Assessing GHG Benefits Induced by ICT Services in Practice

A Case Study and Resulting Challenges

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Abstract—*High expectations are placed on the ability of ICT to play an important role in reducing GHG emissions, now and in the future. Several calculations of such benefits were put forward over the last years, usually performed by the industry. Their methods and assumptions, however, remained often unspecified, and the assessments frequently led to hardly plausible claims.*

In this paper, we present the results of applying a stricter approach to one specific service – the detection of gas leakages in the US through gas sensors installed on Google street view cars, together with an advanced algorithm for translating the collected data to useful information on the location and magnitude of gas leakages. We further discuss a new set of four practical challenges for such assessments that were identified during this exercise, and which are new compared to previous theoretical work: the allocation between ICT and non-ICT sectors, practical challenges in defining the baseline, the usually polluted indirect data at hand, and issues of the generalisation to society-wide potentials. We then discuss to which extent these challenges can be addressed, and which of them are of a more fundamental nature.

Keywords — ICT enablement; enabling effect; abatement potential; avoided emissions; ICT as part of the solution; ICT for sustainability; gas leakage discovery; ontological uncertainty

I. INTRODUCTION

High expectations have been placed on the ability of information and communication technologies (ICT) to play an important role in reducing GHG-emissions now and in future, as several reports argue [1-5]. Such reports have a considerable influence on policy discussion at a high level, being referenced by e.g. the European Commission [6] or the United Nations Framework Convention on Climate Change (UNFCCC) [7]. These reports, however, are often financed by, and sometimes written within, the ICT industry. There are both benefits and weaknesses of this. A benefit with industry participation is that it enables up-to-date raw data that would otherwise not be available. A weakness is the risk for bias towards positive reporting: it can be in the interest of the industry to convene a positive message, so there is a risk of ignoring potential negative effects and of exaggerating the positive parts.

Over the last few years, such assessments have come under increasing academic scrutiny. They have been criticised to yield overly optimistic results through more than one

mechanisms, e.g.: i) by attributing to ICT essentially non-ICT economic activities such as large-scale renewables [8], ii) by overstating ICT's contribution by exaggerating the footprint of the baseline for comparison [9], or iii) by ignoring indirect effects such as rebound or induction effects, which might in fact counterweight or even overcompensate the efficiency gains of the service.

This paper assesses the savings induced by a concrete ICT service, while avoiding such pitfalls. The service, a novel gas leakage discovery technology in city distribution networks, is introduced in the next section. The aims of the paper are threefold: First, to present the results of this preliminary assessment. Secondly, to present a number of novel challenges identified during our study. These issues were derived both from assessing the impact of the gas leakage discovery service, and also from interviews concerning other services that had been screened initially. Thirdly and lastly, the paper discusses which of these challenges can be alleviated and to which extent, and which are more fundamental in nature.

II. METHODS

We first identified several ICT services as potential candidates. Secondly, we performed literature research, conducted interviews with representatives of the companies or organisations developing those services. Complementarily, we asked some of the interviewees to also fill out a survey. We finally chose one of these services and performed a preliminary assessment of its GHG benefits.

This service is a novel ICT-supported identification of gas leaks in urban distribution networks. It was developed by a non-profit environmental advocacy group, the US-based Environmental Defense Fund (EDF), with support from Google's Earth Outreach program. As opposed to many other ICT services, this gas leakage discovery is not likely to induce indirect effects (such as rebound or induction), which otherwise might counterweight many of the benefits.

In 2012, EDF started a large scientific study aiming at understanding where and how much natural gas (NG, which consists mainly of methane, CH_4) is lost across US's natural

gas supply chain.[1] The 16 projects making up the study cover the entire natural gas system, including production, nation-wide distribution, local distribution, etc. One of these projects, "methane maps," equipped Google's street view cars with gas detection sensors.[2] The sensors can distinguish between naturally occurring ethane and the methane leaking from gas mains or service lines. Together with environmental data on e.g. temperature and wind, an algorithm developed by EDF can discover gas leaks throughout the city and map them using Google's Earth Outreach[3] visualisation tools.

