3.3.1	As stated in clause 6.1.3 of [ITU-T L.1410], the environmental impact from both hardware and software shall be considered, if applicable.	N.A.		
6.2.3.3.1	For the ICT good under study, applicable types of parts, as well as amounts of these, shall be defined.		X	Defra tables include RMA in 'materials use' for WEEE types
6.2.3.3.2	Table H.1 of [ITU-T L.1410] provides a mandatory set of raw materials (both ICT-specific and generic) which shall be included in the LCA of ICT goods.		X	Defra tables include RMA in 'materials use' for WEEE types

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.2.3.3.3	Annex E of [ITU-T L.1410] lists a mandatory set of parts to be included where applicable to the studied ICT product system, when performing an LCA of ICT goods, as well as mandatory part unit processes which shall be included for each part.	N.A.		Completed products were used to build the network
6.2.3.3.3	As an example, if batteries are part of the studied ICT goods product system, they shall be included within the system boundary, and for every battery the battery cell manufacturing and battery module manufacturing shall be included.	N.A.		Batteries were not included
6.2.3.3.3	Assembly (B1.2 of [ITU-T L.1410]) shall include as minimum PCBA module assembly, final assembly, warehousing, and packaging.	N.A.		Completed products are to be used to build the network
6.2.3.3.3	In case support goods are part of the studied product system, support goods Production (B2 of [ITU-T L.1410]) is mandatory.	N.A.		
6.2.3.3.3	Support goods (B2.1 of [ITU-T L.1410]) which shall be included if applicable to the studied product system are at least air conditioners, cables, and power supply systems.	YES		
6.2.3.3.3	As stated in Table 2 of [ITU-T L.1410], construction of an ICT-specific site (B3 of [ITU-T L.1410]) is mandatory if the ICT-specific site is included in the studied product system.		X	Site was assumed to exist
6.2.3.3.3	Site building blocks to be included in B3.1 of [ITU-T L.1410], if they are applicable to the studied product system, are antenna towers, fences and shelters.	N.A.		
6.2.3.3.4	Raw material acquisition and Production for the additional PCBAs used during the operating lifetime of the ICT goods are mandatory.	N.A.		Completed products are to be used to build the network
6.2.3.3.5	As shown in Figure 11 of [ITU-T L.1410], Preparation of ICT goods for reuse of ICT goods (D1), ICT-specific EoLT (D2) and Other EoLT (D3) are within the mandatory system boundary for EoLT.	YES		Defra tables assume all WEEE is made from raw materials

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.2.3.3.5	Annex F of [ITU-T L.1410] lists a mandatory set of EoLT processes to be included where applicable when performing an LCA of ICT goods which includes the EoLT stage.	YES		Defra tables assume all WEEE is made from raw materials
6.2.3.3.5	It is thus recognized that compliance to all requirements in Annex F of [ITU-T L.1410] may not be possible at the time this Supplement is published. Deviation(s) from the requirements shall be clearly motivated and reported.	YES		Defra tables assume all WEEE is made from raw materials
6.2.3.4	The network shall be defined in terms of ICT goods, support goods and ICT infrastructure (e.g., cables duct).	YES		
6.2.3.4	For each included product types, the number of units shall be defined, as well as their corresponding lifetimes.	YES		
6.2.3.4	For the assessment of networks, operator activities shall always be included.	YES		Only installation and waste disposal were included
6.2.3.5.1	In addition to the use of ICT goods and networks, an ICT service may also have additional impacts associated with application software development, use of consumables, infrastructure for sales and logistics, associated travel and transport (in addition to those already included for the ICT goods and networks) which shall also be included as appropriate.	N.A.		
6.2.3.5.1	The impact of the data centres where the service is operated shall be assessed.	N.A.		
6.2.3.5.1	The data centre shall be studied and assessed in the same way as other ICT goods.	N.A.		
6.2.3.5.1	The system boundary of the ICT services provided by the ICT network shall be established based on either the actual use scenario of the ICT services, if available, or on an estimated use scenario.	N.A.		
