ETSI TS 104 134 V1.1.1 (2025-09)

TECHNICAL SPECIFICATION

**Environmental Engineering (EE);
Simplified Method for including Uncertainty and
Sensitivity Aspects in Calculations
of the Avoided Environmental Impact of Information and
Communication Technology Solutions**

Reference
DTS/EE-EEPS76

Keywords
LCA

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 - APE 7112B
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° w061004871

Contents

Intellectual Property Rights

Essential patents

IPRs essential or potentially essential to normative deliverables may have been declared to ETSI. The declarations pertaining to these essential IPRs, if any, are publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI IPR online database.

Pursuant to the ETSI Directives including the ETSI IPR Policy, no investigation regarding the essentiality of IPRs, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Trademarks

The present document may include trademarks and/or tradenames which are asserted and/or registered by their owners. ETSI claims no ownership of these except for any which are indicated as being the property of ETSI, and conveys no right to use or reproduce any trademark and/or tradename. Mention of those trademarks in the present document does not constitute an endorsement by ETSI of products, services or organizations associated with those trademarks.

DECT™, **PLUGTESTS™**, **UMTS™** and the ETSI logo are trademarks of ETSI registered for the benefit of its Members. **3GPP™**, **LTE™** and **5G™** logo are trademarks of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners. **oneM2M™** logo is a trademark of ETSI registered for the benefit of its Members and of the oneM2M Partners. **GSM**® and the GSM logo are trademarks registered and owned by the GSM Association.

Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Environmental Engineering (EE).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**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).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Introduction

Investigating the net Environmental Impact (EI) of technologies has become more common. Life Cycle Assessment (LCA) is the preferred quantification methodology however the uncertainty quantification is often not included. This is problematic as the uncertainty determines if conclusions can be drawn. Recently several assessment methods for avoided environmental impact have been proposed [i.1], [i.2], [i.3] and [i.4]. These methods have some commonalities one being the lack of uncertainty and sensitivity quantification methodology [i.5], which might prevent conclusions to be drawn. Attempts to solve these problems have been carried out [i.6].

It is generally accepted that Information and Communication Technology (ICT) is a kind of double-edged sword in this context: more impact for its production, use and disposal, however much less impact when used to address sustainability matters [i.2]. The Rebound Effect (RE) with its uncertainty are not covered by any standard so far.

Simply put the RE is the difference between potential avoided impact and actual avoided impact [i.7]. The relative RE is equal to (potential benefit - actual benefit)/potential benefit [i.7].

The total RE can roughly be divided into the direct RE and the economy-wide RE. The problems addressed are that uncertainty calculations are not systematic in LCA of ICT Services especially including the RE.

The standardization gap is that so far, the uncertainty for avoided EI estimations for ICT has not been included clearly, especially for the intriguing RE. The objective of the present document is to use some existing methods, [i.2] and [i.6], and propose a method which helps assess in a simplified manner the probability that there will be avoided EI resulting from the introduction of ICT Solutions. For the first time, a standard is defined which includes uncertainty and sensitivity calculations to make visible the relation between the degree of simplification and the ability to draw conclusions. The method herein is applicable to net EI LCAs including ICT Services and beyond such as product LCAs.

1 Scope

The present document concerns a methodology for including uncertainty and sensitivity aspects for avoided environmental impact calculations. The objective of the present document is to provide a standardized method to assess in a simplified manner the uncertainty of calculations for avoided environmental impact resulting from the introduction of Information and Communication Technology (ICT) Solutions. Moreover, the sensitivity of individual elements and the contribution to the total uncertainty is outlined. A method is defined based on existing standards, e.g. Recommendation ITU-T L.1480 [i.8] and recognized methods which allow for communication of the results to the public and consumers. The uncertainty and sensitivity calculation procedures are standardized for the method to be developed to make visible the relation between the degree of simplification and the ability to draw conclusions.

2 References

2.1 Normative 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.

Referenced documents which are not found to be publicly available in the expected location might be found in the ETSI docbox.

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 necessary for the application of the present document.

Not applicable.

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 may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

[i.1] L. Lakanen: "Developing handprints to enhance the environmental performance of other actors", 2023.

[i.2] A.S.G. Andrae: "Method for Calculating the Avoided Impact of Specific Information and Communication Technology Services", International Journal of Environmental Engineering and Development, vol. 2, pp. 73-87, 2024. DOI: https://doi.org/10.37394/232033.2024.2.7.

[i.3] AIOTI: "IoT and Edge Computing Carbon Footprint Measurement Methodology", 2024.

[i.4] WBCSD: "Guidance on Avoided Emissions - Helping Business Drive Innovations and Scale Solutions Toward Net Zero", 2023.

[i.5] J.C. Bieser, R. Hintemann, L.M. Hilty, S. Beucker: "A review of assessments of the greenhouse gas footprint and abatement potential of information and communication technology", Environmental Impact Assessment Review, 2023, vol. 99, p. 107033. DOI: 10.1016/j.eiar.2022.107033.

[i.6] A.S.G. Andrae: "Method for Uncertainty and Probability Estimation of Avoided Impacts from Information and Communication Technology Solutions", International Journal of Recent Engineering Science, vol. 11, no. 5, pp. 103-108, 2024. DOI: 10.14445/23497157/IJRES-V11I5P110.

[i.7] D. Font Vivanco, J. Freire-González, R. Galvin, T. Santarius, H.J. Walnum, T. Makov and S. Sala: "Rebound effect and sustainability science: A review", Journal of Industrial Ecology, vol. 26, no. 4, pp. 1543-1563, 2022. DOI: 10.1111/jiec.13295.

[i.8] Recommendation ITU-T L.1480 (2022): "Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors".

[i.9] W. Lu: "Study On The Advanced Technique of Environmental Assessment Based on Life Cycle Assessment Using Matrix Method", Ph.D. Thesis, The University of Tokyo, Tokyo, Japan, 2006.

[i.10] A. Seidel, N. May, E. Guenther, F. Ellinger: "Scenario-based analysis of the carbon mitigation potential of 6G-enabled 3D videoconferencing in 2030", Telematics and Informatics, vol. 64, p. 101686, 2021. DOI: 10.1016/j.tele.2021.101686.

[i.11] C.L. Thiel, N. Mehta, C.S. Sejo, L. Qureshi, M. Moyer, V. Valentino, J. Saleh: "Telemedicine and the environment: life cycle environmental emissions from in-person and virtual clinic visits", NPJ Digital Medicine, vol. 6, no. 1, 87, 2023. DOI: 10.1038/s41746-023-00818-7.

[i.12] F. Bélorgey, J. Fournier, N.L. Omnes: "Application of International Telecommunication Union Recommendation L. 1480 on measuring the greenhouse gas emission effects to a use case for photovoltaic power generation equipment", Environmental Research: Energy, vol. 2, no. 1, 015004, 2025. DOI: 10.1088/2753-3751/ad9f64.

[i.13] C. Mutel: "Brightway: An open source framework for Life Cycle Assessment", Journal of Open Source Software, vol. 2, no. 12, p. 236, 2017. DOI: 10.21105/joss.00236.

[i.14] B. Steubing, D. de Koning, A. Haas, C.L. Mutel: "The Activity Browser — An open source LCA software building on top of the brightway framework", Software Impacts, vol. 3, p. 100012, 2020. DOI: 10.1016/j.simpa.2019.100012.