The insights described in this paper stem mainly from this preliminary assessment of EDF's gas leakage project. They are informed, however, also by the interviews with several professionals who developed some of the other services we identified in our study's first phase as promising. While several of these interviews were insightful, one of them sticks out in particular: the one with the CEO of Romania-based company ISSCO, Nick Verycruyssen. ISSCO develops a fleet management software,[4] which exists in two versions: an older version, developed between 2005-2012 in Belgium and still used in that market, uses as underlying map service Microsoft's MapPoint. In 2012, ISSCO launched a new version of the product, based on Google Maps API, and deployed in the Romanian market. While the mid-term aim is to switch the Belgian market to the new version as well, for now the two versions exist in parallel for their respective markets.

III. A CALCULATION OF GAS LEAKAGE SAVINGS

According to EDF, their gas leakage discovery method, while easily scalable and deployable, is not precise enough to yield exact values for the leakage flows. The variability of wind and other uncertainties only allow for a categorisation in one of three flow ranges: low (1-13 cubic feet/hour), medium (13-85 cubic feet/hour), and high (above 85 cubic feet/hour).[5] At atmospheric pressure and 10 degrees centigrade, the density of the typical natural gas mix is of 0.725 kg/m^3.[6] In mass of natural gas, the three leakage ranges are then:

- 0.5 – 6.4 kg/day (low),

- 6.4 – 41.8 kg/day (medium), and

- > 41.8 kg/day (large).

These flow ranges are mapped as yellow, brown, and red dots, respectively, on the "methane maps" presented by EDF.[7]

Utilities prioritize the replacement of old pipes according to safety – the most urgent hazards being always repaired first, irrespective of the amount of leakage. EDF's vision, however, is to advocate a second level of prioritization that would take into account such comprehensive city-wide data on existing leaks. These are particularly numerous in cities with an old pipe system such as Boston or New Jersey, and much less

dense in cities with a newer distribution system such as Indianapolis.

The availability of this novel technology led to discussions with several gas utilities across the US. One of the most concrete results were tripartite discussions between EDF, the state of New Jersey, and PSE&G (Public Service Enterprise Group, formerly known as Public Service Electric and Gas Company), the largest gas utility in the state. These discussions led to the approval of a 905M$ funding over a three years period for updating New Jersey's aging gas infrastructure. The funding is envisioned to allow PSE&G the replacement of around 510 miles (816 km) of gas mains and 38,000 service lines.[8]

In this context, our research question was: "If EDF's data on gas leakage was to be used to prioritize the replacement of old pipes with known leaks – what would the environmental benefit be, and how could its value be estimated?"

In order to calculate a rough, order-of-magnitude potential for this, we made a number of assumptions. The point of this paper is to illustrate how this kind of calculations can be made, rather than actually finding the exact number. Several of the assumptions below can be made more accurate through further investigations.

1. Gas mains are replaced block-wise, and one block is about 100 m (approximately 1/16th of a mile, the block length in New York). Using the total length of 510 miles yields the replacement of 8160 segments.

2. As the first priority will be on hazardous leaks, we assume ¾ of the replacements being due to this first priority, and one quarter (or 2040) segments to be replaced to reduce leaking.

3. We assume the average replaced leak to have a flow of 6.41 kg/day, at the border between the low and the medium flows.

4. The leak density is on average quite sparse.[9] In the cities where EDF has tested the gas detection system they found one leak per
   - one mile in Boston and Staten Island,
   - two miles in Syracuse,
   - three miles in Chicago,
   - 4-6 miles in Los Angeles,
   - 10 miles in Burlington, and
   - 200 miles in Indianapolis.

   Given this relative sparseness, even for the older pipe systems, we assume that each exchanged segment only catches one leak.

5. As with more traditional methods some of the leaks would have been found and subsequently fixed anyway, we assume that the EDF system lead to an additional discovery of 50% of the 2040 segments, or 1020 leaks.