6.2.3.5.2	Energy consumption, material inputs and environmental releases shall be assessed in accordance with the system boundary.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.2.4	Cut-offs shall be avoided as far as possible.	YES		
6.2.4	Clause 4.2.3.3 of [b-ISO 14044] recommendations shall be used as closely as possible.	YES		
6.2.4	All cut-off criteria stated by [b-ISO 14040] and [b-ISO 14044] are to be considered before cut-off of a certain process – and the process shall be included if significant to at least one criterion.	YES		
6.2.4	The intention of the present standard is to include all mandatory activities of Table 2 of [ITU-T L.1410]. If these activities are not included such cut-offs shall be clearly motivated.	YES		
6.2.4	Any cut-off made shall be clearly described and documented.	YES		
6.2.5.1	A qualitative description of the data quality and any efforts taken to improve it shall be disclosed while considering the following data quality indicators: Methodological appropriateness and consistency Completeness (total LCA level) Uncertainty Data representativeness Data age (timeliness) Acquisition method Supplier independence Geographical correlation Technological correlation Cut-off rules (rules of inclusion/exclusion)	YES		
6.2.5.1	In selecting emission factors for use in calculating GHG emissions under this methodology the following guidance shall be followed: Emission factors used should be the most up to date from publicly available sources.	YES		
6.2.5.1	Where emission factors are sourced from non-public sources, or are not the most up-to-date ones, a justification for their use shall be provided.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.2.5.1	The specific GWP values used shall be those taken from the latest UN IPCC reports. For further guidance see Table XI.1.	N.A.		Assumed to included in JRC and Defra tables
6.2.5.2	In general, data age and technology are especially important in LCAs for ICT goods, networks and services due to the fast technology evolution and the growth in network traffic. e.g., for data traffic, up-to-date figures shall always be used.	YES		
6.2.5.2	For support activities (e.g., ICT manufacturer support activities and operator support activities) primary data shall be used for all individual processes under the financial or operational control of the organization undertaking the LCA	N.A.		Support activities not included
6.2.5.2	… and data shall be representative of the processes for which they are collected.	N.A.		
6.3.1.1	Data shall be collected for each unit process that is included within the system boundary in accordance with Annex B of [ITU-T L.1410].	YES		
6.3.1.1	Data shall be collected for all mandatory processes outlined in Table 2 of [ITU-T L.1410].	YES		
6.3.1.1	When data has been collected from public sources, the source shall be referenced.	YES		
6.3.1.2	Data shall be collected at least for the processes marked with mandatory in Table 2 of [ITU-T L.1410], unless these are found negligible in accordance with the cut-off rules	YES		
6.3.1.4	Use time, goods type, data traffic and network access type give important statistical data that needs to be collected in order to quantify the use of ICT systems.	N.A.		network is not yet operational
6.3.1.2.1	It should be noted that, for many products (especially end-user goods), periods of idling and power off may be significant and are important to consider when modelling the traffic profile/ model the usage profile and shall be included if applicable.	YES		
6.3.1.2.3	When calculating the potential environmental impact the LCA practitioner is encouraged to use the most accurate data for the energy mix that is applicable to the ICT goods under assessment. Particularly the use stage shall use the applicable electricity mix to calculate the potential environmental impact from the use stage more exactly.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.3.2.1	The general requirements for data calculations in [b-ISO 14040] and [b-ISO 14044] shall be applied.	YES		
6.3.2.1	All calculation procedures shall be explicitly documented and the assumptions made shall be clearly stated and explained.	YES		
6.3.2.1	The same calculation procedures shall be consistently applied throughout the study.	YES		
6.3.2.1	A check on data validity shall be conducted during the process of data collection to confirm that the data quality requirements for the intended application have been fulfilled.	YES		
6.3.2.3	The evaluation of the environmental load shall consider both a fixed part which is independent of the usage and a variable part which correlates to the usage.	YES		
6.3.3.1	The same allocation method shall be used for all environmental loads for all products from a common process.	YES		
6.3.3.1	The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below.	YES		
6.3.3.2	Data for generic processes (G1 to G7) shall be allocated as a whole (i.e., for the full life cycle for the generic process) to the associated life cycle stage of the product system.	YES		
6.3.3.2	However all Raw material acquisition (G5) shall be allocated to the life cycle stage Raw material acquisition (A).	YES		
6.3.3.3	Data for relevant part of the organization/operation shall be allocated to the relevant part of the project/product system life cycle.	YES		
6.3.3.3	If no detailed information on organization/operation is available the allocation shall be based on organizational/economic data.	YES		
6.3.3.8	End-user goods (e.g., PCs, smart phones) which are accessing more than one ICT network [e.g., 3G, wireless local area network (WLAN)] shall be allocated to these ICT networks based on use time.	N.A.		CPE was excluded from this assessment
6.3.3.8	The assumptions regarding use time for access to different ICT networks and off line work shall be described and motivated.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
6.3.3.8	Impact from shared network resources (e.g., transmission goods, core nodes and data centres) shall be allocated to an access network based on data traffic.	YES		
6.3.3.8	The assumptions regarding data traffic shall be described and motivated.	YES		
6.3.3.9	The impact from each ICT network supporting the service should be allocated to the service based on access use time or data traffic. More specifically, the following allocation principle of ICT network data to an ICT service shall be used: Data for end-users goods: to be allocated based on active use time of the ICT service. etc.		X	Not all future services are defined in BATS
6.3.3.9	Data traffic is also preferred for e.g., mobile access networks as mobile access networks show a large dependency between data traffic and energy consumption and need a traffic model that takes data traffic into account.	N.A.		