[i.15] A.S.G. Andrae: "Proxy-Based Economic Factors for ICT Emission Avoidance in Cut-Off Frameworks", ResearchGate, 2025. DOI: 10.13140/RG.2.2.22177.31841.

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

accuracy: closeness to the value of the perfect reference system

NOTE: If the perfect reference system would have a score of 100 EI units and the score of the calculated system at hand would be 90 EI units, the accuracy of the LCA would be 90 %.

avoided emission: emission reductions resulting from the use of a solution but occurring outside that solution's lifecycle or value chain

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

direct rebound effect: rebound effect where increased efficiency, associated cost reduction and/or convenience of a product or service results in its increased use because it is cheaper or otherwise more convenient

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

economy-wide rebound effect: rebound effect where more efficiency drives economic productivity overall resulting in more economic growth and consumption at a macroeconomic level

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

element: flow inputs or outputs to unit processes within the studied product system at hand

EXAMPLE: Example of elements are CO_2e emissions from "Car embodied" (output) and amount of "Use of cars" (input) used by "Use of vehicles" in Table A.1. *a* and *b* are elements.

first order effect: direct environmental effect associated with the physical existence of an ICT solution, i.e. the raw materials acquisition, production, use and end-of-life treatment stages, and generic processes supporting those including the use of energy and transportation

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

higher order effect: indirect effect (including but not limited to rebound effects) other than first and second order effects occurring through changes in consumption patterns, lifestyles and value systems

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

net second order effect: resulting second order effect after accounting for emissions due to the first order effects of an ICT solution

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

parameter: unit process within the studied product system at hand

EXAMPLE: Examples of parameters are "Car embodied" (output) and "Use of cars" (input) used by "Use of vehicles" in Table A.1.

rebound effect: increases in consumption due to environmental efficiency interventions that can occur through a price reduction or other mechanism including behavioural responses

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

EXAMPLE: An efficient product being cheaper or in other ways more convenient and hence being consumed to a greater extent.

second order effect: indirect impact created by the use and application of ICTs which includes changes of environmental load due to the use of ICTs that could be positive or negative

NOTE: As defined in Recommendation ITU-T L.1480 [i.8].

3.2 Symbols

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

Av	Avoided environmental impacts
SOE	Second Order Effect
FOE	First Order Effect, ICT Scenario environmental impacts
Rb	Absolute environmental impacts for total rebound effect
A	Technology matrix
p	Process vector
α	Final demand vector
β	Final environmental load vector
k	Environmental load in β
i	Column in *A* or *B*
j	Row in *A* or *B*
a	Element in *A*
b	Element in *B*
B	Environmental load matrix
I_{total}	Total CO_2e (LCA) result

$I_{process}$	Summated CO_2e scores based on Process-sum CO_2e (LCA) data which are specific and granular for the system at hand
I_{EEIO}	Summated CO_2e score based on EEIO CO_2e (LCA) proxy data which cover the remaining processes
c	Cut-off threshold
RRb	Relative total rebound effect

3.3 Abbreviations

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

2D	Two Dimensional
3D	Three Dimensional
5G	Fifth-generation for wireless technology
6G	Sixth-generation for wireless technology
AI	Artificial Intelligence
CO_2e	Carbon Dioxide equivalents
CUVP	Contribution of individual element to total uncertainty
EEIO	Environmentally Extended Input-Output
EI	Environmental Impact
IVP	Input value of individual element
LCA	Life Cycle Assessment
PC	Personal Computer
PV	PhotoVoltaic
RE	Rebound Effect
SVP	Sensitivity of individual element
TU	Total Uncertainty of whole calculation result
UVP	Uncertainty of individual element

4 Methodology

4.1 Framework

Equation 1 based on Equation 1 in [i.6] shows the main factors for the proposed method which shall be applied to any ICT Solution.

$$Av = SOE - (FOE + Rb) \tag{1}$$

where:

Av = All avoided Environmental Impacts (EI) or avoided emissions from the use of the ICT Solution at hand per functional unit. This is the net second order effect of the ICT solution.

SOE = EI changes in the studied product system per functional unit for the Baseline Scenario created by the ICT Solution. This is the second order effect.

FOE = All ICT related EI from the studied product system per functional unit for the use of the ICT Solution Scenario. This is the first order effect.

Rb = Absolute EI for direct and economy-wide rebound effects from studied product system per functional unit for the ICT Solution Scenario.

Equation 1 is in principle applicable to any standard for avoided impact calculations such as Recommendation ITU-T L.1480 [i.8].

4.2 Sensitivity of individual element

Equations 2 to 5 based on page 90 in [i.9], and Equation 6 based on pages 63 and 64 in [i.9], show how the rate sensitivity for activity and environmental load inventory flows shall be calculated.

$$A \times p = \alpha \quad (2)$$

$$p = A^{-1} \times \alpha \quad (3)$$

$$\beta = B \times p \quad (4)$$

$$\beta = B \times A^{-1} \times \alpha \quad (5)$$

$$SVP_{ij} = \frac{\left[\frac{\Delta\beta_k}{\beta_k}\right]}{\left[\frac{\Delta a_{ij}}{a_{ij}}\right]}, \frac{\left[\frac{\Delta\beta_k}{\beta_k}\right]}{\left[\frac{\Delta b_{ij}}{b_{ij}}\right]} \quad (6)$$

where:

A = Technology matrix. Activity flows arranged in a square matrix.

B = Environmental load matrix.

p = Process vector.

α = Final demand vector.

β = Final environmental load vector.

β_k = *k*th environmental load in the final environmental load vector.

$\Delta\beta_k$ = Variation of the *k*th environmental load in the final environmental load vector due to a very small (tiny, miniscule) variation in a_{ij}.

a_{ij} = Value of the element in the *i*th column in the *j*th row of *A*.

Δa_{ij} = Very small (tiny, miniscule) variation of the value of element in the *i*th column in the *j*th row of *A*.

b_{ij} = Value of the element in the *i*th column in the *j*th row of *B*.

Δb_{ij} = Very small (tiny, miniscule) variation of the value of element in the *i*th column in the *j*th row of *B*.

SVP_{ij} = sensitivity of individual element.

NOTE 1: SVP_{ij} can be calculated manually or by specialized software programs such as those mentioned in Annex C (informative).

To explain the factors of Equations 2 to 5 a fictive example (Table 1) is used: the production of one piece of a generic Product G.

α (the final demand vector) in Table 1 is the amount of Product G necessary to fulfil the functional unit.

The production of one piece of Product G may require 5 kWh of "Electricity 1" emitting 0,02 kg CO_2e/kWh, 2 kWh of "Electricity 2" emitting 0,3 kg CO_2e/kWh and 3 kWh of "Electricity 3" emitting 0,5 kg CO_2e/kWh. Additionally Product G may need 10 kg Aluminium emitting 12 kg CO_2e/kg and 0,05 kg IC emitting 1 300 kg CO_2e/kg.

