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A Systematic Literature Review of the Factors of Influence on the Environmental Impact of ICT

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Abstract: *Context:* Many publications have described, measured, tracked or assessed Information and Communication Technology (ICT) activities that impact the environment. A complete conceptual view of the environmental impact of ICT can be described in three orders of effect: Direct, indirect and systemic. *Objective:* The goal of this study is to find out how the existing literature contributes towards our understanding of the environmental impact of ICT. We approach this question by identifying factors that can be of influence on the environmental impact and map these factors onto a conceptual framework of Green ICT. *Method:* We used a systematic literature review to collect factors of influence regarding the environmental impact of ICT. *Results:* From the data we collected and the analyses made, we created a taxonomy, and report on the frequencies of the factors of influence in the primary studies as well as gaps and additions compared to the conceptual framework. We found five main classes of influence that can form a continuous cycle, but noted that the research field is strongly focused on the direct impact of ICT. *Conclusion:* Our study contributes towards a better understanding of the environmental impact of ICT by framing factors of influence in a conceptual framework. The taxonomy we create and the analysis of the studies could be helpful in defining a research agenda, to further enable the full potential of Green ICT. In addition, the taxonomy can be used as a starting point for a practical tool, for organizations that wish to apply Green ICT to its full extent.

Keywords: Green ICT; Green IS; factors of Influence; environmental impact; metrics; indicators; systematic literature review

1. Introduction

Green ICT is often presented as a concept that aims to reduce the environmental footprint of ICT, as well as promote ways in which ICT can help other activities reduce their footprint. There are many publications that describe the potential of using ICT as part of the solution to reduce our environmental footprint. For example, organizations such as the World Wildlife Fund call for a shift of focus "from Green IT to Greening with IT" [1], and the reports by the Global e-Sustainability Initiative [2] claim that the potential of Greening with ICT (possible global CO_2-reduction of ~16%) far outweighs the footprint of ICT itself (~2%). Given that Green ICT is more than reducing the environmental footprint of ICT, we are curious how well this is represented in research on Green ICT.

In scientific publications, there are several descriptions of the different environmental effects that ICT can have. An often used classification in Green ICT, introduced by Berkhout and Hertin [3], is according to the order of impact: Direct, indirect and systemic. Kohler et al. [4] have defined these as follows:

- **First order** or *primary* effects: Effects of the physical existence of ICT (environmental impacts of the production, use, recycling and disposal of ICT hardware).
- **Second order** or *secondary* effects: Indirect environmental effects of ICT due to its power to change processes (such as production or transport processes), resulting in a modification (decrease or increase) of their environmental impacts.
- **Third order** or *tertiary* effects: Environmental effects of the medium- or long-term adaptation of behavior (e.g., consumption patterns) or economic structures due to the stable availability of ICT and the services it provides.

Hilty [5] further developed this classification into a 'framework for ICT Impacts on Sustainability' (Figure 1; henceforth: Hilty's framework). In this framework, Hilty combines the order of impact with whether the environmental impact is positive (part of solution) or negative (part of problem) into a matrix where specific effects are described. We know that when Green ICT solutions are introduced, a number of effects can be active simultaneously, the sum of which determine the actual impact of the ICT solution on the environment. Hilty's framework mentions the life-cycle of ICT; induction, obsolescence, optimization and substitution effects; rebound effects, emerging risks and the decoupling between growth and resource use. Other effects may be data collection and communication or network effects [6].

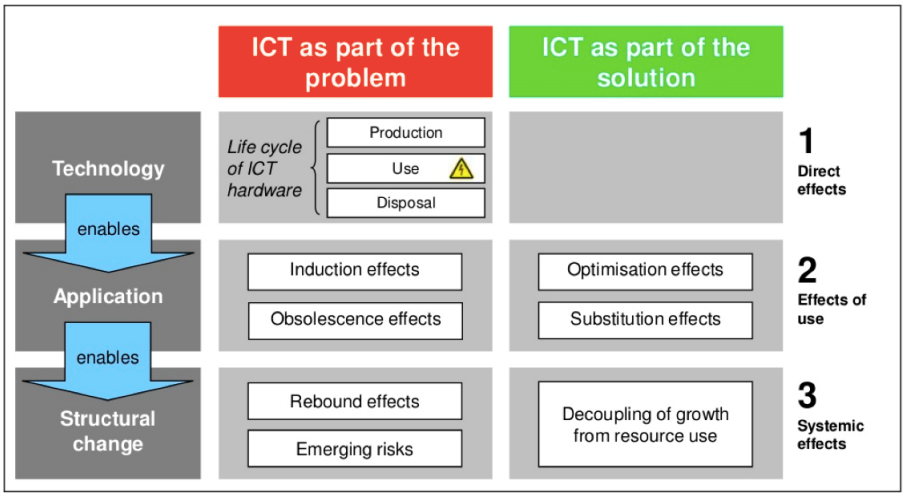

Figure 1. Conceptual framework of the impact of ICT on the environment by Hilty [5].

While the aforementioned frameworks [3,5] take a conceptual approach to describing Green ICT, there have been many publications that describe, measure, track or assess Green ICT activities in a more practical way. These publications discuss Green ICT frameworks, models, indicators, metrics and other similar tools. They may describe the impact of a specific kind of ICT solution or present a set of indicators for organizations to use, for example. The approach is different from the conceptual frameworks because such tools indicate what makes a Green ICT activity successful in practice: They address different factors that can be of influence on the impact of Green ICT.

There have not been many studies that reviewed Green ICT metrics, models or factors of influence. Most focus on first order effects [7] or review a specific area within Green ICT, such as software engineering [8,9] or applications and data centers [10]. The latter surveyed Green Performance Indicators (GPIs) and classified them into four classes: "IT Resource Usage GPIs that compute resource usage, the Application Lifecycle KPIs that define efforts required to develop or redesign applications and reconfigure IT-infrastructure, the Energy Impact GPIs that represent the environmental impact of data centers, and the Organizational GPIs that describe organizational factors". There have not been many comparisons on models: Foogooa et al. [11] compared Green ICT maturity models, but focused

more on the application of the models rather than the contents of the models. Finally, Howard and Lubbe [12] reviewed Green IS Frameworks to synthesize a combined framework. In the framework they present, they list many different factors of influence found in the individual Green IS frameworks from their review. However, other than a categorization based on the researcher's own interpretation, there is no analysis or discussion of the results.

