

# ICT4S 2013

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on Information and Communication Technologies for  
Sustainability, ETH Zurich, February 14-16, 2013

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# ICT4s

ICT for Sustainability

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on Information and Communication Technologies  
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## APPENDIX

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# Link Between Academia and Industry for Green IT

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## ABSTRACT

Technology transfer between different organisms like academia and industry is an important factor for the development of our society. Different organisms mean also different priorities, different points of view and difficulties in working together. Having the same definitions, getting to know the different players, their aims will support the technology and knowledge transfer in order to develop new Green IT technologies. This paper analyzes the various positions of the different possible participants in a project, their different aims but also their common points and how to build bridges for a common understanding of innovative project in the field of Green IT.

## Keywords

Green IT, technology transfer

## 1. INTRODUCTION

Since the last decades Information Technology (IT) is playing an increasing role in our society. But the research was more related to reliability, performance and quality of service than to the ecological impact. Since alarming studies were conducted; academic researchers, governments, funding organisations and companies started research activities in the direction of Green IT [18]. Based on the different definitions [19, 20], and motivations (social, economic, environmental, etc.) a definition of Green IT was stated, which is for now the basis for this work “*Green IT is the environmental and resource saving effort in the IT. The reason for using Green IT may arise from economically or ecologically interests. Actions can affect on the whole lifecycle of information technology - meaning from the construction via utilisation through to disposal.*” [9].

Up to our knowledge this paper is one of the first to explore the relation of academia and industry in the field of Green IT. Firstly we have to be aware that Green IT is a part of the IT research, which has to be seen as a general research field, meaning it is also facing the same problems as other research areas do. Each player (companies, researchers, etc.) is having a different access, a different pace and different aims which are making it difficult to have a permanent and an efficient exchange of results. Moreover the different parties may have difficulties in defining common research interests, even if they agree on the scientific part but still there are different backgrounds.

In this perspective, this article deals with general definitions

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about technology transfers to give common understanding.

Secondly, the focus is set on contracted research between academia and industry, comparing the different points of view before contextualizing the purpose to the Green IT field. Some of these differences are examined more closely and propositions for the technology transfer of Green IT are made.

## 2. TECHNOLOGY TRANSFER WITH/THROUGH MISSION ORIENTATED RESEARCH

The definition of technology, which is used as the base in this article, covers the knowledge of the appliance of scientific knowledge. Scientific cognizance stands in this case for all results and observations of activities in research and development. The constraint that these results had to be received with scientific methods is not taken into account when the transfer is done: Used technologies might be the result of scientific ambitions but also lucky consequences within practice. Finally scientific knowledge in the perspective of this work encompass both empirical and theoretical knowledge; it means all directed processes and methods, including their practical usage and also material artifacts like products, prototypes and software.

Technology is the special knowledge, know-how, in the sense of instructional knowledge and skills. Occasionally knowledge is divided into know-how, know-why, know-what, and know-who, but simplifying all these definitions are summed up under the definition of know-how [23]. In the economical context knowledge is seen as one factor of production respectively as a resource with an important impact on the technical progress (e.g. the virtuous circle in the Green IT that we analyzed previously in [9]) and the long-term development of companies. Technology is the sum of all available procedures of productions in a society. The difference to other production factors is that technology can hardly be measured quantitatively compared to raw materials or capital. The evaluation of the technology potential is therefore very difficult. However, technology is never consumed during the usage or dissemination, the user, the researcher or the teacher is not losing the technology. But technology can lose importance in case of exclusive usage and/or when new knowledge is creating new technology, reducing the value of the previous technology. The particularity of Green IT is the pace of development of new ideas and technologies. These are going on very quickly since there are many opportunities where Green IT can be included (Hardware, Software, Cloud Computing, etc.), speeding up the emergence of new technologies and their disappearance.

Changing the perspective from the generation of technology towards its usage leads to another useful consideration. From this point of view technologies represent all results of research and development contributing to solutions of problems. The

usage of technology suggests linking the term technology to the interaction between scientific/technical perception and the society. This is of particular importance in the field of Green IT because a general awareness about technical possibilities is missing together with a comprehensive study of the user acceptance level for greener solutions at the price of potentially degraded quality of services.