Table 1: Production of one piece of a generic Product G - a fictive example

Electricity production 1		Unit	Amount
Output	Electricity 1	kWh	1
Output	CO_2e	kg	0,02
Electricity production 2			
Output	Electricity 2	kWh	1
Output	CO_2e	kg	0,3
Electricity production 3			
Output	Electricity 3	kWh	1
Output	CO_2e	kg	0,5
Aluminium production			
Output	Aluminium	kg	1
Output	CO_2e	kg	12
IC production			
Output	IC	kg	1
Output	CO_2e	kg	1 300
Product G production			
Output	Product G	pieces	1
Input	Electricity 1	kWh	5
Input	Electricity 2	kWh	2
Input	Electricity 3	kWh	3
Input	Aluminium	kg	10
Input	IC	kg	0,05
Boundary			
α	Product G	piece	1

For the Product G example, a square *A* (in blue) is shown in Table 2.

Table 2: Example of a square technology matrix *A*

A		Electricity production 1	Electricity production 2	Electricity production 3	Aluminium production	IC production	Product G production	
	Electricity 1	1 kWh (output)	0	0	0	0	-20 kWh (input)	
	Electricity 2	0	1 kWh (output)	0	0	0	-5 kWh (input)	
	Electricity 3	0	0	1 kWh (output)	0		-3 kWh (input)	
	Aluminium				1 kg (output)		-10 kg (input)	
	IC					1 kg (output)	-0,05 kg (input)	
	Product G	0	0	0	0	0	1 piece (output)	*α* = 1

NOTE 2: The inputs to processes have to be designated with a minus (-) sign in the present methodology as otherwise the final environmental loadings would be expressed in negative numbers. This can be conveniently shown with numerical computation programs as shown in Annex D.

For the Product G example, *B* is shown in Table 3.

Table 3: Example of an environmental load matrix *B*

B		Electricity production 1	Electricity production 2	Electricity production 3	Aluminium production	IC production	Product G production
	CO_2e	0,02 kg (output)	0,3 kg (output)	0,5 kg (output)	12 kg (output)	1 300 kg (output)	0 (output)

NOTE 3: Occasionally *B* can be simplified to consider e.g. CO_2e for each process as a whole instead of CO_2, CH_4, N_2O, etc. or weighted EI values. This principle is applied in Annex A (informative) in the present document. Annex B (informative) on cut-off procedures for *SOE* and *FOE* (larger product systems) also uses CO_2e for each process.

For the Product G example, A^{-1} (in yellow) and p are shown in Table 4.

Table 4: Example of an inverse technology matrix A^{-1} and a process vector p

Electricity production 1	Electricity production 2	Electricity production 3	Aluminium production	IC production	Product G production	$p = A^{-1} \times \alpha$
1	0	0	0	0	5	5
0	1	0	0	0	2	2
0	0	1	0	0	3	3
0	0	0	1	0	10	10
0	0	0	0	1	0,05	0,05
0	0	0	0	0	1	1

NOTE 4: Each item in the p vector is the scaling factor corresponding to one unit process.

For the Product G example, α is shown in Table 5.

Table 5: Example of a final demand vector (α)

	Electricity production 1	Electricity production 2	Electricity production 3	Aluminium production	IC production	Product G production	α
Electricity 1							0
Electricity 2							0
Electricity 3							0
Aluminium							0
IC							0
Product G							1

NOTE 5: This α vector expresses the boundary condition for the economic flows at the system boundary.

For the Product G example, β is shown in Table 6.

Table 6: Example of a final environmental load vector β

		Electricity production 1	Electricity production 2	Electricity production 3	Aluminium production	IC production	Product G production	Total Sum
$\beta = B \times A^{-1} \times \alpha$	CO_2e	0,02 × 5 × 1 = 0,1 kg	0,3 × 2 × 1 = 0,6 kg	0,5 × 3 × 1 = 1,5 kg	12 × 10 × 1 = 120 kg	1 300 × 0,05 × 1 = 65 kg	0	187,2 kg

In summary manufacturing of one piece of Product G emits 187,2 kg CO_2e.

NOTE 6: In the present method the final results in Annex A (informative), e.g. 48 502 g CO_2e in clause A.1, are examples of final environmental load vectors.

Table 7 shows the SVP_{ij} for the generic Product G example.

Table 7: Sensitivity of individual elements in the Production of one piece of a generic Product G

Electricity production 1		**SVP**
Output	Electricity 1	
Output	CO_2e	-0,000534
Electricity production 2		
Output	Electricity 2	
Output	CO_2e	-0,00320
Electricity production 3		
Output	Electricity 3	
Output	CO_2e	-0,00801
Aluminium production		
Output	Aluminium	
Output	CO_2e	-0,641
IC production		
Output	IC	
Output	CO_2e	-0,347
Product G production		
Output	Product G	
Input	Electricity 1	0,000534
Input	Electricity 2	0,00320
Input	Electricity 3	0,008013
Input	Aluminium	0,641
Input	IC	0,347

4.3 Estimation of contribution to total uncertainty

Equation 7 shows how the share of the total uncertainty shall be calculated.

$$CUVP_{ij} = \frac{\left(\frac{Av}{IVP_{ij}} \times SVP_{ij}\right)^2 \times (UVP_{ij})^2}{TU^2} \tag{7}$$

where:

CUVP$_{ij}$ = contribution of an individual element to total uncertainty.

NOTE 1: As shown in Annex A (informative), the *CUVP* is valid both for uncertainty contributions from environmental flows and from amount flows.

NOTE 2: A $CUVP_{ij}$ is unitless and $\sum CUVP_{ij} = 1$.

IVP$_{ij}$ = input value of an individual element.

UVP$_{ij}$ = uncertainty of an individual element.

TU = Total uncertainty of whole calculation result.

Equation 7 helps prioritize the data for which the variability should be minimized in order to achieve robust conclusions. Equation 7 is generally applicable to any standard - such as Recommendation ITU-T L.1480 [i.8] - for avoided impact calculations.

4.4 Estimation of relative rebound effect

Equation 8 shows how the relative total rebound effect shall be calculated.

$$RRb = \frac{Rb}{SOE - FOE} \tag{8}$$

where:

RRb = relative total rebound effect.

Four examples are shown in Annex A (informative) on how the methodology in the present document can be applied.

Annex A (informative): Examples using the uncertainty and sensitivity methodology

A.0 Introduction

Here are included four examples which show how the proposed methodology is applied.

A.1 Business meeting

This example is based on [i.10]. Here the method is applied to a business meeting comparison between a physical business trip with travel and a virtual business trip with video. The comparison is done for a future case in 2030.

The function is to enable a business meeting and the functional unit is "the enabling of a 10-hour business meeting (at a conference, seminar training, trade fair, exhibition) attended by a German in Germany in 2030".

SOE in [i.10] is calculated as follows: 2 × 355,9 km × (64 % × 19,3 g CO_2e/personkm for cars + 32 % × 20,5 g CO_2e/personkm for trains + 4 % × 6,9 g CO_2e/personkm for buses {Embodied of transport vehicles} + 2 × 355,9 km × (64 % × 115 g CO_2e/personkm for cars + 32 % × 13 g CO_2e/personkm for trains + 4 % × 29 g CO_2e/personkm for buses {Use of transport vehicles} = **69 833,7 g CO_2e/10-hour meeting**.