To the best of our knowledge, there is no publication that connects factors of influence to the orders of effect that ICT may have on the environment. We think that this connection between the practical and the conceptual contributes towards enabling the full potential of Green ICT. In this study we have carried out a systematic review of the factors of influence in scientific literature. We mapped the factors of influence found in Hilty's framework to find how well they fit, which areas research are mostly focused on and identify gaps. The following sections describe the method we applied, the results we found and a discussion of the results.

2. Design of the Literature Review

The Systematic Literature Review (SLR) is designed according to the methodological guidelines by Kitchenham [13]. Below, we describe each step we took for the literature review.

2.1. Research Questions

Our main research question is: how does the existing literature contribute towards our understanding of the environmental impact of ICT? We approach this question by identifying factors that can be of influence on the environmental impact and map these factors onto a conceptual framework of Green ICT. The main research question is broken down into two sub-research questions:

- *RQ1: Which Green ICT factors of influence have been published?*
- *RQ2: How do these factors of influence map onto the classification of environmental effects of ICT?*

To answer RQ1, we have to collect factors of influence from scientific publications. There is no formal definition of such factors. As a consequence, we will analyze studies that do not recognize such a construct. This might introduce a threat to validity as we interpret these as factors ourselves. We will address this by using the following definition for factors of influence: *A Green ICT factor of influence is something that influences the impact of ICT on the environment*.

For RQ2 we require a formal interpretation of the factors in order to be able to classify them according to their environmental effects. We explain the process we followed in Section 2.4 (addressing data analysis).

2.2. Search Process

The SLR should cover those studies that present or discuss Green ICT factors of influence. These studies are identified by searching in electronic libraries. Three libraries are selected for this review: Google Scholar, Web of Science and Scopus. These three are selected because they are meta-search engines that cover many different libraries. For all libraries, we used the same search query (the exact query may vary slightly because the libraries do not operate in the same way).

As there is no formal definition for factors of influence, we had to find the right search query. Breaking down the research question, the search query should be a combination of (a) variations of the label Green ICT, since scholars do not use the same name everywhere, and (b) keywords for items that could be interpreted as factors of influence.

We used several trial searches to determine what we should include in the search query. The variations on Green ICT are rather straightforward. For the factors of influence, we collected keywords that in some way describe, indicate or measure Green ICT. The resulting query that was used in this SLR is—in pseudo code—as follows:

TITLE:("green ict" OR "green is" OR "green it" OR "sustainable it" OR "sustainable ict" OR "environmental informatics" OR "environmental ict")

AND

(maturity OR model OR framework OR metric* OR indicator* OR assess* OR agenda OR capabilit* OR system OR measur* OR approach OR method* OR scheme OR scorecard OR performance)*

We applied this search query to the title of publications only. We were forced to limit our search process in this way, because a search in the body of articles would have resulted in a collection of hundreds of thousands of publications. Aside from practical issues, such as export limitations of the libraries, there would also be a large body of studies in which, for example, 'green is' is part of sentence; a common phrase resulting in false positives.

Finally, since the query is applied to meta-libraries, there will be publications that can be found in more than one library. We want to combine the results of searching in multiple libraries into one list of publications, so the first step is to remove duplicates from the combined list of publications. The resulting list of unique publications we then used for further selection.

2.3. Study Selection

In the selection phase, we want to select those publications that are relevant for our research questions and remove the others from the results, to end up with our primary studies. We therefore screen the studies found in the libraries on eligibility criteria. These are inclusion and exclusion criteria that are applied to all studies. The inclusion criteria should apply to all remaining studies, while none of the exclusion criteria apply. In Table 1 we list the criteria we used for this SLR.

Table 1. Inclusion and exclusion criteria.

ID	Description	Rationale
	Inclusion Criteria	
I1	The study is written in English.	This is to exclude all studies not written in English to keep the SLR accessible to the broader public.
I2	The study is a scientific publication.	This is to exclude those publications that have not been published under scientific scrutiny; for example by consultants. The purpose is to ensure a minimal level of objectivity and quality.
I3	The study should measure or model Green ICT itself.	This is to include only those studies on the topic of Green ICT, not those that use ICT to measure or model another topic of sustainability (e.g., water consumption).
I4	The study must define a Green ICT factor of influence.	This is to exclude those studies that do not define Green ICT factors of influence but only apply them (and cite from other work). Alternatively, exclude studies that do not fit because they present too-abstract items, for example.
	Exclusion Criteria	
E1	The study was not accessible.	For some studies, the full-text version was not accessible at the time of review (e.g., pre-publication), rendering further analysis impossible.
E2	The study is a collection of scientific publications.	Some publications described conference proceedings or books on the topic of which the chapters or papers were also published separately. These were excluded to avoid double counting.
E3	The main topic of the study is not related to ICT.	This is to exclude studies from other research fields that were caught by the search query but are not relevant to the research question.
E4	The study only focuses on a specific area of Green ICT.	This is to exclude those studies that only measure or model a very detailed area within Green ICT, for example the temperature of a hardware component that is part of a server. This is too specific for the purpose of the research question.
E5	The content of the study is aimed at describing a Green ICT topic for scholars.	This is to exclude those studies that are only relevant for scholars discussing Green ICT, for example detailing a research agenda.
E6	The content of the study only describes results of measurements of the impact of ICT on the environment.	This is to exclude those studies that only describe work that is about the actual impact of ICT on the environment, for example the global footprint of ICT, or how successful feedback technology can be for individual users.
E7	The study presents duplicate factors of influence	This is to exclude those studies that are by the same authors explaining the same factors of influence.

2.4. Data Analysis

In order to further process the factors of influence, we first need unique examples of factors and to remove multiple mentions of the same factor in our primary studies set. We base this step on the title and explanation of the factor we extracted from the primary studies. We also grouped slight variations in interpretations of the factors into one unique factor. This step is not trivial, and we will return to this in the Threats of Validity section.

