SSRG International Journal of Recent Engineering Science
ISSN: 2349–7157 / https://doi.org/10.14445/23497157/IJRES-V11I5P110
Volume 11 Issue 5, 103-108, Sep-Oct 2024

Original Article

Method for Uncertainty and Probability Estimation of Avoided Impacts from Information and Communication Technology Solutions

Anders S.G. Andrae

Huawei Technologies Sweden AB, Sweden.

Corresponding Author : anders.andrae@huawei.com

Received: 12 August 2024 Revised: 15 September 2024 Accepted: 29 September 2024 Published: 23 October 2024

Abstract *- Solutions provided by Information and Communication Technology (ICT) may help avoid environmental impacts. Several methodologies exist by which the avoided impact can be estimated. However, so far there is a lack of treatment of the uncertainty within the calculations. Especially the uncertainty range of the rebound effects compared to others is not part of existing methods. As such, there is no way of knowing how large the errors can be - for different elements of the equation for avoided impacts - while still being able to draw conclusions regarding the benefit of the ICT Solution. Here is presented a complete method for simplified assessment of ICT Solutions avoided impact potential including uncertainty and probability calculations. An example of gas pipe inspection, using either manual inspection or 5G drone inspection, is shown, which demonstrates the usefulness and efficiency of the proposed method. When the relative rebound effect is 55%, the target technology for pipe inspection is shown to avoid impact compared to the reference technology for gas pipe inspection. Sensitivity factors much larger than 1 for impacts related to the use of vehicles are shown to overestimate contributions to the total uncertainty. It should be explored how emerging standards will affect the practice in the area of avoided impact calculations.*

Keywords *- Avoided environmental impact, ICT solutions, Life cycle assessment, Probability, Uncertainty.*

1. Introduction

Research on the net Environmental Impact (EI) of technologies has become more pronounced. [1,2,3] Life Cycle Assessment (LCA) is the preferred quantification methodology; however, uncertainty quantification is often neglected. [4,5] This is problematic as the uncertainty determines if conclusions can be drawn. Recently, a major work was published, which will help practitioners improve the uncertainty modelling in LCA. [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 comprehensively less impact when used to address sustainability matters. See [2] for a review of methodologies by which the avoided impact of ICT Solutions can be estimated. A clear example of avoided impacts by telemedicine is [7], also handled in [2]. The rebound effect (RE) and uncertainty are not covered. The RE of ICT is the known unknown in the total calculation. Simply put, the RE is the difference between potential avoided impact and actual avoided impact. [8] The relative RE is equal to (potential benefit – actual benefit)/potential benefit. [8] The total RE can roughly be divided into the direct RE and the economy-wide RE. The direct RE is easier to estimate than the economy-wide RE, for which the uncertainty is higher. It has been estimated that the total RE may not be above 30%. [9] 4% relative RE due to energy spending when making buildings more energy efficient, 37% for e-commerce due to more logistics, 7% for car sharing and 27.4% for remote work have also been mentioned. [1]. REs usually occur over time when the ICT Solution has been in use for a while. Therefore, limited snapshot bottom-up LCA case studies may face difficulties in estimating the REs. Still, the functional unit could be scaled up to, e.g. 1 year so that the REs may realistically take place. The problems addressed are that uncertainty calculations are not systematic in LCA of ICT Services especially including the RE. The research gap is that so far, the uncertainty for avoided EI estimations for ICT has not been estimated clearly, especially for the intriguing RE. The direct quantitative transformation of the uncertainty [10] has not been achieved convincingly for avoided EI calculations for ICT. There is a need to go beyond semi-quantitative uncertainty calculations. [10] The objective of this research is to develop further an existing method [2] that assesses in a simplified manner the avoided EI resulting from the introduction of ICT Solutions. For the first time, a novel method 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 is applicable to net environmental impact LCAs including ICT Services and beyond. The method is applied to a case study on pipe inspection.

2. Materials and Methods

Equation 1 shows the main parameters for the proposed method, which can be applied to any ICT Solution.

$$A = B - (C + D) \quad (1)$$

Where

A = All avoided environmental impacts (EI) from the ICT Solution at hand per functional unit.

B = EI from the studied product system per functional unit for the Reference Scenario for the baseline.

C = EI from the studied product system per functional unit for the ICT Solution Scenario. This scenario involves target products and assessed products.