[1] https://www.edf.org/sites/default/files/methane_studies_fact_sheet.pdf
[2] https://www.edf.org/climate/methanemaps/how-this-data-is-different
[3] https://www.google.co.uk/earth/outreach/
[4] http://www.gps-protect.ro/
[5] https://www.edf.org/climate/methanemaps/methodology
[6] http://unitrove.com/engineering/tools/gas/natural-gas-density
[7] https://www.edf.org/climate/methanemaps

[8] https://www.pseg.com/info/media/newsreleases/2015/2015-11-16.jsp
[9] https://www.edf.org/climate/methanemaps/city-snapshots

With those assumptions we find that the yearly avoided leakage per leak is 6.41 kg/day * 365 days/year = 2340 kg NG. For 1020 leaks, this yields 2.4 million kg NG avoided emissions per year. The greenhouse warming potential of NG is about 25 times that of CO2 in a hundred year perspective.[10] *Thus, in this calculation, the yearly avoided NG leakage corresponds to a reduction of 60,000 tonnes CO2eq/year.*

These assumptions can be expressed mathematically as

$$S_{CH_4} = \varepsilon * \frac{L}{\lambda} * \alpha * (1 - \beta)$$
$$S_{CO_2eq} = \varepsilon * \frac{L}{\lambda} * \alpha * (1 - \beta) * gwp_{CH_4}$$

where S are the GHG savings (i.e., avoided emissions), ξ the average flow per leak, L the total length of mains replaced, λ the average length of a repaired segment, α the percentage of segments replaced for climate reasons, β the percentage of leaks that would have been fixed by traditional methods as well, and gwp_{CH_4} the relative radiative force of CH_4 as compared to CO_2. Greek letters denote assumptions, in our example ξ=6.41 kg/day, λ=100m, α=0.25, β=0.5.

The monetary value of the avoided NG-emissions can be divided in two parts – the value of the gas that would otherwise be lost, and the value of avoided greenhouse gases. The second value is of course generally not internalized in today's economic system – assessing its value is nevertheless of scientific and societal interest.

The price of natural gas in the US has been $3-$13 per thousand cubic feet for the last 15 years.[11] For the sake of this calculation, we set the value $5 per cubic foot, corresponding to $0.128 per kg of NG, yielding a direct saving of $310,000 per year.

The offset value of one tonne CO_2eq can be estimated in several ways. The US have a politically set social cost of carbon of $37 per tonne.[12] But several much higher estimates exist, such as in the model calculation by Moore and Diaz who estimate the cost to $220 per tonne [10]. And in a paper by Isacs et al [11], many different ways of estimating GHG-values are discussed. One conclusion is that the value ultimately depends on the ethical standpoint of the user – a low value, down €6 per tonne can be used if the importance of future generations is low, whereas the value is much higher, up to €1200 per ton, when long-term considerations are included. [11] suggests using an intermediate value of €365 per tonne. This corresponds to $412 per tonne; a factor of 10 higher than the current US government value. With the low value, the total value of the avoided GHG-leakage would be M$2.2 per year and with the higher value it is M$25 per year. Together with the market value of NG, *the total value of the reduced leakage would be M$2.5-25*.

This number can be compared to the investment. As stated above, the investment budget in repairing both gas mains and service lines was M$905. If we assume an even distribution

between gas mains and service lines, and that 75% of the investment in mains is put on avoiding hazardous leaks, we come down to an investment of about M$113 as one-time investment for fixing non-hazardous leaks in gas mains. Ignoring half of the leaks that would have been discovered by traditional methods as well (according to assumption 5 above), and which were excluded from the benefit calculation as well, the investment for the newly discovered leaks can be understood as half this value, M$56. It could also be argued, however, that the investment for the newly discovered leaks is nil, as the total M$133 investment would have been needed with traditional discovery methods to discover only half of the leaks; in this interpretation, the other half comes at zero additional costs. This can then be compared to yearly benefits of M$2.5-25. The span here is due to the large variations in assessing the societal value of avoided GHGs. On top of this, the calculation of GHG-leakage is based on highly uncertain assumptions, as stated above.

IV. ASSESSMENT CHALLENGES

This section presents four challenges to be considered when calculating GHG-savings induced by ICT-services. They were derived both during interviews with the developers of different ICT services, and during our own assessment of EDF's gas leakage discovery. Each of the sections below first describes the challenge and then discusses how it is relevant to the gas leakage calculation above.