6.3.3.9	Data for data centres and service provider activities: The data centre(s) where the ICT service is operated as well as the service provider activities shall be allocated based on number of subscriptions and service users or amount of data/transactions.	N.A.		
7	ISO states that the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration.	YES		
7	In the LCA, it shall be ensured that the inventory elementary flows (see Annex G of [ITU-T L.1410]), are correctly linked with appropriate LCIA characterization factors.	YES		
7	For climate change, the most recent global warming characterization factors from the IPCC for each GHG shall be used and the timeframe should be 100 years.	YES		
7	The midpoint category Climate change is mandatory.	YES		
7	For other impact categories there is no methodological consensus in the LCA community, thus the practitioner shall decide which impact categories to consider and how to calculate them, based on the studied ICT product system and purpose of the LCA study.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
7	All impact categories and category indicators included shall be disclosed (Table L.10) and justified.	YES		
8.2	The sources of uncertainty and methodological choices made shall be assessed and disclosed.	YES		
8.3	The results of the LCI or LCIA phases shall be interpreted according to the goal and scope of the study.	YES		
8.3	The interpretation shall include a sensitivity check of the significant inputs, outputs and methodological choices, and defined use scenarios, in order to understand the uncertainty of the results.	YES		
9.1	The reporting of ICT product systems shall fulfil the reporting rules as defined by [b-ISO 14040] and [b-ISO 14044].	YES		
9.1	In the case of reporting, a public GHG inventory report, the key accounting principles (relevance, accuracy, completeness, consistency, and transparency) shall be met.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
9.1	In addition to the reporting obligations outlined by [b-ISO 14040] and [b-ISO 14044], the report shall include the following information: • contact information • studied goods, networks and services product system name and description • type of inventory (i.e., final product cradle-to-grave or intermediate product cradle-to-gate inventory) • goals of the study. The reporting of results shall include: • total GHG emissions reported as amount of CO_2e per functional unit for ICT good, network and service that have been assessed • percentage for each life cycle stage contributing to the total results • electricity (with use stage separated from the other stages) • primary energy • fuels • value and sources of emission factors for CO_2 and CO_2e, and Global Warming Potential (GWP) metric used in the report • other data, justifications and explanations as stated throughout this report. NOTE – primary energy and electricity cannot be summarized because electricity is contributing to the total primary energy.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
9.1	In addition, the rules outlined in clause 9.1 of [ITU-T L.1410] and what is stated in Annex L of [ITU-T L.1410] shall be followed for reporting of studies claiming compliance with [ITU-T L.1410].		X	The assessment was made for a future product so actual figures for manufacturing were not available
9.1	The report shall contain a compliance statement saying either that the LCA fully complies with [ITU-T L.1410] (in case of full compliance) or that the LCA partially complies with [ITU-T L.1410] with the exceptions transparently listed and justified (partial compliance).	YES		
9.1	The extent to which support activities and other optional/recommended activities are excluded for different parts of the life cycle shall be clearly described and for recommendations also motivated in the study report.	YES		
9.1	For each product system (including ICT goods, networks and services) the following aspects, being of special importance to ICT applications, shall be transparently motivated and described in accordance with the principles defined in clause 9.1 of [ITU-T L.1410]: Operating lifetime: All lifetime assumptions shall be stated and motivated.	YES		
9.1	Cut-off: Any cut-off made shall be clearly stated and motivated.	YES		
9.1	Allocations: Basis for allocations made shall be described, especially for recycling, use of recycled materials, distribution of facility data and support activities.	YES		
9.1	Data sources: Data sources (i.e., specific/generic) shall be clearly stated, and deviations from Table 2 of [ITU-T L.1410] shall be motivated.	YES		
9.1	For each product system (including ICT goods, networks and services) an additional diagram shall be presented whenever optional activities in Table 2 of [ITU-T L.1410] have been included.	YES		
9.1	The emission factors used shall be clearly stated. The source used and the year they represent shall be clearly stated.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
9.1	In the case of emission factors for grid electricity the source, year and location (specific, country, global average) shall be clearly stated.	YES		
9.1	Where emission factors are sourced from non-public sources, or are not the most up-to-date ones, a justification for their use shall be provided.	YES		
9.2.1	For each impact category studied, diagrams corresponding to Figure 14a and 14b of [ITU-T L.1410] shall be reported for the corresponding category indicator result.	YES		
9.2.1	Due to the importance of operating lifetime to results, information regarding this shall always be present in the diagram, together with some other basic modelling statements including total result for the indicator, LCA study year operating lifetime, etc. as shown below.	YES		
9.2.1	Figure 14b of [ITU-T L.1410] shall be presented whenever optional activities/processes from Table 2 of [ITU-T L.1410] have been included in the studied product system.	N.A.		