FOE in [i.10] is calculated as follows: 10 hours × 40,8 g CO_2e/h {embodied of average of PC with display and laptop} + 10 hours × 189 g/kWh × (10 % 3D holographic × 0,0425 kW + 90 % 2D high-quality × 0,0375 kW) g CO_2e {local cloud&on board computation, Local cloud + 6G AI + holographic data computing} + {Internet + local network} 10 hours × 189 g/kWh × (10 % 3D holographic × 0,1642 kW + 90 % 2D high-quality × 0,0169 kW) g CO_2e = **539,6 g CO_2e/10 hour meeting**.

The relative rebound effect is assumed to be 30 % [i.6].

NOTE: The relative rebound effect is calculated with Equation 8 as [38,53 × 539,6] / [69 833,7 - 539,6] = 0,3.

Using the data with Equation 1:

$$Av = SOE - (FOE+Rb) = 69\,833{,}7 - (539{,}6 + 38{,}53 \times 539{,}6) = 48\,503 \text{ g } CO_2\text{e}.$$

Table A.1 shows the data to be used for Equation 7 and Figure A.1. The uncertainty range values, *UVP*, have all been assumed.

SVP can be derived with different software programs.

Table A.1: CO_2e intensities, uncertainties and sensitivities for proposed methodology applied to business meetings

Parameter and combinations	Unit used	Proxy value (*IVP*) (g CO_2e/unit), (mean value, μ)	Uncertainty range for EI flow value and activity flow value (*UVP*), (2Ʊ)	Sensitivity factor (*SVP*)	Contribution to total Uncertainty (*CUVP*) calculated by Equation 7
Car embodied (output)	personkm	19,3	5	-0,181	1,27 % = ((48 502 / 19,3 × -0,181)^2 × 5^2) / 20 184^2 {share of the uncertainty of the CO_2e emissions from Car embodied of the total uncertainty}
Train embodied (output)	personkm	20,5	5	-0,096	0,32 %
Bus embodied (output)	personkm	6,90	2,00	-0,00405	≈ 0 %

Parameter and combinations	Unit used	Proxy value (*IVP*) (g CO_2e/unit), (mean value, μ)	Uncertainty range for EI flow value and activity flow value (*UVP*), (2σ)	Sensitivity factor (*SVP*)	Contribution to total Uncertainty (*CUVP*) calculated by Equation 7
Use of cars (output)	personkm	115	20	-1,08	20,4 % = ((48 502 / 115 × -1,08)^2 × 20^2) / 20 184^2 {share of the uncertainty of the CO_2e emissions from Car use of the total uncertainty}
Use of trains (output)	personkm	13	5	-0,061	0,32 %
Use of buses (output)	personkm	29	2	-0,017	≈ 0 %
Embodied of vehicles (output)	personkm	1			
Car embodied (input)	personkm	0,64	0,05	0,181	0,12 %
Train embodied (input)	personkm	0,32	0,05	0,096	0,13 %
Bus embodied (input)	personkm	0,04	0,05	0,00405	0,01 %
Use of vehicles (output)	personkm	1			
Use of cars (input)	personkm	0,64	0,05	1,08	4,411 % = ((48 502 / 0,64 × 1,08)^2 × 0,05^2) / 20 184^2 {share of the uncertainty of the amount of "Use of cars", used by "Use of vehicles", of the total uncertainty}
Use of trains (input)	personkm	0,32	0,05	0,061	0,05 %
Use of buses (input)	personkm	0,04	0,05	0,017	0,26 %
10 hour meeting physical (output)	piece	1	0		
Embodied of vehicles (input)	personkm	711,8	200	0,28	3,61 %
Use of vehicles (input)	personkm	711,8	200	1,15	61,15 % = ((48 502 / 711,8 × -1,15)^2 × 200^2) / 20 184^2 {share of the uncertainty of the amount of "use of vehicles" used by the "10-hour meeting physical" of the total uncertainty}
PC (display+laptop) embodied (output)	hour	40,8	10	0,33	3,83 %
German power 2030 (output)	W	0,19	0,02	0,107	0,07 %
3D holographic local power (output)	piece	1		-	
German power 2030 (input)	W	42,5	4	0,0006	≈ 0 %

Parameter and combinations	**Unit used**	**Proxy value (*IVP*) (g CO_2e/unit), (mean value, μ)**	**Uncertainty range for EI flow value and activity flow value (*UVP*), (2Ʊ)**	**Sensitivity factor (*SVP*)**	**Contribution to total Uncertainty (*CUVP*) calculated by Equation 7**
2D high-quality local power (output)	piece	1			
German power 2030 (input)	W	37,5	3	0,005	≈ 0 %
3D holographic network power (output)	piece	1			
German power 2030 (input)	W	164,5	4	0,00025	≈ 0 %
2D high-quality network power (output)	piece	1			
German power 2030 (input)	W	16,9	3	0,00023	≈ 0 %
local cloud&on board computation, Local cloud + 6G AI + holographic data computing (output)	hours	1			
PC (display+laptop) embodied (input)	hours	1			
3D holographic local power (input)	piece	0,1	0,02	-0,0006	≈ 0 %
2D high-quality local power (input)	piece	0,9	0,18	-0,005	0,06 %
Internet + local network (output)	hours	1			
3D holographic network power (input)	piece	0,1	0,02	-0,00025	≈ 0 %
2D high-quality network power (input)	piece	0,9	0,18	-0,00023	≈ 0 %
Total meeting 10 hour 6G (output)	piece	1			
computation, Local cloud + 6G AI + holographic data computing (input)	hours	10		-0,39	≈ 0 %
Internet + local network (input)	hours	10		-0,048	≈ 0 %
Rebound effect (output)	piece	1			
Total meeting 10 hour 6G (input)	pieces	38,53	7,72	0,428	4,24 %
Sum of uncertainty contributions					**100 %**
Avoided CO_2e (*Av*) (output)	**piece**	1			
10 hour meeting physical (*SOE*) (input)	piece	1			
Total meeting 10 hour 6G (*FOE*) (output)	piece	1			

Parameter and combinations	Unit used	Proxy value (*IVP*) (g CO_2e/unit), (mean value, μ)	Uncertainty range for EI flow value and activity flow value (*UVP*), (2σ)	Sensitivity factor (*SVP*)	Contribution to total Uncertainty (*CUVP*) calculated by Equation 7
Rebound effect (*Rb*) (output)	piece	1			

The interpretation of Table A.1 is that is most worthwhile to focus effort on reducing the uncertainty of the amount of personkm used for the physical meeting and also reduce the uncertainty for the emissions from the cars.

Av result is 48 503 ± 20 184 g CO_2e as shown in Figure A.1. *TU* in Equation 7 is here 20 184 g.