A. Allocation between the ICT sector and the rest of the economy

Companies that recently started to make enablement claims typically claim the entire reductions of a service, for example in [12, 13]. A service, however, is virtually never produced by one company alone. Several companies and organizations generally contribute to its development. Claiming the entire enabling effect by one company alone can easily lead to double counting of the same reductions when aggregating bottom-up on a sector or geographic level, as the same reductions might have been devised by several organizations. If double counting is to be avoided, an allocation between the organizations contributing to a service is needed, and a "100% rule" needed, which stipulates that the sum of the individually allocated claims does not exceed 100% of the total savings. The research in this field is incipient.

Malmodin and colleagues [8] looked into a related topic, the allocation between the ICT sector and other sectors, when they contribute jointly to a service. [8] takes a conservative approach and attributes to the ICT sector only services which have ICT at their very core. Other services, for which the ICT sector is only one among several contributors would be excluded altogether. This all-or-nothing principle was proposed by [8] upon analysis of the methodological flaws in the GeSI studies [3-5]. Those studies, for example, attribute large renewable electricity systems to 100% to the ICT sector because of the ICT control units they use [3]. Arguably, though, the steel structure and electrical motors of large windmills are at least as important to the service as the ICT control unit. [8] thus suggests to exclude in particular:

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[10] According to IPCC's fourth assessment report AR4, http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf, Chapter 2, Table 2.14 on p 212.
[11] https://www.eia.gov/dnav/ng/hist/n3035us3m.htm
[12] https://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

- "other electronic systems, like embedded microprocessor systems (e.g., motor optimization system), which are not considered as ICT systems", and

- "solutions where ICT is mainly used as a tool for administration or design, and is not impacting the performance of the associated activity, e.g., a building design process" [8].

This approach excludes the efficiency gains of an industrial engine due to new microcontrollers, but attributes to ICT the savings due to a smart navigation system aware of traffic. It does not consider the computer-aided energy efficient design of a house, but takes into account the savings of a smart home, which only heats before its inhabitants are returning home, uses off-peak power, etc. Finally, it counts small-scale renewable energy production and feedback into the grid, where ICT plays a pivotal role, but not large-scale renewable energy sources, where ICT merely plays a role in monitoring and control. This demarcation is also in line with OECD's definition of ICT products, which "must primarily be intended to fulfill or enable the function of information processing and communication by electronic means" [14].

While this basic rule should apply well in several cases, sometimes an all-or-nothing approach does not seem sufficient, as technical systems may essentially rely on both ICT and non-ICT components. EDF's gas leakage, for example, contains essential components that are both from within ICT as well as from outside. The detection algorithm and the back-end Google map service are examples of the former, the gas sensors and Google street view cars for the latter. In such cases, an allocation between ICT and non-ICT actors contributing to a service is probably required, and it stands to reason to include non-ICT actors within an allocation paradigm as well.

B. The baseline in the real world

The environmental benefit of an ICT service can be computed by comparing a situation in which a specific ICT service exists to a reference situation without that service, called baseline. To devise a resulting benefit as a positive number, the situation with ICT service is usually subtracted from the baseline, and not the other way around: If the environmental footprint after service introduction is smaller than the footprint of the baseline, the subtraction yields a positive result, intuitively a benefit. This basic principle has been respected from the quite simplistic formula in the common ETSI [15] and ITU [16] standard and until today.

A fundamental issue with this calculation principle is that both situations cannot occur at the same time:

- If the service does not exist yet, a prospective study will try to understand the expected environmental effects of its introduction. No matter how good the assumptions, however, such analysis is bound to remain a hypothetical speculation about the future.

- If the service is already in use, the baseline lies in the past, and data on both before and after the service's introduction could in principle be available. In practice, however, there was often no assessment performed before the appearance of the service. Moreover, reality is in a constant flux and the new service is not the only difference from the past to the present. Distinguishing its effects from those of other influencing factors might be impossible in practice.