9.2.1	For transport, the total result including all transport throughout the life cycle (Table L.4 of [ITU-T L.1410]) shall be stated in the immediate proximity of the diagram (Figure 14a and 14b of [ITU-T L.1410]).	YES		
9.2.1	If used data sets do not report transport separately any missing transport shall be listed and motivated.	YES		
9.2.1	Figure 15 of [ITU-T L.1410] shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".	YES		
9.2.1	A diagram summarizing distribution of selected environmental impact category indicators between life cycle stages shall be prepared together with absolute figures as shown in the Table L.10 of [ITU-T L.1410].	N.A.		A possible future network was assessed
9.2.1	Figure 16 of [ITU-T L.1410] shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal". See further explanation in the scope.	N.A.		A network level assessment was performed
9.2.2.1	Any deviation from Table 2 and clause 6.2.3 of [ITU-T L.1410] with respect to mandatory life cycle stages/unit processes shall be clearly stated and motivated.	YES		
9.2.2.1	Additionally, inclusion of generic processes for the different life cycle stages shall be clearly stated and reported.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
9.2.2.1	Deviations for Generic processes shall be reported according to Table L.3	YES		
9.2.2.2	The use of raw materials shall be transparently reported as outlined below.	YES		
9.2.2.2	The most important metals from recycling point of view shall always be included. For an appropriate reporting format refer to Table L.5 of [ITU-T L.1410].	YES	X	Defra tables assume all WEEE is made from raw materials
9.2.2.2	Deviation(s) from the requirements shall be clearly motivated and reported.	YES		
9.2.2.3.1	Compliance to Table E.1 of [ITU-T L.1410] shall be reported and any deviation shall be described and motivated. For an appropriate reporting format refer to Table L.6 of [ITU-T L.1410].	YES		
9.2.2.4.1	Compliance to Table E.1 of [ITU-T L.1410] shall be reported and any deviation shall be described and motivated. For an appropriate reporting format refer to Table L.6 of [ITU-T L.1410].	YES		
9.2.2.4.1	The model of distribution over time of different usage modes including power off and idle and the rationale for those shall be transparently reported. For an appropriate reporting format refer to Table L.7 of [ITU-T L.1410].	YES		
9.2.2.4.2	The rationale for the energy consumption values for support goods use shall be transparently described and motivated. For an appropriate reporting format refer to Table L.7 of [ITU-T L.1410].	N.A.		A possible future network was assessed
9.2.2.5	If EoLT is included, any deviations from Annex F of [ITU-T L.1410] shall be transparently reported and motivated. For an appropriate reporting format refer to Table L.8 of [ITU-T L.1410].	N.A.		