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

All data are used in the Excel Management Life Cycle Assessment (EMLCA) Tool. [5] EMLCA can help quantify the uncertainty and the sensitivity by which, in turn, the shares of the total uncertainty can be calculated.

If A>0, the ICT Solution will lead to reduced EI, and if A<0, the ICT Solution will lead to increased EI.

Table 1. Environmental impact (EI) intensities, uncertainties and sensitivities for proposed simplified probability assessment method for ICT solutions

Parameter and combinations	Unit used	Proxy value (F) (EI/unit), (mean value, μ) – input to EMLCA	Uncertainty range for EI flow value and activity flow value (H), (2Ơ) – input to EMLCA	Sensitivity from EMLCA (G) – output from EMLCA
Marginal electricity production in China	kWh	0.9	0.09	1.15
Vehicle production	piece	12506	1250	-0.71
Petrol production	kg	0.57	0.057	-0.98
UAV production	piece	913	91.3	0.81
Diesel production	kg	0.45	0.045	0.028
PC production	piece	303	30.3	0.56
Human inspection of pipe Vehicle use (output)	km	160	0	
Vehicle production (input)	pieces	6.4×10^{-4}	6.4×10^{-5}	0.71
Petrol production (input)	kg	19.47	1.95	0.98
EI (output)	kg	61.58	6.15	-7.14
PC use (output)	hour	1	0	
PC production (input)	pieces	2.85×10^{-5}	2.85×10^{-6}	-0.56
Marginal electricity production in China (input)	kWh	0.01	0.001	-0.58
5G network use (output)	year	1	0	
Marginal electricity production in China (input)	kWh	85.4	8.54	-0.57
5G UAV inspection of pipe UAV use (output)	km	160	0	
UAV production (input)	pieces	0.01	0.001	-0.81
PC use (input)	hr	730	73	-1.14
Diesel production (input)	kg	0.7	0.07	-0.028
5G network use (input)	year	0.08	8×10^{-3}	-0.57
EI (output)	kg	25.6	2.56	4.82
Rebound effect (output)	piece	1		
EI (output)	kg	15	1.5	1.33
Avoided EI (A)	**piece**	**1**	**0**	
Human inspection of pipe (B) (input)	km	160	0	
5G UAV inspection of pipe (C) (output)	km	160	0	
Rebound effect (D) (output)	p	1	0	

3. Results and Discussion

The example case study in the present research, which includes an ICT Solution that can help avoid EI, is on gas pipe inspection. [2] Such inspection can be done with humans visiting the pipes for inspection or by an Unmanned Aerial Vehicle (UAV) in combination with 5G wireless networks. [11,12] The example shows a kind of Smart Inspection and preventive maintenance. The function is "providing inspection of gas pipes". The functional unit is "a subsystem providing the inspection to be suited for the needs of 160 km of gas pipe in China." 160 km inspection is equal to about 2 months of inspection. This case study is limited as it neither considers the annual or long-term impacts of changing gas inspection methods. Table 1 shows how the present methodology is applied to pipe inspection. All data from Table 1 are used in EMLCA. As shown in [2], *B* is 81 kg EI, and *C* is 54 kg EI. The potential benefit is, therefore, 27 kg EI. As shown in Figure 1, for the present case study, the conclusion can be drawn that 5G pipe inspection is beneficial, especially if the rebound effect is 15 kg EI and its uncertainty range is 1.5 kg EI. 15 kg EI for *D* means a relative RE of 55% for *A* when *D*=0, i.e. the total relative RE is 50-61%, which is higher than "normal". [9] The validity of this assumption will be checked later. As shown in Figure 1, if the uncertainty range (two standard deviations, 2Ο) for *D* is 1.5, *I* becomes 7.58, and *A*>0 is certain.