Finally, even if the assessment is performed after service introduction and there is also sufficient data on the baseline, the assessment might still need to speculate. More often than not, studies on ICT's environmental effect assess some future abatement potential, e.g. [4-6]. If a study's aim lies in the future, both sides of the equation are hypothetical and must be speculated upon: the reality with ICT service due to uncertain future developments, but also the baseline, because if the service had not been introduced, the baseline would also have evolved into the future. Aged data on a distant baseline would no longer serve as meaningful reference.

Besides these conceptual limitations, there is one additional pragmatic issue that has so far not been addressed. A novel ICT service does not necessarily need to replace a non-ICT activity; it can merely update another, already existing ICT service. In this case, the enabling effect attributed to the new service should only reflect the incremental effect as compared to the old service, if any. In other words, the baseline is represented by the old service, not by the situation with no service at all.

As mentioned above, ISSCO's asset tracking software exists in two versions: the older one built on top of Microsoft's MapPoint, and the current one based on Google Maps. Additionally, the CEO pointed out in the interview that "most of our customers had a different fleet management system" before having used any of the products. The issue of a previously existing service appears here both for the service itself and for its constituting components: The benefits of ISSCO's fleet management service should only reflect the incremental improvements over the formerly used service (if any), and not the difference to no fleet management at all. On the level of the map component the service uses, Google's Maps API should only be attributed the improvements over the previous service version that used MapPoint.

In the same way, the calculation of the benefits brought by EDF's gas leakage discovery should consider the current state-of-the-art in pipe replacement. We represent this through the parameter β in the equations above. We assumed this parameter to be 50% because even the mere replacement of the oldest pipes should probably be a decent heuristic. The uncertainty regarding the true value for β should be decreased by more in-depth research. Uncertainties are discussed below.

C. Epistemic uncertainty and polluted indirect data

The assessment of current natural, economic or social systems, let alone hypothetical future ones, is complex and characterized by uncertainties, some of which are irreducible [17]. Sustainability, however, is defined not only by the intra-generational balancing of its environmental, social and economic goals, but also by (inherently long-term) inter-generational justice. As [18] notes, "actions taken to meet the needs of the present can have long-lasting and potentially unforeseen consequences for future generations (e.g. carbon emissions)". For all the uncertainties involved, assessing the

short- and long-term consequences of current actions (including new policies) is thus essential for sustainable development.

Uncertainty has been differently defined but most definitions see it as the discrepancy between the ideal, complete information about a system and the information existing in reality: "uncertainty refers most generally to the disparity between what is known and what actually *is* or *will be*" [19], or "[...] uncertainty as being any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system" [17].

There are different causes for, as well as types of uncertainties – [17] provides a theoretical framework and a typology of uncertainties. The nature of uncertainties can be twofold: *epistemic uncertainties*, which are due to the imperfection of our knowledge (facts that could be known in principle, but are unknown), and *variability uncertainties*, due to the inherent variability of human and natural systems. This latter type is better known as *ontic* or *ontological* variability, a name influenced by philosophy, or *aleatory* variability, under the influence of physics. As opposed to the epistemic variability, the ontological one cannot be completely overcome by gathering more data, and sometimes not even alleviated: "in the case of variability uncertainty, additional research may not yield an improvement in the quality of the output" [17]. In fact, gathering more data may even have the adverse effect and increase the ontological uncertainty – a phenomenon that [19] calls "excess of objectivity".

In assessments of ICT's enabling effect, there are typically both epistemological and ontological uncertainties, and which of the two prevails depends a lot on the scope of the assessment. When assessing the effects of one specific fleet management system, for example, lots of data is unknown although in principle it could be known: ideally, the analysis would compare before-after data with respect to the introduction of the system. Often, however, there is no 'before' data available on essential parameters such as the yearly driven distance by the entire fleet or the total fuel consumption. The service analysed has generally already been introduced for some time at the time of assessment and no information from before its introduction has been stored. Even less might be known about other 'before' parameters which could also have had an influence on the result, such as number of customers in the past and their location, former general traffic situation, weather, etc. But also for the current data, there is often a lack of directly relevant parameters, and they have to be indirectly derived from the available data such as fuel consumption bills. All these are of course epistemic causes of uncertainty, which often dominate the assessment of case studies.