9.2.3	For LCI, the following items shall be reported transparently: total use of primary energy and electricity.	YES		
9.2.3	Additionally, results for elementary flows according to Table G.1 of [ITU-T L.1410] could be transparently reported on an optional basis. If such reporting is not made it is mandatory to describe unexpected results, lack of data, and other findings associated with the elementary flows.	N.A.		Only a GHG emission assessment was made
9.3.1	Operating lifetime is important also for networks, but is associated with the lifetime of the different nodes, which shall be reported	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
9.3.1	It shall be reported following the format of Table L.11 of [ITU-T L.1410] which also describes the studied network.	N.A.		A possible future network was assessed
9.3.1	Figure 18 of [ITU-T L.1410] shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".	YES		
9.3.1	Additionally a diagram summarizing distribution of environmental impact category indicators between life cycle stages shall be prepared together with absolute figures as shown in Table L.10 of [ITU-T L.1410].	N.A.		Only a GHG emission assessment was made
9.3.1	Figure 19 of [ITU-T L.1410] shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".	N.A.		
9.3.1	Details of network energy consumption shall be reported with a split of different elements of the network. An example of Table for Reporting is provided In Table L.12.	YES		
9.4.1	Operating lifetime is important also for services, but it is associated with the lifetime of the different nodes, which shall be reported.	YES		
9.4.1	Allocation of network data to the service shall be reported. It should be reported according to Table L.13 of [ITU-T L.1410].	N.A.		Future services have yet to be defined
9.4.1	Additionally, a diagram summarizing distribution of impact category indicators between life cycle stages for the service product system under study shall be presented together with absolute figures as shown in the Table L.10.	N.A.		A network level assessment was made
9.4.1	Figure 22 of [ITU-T L.1410] shall be accompanied by the disclaimer "This LCA result cannot be compared to the result of another LCA unless all assumptions and modelling choices are equal".	N.A.		A network level assessment was made
10	Any critical review shall be performed according to the requirements of [b-ISO 14040] and [b-ISO 14044] and in [ITU-T L.1410].	N.A		
10	The scope and type of critical review desired shall be defined in accordance with clauses 4.2.3.8 and 6 of [b-ISO 14044].	N.A.		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
11.1	Infrastructure, e.g., highways for transportation, is generally assumed to exist independently of introduction of new services and shall be excluded.	Yes		
11.1	The handling of time perspective and scale shall be disclosed and motivated in the report.	YES		
11.1	To be able to quantify the net environmental impact when introducing an ICT based service the environmental impact of both the ICT service itself and of the reference product system need to/shall be assessed from a life cycle perspective.	N.A.		A network level assessment was made
11.1	To make sure that the comparative assessment gives a relevant result, the full life cycle of both systems shall always be considered.	N.A.		
11.1	From an LCA perspective the reference product system and the ICT service based system shall mimic each other as far as possible.	N.A.		
11.1	The practitioner shall model both systems in an unbiased way.	N.A.		
11.2	Goods shall be compared with other goods.	N.A.		
11.2	ICT networks shall be compared between themselves.	N.A.		
11.2	ICT services shall be compared between themselves.	N.A.		
11.3.1	In this comparative LCA study, the scope of the LCA study shall be defined in such a way that the two systems can be compared.	N.A.		
11.3.1	Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures and cut-off rules.	N.A.		
11.3.1	Any differences between systems regarding these parameters shall be identified and reported.	N.A.		
11.3.2	Also in this case, the scope of the LCA study shall be defined in such a way that the two systems can be compared.	N.A.		
11.3.2	Both systems shall be assessed using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures and cut-off rules.	N.A.		
11.3.2	Any differences between systems regarding these parameters shall be identified and reported.	N.A.		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
11.3.3	The assessment of the ICT based system shall be performed in accordance with Part I of [ITU-T L.1410].	N.A.		
11.3.3	When making comparisons, it is important to keep in mind that the functional unit used shall be applicable to both the reference product system and the system of ICT goods, networks and services.	N.A.		
11.3.3	For the reference product system applicable requirements in [ITU-T L.1410] shall be applied, e.g., requirements regarding data quality, cut-off etc.	N.A.		
12.2	All the requirements stipulated in Part I of [ITU-T L.1410] for a system boundary definition shall be applied.	N.A.		
12.2.1	The functional unit shall take into account the general rules outlined in Part I, clause 6.2.2 of [ITU-T L.1410] and clause 4.2.3.2 of [b-ISO 14044].	N.A.		
12.2.1	Additionally, the functional unit shall be defined so that it is applicable both to the ICT goods, networks and services product system and the reference product system.	N.A.		
12.2.1	The reference flow shall be defined to quantify the functional unit.	N.A.		
12.2.1	In other words, for the functional unit of one meeting, for instance, the reference flow for the systems of ICT goods, networks and services and the reference product system shall be defined.	N.A.		