This article does not lodge claim of a complete classification of interactions of parties in all sorts of technology transfers. This is not feasible as classifications can be done with different parameters (vertical, horizontal, product-oriented, procedure-oriented, infrastructure-oriented transfer, etc.) [1, 2, 3]. To examine each interaction in an isolated way has only a limited value for the global point of view. Therefore we decided to focus on two kinds of transfers to reach a profound understanding of the potential interaction of parties. Indeed non-pointed and focused transfers are/will be the most profitable ways of technology transfer in Green IT:

Within the area of non-pointed transfer the technology disposer provides information to (for him) unknown public. The receivers decide about the individual relevance of the information and about the implementation of the information. There is no direct contact between the provider and the receiver. Non-pointed technology transfer is often defined as a process in which ideas are spread from a provider to the receivers [4, 5], in a broadcasting way. These definitions are pointing out the passive diffusion from the origin to receivers using this knowledge. The technology provider offers – knowingly or unknowingly - a potential solution, in general without having an idea of the concrete request. An individual adjustment is not possible due to the missing interaction but it is possible to use, to develop this idea, this result by the receivers. A large set of white papers, recommendations, leaflets made by industry, groups of interest or more rarely researchers are freely available online in the Green IT field, in particular for datacenter construction and operation: EU Code of Conduct for Datacenter (EU CoC), The Green Grid white papers (53 white papers as of today), to name a few.

The basis of the diffusion is the availability of the technology by the producer. This can occur in a communicative way like presentations and publications or by the nature of the technical artefact (for instance open source software).

With the focused transfer it is possible that a precise solution is transferred target-oriented to the recipient. In this situation the partners are in an equal position. Mainly the constructor modifies and develops the technology according to the needs of the user. The developer has an active role as he supports the user in the implementation and in the gainful use. Therefore an interactive relation between the partners is mandatory. This active interaction results in a lot of work but also boosts the success of this technology. This technology transfer is similar to a vendor-client-relation.

The difference between these two models is shown in the observation levels: the process of diffusion, the relation between the parties, the kind of information transferred, the way it is transferred, the receivers of the information. The non-pointed transfer can be seen as a process of diffusion of an ideal innovation in a social system. The interest in the focused transfer is in the microeconomics, highlighting the relation between two or more economic entities. The questions of interest in the non-pointed transfer of technologies are the rate of spread, kind of spread, channel of diffusion, and classification of technology users. In the central research of the focused transfer are the

characteristics of the transfer partners, the interaction process, and the implementation process. The non-pointed transfer is uncontrolled, unmanaged and spontaneous; the focused transfer is controlled and precise. Finally a last crucial observation level is to know if the technology constructor sent implicit or explicit information to selected users (e.g. meaning a defined and limited circle of potential users, who he has already a relation with).

Having a non-pointed technology transfer and the offered solution correspond to the challenge of the potential user, then a similar benefit may be achieved as with a focused transfer. The non-pointed transfer cannot replace the focused one but may result into a passage from the non-pointed to the focused transfer - assuming the willingness of both partners.

Similarly, a focused transfer can deliver results openly in the same way as a non-pointed transfer does. For instance, open source software for energy consumption characterization developed in a European project on Green IT like CoolEmAll [24] is offered to the public as a side effect since all partners agreed on a GPL-like license.

### **3. ANALYZE OF IT-CONTRACTED RESEARCH BETWEEN ACADEMIA AND INDUSTRY**

For innovation oriented companies the academic research represents a fundamental resource of external produced technologies. The more the industry is oriented towards novelties on the market and leadership in technology, the more the cooperation with public research institutes is interesting for it. Academic institutes could be considered as the best partners as they have a wide experience in cutting-edge-research but also because their interest is not only focused on one product. They have no business interests, but an interest in independent and fair research - they are impartial! Despite this high synergetic potential academic researcher and industry operate in unconnected systems. In reality there exist a variety of options for arrangements in the cooperation, like patents, licenses, specific consulting. Contracted research is a specific form of focused technology transfer with its challenges and chances for research projects and for future cooperation between industry and research institutes. In the contracted research there is the presumption that the company contracts a research to an university for implementing the result out of this contract in its organization, using this outcome and having an advantage in competition. The contracted research project is the instrument for the technology transfer.