If the aim of assessment is the generalisation to a theoretical country- or even worldwide potential, the dominating uncertainties will most likely be ontological ones. This issue will be discussed in the next subsection.

Gathering more data promises to reduce the epistemic uncertainty of small case study assessments. Due either to the unavailability of direct data, or resource constraints (time, finances), the assessment often derives the relevant parameters from indirect data already available. For ISSCO's asset tracking system, for example, a previous economic assessment,[13] citing the company's CEO Nick Vercruyssen, states that "Nick is confident that GPS-Protect will, on average, offer customers [...] a 10-per-cent reduction in transport costs". Using this data to derive the environmental potential seems straightforward. In our interview with Nick Vercruyssen, however, he stated: "it was a bit of a forced estimate. This was one of the most important questions the consultants had during the interview. My first reaction was <I have no clue!>. When they insisted, I came up with these 10%." This example shows how easily indirect data could be polluted and unsuitable for a scientific assessment.

Looking at our calculation for the EDF gas leakage discovery, the parameters ξ, λ, and α (the average flow of a fixed leak, the average length of fixed segments, and the percentage of leaks fixed for climate reasons, respectively) are epistemic. By more research, each of them could be approximated quite well or even be exactly determined (e.g., λ). The parameter β, on the other hand, representing the percentage of leaks that would have been found by traditional methods, is ontological by nature.

D. Generalising individual case studies and ontological uncertainty

ICT is envisioned as an enabler of GHG reduction across the entire society. The truly interesting questions are thus arguably not about the benefits of individual systems, but about the aggregated society-wide potential of entire ICT applications classes, such as asset tracking, navigation software (both of which can reduce the travelled distance or time, and as a consequence fuel consumption and related GHGs), substituting videoconferencing for travel, or the precise mapping (and thus easier management) of environmental problems.

Many studies on ICT's potential benefits have thus aimed at estimating these overarching potentials. Well-known are the studies by GeSI [3-5], but also e.g. [20, 21]. The method typically deployed for such assessments is the extrapolation from one or a couple of case studies to country- or world-wide potentials using estimates about the current or future spread of the technology, depending on the time horizon of the assessment. As it quickly became clear while assessing EDF's gas leakage project, as well as during interviews with developers of other services, however, the extrapolation from case studies to society-wide potentials involves uncertainties that are of fundamental nature.

The company ICCSO, for example, offers a similar asset tracking product in two markets: in Belgium, an older version of the software is deployed by around 3000 vehicles, while in Romania the newer version is used in around 450 vehicles. The Romanian version, newer and used by a smaller fleet, is easier to assess. However, even if this case study was to be assessed thoroughly, leading to a high quality case study, the differences to the Belgian case are of essence: according to ICCSO's CEO, in Romania the system is deployed relatively homogeneously for food and non-food distribution via smaller and larger vans. In Belgium, meanwhile, the system is also used by taxis, road construction vehicles, and even by agricultural and forestry

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[13] http://services.google.com/fh/files/misc/case-study-romania-issco-eng.pdf

vehicles, which are required by law to be tracked. Not only do the applications differ, but also the vehicles: they include cars, small and large vans, trucks, and specialty vehicles. Some applications, moreover, such as the agricultural and forestry ones, do not aim at inducing any efficiency gains, they are simply required. A case study on the Romanian system, no matter how well conceived and done, has little extrapolation value to the much more heterogeneous Belgian case. And while the uncertainties when extrapolating from one case to another one are epistemic in nature (the particularities of the second system can, in principle, be explored in all details), the extrapolation to country- or world-wide situations that will differ in so many more ways than these two simple cases among each other, becomes an ontological problem – the uncertainties are irreducible.

For the EDF case study, we have argued above that the parameter β (percentage of leaks that would have been found anyway) is of ontological nature. The extrapolation to US or worldwide potentials introduces various further ontological uncertainties: practicability depends on funding and further economic and pragmatic constraints. Fixing a leak is probably going to cost a lot more in Manhattan than in Indianapolis, for example, so it is unlikely to find any meaningful generalisations. The different ages and leakage intervals in the various systems also make any meaningful generalisations appear next to impossible.