12.2.2	Two different system boundaries shall be defined which are applicable for the ICT goods, networks and services product system and for the reference product systems respectively.	N.A.		
12.2.2	Considerations shall be made to which electricity is used when assessing the environmental impact of the ICT goods, networks and services product system and the reference product systems.	N.A.		
12.3	The calculation for the inventory analysis shall be performed in accordance with Part I, clause 6.3 of [ITU-T L.1410].	N.A.		
12.4	The calculation for the inventory analysis shall be performed in accordance with Part I, clause 6.3 of [ITU-T L.1410].	N.A.		
13	Any cut-off made during a study shall be clearly stated in the study report, e.g., the exclusion of life cycle processes which are considered insignificant should be justified.	N.A.		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
Annex B	A mandatory list of generic activities (unit processes) that have been found to be of importance for LCA of ICT goods, networks and services can be found in Annex D of [ITU-T L.1410].	YES		
Annex B	The following emissions shall be taken into account if applicable to the studied impact category(ies): emissions to air emissions to water emissions to soil.	N.A.		
Annex B	The following resource objects shall be taken into account if applicable to the studied impact category(ies): material resource use (or material depletion) energy resource use (or energy resources depletion).	YES		
Annex B	A list of emissions and resource objects that shall be included, if applicable to the studied product system and impact category(ies), can be found in Table G.1 of [ITU-T L.1410].	N.A.		Only a GHG emission assessment was made
Annex B	Furthermore, the following inputs shall also be included if applicable to the studied impact category(ies): electricity; other forms of delivered energy (district heating and cooling); fuels (typically indicates the fuels are incinerated on-facility or in a vehicle connected to the facility); primary products (products that are part of the final product in operation); secondary products (products that are not part of the final product in operation); transport, travel and other services (can be seen as a special non-material secondary product input).	YES		
Annex B	Finally, the following flows shall also be included if applicable to the studied impact category(ies): water discharge (to municipal sewage or recipient);	N.A.		Only a GHG emission

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
	waste fractions (residual waste fractions or waste fractions that need further treatment, also including material recycling and energy recovery); product output (the main purpose with the unit process or activity).			assessment was made
Annex C	Any support activities included in the LCA scope shall be clearly reported in terms of organization activities considered.	N.A.		Support activities were not included
Annex D	G7….Other material shall be considered	YES		
Annex E	Table E.1 of [ITU-T L.1410] lists the applicable parts and assembly types which shall be taken into account when performing an LCA of ICT goods, if applicable to the ICT good (not ICT network). It also lists the corresponding part and assembly categories and unit processes.	YES		
Annex G	Table G.1 of [ITU-T L.1410] contains elementary flows which shall be taken into account in LCA analyses for ICT.	N.A.		Only a GHG emission assessment was made
Annex G	The substance names listed in Table G.1 of [ITU-T L.1410] shall be used in the report.	N.A.		Only a GHG emission assessment was made
Annex G	Deviation(s) from the requirements shall be clearly motivated and reported.	YES		Only a GHG emission assessment was made
Annex H	Table H.1 of [ITU-T L.1410] lists the minimum raw materials groups (chemicals, fuels, metals, plastics, packaging materials, and additives) which shall be taken into account in LCAs of ICT goods, if applicable to the studied ICT product system.	YES		

Table I.1 – Summary of fulfilment of requirements of [ITU-T L.1410]

Clause in [ITU-T L.1410]	Requirement	Fulfilled	Not fulfilled	Explanation/ Motivation
Annex L	Annex L of [ITU-T L.1410] contains tables that shall be used to report the result of the assessment.	N.A.		The assessment was carried out for possible future network
Annex L	Deviation(s) from the requirements shall be clearly motivated and reported.	YES		The assessment was carried out for possible future network

Bibliography

[b-IEEE 802.11n]	IEEE 802.11n (2009), *MIMO*.
[b-ISO 14040]	International Standard, ISO 14040 (2006), *Environmental management – Life cycle assessment – Principles and framework*.
[b-ISO 14044]	International Standard, ISO 14044 (2006), *Environmental management – Life cycle assessment – Requirements and guidelines*.
[b-ACC, 2005]	ACC (2005). *Ammonium perchlorate: Helping to launch the space shuttle Discovery* [viewed 2016-09-11]. Washington, DC: American Chemistry Council.
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