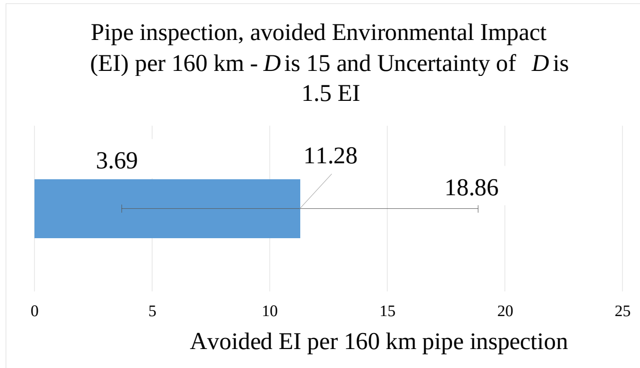

Fig. 1 Uncertainty of avoided impacts with *D* 15 kg EI and *D* uncertainty 1.5 kg EI

Table 2. Contribution to total uncertainty for parameters

Parameter and combinations	Contribution to total Uncertainty (*E*) calculated by Equation 2	Proportional contribution to total Uncertainty (*E*)
Marginal electricity production in China	2.92%	1.57%
Vehicle production	1.11%	0.6%
Petrol production	2.11%	1.13%
UAV production	1.44%	0.77%
Diesel production	0%	0%
PC production	0.69%	0.37%
Human inspection of pipe Vehicle use (output)		
Vehicle production (input)	1.11%	0.6%
Petrol production (input)	2.11%	1.13%
EI (output)	$(11.28/61.58\times-7.14)^2 \times 6.15^2/ 7.58^2 = 113\%$	113%/187%=60.4%
PC use (output)		
PC production (input)	0.69%	0.37%
Marginal electricity production in China (input)	0.75%	0.4%
5G network use (output)		
Marginal electricity production in China (input)	0.71%	0.38%
5G UAV inspection of pipe UAV use (output)		
UAV production (input)	1.44%	0.77%
PC use (input)	2.88%	1.54%
Diesel production (input)	0%	0%
5G network use (input)	0.71%	0.38%
EI (output)	$(11.28/25.6\times4.81)^2 \times 2.56^2/ 7.58^2 = 51.2\%$	51.2%/187%=27.4%
Rebound effect (output)		
EI (output)	$(11.28/15\times1.33)^2 \times 1.5^2/ 7.58^2 =3.9\%$	3.9%/187%=2.1%
Sum of uncertainty contributions	**187%**	**100%**
Avoided EI (A)		
Human inspection of pipe (B)		
5G UAV inspection of pipe (C) (output)		
Rebound effect (D) (output)		

3.1. Share of Uncertainty – Further Keys to Understand the Importance of the Rebound Effect Magnitude

Equation 2 (adapted from Equation 3.33 in [5]) shows how the share of the total uncertainty is calculated.

$$E = \frac{\left(\frac{A}{F}\times G\right)^2 \times H^2}{I^2} \quad (2)$$

Where
E = contribution of the individual parameter to total uncertainty
F = input value of the individual parameter (input to EMLCA)
G = sensitivity of individual parameter (obtained from EMLCA)
H = uncertainty of individual parameter (input to EMLCA)
I = Total uncertainty of whole calculation result (obtained from EMLCA).

As shown in Table 2, the contribution of the rebound effect to the total uncertainty is around 3.9%, while its share of the total result is 10% (15/(│81│+│-54│+│-15│)).

According to Table 2, for certain calculation setups and examples, the sum of the contributions to the total uncertainty is occasionally not exactly 100%. For example, the EI output from Human inspection contributes 113%, which likely has to do with the large sensitivity factor of -7.14. The total sum of the contributions in the second column is 187%. These effects have to be carefully monitored when using the proposed methodology for avoided EI calculations.

Table 2 shows that the proportional uncertainty contribution ratios are still reasonable, and the method will show the user where to decrease the variance most effectively.

3.2. How Large could the Total Rebound Effect be?

It is highly important to know if the results of LCAs can be trusted, especially for avoided EI calculations that involve several LCAs. Direct and economy-wide relative REs are generally between 10 and 20 %, and therefore, the total relative RE typically is between 20 and 30 %. [9] This suggests that the assumption *D*=15 kg EI is reasonable.

For the base case, the total RE (*D*) has to be more than 27 kg EI (i.e. actual benefit is <0 and relative RE is >100%) to offset the entire difference between *B* and *C*. Suppose only the direct RE (roughly happening after one year) is considered. In that case, this offset is not likely as the present case study is very specific, and the direct RE is usually around 10%. [9] To offset the saving, *D* then would have to be 33% of *B* and 50% of *C*. How could REs happen? Generally, resources saved will be used short-term for other activities in specific markets. To a certain degree, the petrol not used for manual inspection of gas pipes will be used for other purposes if the petrol consumption increases in the region within one year. If the petrol consumption is shrinking, *D* will be very low. Likely, the petrol consumption in many markets is decreasing due to a higher share of fuel-efficient hybrid vehicles.