To analyze how the factors of influence map onto the classification of environmental effects of ICT, We use the structure of Hilty's framework (Figure 1) to classify the factors. The framework can be broken down in two aspects: Order of effect; problem vs solution.

The first aspect is the order of effect. The factor of influence can target the direct impact of ICT, for example energy consumption of ICT equipment; target the indirect impact of ICT, for example the avoided CO_2 emissions of traveling by using videoconferencing; or target the systemic impact of ICT, for example a large increase of use of videoconferencing that provides a counter effect to the reduction of CO_2 emissions [14].

The second aspect is whether ICT is part of the problem (reduce negative impact on the environment) or part of the solution (the net effect of the introduction of ICT is positive). Some factors can be unbiased because they can include both, for example *Innovation* can focus on reducing the footprint of ICT itself, but also on optimizing other processes with the use of ICT.

The next step is to present this classification as a taxonomy of factors of influence. This is to do justice to the difference in the levels of detail in the different primary studies. Some studies, for example, only mention the 'Indirect impact of ICT', whereas others mention a subclass such as 'Teleconferencing'. We used the cluster title to identify where the factor should be placed. We also use this taxonomy to limit the results to two class levels: The main classes and their subclasses. Subsubclasses lower in the tree are collapsed into their parent class.

With this taxonomy, we can then analyze which order of effects the factors of influence are most focused on and whether there are any gaps. Conversely, there may be factors of influence that do not fit the framework. If possible, we propose a classification for these factors as an addition to the framework.

In summary, the data extraction and analysis consists of the following steps:

1. *Collect factors from each study.* All factors of influence are copied in their original wording and annotated with an explanation of the factor, as well as how to use it if provided by the study.
2. *Classify each factor to order of effect.* Each factor of influence is classified according to the order of effect and the problem vs solution aspect.
3. *Present classification as a taxonomy.* After classification, we create a taxonomy of factors of influence that presents the factors in two levels relative to each other.
4. *Identify gaps and additions*. Using the taxonomy, we can then identify gaps in the total set of factors compared to the framework, as well as additions when we find factors that do not fit the framework.

3. Results

We describe each step of the search and selection process in Figure 2. The search in the three digital libraries resulted in 868 studies. After removing duplicates, 589 studies remained. We applied the inclusion and exclusion criteria to these studies, and obtained 40 primary studies, of which 6 papers were not accessible. The remaining 34 primary studies were used for our research.

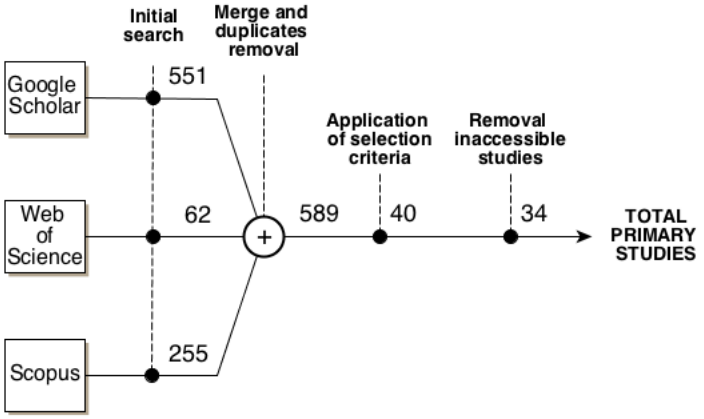

Figure 2. The search and selection process.

3.1. Factors of Influence Found

From the 34 primary studies, we extracted 444 items that were factors of influence. Going through the factors, we encountered a number of issues that we had to resolve, resulting in the removal of some of the factors. First, some factors combined multiple types of effect, for example Procurement and E-waste, or Use of ICT (energy consumption) and Teleworking. If these combinations were mixes of different orders of effect (such as the second example), we dropped these. Also, some factors were dropped that were too specific, for example 'use of sleep mode on personal computers'. These first two issues were marginal; the most factors we dropped were out of scope: Some studies not only report factors of influence on the impact of ICT on the environment, but also include factors on social and financial sustainability. All these were dropped as well because our focus is on environmental sustainability. The final list consisted of 380 factors of influence that we used for further analysis.

3.2. Classification of Factors of Influence

After collecting the factors of influence, we wanted to classify them following the two dimensions we extracted from Hilty's framework: Order of effect and problem vs solution aspects.

First we started with the classification of order of effect. It quickly became evident that not all factors fit a direct, indirect or systemic impact on the environment. Many factors address topics regarding the organization wishing to use Green ICT, such as having a Green ICT strategy, or external drivers or pressures such as compliance to laws and regulation. Out of the 380 factors, 157 did not fit the original three orders of effect. This was enough reason to warrant an extension to the three orders of effect.

Based on the data we collected, we added two classes of factors that precede the introduction of a Green ICT solution, these being 'Societal impact on organization' and 'Organizational impact on ICT'. We chose these because many of the factors that did not fit were part of clusters that were labeled 'drivers' or 'pressures'. Inspired by the Drivers-Pressures-State change-Impact-Response (DPSIR) framework [15], which is commonly used to describe (causal) interactions between society and environment, and the three-layered orders of effect, we identified a similar layered order in the decision making process leading to the execution of a Green ICT activity. We call the resulting five main classes *domains of factors of influence*. We elaborate on this further in the Discussion section.

Next, we classified the factors on whether they aim to reduce the impact of ICT on the environment (problem) or whether they promote the enabling aspects of ICT in providing solutions to reduce the environmental impact of other processes (solution). Note that this is about *where* they impact; we did not discriminate the factors on *how* they influenced the environmental impact of ICT (i.e., whether they would have a negative or positive impact).

The results of the classification are shown in Table 2. In particular, the domains with the largest number of factors of influence mentioned in the primary studies are the 'Direct impact of ICT' (137 factors, corresponding to 36% of the total number of factors) and the 'Organizational impact on ICT' (120 factors, 31%). As for the problem vs solution aspect: 140 out of 380 factors address the problem of ICT, 55 ICT as a solution and 185 as both. When we combine these with the orders of effect, the two domains we added, 'Societal impact on organization' and 'Organizational impact on ICT' contain factors that address both issues (with a small exception). The 'Direct impact of ICT' is fully dedicated to the ICT as a problem, the 'Indirect impact of ICT' to ICT as a solution and the 'Systemic impact of ICT' to both. Already we see a gap here when we compare these results to Hilty's framework: Hilty mentions effects in the indirect impact of ICT that are part of the problem, whereas the factors we found only focus on ICT as part of the solution.