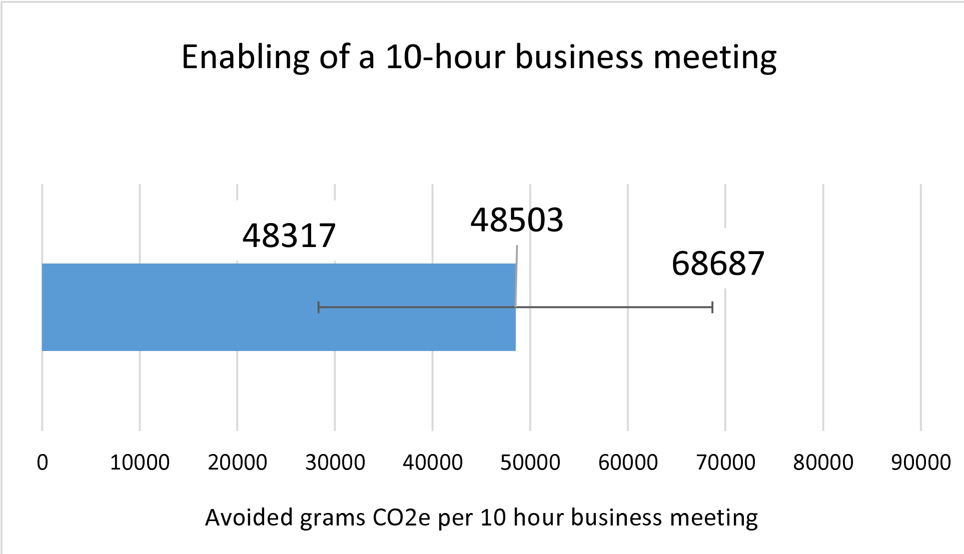

Figure A.1: Resulting probability analysis of avoided emissions for changing ways to have a business meeting

The conclusion that can be drawn from Figure A.1. is that the virtual meeting will help avoid emissions as the uncertainty is not too large.

A.2 Health consultation

This example is based on [i.2]. Here the method is applied to a health consultation comparison between physical and remote consultation.

The function is "Providing health consultation of Computerized Tomography (CT) scans" and the functional unit is "A health consultation subsystem for 24 consultations per day involving analysis of CT scans to be suited for the needs of the purchasing customer".

SOE in [i.2] is calculated as follows: 320 km × (4 cars / 250 000 km × 10 000) {Petrol car embodied} + 320 km × (5,58 dm3 / 100 km × 0,73 kg/dm3 × 0,45) {Petrol used} + 320 km × (5,58 dm3 / 100 km × 2,31) {Use of petrol car} + 8 hr × (243 / (4 × 8 760 hr) + 0,01 kW × 0,6) {PC embodied and use} + 8 hr × (400 / (4 × 8 760 hr) + 0,01 kW × 0,6) {Monitors embodied and use}} = **99 kg CO_2e/24 consultations**.

FOE in [i.2] is calculated as follows: 3 pcs × 13 hr × (243 / (4 yr × 8 760 hr) + 0,01 kW × 0,6) {PC embodied and use} + 3 pcs × 13 hr × (400 / (4 yr × 8 760 hr) + 0,01 kW × 0,6) {Monitors embodied and use} + 5 GB/hr × 13 hr × 2 kWh / 44 GB × 0,6 {5G wireless network use} = **3 kg CO_2e/24 consultations**.

The relative rebound effect is assumed to be 30 % [i.6].

NOTE: The relative rebound effect is calculated with Equation 8 as [9,6 × 3] / [99 - 3] = 0,3.

Using the data with Equation 1:

$$Av = SOE - (FOE+Rb) = 99 - (3 + 9{,}6 \times 3) = 67{,}2 \text{ kg } CO_2\text{e}.$$

Table A.2 shows data to be used for Equation 7 and Figure A.2. The uncertainty range values, *UVP*, have all been assumed.

SVP factors can be derived with different software programs or manually.

Table A.2: CO_2e intensities, uncertainties and sensitivities for proposed methodology applied to health consultation

Parameters and combinations	**Unit used**	**Proxy value (*IVP*) (kg CO_2e/unit), (mean value, μ)**	**Uncertainty range for EI flow value and activity flow value (*UVP*), (2Ʊ)**	**Sensitivity factor (*SVP*)**	**Contribution to total Uncertainty (*CUVP*) calculated by Equation 7**
Electricity production (output)	kWh	0,6	0,06	0,35	0,75 %
Vehicle embodied (output)	piece	10 000	1 900	-0,76	12,64 %
Petrol production (output)	kg	0,45	0,05	-0,087	0,07 %
PC embodied (output)	piece	243	24,3	0,041	0,01 %
Monitor embodied	piece	400	49	0,069	0,03 %
Vehicle use (output)	km	1			
Vehicle embodied (input)	pieces	1,6E-5	2,72E-6	0,76	10,12 %
Petrol production (input)	kg	0,04	0,004	0,08	0,05 %
CO_2e (output)	kg	0,13	0,0013	-1,46	0,13 %
PC use (output)	hour	1			
PC embodied (input)	pieces	2,9E-5	2,9E-6	-0,041	0,01 %
Electricity production (input)	kWh	0,01	0,001	-0,036	0,01 %
Monitor use (output)	hour	1			
Monitor embodied (input)	pieces	2,9E-5	2,9E-6	-0,069	0,03 %
Electricity production (input)	kWh	0,01	0,001	-0,036	0,01 %
5G network use (output)	GB	1			
Electricity production (input)	kWh	0,046	0,0046	-0,024	0,47 %
24 physical consultations (output)	piece	1			
Vehicle use (input)	km	320	75	1,46	70,91 %
PC use (input)	hours	8	0,8	0,0015	0 %
Monitor use (input)	hours	8	0,8	0,002	0 %
24 remote consultations (output)	piece				
5G network use (input)	GB	65	6,5	-0,28	0,07 %
PC use (input)	hours	39	3,9	-0,08	0,47 %
Monitor use (input)	hours	39	3,9	-0,107	0,04 %
Rebound effect (output)	piece	1			
24 remote consultations (input)	piece	9,6	1,92	0,378	4,3 %
Sum of uncertainty contributions					**100 %**

Parameters and combinations	Unit used	Proxy value (*IVP*) (kg CO_2e/unit), (mean value, μ)	Uncertainty range for EI flow value and activity flow value (*UVP*), (2σ)	Sensitivity factor (*SVP*)	Contribution to total Uncertainty (*CUVP*) calculated by Equation 7
Avoided CO_2e (*Av*)	**piece**	1			
24 physical consultations (*SOE*) (input)	piece	1			
24 remote consultations (*FOE*) (output)	piece	1			
Rebound effect (*Rb*) (output)	piece	1			

Av result is 67,22 ± 27,36 kg CO_2e as shown in Figure A.2.

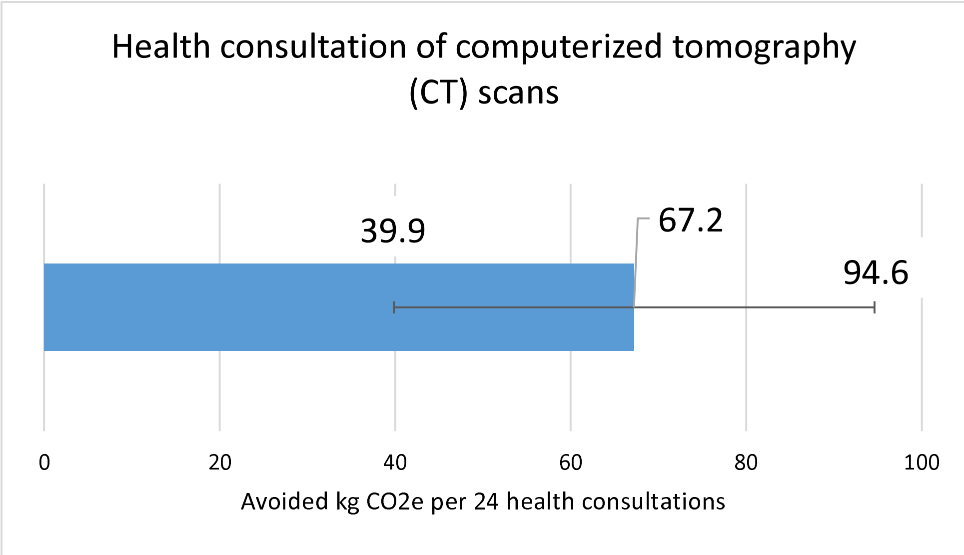

Figure A.2: Resulting probability analysis for avoided emissions by changing health consultation technologies for CT scans

Figure A.2 suggests that the conclusion that remote consultation will lead to avoided emissions is well-founded.