V. CONCLUDING DISCUSSION AND FUTURE RESEARCH

In this paper, we have shown two things. First, that it is possible to calculate the avoided GHG-emissions from an ICT-service. Secondly, that it is very hard to tell how good a calculation of the effects of and ICT service is. We will revisit these outcomes shortly below.

The calculation of the volume and value of the avoided emissions of natural gas is useful in that it shows step by step what it takes to make a calculation of that kind. We manage to come up with a number based on clearly stated assumptions. Thus, the calculation is entirely transparent and can be questioned, approved or improved by anyone. The numbers we put forward – avoided emissions thanks to the gas leakage detection service of 60,000 tonnes CO_2eq per year, valued to M\$2.5-25 per year, in New Jersey alone – are substantial. The monetary value depends on considering the societal value of avoided emissions – the value of the saved gas alone is quite minor.

This is a highly preliminary calculation, and it is our intention to continue this work and refine it. In future work, we will also look further into the cost side. It is not trivial to state what the investment cost for the service is. Even if the size of the investment in new main pipes can be identified, it is not straightforward to state how much of that investment should be attributed to the exchange of detected pipes. In principle, the whole amount could be attributed to the service (in our case M\$56), implicitly claiming that no investments would have been done without the detection service. Or nothing could be attributed to the gas leakage system, indicating that the gas leakage detection is only improving the efficiency of a maintenance work that was going to be done anyway.

Now looking into the more general results from our work on assessing the value of ICT services, we derived four general reasons explaining why it is so hard to come up with data on the benefits of ICT services. The *first* is that it is difficult to allocate benefits and burdens to different parts of the system. As a novelty, the gas leakage detection example has also revealed that finding an issue and fixing it are different stories. For services typically considered in such assessments, such as videoconferencing or fleet management systems, the ICT solution either substitutes the problem altogether or discovers and fixes it at the same time. That the two can be separate steps fulfilled by distinct actors induces further complexity. Thus – even if we could identify effects from a specific service (as the gas leakage detection) – are there any meaningful ways of allocating those effects between different parts of the systems behind that service? The *second* handles the difficulty of deciding what to compare with. Since reality changes no matter what measures are taken, it is often impossible to state which changes actually stem from a certain service. The *third* is the difficulty of finding and validating data. In the gas leakage calculation, we made bold assumptions in order to be able to demonstrate that the calculation was in principle possible to perform. But there are major uncertainties left. Some data can be improved through interviews, but it will still be difficult to judge the precision of the replies and there will be room for misunderstandings. The *fourth* and final reason is about the uncertainties that cannot be avoided. These ontological uncertainties unfortunately seem typical for the most overarching (and thus the most crucial) questions about society-wide potentials.

The chosen gas leakage discovery service, on the other hand, avoids the issue of indirect effects, such as rebound or induction effects. Broadly speaking, the mechanism of indirect effects is that increased energy efficiency leads to lower prices and thus to increased overall demand, which in turn reduces the potential energy savings from the initial improved energy efficiency [22]. It can even lead to the adverse effect of more overall energy consumption as a consequence of increased efficiency [23]. The gas leakage discovery seems to be a good example for a service that comes with low or no indirect effects due to the inelasticity of gas demand.

As can be seen above, there are severe difficulties in calculating changes in GHG emissions from ICT services. This fact, however, does not render assessment exercises such as we did here entirely futile. First, the allocation issue is not a problem unless companies or sectors (such as the ICT sector) want to claim contributions to a certain service. As long as they would be interested only in the greater goal of the service's overall impact, this issue does not appear. Secondly, the difficulty related to not knowing what to compare with increases with time. A service with a short pay-off time is less vulnerable to this. The epistemic uncertainties are by definition possible to reduce, so this is merely a question of resources, whereas ontological uncertainty is the most problematic from an evaluative point of view. For this least manageable challenge, it is important is to display the uncertainty, report how it is dealt with and try to ensure that the implications of the uncertainty are clearly communicated.

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