Table 2. Result of classification of factors.

	Problem	**Solution**	**Both**	**Total**
Societal impact on organisation	-	-	*37*	*37*
Organisational impact on ICT	3	-	117	*120*
Direct impact of ICT	137	-	-	*137*
Indirect impact of ICT	-	55	8	*63*
Systemic impact of ICT	-	-	23	*23*
	140	*55*	*185*	*380*

3.3. Taxonomy of Factors of Influence

In order to structure the factors of influence into a taxonomy, we first needed to identify the unique factors of influence. Many papers mention the same factor of influence. For example 'Green ICT Procurement' was mentioned more than once amongst the primary studies. Out of the 380 factors of influence on the environmental impact of ICT, we found 97 unique factors.

We used the five domains identified above as a starting point for the taxonomy, and added the factors based on the cluster information we extracted from the primary studies. This resulted in a comprehensive taxonomy, as the 97 unique factors are defined at various levels of abstraction. Some address subsections of subsections, for example 'Servers' within 'Data Centers' within the 'Use of ICT' (which is part of the domain 'Direct impact of ICT').

As we are interested in the main elements of each domain, we limited the taxonomy to two levels (see Table 3 for an overview of the taxonomy; the full taxonomy is available on-line, see Appendix A). The factors we found that were subsubclasses were counted as part of their parent class. We lost some nuance by doing so: Some factors cover everything, some partially, some in more detail. For example, 'End user computing' and 'Networking' are combined in 'Use of ICT'. We chose to be inclusive here: If an item covers a class only partially, but that part clearly belongs to that class, we included it. Out of the 97 unique factors, 34 remained (5 main classes and 29 subclasses).

As a consequence of the pruning process to two levels, some studies mentioned a factor more than once. For example, the study including 'End user computing' and 'Networking' now had two instances of the same class, 'Use of ICT'. If we remove such duplications and re-apply the pruned classification to all 380 factors of influence found, 257 instances of factors of influence remained in the two-level taxonomy. Figure 3 shows each step we have taken with the factors of influence.

In Table 3 we also show how frequently the factor is mentioned in the primary studies. Note that some studies only mention a domain as a factor itself, and some have more detailed factors. We reported on both of these. For example, the domain 'Societal impact on organization' is mentioned once as a factor, and its subclasses 31 times (the total is therefore 32 different mentions of the entire domain). In Appendix B, we include a table that links all the primary studies to each element in the taxonomy.

Table 3. Overview of factors of influence of ICT on the environment and the number of papers mentioning the factor.

Domains	#	Factor of Influence	#
Societal impact on organisation	*1*	Compliance	12
		Transparency	8
		Market forces	5
		Reputation	4
		Environmental risks	1
		Uncertainties	1
			31
Organisational impact on ICT	*4*	Culture	12
		Strategy	12
		External interaction	11
		Current state	10
		Governance	9
		Green ICT business case	7
		Corporate policies	7
		Use of renewable energy	3
			71
Direct impact of ICT	*5*	Design	13
		Production	1
		Packaging	1
		Procurement	12
		Use of ICT	29
		E-waste	21
			77
Indirect impact of ICT	*9*	Teleworking & collab.	9
		Paper reduction	8
		Smart buildings	6
		Smart energy	3
		E-commerce	1
		Smart motors	1
		Smart logistics	1
		Feedback & reporting	12
			41
Systemic impact of ICT	*0*	Adoption	14
		Innovation	4
			18

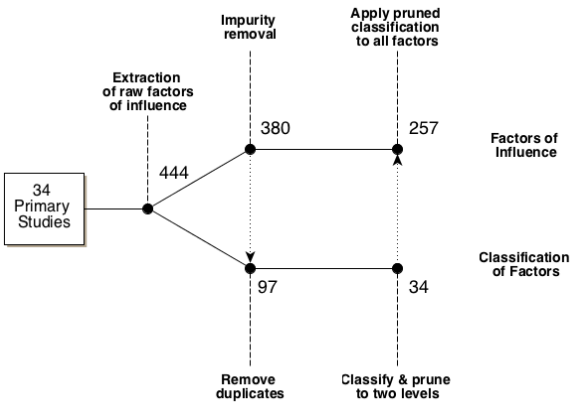

Figure 3. Factors extracted from the primary studies.

3.4. Description of Taxonomy and the Factors of Influence

This section describes each of the domains in the taxonomy given the subclasses of factors of influence found.

We introduced the domain of 'Societal impact on organization' because many studies included external factors that put pressure on or drive organizations to do something with Green ICT. The most mentioned factor here is 'Compliance': Compliance with laws and regulations, but also with standards, for example. 'Transparency' is about publicly sharing what the environmental impact of an organization is, and also about sharing best practices. 'Market forces' are the influences of consumers and also competitors. 'Reputation' is how the organization is viewed by the public. 'Environmental risks', such as flooding, may well affect choices in the organization too. The same goes for 'Uncertainties', a lack of knowledge in the discourse on climate change or information technologies in particular.

The domain of 'Organizational impact on ICT' includes the factor of 'Culture', the general attitude of employees towards the environment and Green ICT activities, and also elements such as leadership. 'Strategy' is important as well, not only for Green ICT activities themselves, but also in aligning these activities with general corporate strategies. 'External interactions' are how the organization tries to influence the outside world through, for example, stakeholder management or supply chain management. The 'Current state' is a limiting factor in what the organization is capable of in terms of financial reality, technical infrastructure, et cetera. 'Governance' details who is responsible for ICT and who has the mandate to carry out Green ICT activities. 'Corporate policies' are the rules that an organization abides to, which affect how ICT can successfully reduce the environmental footprint. Finally, the 'Use of renewable energy' can directly affect the footprint of ICT (as an energy consumer).