Contracted research is getting more importance during the last years and it is finding also the influence in national and international research programs, calls of tender and open calls [6, 7]. The idea is to define certain criteria for this special way of transfer. The first point is the client-supplier relation, in which the client is a company and the supplier is a research institute. Secondly, it has to be mentioned that the primary purpose of this cooperation is the exchange of scientific knowledge. This exchange is interactive, organizational, service based and focused-mainly between two actors, without a 3<sup>rd</sup> party involved. Thirdly, the relation is contract-based with a time limit and with the obligation of providing a result, a solution. A particular issue of contracted research is when there is a funding organization (like NSF, EU, etc.) involved as in this case the client-supplier relationship is supervised by this organization: progress reports have to be provided, and the parties have (probably) less opportunities in creating their relationship.

### 3.1 Comparing academic and company points of view

With a contracted research project a temporary bridge is built between the system of economy and the system of science. To be successful elements of both contexts have to be taken into account and further stimulations have to be provided [8]. The interaction between partners with different background and a different environment is challenging. The internal systems cannot be compared and assumptions may often be wrong because of a lack of knowledge about the other partner. We propose Table 1 “Similarities and differences of academia and industry” in order to give an overview over the various aspects and to point out the important approaches. It presents the different aspects of the two partners of a contracted research.

### 3.2 Analyses

In the first part of Table 1 there are all the different topics linked to research and innovation in IT. We can see clearly in line A the different core competences pointing out that an exchange between academia and industry is needed to get a very complex outcome. Product development can only be done if there is a good fundamental research provided, and also if the approach is general enough: Like this it gives the opportunity to the industry to propose concrete solutions in answering to various demands concerning different kind of demands. For instance, a solution can be tight to a specific server (typically by a vendor industry) or general enough to encompass a variety of servers and datacenters at various scale.

The second part of Table 1 deals with the criteria and the dissemination where a gap is also seen. Currently Academia mainly distributes their results to the scientific community while industry stakeholders need to address their clients, and their demands. A very known actual topic concerns Server Virtualization, a very good example to see that an exchange is necessary. Server virtualization decreases the number of needed actual servers to handle users’ requests to services. On the paper this can save a large amount of energy. But the system has to be developed, to be studied and to be proved before large investments are made. Measurements are needed, different solutions challenged against synthetic and real workloads. Only universities had the opportunity to invest time and to create a platform to do so in early ages of server virtualization. With additional exchange with industry about their demands the result were achieved more quickly and more precisely: Indeed using real trace workloads is the key for researchers to prove their results. Unfortunately these workload traces are often kept secret and not shared by company without contracted research and non-disclosure agreement (NDA). When a first proof of concept has been established, the industry can develop itself its own business, directly with other industry partners, for instance to develop and test solutions for server virtualization in real world at a very large scale only available at large privately owned datacenters.

In the third part of Table 1, we have a look on the organization of the different parties. We can see clearly what may lead to difficulties in the cooperation; both parties have to show some understanding concerning the framework of the other one. What is clearly an advantage of the academia is that they have existing cooperation with other research units in their university, while industry partner often have only one major experience or one major activity. Let’s take the example of cooling in server rooms. It may appear that a company is able to build energy efficient servers but doesn’t have the experience in modelling the airflow in a datacenter, which is another expertise. It belongs to another industry player for small companies, another department in large groups, can be simply taken from

recommendations or best practices developed in the past, or develop with the help of academic partners. Academics do have workshops on a large field of research where they exchange with each other, where they learn from other as well. Academics are linked to other fields of research and they are not in concurrence if they are in different research fields, or at least not at the same level of fierce competition. Having a close link between industry and academic helps to find inexpensive solutions quickly by using the research network of the academic partners

One possibility to build a bridge between different interests is the creation of a Technology Transfer Office (TTO). These offices are dedicated to identify research having potential commercial interest and they develop strategies for exploitation.