For the economy-wide RE, it is notoriously difficult to determine where the money saved from increased efficiency will be spent. The pending cases will differ for consumers and industries. 5G drone ICT inspection is 6 times as time-efficient as manual inspection with vehicles. In this case, for direct RE, it means that more km of pipe can be inspected per year. The amount of gas pipes that can be inspected is limited so the demand for pipe inspection service is rather inelastic. Petrol production and use are 72.6 kg EI of 81 kg EI for *B*. This means that *D* cannot be more than 37% of the petrol supply chain. I.e. if 37% of the petrol not used for manual inspection is used in other applications - in about a year from the study - the EI will increase. However, this implies a total relative RE of 100%, which is unrealistic. Manufacturing of petrol vehicles (8 of 81 kg EI for *B*) is not assumed to be related to the direct RE. For the baseline case, 15 kg EI for RE is assumed, which is around 20% of *B* and 28% of *C*.

Anyway, as shown in Figure 2, if the uncertainty range (2Ʊ) for *D* is increased from 1.5 to 8.5, the avoided EI cannot be guaranteed, i.e. *A*<0. The reason is that *A* is 11.28 kg EI, and *I* becomes 11.29 kg EI. However, an uncertainty range of 8.5 implies the total relative RE would be up to 87% ((15+8.5)/(81-54)), which is more than expected. Hypothetically, if, for example, *B* is >100 times larger than *C*, it can be estimated that *D* will, for most cases, not be large enough to make *A* negative, i.e. the ICT Solution will lead to lower impacts instead of higher. This is probably the case for the health consultation example in section 2.4 in [2], for which *B* is >20 times larger than *C*. In this research the uncertainty of each parameter for *B* and *C*, and the uncertainty of *D*, are considered to find the limits. The proposed methodology can be used to screen the situation in which avoided EI are more or less certain. Figure 3 shows the effect of reducing the uncertainty of EI from Human inspection by 90%.

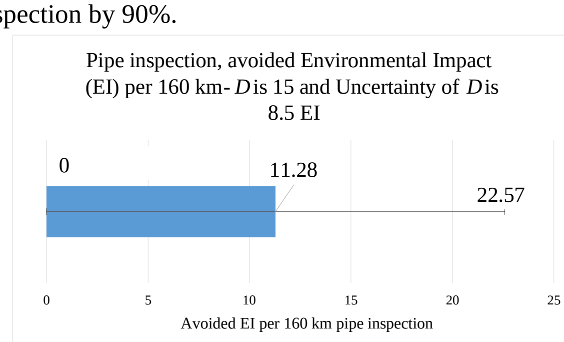

Fig. 2 Uncertainty of avoided impacts with *D* 15 kg EI and *D* uncertainty 8.5 kg EI

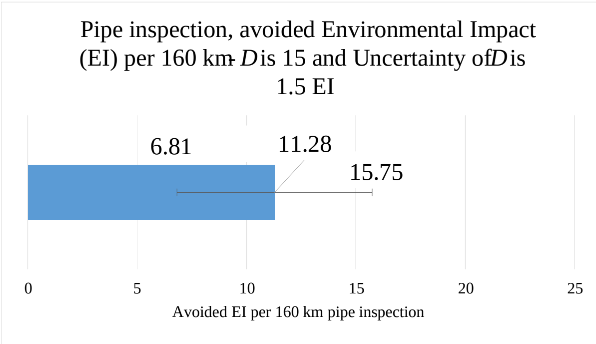

Fig. 3 Uncertainty of avoided impacts with *D* is 15 kg EI and *D* uncertainty 1.5 kg EI, and a major contributor to uncertainty reduced by 90%