The factors in 'Direct impact of ICT' are basically phases in the life cycle of ICT itself. 'Design' includes hardware design and also software design. 'Production' and 'Packaging' of ICT equipment require the use of energy and material resources, and therefore are part of the life cycle of ICT. Organizations can reduce their footprint by considering the environment while procuring ICT equipment and services, for example considering total-cost-of-ownership ('Procurement'). The 'Use of ICT' includes many areas, such as 'End user computing', 'Data centers', 'Networking' and 'Outsourcing (including cloud services)'; all of which contribute towards the environmental footprint of the organization. Finally, 'E-waste' is about recycling or disposing ICT equipment in a responsible manner.

The 'Indirect impact of ICT' includes factors that use ICT as an enabler to reduce the environmental footprint elsewhere. In this way, ICT can affect traveling ('Teleworking and collaboration') the use and management of space ('Smart buildings'), energy consumption ('Smart energy'), shopping ('E-commerce'), production processes ('Smart motors') and transport ('Smart logistics'). Also, many business processes can be de-materialized (such as financial administration) through ICT reducing the demand for paper ('Paper reduction'). While ICT can have optimization and de-materialization effects, by replacing (substituting) non-ICT processes with ICT-powered processes, ICT can have another function in the organization through 'Feedback and reporting'. This is the effective collection of data, analysis of them and generation of feedback just in time or to the right people.

The final domain is the 'Systemic impact of ICT'. Here, we only found two factors of influence. 'Adoption' is about what happens after a Green ICT solution is introduced: Will it be used, how will it be used, et cetera. It may well be used in a different way than intended, which can have positive or negative consequences for the environment. Another factor is 'Innovation', which also comes into effect after the introduction of Green ICT: New activities and solutions that now have become possible.

In Figure 4 we present the domains in a cycle, as we would argue there is a natural flow from one domain to the next. The three orders of effect in Hilty's framework are well established and describe (roughly) the impact of ICT itself, to the role ICT can have in other processes, to the way the (eco)system responds to the introduction of a new ICT solution. The two new domains follow a similar pattern, in which external factors ('Societal impact on organization') influence an organization, where internal factors ('Organizational impact on ICT') determine how *green* the introduction of an ICT

solution is ('Direct impact' and further). When long term effects of new technologies become apparent ('Systemic impact of ICT'), society will respond through stimulating or regulating such technologies, through market forces, et cetera ('Societal impact on organization'), closing the cycle.

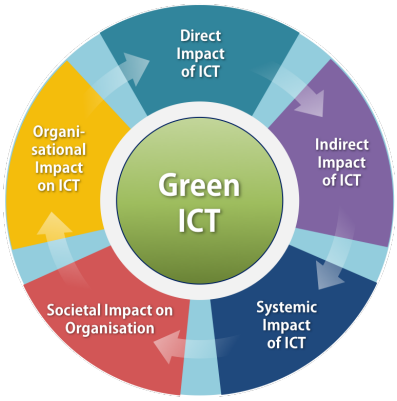

Figure 4. The five domains presented in a cycle.

3.5. Comparison between Taxonomy and Conceptual Framework

Now that we have created a taxonomy based on the factors of influence found in the primary studies, we can compare this taxonomy to Hilty's framework, which we used as a conceptual starting point.

Obviously, the introduction of two domains is the biggest difference between the two. This is not an omission in Hilty's framework, but rather an extension to it when asking a different kind of question. Hilty's framework is a conceptual description of the impact of ICT on the environment, whereas the taxonomy we created is a description of the dynamics surrounding the introduction of a Green ICT solution in practice.

Given Hilty's framework (Figure 1), a number of second and third order effects are not present in the taxonomy. In the 'Direct impact of ICT', the taxonomy extends on the life cycle mentioned in Hilty's framework by adding 'Design', 'Procurement' and 'Packaging'. Both the framework and the taxonomy position all effects and factors as 'part of the problem'.

Hilty describes the second order with effects that can be part of the problem or part of the solution. These are general patterns that occur when ICT is used as an enabler in other processes and describe *how* they may affect the environmental impact. The factors of influence in the taxonomy describe which areas or processes can benefit from Green ICT, which is more goal-oriented (not '*how*' but '*what*'). As a consequence, it seems that the problematic effects of the indirect impact of ICT are neglected in the primary studies. A different factor altogether in the taxonomy is the factor 'Feedback and reporting', which is purely focused on the *information* quality of ICT, whereas the other factors rather make us of the *automation* and *digitization* properties of ICT.

Similarly, we did not find any of Hilty's third order effects directly in the primary studies. The factors found in the 'Systemic impact of ICT' are difficult to map onto the effects in Hilty's framework. Both 'Innovation' and 'Adoption' can have an effect on *emerging risks from new technologies* and *decoupling*, but not necessarily so. 'Adoption' can also carry some *rebound effect*, but there is no direct link. This implies that there are more factors of influence on the systemic level than we found in the primary studies.

3.6. Coverage and Spread of Domains and Factors

With the taxonomy we created, we can now also take a look at the primary studies and see how well all the factors of influence are represented in literature. As we have seen above, we know that among the primary studies there is no study that covers the entire Hilty framework, but we are

interested in whether a study covers all five domains. In order to do so, we follow the same pruning process to collapse the two levels of the taxonomy into one (see Table 4). Now it is clear that most studies include the 'Direct impact of ICT' and 'Organizational impact on ICT'. The other three domains are each present in roughly half the papers.

Table 4. Number of primary studies that report on the five domains.

Domain	#	%
Direct impact of ICT	32	94%
Organisational impact on ICT	27	79%
Indirect impact of ICT	19	56%
Societal impact on organisation	18	53%
Systemic impact of ICT	15	44%

There are eight primary studies that include all five domains. We list these in Table 5 and show how many factors they include out of all the factors we found. The table shows that even though the studies cover all domains, they only cover, at maximum, 59% of all second level factors found. Therefore, there is no study that published a model that has a complete coverage of all the factors. The average number of first and second level factors over all 34 primary studies is 8 out of 34 (24%) factors of influence.

Table 5. Coverage of factors of influence in papers which include all domains.