### 3.3 Critics on the model

Before moving on to the contextualization to Green IT, it appears necessary to discuss one hypothesis mentioned hereby: Researchers are impartial, and act for common welfare (line A, Table 1). This idealistic view is naïve especially in a fierce competition for faculty positions and lack of government funding. Indeed a research institute can act like a company except that the benefit is different. It needs third party to build contracted research with. Besides money that allows to hire students, PostDoc and Engineers to conduct researches, the reputation is a key point. Anyway, researchers have to finish in time the projects, in order to keep a position or to get a new one. However we do believe that most of researchers in research institutes would prefer to act differently and we rely on this assumption to build our work, especially in the context of Green IT where societal welfare might be a side-motivation for researchers. Actually one long-term motivation of this work is to improve the technology transfer without the researchers to behave as competitors so that they can return to their fundamental motivation.

## 4. CONTEXTUALIZING TO GREEN IT

This article will not line out all the above-mentioned points, but will highlight significant examples in the context of Green IT.

### 4.1 Duties and responsibilities

For the line A in Table 1 there is currently a big hype in our society about all topics related to Green IT. Therefore companies are interested in having a green label on their products or that in their name “Green” is appearing. It is their way of showing that they care about our planet. There are many different aspects making IT to Green IT. It starts with the production over the usage, the energy consumption, the cooling towards the recycling. The individual funding enterprises can get from the State, from individual programs are quite high, therefore they are interested in getting the “green label” [20, 21] even if it is only “green washing”. The Industry is more aware of this hype because they see the new market for business and for extending their field of activity than researchers who are more interested in long-term research, in a contribution to the welfare of the society. These two different approaches will also lead to developments into different directions.

### 4.2 Approach

In line C the different approaches between academia and industry are highlighted. For the industry it is important that a perfect solution (e.g. Datacenter Infrastructure Management-DCIM software ready to use) is presented/proposed. Solutions, which are not costly, working immediately and non high-maintenance products are definitely the ideal outcome. Operating research and development departments in companies prefer simple solutions. Even if with more investments e.g. measuring the load of servers, or thinking about different

methods of cooling the companies could achieve better greener solutions they keep in mind the profit and the management is setting the priorities – see line F.

Then the management decides to buy or not to buy the product (having a look on the costs, the balance of accounts, the penalties for producing CO<sub>2</sub>), and the last step is the usage of it. The industry is having a very concrete approach: Saving money, having a Green Label, an easy usage.

Academia are interested in searching and finding a better solution than the ones already existing. Researchers are measuring the load of servers, changing the cooling and as a result new DCIM software is developed. There is a general approach as the view of the researchers is broader—they see also the welfare of the society and the interest to improve research—maybe in also other disciplines.

### 4.3 Criteria of efficiency

Green IT must give more value in terms of money to the company (e.g. stock options must go up, more possibilities for getting new contracts). A company is interested in making money. So for the industry Green IT is only interesting if there are tax advantages, if it helps to save money immediately and directly—companies often forget the impact of electricity consumption and the costs for electricity. As costs for energy are almost a point of discussion (not like costs for stuff) Green IT has to provide clear numbers how much costs can be saved in using Green IT.

For researchers the only criteria of efficiency is the scientific reputation. In the young area of Green IT there are a lot of unsolved problems and plenty of not investigated fields. If researchers propose innovative solutions they can get a higher reputation, which is their main interest, beside the extension of knowledge. Actually their motivation is reputation, i.e. the number of published papers (and not research results) and even if it means to re-invent the wheel, they would do so with sometimes and for some of them a short term perspective.

There are not a lot of conferences dedicated not only to technical Green ICT but also including other overlapping research topics like management or business process, where researchers can confront their ideas with industry players, having a high reputation in this still young research field. For instance, IEEE IGCC [10] started only in 2009, ACM/IEEE e-Energy [11] in 2010, IEEE GreenCom [12] in 2010, while workshops attached to larger events started a bit earlier (HPPAC [13] in 2005 or E2GC2 [14] in 2009), and so on and are mainly technical conferences. Academic journals on sustainable computing or Green IT have been launched only recently by major publishers ([17] in 2011 for instance). Academic initiatives attracting interests such as Green500 [15] or the European COST Action IC0804 [16] are also not very old compared with traditional computer science.