The EI from Human inspection (61.58 kg EI) contributes most to the total result (54%) of the entire calculation and the most to the total uncertainty (60%) if the *H* uncertainty for output EI in Human inspection is reduced by 90% from 6.15 kg EI to 0.615 kg EI. Compared to Figure 1, it can be observed that the uncertainty range decreased by 41%. The economy-wide RE is intrinsically difficult to estimate, but it could be important for certain applications. However, if [1,9] are reasonable, the total RE is at the most 30% in most cases.The actual measurement of the uncertainty range for each input and output parameter is also challenging. While Equation 1 is applicable to any comparative analysis, the collection of primary data may be burdensome. This will be reflected in the uncertainty range *H*. However, these ranges are not easily determined. As shown, it is straightforward to identify the most important parameters (in the systems at hand) and for which ones it is most pressing to collect more precise data. The presented method is hence able to provide a better understanding than state-of-the-art such as [2]. At the end of the day, the "conclusionability" of Equation 1 will especially be determined by the absolute value of *D* and its uncertainty *H*, and the precision of the remaining *H* values.

4. Conclusion

A method is presented by which it is possible to determine the magnitude of the uncertainty and the share of the total uncertainty in calculations of the net environmental impact effect of ICT solutions. Especially novel is that the rebound effect is included. The proposed method facilitates simplified assessments and helps clarify which amount of uncertainty is allowed before hindering robust conclusions on whether the introduction of an ICT Solution is environmentally beneficial or not.

Future Work

There is a lack of standards for the avoided impact topic. [13] Anyway, such standardisation is ongoing on the avoided impact topic, but it is not yet ready. It should be explored how it will affect the practise in this field. Moreover, the effect on the avoided impact of circular strategies, including the rebound effect and multicriteria weighing of environmental impacts, is another less understood topic.Other tools than EMLCA, which offer more variation regarding uncertainty distributions, should be used to develop the proposed method. Also, it should be confirmed whether large sensitivity factors generally overestimate contributions to the total uncertainty.

References

[1] Jan C.T. Bieser, and Lorenz M. Hilty, "Assessing Indirect Environmental Effects of Information and Communication Technology (ICT): A Systematic Literature Review," *Sustainability*, vol. 10, no. 8, pp. 1-19, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] Anders 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. [CrossRef] [Google Scholar] [Publisher Link]

[3] F. Chionchio et al., "Estimation of GHG Avoided Emissions: A Way to Quantify How Energy Transition is Enabled," *SPE International Conference and Exhibition on Health, Safety, Environment, and Sustainability*, Abu Dhabi, UAE, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[4] Reinout Heijungs, "A Generic Method for the Identification of Options for Cleaner Products," *Ecological Economics*, vol. 10, no. 1, pp. 69-81, 1994. [CrossRef] [Google Scholar] [Publisher Link]

[5] Wei Zhe 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. [Google Scholar] [Publisher Link]

[6] Reinout Heijungs, *Probability, Statistics and Life Cycle Assessment: Guidance for Dealing with Uncertainty and Sensitivity*, 1st ed., Springer International Publishing, pp. 1-1144, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[7] César Morcillo Serra et al., "Impact on the Reduction of CO2 Emissions Due to the Use of Telemedicine," *Scientific Reports*, vol. 12, no. 1, pp. 1-6, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] David Font Vivanco et al., "Rebound Effect and Sustainability Science: A Review," *Journal of Industrial Ecology*, vol. 26, no. 4, pp. 1543-1563, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[9] Steven Nadel, "The Potential for Additional Energy Efficiency Savings Including How the Rebound Effect Could Affect this Potential," *Current Sustainable/Renewable Energy Reports*, vol. 3, pp. 35-41, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[10] Xiaobo Chen, and Jacquetta Lee, "The Identification and Selection of Good Quality Data Using Pedigree Matrix," *Proceedings of the 7th International Conference on Sustainable Design and Manufacturing (KES-SDM 2020)*, pp. 13-25, 2020. [CrossRef] [Google

Scholar] [Publisher Link]

[11] Diego Galar, Uday Kumar, and Dammika Seneviratne, *Robots, Drones, UAVs and UGVs for Operation and Maintenance,* 1st ed., CRC Press, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Sadik Jadir Al-Jadir, "The Use of 5G Technologies in the Digital Transformation of the Oil/Gas Industry," *Abu Dhabi International Petroleum Exhibition and Conference*, Abu Dhabi, UAE, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] Anna Young-Ferris et al., "Making Things (That Don't Exist) Count: A Study of Scope 4 Emissions Accounting Claims," *Accounting, Auditing & Accountability Journal,* 2024. [CrossRef] [Google Scholar] [Publisher Link]