Primary Studies Covering All Five Domains	Level 1 + 2	Level 2
Towards a Practice-oriented Green IS Framework [16]	18 (53%)	17 (59%)
Green IT balanced scorecard [17]	16 (47%)	16 (55%)
A model for green IT strategy: a content analysis approach [18]	16 (47%)	15 (52%)
SustainaBits: A framework and rating system for sustainable IT [19]	14 (41%)	14 (48%)
Green ICT Maturity Model for Czech SMEs [20]	14 (41%)	13 (45%)
Green IT framework for small and medium scale Indian IT services companies [21]	12 (35%)	12 (41%)
A Capability Maturity Framework for Sustainable Information and Communication Technology [22]	7 (21%)	5 (17%)
A Sustainable BSC-IT based Framework for Assessing the Strategic Impacts of Green IT Initiatives [23]	7 (21%)	4 (14%)

4. Discussion

With the SLR presented in this paper, we set out to collect all factors of influence on the environmental impact of ICT from scientific publications. We used Hilty's framework, notably the three orders of effect, as a starting point for classification, but during the analysis we observed that we needed to add two more domains to properly classify the factors. Conversely, we also found that a number of effects mentioned in Hilty's framework are not covered by the factors. Below, we discuss several reflection points that follow from our SLR and our findings.

4.1. Factors Found

In our SLR, we found 97 unique factors of influence and 34 when pruned to two levels in a taxonomy. Because we approached the taxonomy in a bottom-up fashion, it is difficult to say if we found all possible factors of influence. In fact, we think there might be more, because Hilty's framework mentions some effects that are not present in our list of factors. They are not one-to-one comparable though, because our factors approach the impact of ICT on the environment from a practical point of

view, whereas Hilty's framework does so from a conceptual perspective. The more indirect the effect is, the more difficult it is to translate the conceptual to the practical. For example, the factor 'Adoption' can have a strong link with the *rebound effect*, but they are not the same. In terms of completeness, we would argue that we found the most important ones (or at least the most directly relevant ones), since we think there is a relation between this and the frequency of a factor of influence in the primary studies.

What can we say about the quality of the factors of influence found? This SLR reports on the possible factors of influence on the environmental impact of ICT, regardless of how many times they are mentioned. The frequency of the factors in the primary studies is highly variable, spanning from 29 times to only once. We did not use this frequency to build the taxonomy, and decided to be inclusive. If we would say that the more frequent a factor is amongst the primary studies, the more certain we are that the factor of influence is relevant for our taxonomy, what does this mean for those factors that are only mentioned once or twice?

In Table 3 we show all the factors of influence and their frequencies. As a thought exercise, let us assume that factors mentioned three times or less would not be part of the taxonomy. This would drop 9 factors from the list. In the domain 'Societal impact on organization', those are 'Environmental risks' and 'Uncertainties'. These are two factors of influence that are different from the more common factors in this domain, such as 'Reputation' or 'Compliance'. The difference is the distance from the reality of the organization (the next domain): The first are more abstract (e.g., what if there is a flood?) versus the latter, which are more directly felt (e.g., we must adhere to the new law). In the domain 'Organizational impact on ICT', we find the 'Use of Renewable Energy'. While this factor seems more relevant to sustainability in general rather than ICT, there are some interesting dynamics (both positive and negative) that could become lost (e.g., if energy is CO_2-neutral and free of cost, why should we try to save energy with ICT?). In the domain 'Direct impact of ICT' we have 'Production' and 'Packaging'. 'Production' is particularly interesting, because this is mentioned in Hilty's framework. From a practical point of view this makes sense, as most organizations do not produce ICT themselves but rather procure it (as reflected in the frequencies for these factors). Finally, in the domain 'Indirect impact of ICT' we find four factors that are mentioned three times or less: 'Smart energy', 'E-commerce', 'Smart motors' and 'Smart logistics'. Compare these to the factors most frequently mentioned, and the difference becomes clear: Some areas of activities are relevant to most organizations (e.g., teleworking or paper trails in administrations), and some are very specific. Because the factors in this domain are applied to areas of activities, it is easy to imagine more factors of influence such as 'Smart agriculture' or 'Smart chemistry'. Perhaps it would make more sense to translate the factors in this domain to what the factor aims to reduce: Paper use reduction, water use reduction, toxic waste reduction, et cetera.

Given the above thought exercise, we see added value in all the factors of influence, regardless of their frequency. We do think there is a relation between the frequency of a factor of influence and its relevancy to all organizations.

4.2. On the Taxonomy

We started our classification of factors of influence using Hilty's framework and the three orders of effect. We found that the three orders were not sufficient to classify the factors of influence, and added two more domains that precede the introduction of the ICT solution: These influence the decision process up until the introduction of ICT solutions. The factors of influence in these domains drive or pressure an organization into a certain direction (e.g., laws and regulation, a Green ICT strategy), but they can also take the form of requirements, for example whether the current state of the organization is capable of applying Green ICT. Similar to the orders of impact, where a ripple effect spreads from ICT itself to other (business/organizational) processes to structural changes, we see a ripple effect of changes in society that affect business choices and culture, which in turn lead up to the decision to apply Green ICT.

As we presented in Figure 4 in Section 3.4, the five domains form a cycle connecting the 'Systemic impact of ICT' to the 'Societal impact on the organization'. The systemic effects, structural changes

that follow from Green ICT, generally influence the view of society on ICT and environmental issues. This, in turn, may change standards in industry or even laws and regulations, which then become part of the domain 'Societal impact on organization'.

Presenting the domains as a cycle implies that there is a causal and/or temporal relationship between the domains. We do not think such a relationship holds in its purest form, but in general we think this is the main flow of interaction between the factors of influence. However, if we zoom in, we think that there are interactions between factors of all domains. Large factors of influence in any of the domains of the Direct, Indirect or Systemic impact of ICT may lead to changes in laws or regulation. For example, successes in e-waste processing may directly become industry standards. Similarly, the factor 'Feedback and reporting' may directly influence the decision process in an organization deciding to introduce an ICT solution.

We think the five main classes in the taxonomy provide a sound base for the factors of influence. On the lower levels (beyond the two levels presented in this study; the complete taxonomy can be found online, see Appendix A), we observed some interesting patterns that we want to share.