NOTE: Example of cut-off procedure for clause A.2 is shown in clause B.1.1.

A.3 Telemedicine

This example is based on [i.11]. Here the method is applied to a health care clinic visit comparison between physical and mixed physical and remote consultation.

The function is to enable hospital visits and the functional unit is "the enabling of 1 961 768 visits to the health care clinic in 2021".

SOE in [i.11] is **43 160 132 kg CO_2e/1 961 768 visits**.

FOE in [i.11] is **25 863 762 kg CO_2e/1 961 768 visits**.

The relative rebound effect is assumed to be 30 % [i.6].

NOTE: The relative rebound effect is calculated with Equation 8 as: [0,2 × 25 863 762] / [43 160 132 - 25 863 762] = 0,3.

Using the data with Equation 1:

$$Av = SOE - (FOE + Rb) = 43\,160\,132 - (25\,863\,762 + 0{,}2 \times 25\,863\,762) = 12\,123\,617 \text{ kg } CO_2\text{e}.$$

Table A.3 shows data to be used for Equation 7 and Figure A.3. The uncertainty range values, *UVP*, have all been assumed.

SVP factors can be derived with different software programs or manually.

Table A.3: CO_2e intensities, uncertainties and sensitivities for proposed methodology applied to telemedicine

Parameters and combinations	**Unit used**	**Proxy value (*IVP*) (kg CO_2e/unit), (mean value, μ)**	**Uncertainty range for EI flow value and activity flow value (*UVP*), (2Ʊ)**	**Sensitivity factor (*SVP*)**	**Contribution to total Uncertainty (*CUVP*) calculated by Equation 7**
Video (output)	minutes	0,0014	0,00028	0,0027	≈ 0 %
Phone (output)	minutes	0,00072	0,000144	0,000119	≈ 0 %
Car travel (output)	km	0,335	0,067	-0,701	6,60 %
Air travel (output)	pkm	0,129	0,0258	-0,301	1,22 %
CV with Virtual Video (output)	visit	1			
Video (input)	minutes	31,8	6,36	-0,0027	≈ 0 %
CV with Virtual Phone (output)	visit	1			
Phone (input)	minutes	27,5	5,5	-0,000119	≈ 0 %
CV by Car in person, (output)	visit	1			
Car travel (input)	km	39,35	7,9	2,13	61,03 %
CV by Car in person, V, (output)	visit	1			
Car travel (input)	km	33,5	6,7	-1,43	27,49 %
CV by Air in person, (output)	visit	1			
Air travel (input)	pkm	68,35	13,7	0,301	1,22 %
Annual Person Visits (output)	piece	1			
CV by Car in person	visits	1 961 768			
CV by Air in person	visits	1 961 768			
Annual Virtual Visits (output)	piece	1			
CV with Virtual Video (input)	visits	612 700			
CV with Virtual Phone (input)	visits	59 635			
CV by Car in person, V, (input)	visits	1 289 433			
CV by Air in person, (input)	visits	1 289 433			
Rebound effect (output)	piece	1			
Annual Virtual Visits (input)	piece	0,2	0,04	-0,43	2,44 %
Sum of uncertainty contributions					**100 %**
Avoided CO_2e (*Av*)	**piece**	1			
Annual Person Visits (*SOE*) (input)	piece	1			

Parameters and combinations	Unit used	Proxy value (*IVP*) (kg CO_2e/unit), (mean value, µ)	Uncertainty range for EI flow value and activity flow value (*UVP*), (2σ)	Sensitivity factor (*SVP*)	Contribution to total Uncertainty (*CUVP*) calculated by Equation 7
Annual Virtual Visits (*FOE*) (output)	piece	1			
Rebound effect (*Rb*) (output)	piece	1			

Av result is 12 123 617 ± 6 621 361 kg CO_2e as shown in Figure A.3.

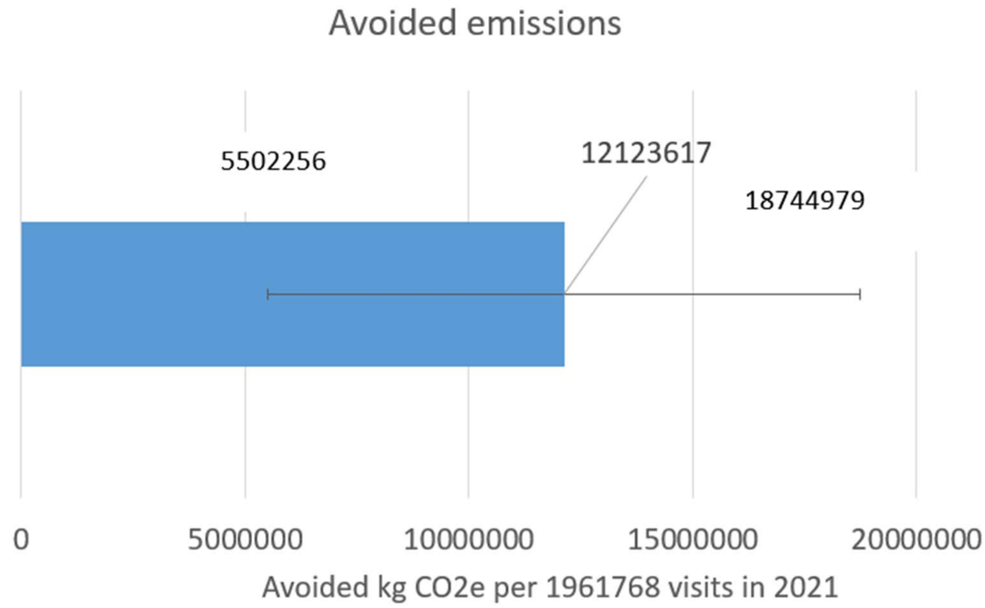

Figure A.3: Resulting probability analysis for avoided emissions by changing visit type in hospitals

Figure A.3 suggests that the conclusion that telemedicine will lead to avoided emissions is well-founded.

A.4 Solar electricity

This example is based on [i.12]. Here the method is applied to an electricity generation comparison between a PV solar plant installation and average grid mix.

The function is to provide some of the electricity needs for one single-family detached house and to the grid.

The functional unit is "generation of 39 968 kWh of electricity needed by one specific single-family detached house in Warzaw area in Poland and generation of 101 948 kWh of electricity needed elsewhere in Warzaw area in Poland during 25 years between 2022 and 2047".

SOE in [i.12] is **63 365 kg CO_2e/25 years**.

FOE in [i.12] is **10 215 kg CO_2e/25 years**.

The higher-order effect in [i.12], including the rebound effect, is estimated to be 3 694 kg CO_2e.