For researchers it is mandatory to publish paper in well established conference or journals, and at the same time to reach a large community interested in energy saving. This duality makes it therefore more limited to progress in their carrier than in other well-established fields of research. Researchers may prefer to publish in other related medium to increase their visibility and reputation (for instance conferences existing since 20 years having some tracks on Green IT rather in specialized events organized since only a couple of years). These events/journals have a higher impact (e.g. a higher Impact Factor, a better conference ranking) leading to be more appreciated by researchers. And where will these researchers not meet numerous members of their community on Green IT as compared to a specialized event.

This criteria in the field of efficiency shows totally divergent points of view, and may result in difficulties in the transfer of technology and building up a long lasting cooperation.

While for research institutes it is more important to have a general approach, to look after complete solutions, applicable in many cases. Costs are less important, and also the time, which is needed to achieve results, is not the main interest of the research institute, except when a contract is established with a industry player as mentioned before.

### 4.4 Freedom of Action

The research institutes are opened concerning new approaches, new ideas. The researchers are free in their decision which research to bring forward and where to put the focus but they have limits through resources like stuff, funding. Many open public calls, where Green IT is present, are limited to iterative research even if Green IT would allow breakthrough research. This effect may lead to difficulties between researchers and the management as the company sold a certain result to one of the clients and is not able to change the contract, even if the solution proposed by researchers having better results in saving energy.

## 5. CONCLUSION

Green IT is a rather young research area and therefore there are still a lot of topics to explore. Still there is a strong change in the different areas of IT, with the tendency to Green IT as it is a strongly discussed topic in our society. Energy saving, protection of resources, recycling, limited possibility in the utilization of technology are catchwords which are accompanying our society. Green IT is a part of this discussion and its involvement in different research field has to get stronger. Green IT has been recently embraced in different manners by academic researchers and industrial leaders. This should happen in a strong exchange with researchers of different fields but also in including companies, even if they are not at the first sight in the IT field. It is necessary to enforce the cooperation between academia and industry to advance in the Green IT for our society. To achieve this TTOs should be integrated in research centres, where technical knowledge is collected, but also the knowledge of funding possibilities and contact data are prepared for usage for Green IT. As Green IT is a young research field it is still possible to build up good databases and to follow the innovations. These TTO are points of contact for companies and for researchers. Even the creation of spin-offs could be integrated in their activity field. As these offices are a part of the academia they are also in the centre of innovation and research and they can connect researchers with a research result easily with the companies working in this field. On the other hand companies should use the concept of Angel investors for financing projects and collaborations. An innovative idea can be funded by investors and have a big impact on the society, while waiting until the next open call from a funding organization may just be a loss of time and at the end this innovative idea will never be provided—neither to the research nor to the society.

Due to pointing out the different objectives, aims and approaches in Table 1 we are convinced that there will be a better understanding between the partners, but also that there will be a change in the cooperation and in the transfer of knowledge due to the better understanding between industry and academia but also there will be a change in the different funding systems. Future works will have to be done in investigating more in details the current difficulties, developing the understanding of the partners and pointing out more clearly the needs of having a permanent exchange between industry, academia and funding organizations.