There are some areas in our taxonomy where the factors of influence branch in different ways. The most apparent is in the domain 'Direct Impact of ICT'. Here, we chose to follow the life cycle process on the second level classifications, but many primary studies have factors that describe part of the ICT domain itself, for example 'End user computing', 'data centers', 'networking', et cetera. Generally speaking, these factors describe how ICT can be used in a more environmentally friendly manner. Accordingly, we classified these as part of the factor 'Use of ICT'. This shows that some primary studies focus more on the process, the 'how' (life cycle), and some studies focus more on the 'what' (e.g., data centers). There are more places in the taxonomy of factors that branch into 'how' and 'what', such as under the 'Design' factor, where we found 'Hardware design' and 'Software design', and also 'Planning', 'Analysis' and 'Blueprinting', as sub-phases of 'Design'.

For the 'Direct impact of ICT', we chose the 'how', and for the 'Indirect impact of ICT', we chose the 'what'. There are several reasons for doing so. First, the nature of the domain is different: For the 'Direct impact of ICT', both 'how' and 'what' can be easily connected to processes and persons in an organization (e.g., 'Procurement' or 'End user computing'). For the 'Indirect impact of ICT', this is different, as this domain is all about how Green ICT can influence *everything else*. Take as an example the optimization effect ('how'): It will be difficult for someone in an organization to be responsible for the optimization effect of ICT, as this would mean connecting to all areas of activity within that organization. Rather, it makes more sense to start from the area of activity, such as buildings or logistics, and improve these with ICT. This is also what we observed in the primary studies, where most either generalize by mentioning the main domain only, or mention areas such as 'Smart buildings' or 'Teleworking and collaboration'. Another reason is that the 'areas of activity'-factors seem more complete than the 'how'-factors, such as de-materialization and optimization. Both branches in the taxonomy, however, do not mention the problem-side of effects that can happen in the 'Indirect impact of ICT'.

4.3. Gaps in the Taxonomy

In our analysis of the factors of influence found in the primary studies, we identified a number of gaps based on Hilty's framework. These gaps were present in the domains of 'Indirect impact of ICT' and 'Systemic impact of ICT'. Why are these effects missing in our primary studies?

In the domain of 'Indirect impact of ICT', the induction effects and obsolescence effects are not represented by the factors we found. Both effects are problem-side indirect effects of ICT on the environment. The induction effect is described as how the introduction of ICT can stimulate "the consumption of another resource (e.g., a printer stimulates the consumption of paper as it uses it faster than a typewriter)" [5]. The obsolescence effect happens when ICT shortens "the useful life of another resource due to incompatibility (a device that is no longer supported by software updates is rendered obsolete)" [5]. Both effects point to side-effects of the introduction of an ICT solution,

presumably because consumers or users are not (initially) aware of these effects (suppliers may very well be though).

As for the gaps at the 'Systemic impact of ICT', we found a different interpretation in the factors of influence that may or may not be covered by the effects mentioned in Hilty's framework (Figure 1). For an organization introducing an ICT solution, it may be difficult to pinpoint the rebound effects, emerging risks or decoupling effects. We believe the main reason for this is the scope of effects: The boundaries are not within the organization, but may affect society as a whole. This implies that knowledge is required of interactions between the ICT solution and other processes and behaviors, making it very complex to carry out. The two factors we found that are part of the 'Systemic impact of ICT' are closely related to the ICT solution, whereas the effects mentioned by Hilty are more related to the impact the ICT solution has on society and the environmental consequences. Can we ask an actor, such as an organization delivering an ICT solution, to take responsibility for such effects?

We think that the main reason for these gaps is that they all describe effects that are not part of a narrow view of (using an) ICT (solution). They raise concerns about side-effects or effects caused by (complex) interactions between technology, behavior and structure. Having the right information at the right time may be a way to increase awareness of these effects and to allow individuals and organizations to make better decisions. Therefore, introducing these as awareness factors (e.g., 'Rebound effect awareness'), for example part of 'Feedback and reporting', could be a way to complement the factors we found in the primary studies.

4.4. State of the Art of the Research Field

The Green ICT research field is diverse, spanning from designing energy efficient hardware components, to calculating the environmental impact (and savings) of the use of teleconferencing, to following the adoption of Green ICT solutions in an organization. This diversity is also present in the list of primary studies, where some focus on the direct impact of ICT on the environment, whereas others take a broader approach.

In Table 4, we reported that almost all primary studies report on the 'Direct impact of ICT', most on the 'Organizational impact on ICT', and that the other three domains are each reported on in roughly half the studies. This supports our view that the research field is unbalanced, especially in light of the large potential of ICT as an enabler (16% global CO_2 reduction) versus the 2% global carbon footprint of ICT itself. A large effort seems to be on the 'Direct impact of ICT', whereas we think there should be more focus on the indirect and systemic impacts. This is further strengthened by zooming in on the second level in the taxonomy, where we find that the factors of influence in the 'Direct impact of ICT' domain are mentioned 82 out of 257 times in the studies (see Table 3) or 32% of all the factors in this domain, versus 19% in 'Indirect impact of ICT' and 7% in the 'Systemic impact of ICT' domain.

As for the problem versus solution dimension: 49% of the factors cannot be attributed to one side specifically, 37% to the problem side and 14% to the solution side. Combining these, we see that most primary studies focus on 'problem'-factors in the 'Direct impact of ICT'. It makes sense that factors in the two domains of 'Societal impact on the organization' and 'Organizational impact on ICT' are problem/solution-neutral, because they can affect both ICT itself as well as business processes making use of ICT. For the 'Indirect impact of ICT', however, one would expect both 'problem'- and 'solution'-factors, but as we have seen, the first are entirely missing. Finally, the 'Systemic impact of ICT' has the smallest representation, with factors not (exactly) covering the known systemic effects.

In Table 5, we reported on those primary studies that cover all five domains. Eight out of 34 primary studies mention each of the five domains, but looking at the factor level, they only cover 59% at most. There is no study that published a complete coverage of all the factors. In light of the previous finding that there is a lack of attention for some of the domains, this makes sense. Even so, we think it is important that the research field is moving towards a complete approach of all five domains, to contribute towards enabling the full potential of Green ICT.