NOTE: The relative rebound effect is calculated with Equation 8 as [3 694] / [63 365 - 10 215] = 0,0695.

Using the data with Equation 1:

$$Av = SOE - (FOE + Rb) = 63\ 365 - (10\ 215 + 3\ 694) = 49\ 456 \text{ kg } CO_2\text{e}.$$

Table A.4 shows data to be used for Equation 7 and Figure A.4. The uncertainty range values, *UVP*, have all been assumed.

SVP factors can be derived with different software programs or manually.

Table A.4: CO_2e intensities, uncertainties and sensitivities for proposed methodology applied to solarization

Parameters and combinations	Unit used	Proxy value (*IVP*) (kg CO_2e/unit), (mean value, μ)	Uncertainty range for EI flow value and activity flow value (*UVP*), (2Ʊ)	Sensitivity factor (*SVP*)	Contribution to total Uncertainty (*CUVP*) calculated by Equation 7
Electricity mix which Solar will replace during 25 years (output)	kWh	0,4465	0,12	-1,28	49,02 %
PV panel (output)	piece	456	91,2	0,16	0,81 %
Inverter (output)	piece	359,19	71,8	0,066	0,0013 %
Other Solar embodied (output)	piece	1 894	379	0,035	0,04 %
Solar electricity (output)	kWh	1			
PV panel (input)	piece	1,26E-4	2,52E-6	-0,16	0,81 %
Inverter (input)	piece	6,41E-6	1,28E-6	-0,066	0,0013 %
Other Solar embodied (input)	piece	6,41E-6	1,28E-6	-0,035	0,04 %
Rebound effect (output)	piece	3 694	739	0,075	0,17 %
Avoided CO_2e (*Av*)	**piece**	**1**			
Electricity mix which Solar will replace during 25 years (*SOE*) (input)	kWh	141 916	28 383	1,28	49,02 %
Solar electricity (*FOE*) (output)	kWh	141 916	7 096	-0,21	0,08 %
Rebound effect (*Rb*) (output)	piece	1	0,05	-0,075	0,01 %
Sum of uncertainty contributions					**100 %**

Av result is 49 456 ± 18 100 kg CO_2e as shown in Figure A.4.

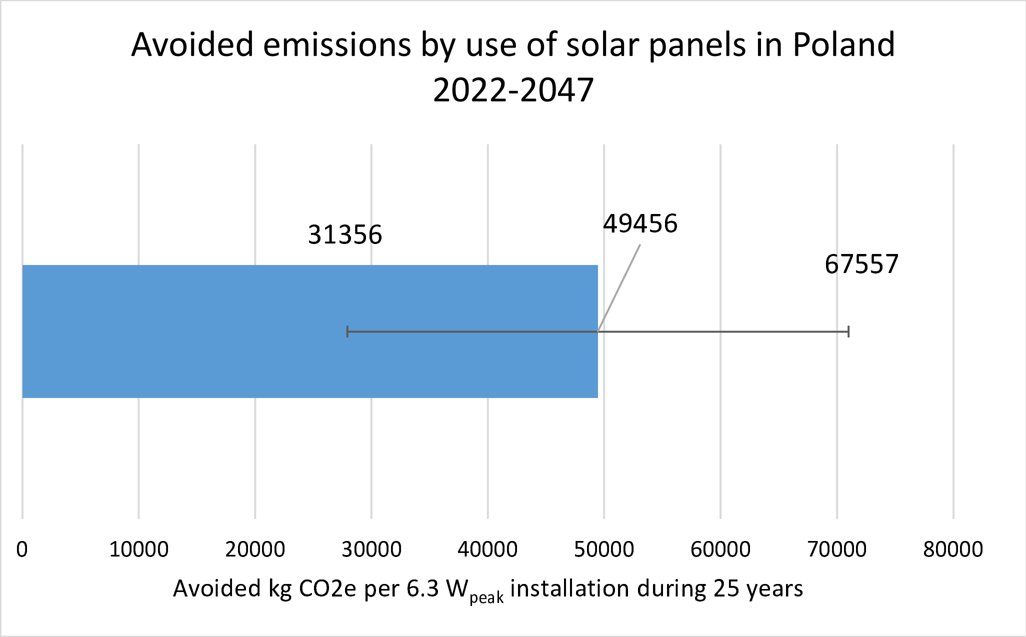

Figure A.4: Resulting probability analysis for avoided emissions µby introducing solar electricity in detached houses

Figure A.4 suggests that the conclusion that introducing solar electricity will lead to avoided emissions is well-founded.

Annex B (informative): Method for knowing if enough data have been collected to meet cut-off threshold

B.0 Introduction

Generally, a complete life cycle product system with a perfect accuracy includes all connected processes and primary data for all. This will be challenging to achieve in most situations and therefore a smaller product system can be identified (for which more accurate and specific data should be used) for the technology matrix *A* mentioned in clause 4.2. In this annex, a method for knowing if enough data have been collected to meet the preset cut-off threshold, is outlined. It is based on pages 92-103 in [i.9]. The method should be applied separately to *SOE*, *FOE* and *Rb* as in the present document there is no method developed for aggregating one *c* for Equation 1.

B.1 Method description

B.1.0 Detailed description of the method

The Process-Sum (PS) method is combined with the Environmentally Extended Input−Output (EEIO) method (Equation B.1).

$$I_{total} = I_{process} + I_{EEIO} \quad \text{(B.1)}$$

The cut-off criterion equation is (Equation B.2).

$$\frac{I_{process}}{I_{process}+I_{EEIO}} \geq 1 - c \quad \text{(B.2)}$$

where:

I_{total} = Total CO_2e (LCA) result.

$I_{process}$ = Summated CO_2e scores based on Process-sum CO_2e (LCA) data which are specific and granular for the system at hand.

I_{EEIO} = Summated CO_2e score based on EEIO CO_2e (LCA) proxy data which cover the remaining processes.

c = cut-off threshold, e.g. 0,05 for 5 %.

The method has the following steps:

1) Define the goal of the CO_2e (LCA) analysis.

2) Compose a preliminary product system indiscriminately by including important processes from all life cycle stages.

3) Analyse the preliminary product system with the PS LCA method for $I_{process}$ and note which remaining (surplus) processes were not be modelled with PS.

4) Analyse these processes with the EEIO LCA method for obtaining I_{EEIO}.

5) Determine if $\frac{I_{process}}{I_{process}+I_{EEIO}} \geq 1 - c$.

6) If not, determine if there are some essential processes modelled with the EEIO method which need to be included and modelled with the PS method.

7) Analyse again the new preliminary product system with the PS LCA method for obtaining $I_{process}$ and note again which processes could not be modelled with PS.

8) Repeat steps 5 and 6.

9) When $\frac{I_{process}}{I_{process}+I_{EEIO}} \geq 1 - c$, i.e. $\left(\frac{I_{EEIO}}{I_{total}} \leq c\right)$, the cut-off threshold has been met.

Next follows an example of avoided emissions of health consultation.

B.1.1 Example application of the method

B.1.1.0 Avoided emissions of health consultation

The goal is to perform a CO_2e analysis of the avoided impact associated with a health consultation comparison between physical and remote consultation shown in clause A.2. The scope is from cradle-to-use. The required value of c is 0,05 for *SOE*, 0,05 for *FOE* and 0,5 for *Rb*.