4.5. Impact of Findings on Practice

One of our motivations for carrying out this SLR is to find out how scientific literature can help organizations and practitioners apply Green ICT to its full extent. How can scholars help organizations apply ICT as an enabler to reduce the environmental impact of their business processes and let them consider the systemic impact as well? We found in previous work [24] and from personal experience working in Green ICT communities that organizations focus mostly on greening their data centers and are not mature enough to use any further potential of Green ICT. This view is supported by several publications, mainly on the adoption of Green ICT, stating that adoption is not trivial [25,26]. Furthermore, often Green ICT means something different depending on whom you ask in an organization, depending on their perspective. In short, a practical holistic approach to Green ICT is missing [27], which is necessary to enable its full potential.

The factors of influence we found and the taxonomy we presented contribute towards this holistic approach. The five main domains offer a good structure for organizations to use, and the factors of influence pinpoint areas to which an organization can pay attention to. However, more is required to turn the taxonomy into something that can be used in practice. The taxonomy describes what factors are of influence, but not how the factors can be manipulated. The primary studies do provide some material to do so, in the form of tools like maturity models, balanced score cards or metrics and performance indicators. Since the taxonomy is synthesized from multiple primary studies (the maximum coverage of a single study is 59%), such metrics must be synthesized or extrapolated as well. It would be an interesting follow-up to our study to create a model based on the taxonomy which would guide organizations into manipulating the factors of influence and optimizing the full potential of Green ICT.

5. Threats to Validity

There are a number of limitations to our study that may have influenced our results. The main limitation was in our search process, as we had to limit our query to the titles of publications only. It could very well be possible that more factors of influence have been defined in the research field that were not captured by our search query. The reason for limiting our review as such is practical: Due to the explosion in the number of hits, it would have not been feasible to carry out a full text search and still perform the analysis with the same thoroughness. Even though we would have liked to have a complete list of factors of influence, we place relevance and scientific soundness as more important than completeness. However, to mitigate this limitation we have designed our search string so that it would be broad enough to uncover as many relevant studies as possible.

Another potential issue regarding the search process was that there was no definition for factors of influence. We addressed this potential limitation by including many variations of metrics and models in our search query. Given the large number of factors of influence we have found, we believe that this strategy was successful.

The other area of limitations is in the analysis of the data. Because of the qualitative nature of the analysis, there were steps that required interpretation by the authors. We did this as objectively as possible, by using I/E criteria in selecting the primary studies and to use a simple rule of being as inclusive as possible in interpreting and translating the factors of influence into classes. We further mitigate this threat by publishing each step in the analysis online (See Appendix A).

6. Conclusions

This study presents the results of a systematic literature review on the factors of influence on the environmental impact of ICT. We used this SLR to find which factors of influence have been published and how they would map onto a classification of environmental effects of ICT (Hilty's framework, Figure 1). From the data we collected and the analyses made, we created a taxonomy and reported on

the frequencies of the factors of influence in the primary studies and gaps and additions compared to Hilty's framework.

The SLR resulted in 34 primary studies, from which we extracted 380 factors of influence. Out of these, we found 97 unique factors of influence that we classified into five domains in a taxonomy: 'Societal impact on organization', 'Organizational impact on ICT', 'Direct impact of ICT', 'Indirect impact of ICT' and 'Systemic impact of ICT'. We pruned the taxonomy to two levels for further analysis using the 34 remaining factors.

Comparing the taxonomy with Hilty's framework, we identified gaps on the indirect and systemic orders of impact. The problem-side particularly is missing amongst the factors of influence found, but the domain 'Systemic impact of ICT' is weakly represented in general. We used Hilty's framework as a conceptual starting point, but from a practical perspective it makes sense to add two domains to the taxonomy, being 'Societal impact on the organization' and 'Organizational impact on ICT'. We think there is natural flow between the domains that can be represented as a cycle (Figure 4).

Taking the primary studies as a representation of the research field, we found that there is a strong focus on the domains 'Direct impact of ICT' and 'Organizational impact on ICT'. Given the enabling potential of Green ICT, the lack of attention to the indirect and systemic impacts of ICT is striking. In addition, none of the primary studies comes close to a complete coverage of all the factors of influence found. Approaching the five domains and their factors of influence, including the gaps we already identified, in a holistic manner would be helpful towards enabling the full potential of Green ICT.

Finally, we think that the taxonomy can be used as a starting point for a practical tool that organizations can use to see how well they are doing with regards to Green ICT. Further research is needed to make a complete list of the factors that should be part of such a model: For example, by adding awareness factors to cover the gaps from Hilty's framework. Also, each factor needs to be described with metrics that indicate how the factors can be manipulated such that organizations can apply Green ICT in the best possible manner.

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Appendix A. Reference to Online Material

- The full taxonomy of factors of influence can be found here: https://goo.gl/oh2tC4;
- Each step of the data analysis can be found here: https://goo.gl/vvr2vo.

Appendix B. Mapping of Primary Studies on the Taxonomy

Factor	Primary Studies
Societal impact on organisation	[28]
Compliance	[16–20,29–35]
Transparency	[17–19,21–23,36,37]
Market forces	[16,18,30,34,35]
Reputation	[17–19,31]
Environmental risks	[18]
Uncertainties	[35]
Direct impact of ICT	[16,22,23,31,38]
Design	[18,19,21,29,33–35,39–44]
Production	[43]
Packaging	[16]
Procurement	[17,18,20,25,30,34,37,39–41,45,46]
Use of ICT	[16–21,25,28,30,31,33,34,36–51]
E-waste	[16–21,25,30,34,36,37,39–43,45,46,48–50]

Indirect impact of ICT	[18,20,22,23,29,39,41,46,52]
Teleworking & collaboration	[16,17,21,37,39–41,46,51]
Paper reduction	[16,17,21,40,41,49–51]
Smart buildings	[16,17,20,21,40,46]
Smart energy	[20,40,51]
E-commerce	[16]
Smart motors	[20]
Smart logistics	[20]
Feedback & reporting	[16–22,34,39–41,52]
Systemic impact of ICT	
Adoption	[16–23,30,31,35,36,44,46]
Innovation	[17,19,33,36]

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