Next follows the cut-off method applied to SOE and FOE of clause A.2.

B.1.1.1 Cut-off method applied to clause A.2

Table B.1 shows the CO_2e score for the preliminary product system for *SOE*. The first iteration represents the first preliminary product system.

Table B.1: Score for preliminary product system with the PS LCA method ($I_{process}$)

Process name(s)	$I_{process}$ **(kg CO_2e generated by PS method)**
Petrol car embodied	51,2
SUM of CO_2e emission (kg)	**51,2**

Table B.2 shows the CO_2e score for the remaining surplus processes.

Table B.2: Scores for remaining processes analysed with the EEIO LCA method

Process name	I_{EEIO} **(kg CO_2e generated by EEIO method)**
Use of petrol car	2,25 kg CO_2e/USD [i.15] × 20 USD = 45 kg
Petrol production	0,772 kg CO_2e/USD [i.15] × 20 USD = 15,44 kg
Others	5
SUM of CO_2e emission (kg)	**65,44**

Table B.3 shows how $\frac{I_{process}}{I_{total}}$ (Equation B.2) is determined gradually for *SOE* with the proposed method.

Table B.3: Calculation of $\frac{I_{process}}{I_{total}}$ by iterative process for *SOE* in clause A.2

Iteration number	**Added processes**	**kg CO_2e**		$\frac{I_{process}}{I_{process}+I_{EEIO}}$
		$I_{process}$	I_{EEIO}	
1	Petrol car embodied	51,2	65,44	0,4389 which is < 1 - 0,05
2	Use of petrol car	92,44	20,44	0,8189 which < 1 - 0,05
3	Petrol production	98,31	5	0,9516 which > 1 - 0,05 The cut-off threshold has been met.

All added processes in column 2 of Table B.3 represent the final product system for which the PS method should be used.

B.1.1.2 Cut-off method applied to *FOE* of clause A.2

Table B.4 shows the CO_2e score for the preliminary product system for *FOE*. The first iteration represents the first preliminary product system.

Table B.4: Score for preliminary product system for *FOE* with the PS LCA method ($I_{process}$)

Process name(s)	$I_{process}$ (kg CO_2e generated by PS method)
Use of 5G	1,77
SUM of CO_2e emission (kg)	**1,77**

Table B.5 shows the CO_2e score for the remaining surplus processes.

Table B.5: Scores for remaining processes of *FOE* analysed with the EEIO LCA method

Process name	I_{EEIO} (kg CO_2e generated by EEIO method)
Production of Monitor	0,488 kg CO_2e/USD [i.15] computers and electronics × 15 USD = 1,464
Production of PC	0,488 kg CO_2e/USD [i.15] computers and electronics × 50 USD = 4,88
Use of PC	6 kg CO_2e/USD [i.15] computers and electronics × 0,6 USD = 3,6
Use of Monitor	6 kg CO_2e/USD [i.15] computers and electronics × 0,2 USD = 1,2
Others	0,1
SUM of CO_2e emission (kg)	**36,62**

Table B.6 shows how $\frac{I_{process}}{I_{total}}$ (Equation B.2) is determined gradually for *FOE* with the proposed method.

Table B.6: Calculation of $\frac{I_{process}}{I_{total}}$ by iterative process for *FOE*

Iteration number	Added processes	kg CO_2e		$\frac{I_{process}}{I_{process}+I_{EEIO}}$
		$I_{process}$	I_{EEIO}	
1	Use of 5G	1,77	36,62	0,046 which is < 1 - 0,05
2	Production of Monitor	2,21	29,3	0,071 which is < 1 - 0,05
3	Production of PC	2,48	4,9	0,336 which is < 1 - 0,05
4	Use of PC	2,72	3,7	0,676 which is < 1 - 0,05
5	Use of Monitor	2,95	0,1	0,9673 which > 1 - 0,05 The cut-off threshold has been met.

All added processes in column 2 of Table B.6 represent the final product system for which the PS method should be used.

NOTE: The practitioner is advised to take care when applying cut-off to FOE or Rb in order to make sure that the avoided environmental impact result is realistic and representative and not only resulting from the use of cut-off.

B.1.1.3 Cut-off method applied to *Rb* for clause A.2

The way *Rb* is used in the present document, it is not tied to any measurable activity like *SOE* and *FOE*. *Rb* is therefore 100 % proxy and a required value of *c* cannot be applied. Therefore, there is no pathway to increase $\boldsymbol{I_{process}}$ without redefining *Rb* so process-sum data and EEIO data can be separated. This is beyond the scope of the present document and it is acknowledged that *Rb* is 100 % proxy.

Annex C (informative): Examples of software programs for implementation

This annex lists examples of software programs which can be used to implement the present document.

Examples are openLCA found at https://www.openlca.org/openlca/openlca-features/, Brightway [i.13] at https://docs.brightway.dev/en/latest/index.html and the related Activity Browser [i.14].

Another is Chain management by Life Cycle Assessment, found at https://www.universiteitleiden.nl/en/research/research-output/science/cml-cmlca.

Annex D (informative): Example of code for implementation of clause 4.2 in the present document

This code can be used in the program GNU Octave [https://octave.org/] to calculate the 187,2 kg CO_2e for the example in clause 4.2:

```
A=[1,0,0,0,0,-5;0,1,0,0,0,-2;0,0,1,0,0,-3;0,0,0,1,0,-10;0,0,0,0,1,-0.05;0,0,0,0,0,1]
B=[0.02;0.3;0.5;12;1300;0]
alfa=[0;0;0;0;0;1]
p=inv(A)*alfa
beta=transpose(p)*B
```

→

```
A=[1,0,0,0,0,-5;0,1,0,0,0,-2;0,0,1,0,0,-3;0,0,0,1,0,-10;0,0,0,0,1,-0.05;0,0,0,0,0,1]
A =

    1.0000         0         0         0         0   -5.0000
         0    1.0000         0         0         0   -2.0000
         0         0    1.0000         0         0   -3.0000
         0         0         0    1.0000         0  -10.0000
         0         0         0         0    1.0000   -0.0500
         0         0         0         0         0    1.0000

>> B=[0.02;0.3;0.5;12;1300;0]
B =

   2.0000e-02
   3.0000e-01
   5.0000e-01
   1.2000e+01
   1.3000e+03
            0

>> alfa=[0;0;0;0;0;1]
alfa =

   0
   0
   0
   0
   0
   1

>> p=inv(A)*alfa
p =

   5.0000e+00
   2.0000e+00
   3.0000e+00
   1.0000e+01
   5.0000e-02
   1.0000e+00

>> beta=transpose(p)*B
beta = 187.20
>>
```

Annex E (informative): Change history

Date	Version	Information about changes
June 2024	V0.0.1	Added some initial text and heading
12 November 2024	V0.0.2	Stable draft
22 November 2024	V0.0.3	Final draft for approval
3 January 2025	V0.0.4	Final draft for approval
17 January 2025	V0.0.5	Stable draft
31 January 2025	V0.0.6	Stable draft
14 February 2025	V0.0.7	Stable draft
16 April 2025	V0.0.8	Final draft for approval
16 April 2025	V0.0.9	Final draft for approval

History

Version	Date	Status
V1.1.1	September 2025	Publication