Research and Innovation process			Academia	Industry
	A	Duties/responsibilities	Common welfare Extension of knowledge	Profit orientation Offering service and products for the market
	B	Core competence	Fundamental research in Software and Hardware User oriented research Experimental research	User oriented research Experimental research Product development
	C	Approach	Search and find General	Decide and act Concrete
	D	Priorities of topics	Personal interests Expected appreciation Financing	Strategic development of the company Portfolio of the products
	E	Selection of topics	Autonomic Funding relevant	Innovation management Top management
Criteria and dissemination	F	Criteria of efficiency	Scientific reputation	Profit and company value
	G	Criteria of quality of the work	Systematic production Reconstructable processes and results Big application area Explanatory contribution	Usability of the results Big effects for the clients usage Advantageous economic solution for a concrete application areal Production of an innovation leading to a temporary monopoly position
	H	Reference groups	Scientific community student	Clients Other units within the company
	I	Distribution of the results	Conferences Publications Patents	Products Internal processes Services Patents
Organisation	J	Freedom of action	High Limited through resources (funding, staff, equipment, ...)	Average limits through management
	K	Funding	Non-performance related basic financing Calls of funding organisations Services for companies	Budget of the innovation management In-house accounting
	L	Organisational framework	Fixed and solid Influenced through scientific community Need safety concerning the expenses	Flexible Influenced through market needs, clients' needs Searching for information about efficiency and risk
	M	Relation with other units of the organisation	Limited administrative support is offered Interaction within a given framework Parallel units with other fields of competences	Part of a chain within the company Targets given by the management

**Table 1: Similarities and differences of academia and industry**

## REFERENCES

- [1] Brooks, H. (1966): National Science Policy and Technology Transfer, in: National science Policy and technology transfer. Conference on technology transfer and innovation, Washington, DC, S 53-63
- [2] Auer, M. (2000): Transferunternehmertum. Erfolgreiche Organisation des Technologietransfers. Wiesbaden: Gabler; Deutscher Universitätsverlag (DUV Wirtschaftswissenschaft)
- [3] Corsten, H (1982): Der nationale Technologietransfer. Formen, Elemente, Gestaltungsmöglichkeiten, Probleme. Berlin: Schmidt (Technological economics, 7)
- [4] Chakrabarti, A.K.: (1973): Some concepts of technology transfer. Adoption of innovations in organizational context; In: R&D Management, Jg. 3, H.3, S. 111-120
- [5] Rogers, E.M. (1995): Diffusion of innovations, 4. Ed. New York: Free Press.
- [6] Rüdiger, M. (2000): Forschung und Entwicklung als Dienstleistung. Grundlagen und Erfolgsbedingungen der Vertragsforschung. Wiesbaden: Deutscher Universitätsverlag (Wirtschaftswissenschaft, 36)
- [7] Walter, A.; Gemünden, H. G.; Auer, M. (2003): Unernehmerische Aktivitäten im Technologietransfer. In: Zeitschrift für Betriebswirtschaft, Jg. 73, H. 7.
- [8] Zissler, M. (2011): Technologietransfer durch Auftragsforschung, Wiesbaden: Gabler Verlag
- [9] Herzog, C.; Lefevre, L.; Pierson, JM.(2012): Green IT for Innovation and Innovation for Green IT: The virtuous circle. Human Choice and Computers (HCC10) International Conference (Technical Committee 9 – Relationship between Computers and Society, International Federation of Information Processing IFIP, September Amsterdam, published in Springer.
- [10] International Green Computing Conference, <http://www.green-conf.org/>
- [11] International Conference on energy-efficient computing and networking, <http://www.e-energy.uni-passau.de/>
- [12] IEEE International Conference on Green Computing and Communications, <http://cse.stfx.ca/~GreenCom2010/>
- [13] Workshop on High-Performance, Power-Aware Computing, <http://fortknox.csc.ncsu.edu/proj/hppac/2005/index2005.html>
- [14] Energy Efficient Grids, Clouds and Clusters Workshop, <http://www.ens-lyon.fr/LIP/RESO/e2gc2/>
- [15] Green500, [www.green500.org](http://www.green500.org)
- [16] COST IC0804 on Energy Efficiency in Large Scale Distributed Systems, <http://www.cost804.org>
- [17] Sustainable Computing: Informatics and Systems, Elsevier, <http://www.journals.elsevier.com/sustainable-computing/>
- [18] U.S. Environmental Protection Agency ENERGY STAR Program (2007): Report to congress on server and data center energy efficiency, available online [http://www.energystar.gov/ia/partners/prod\\_development/downloads/epa\\_datacenter\\_report\\_congress\\_final1.pdf](http://www.energystar.gov/ia/partners/prod_development/downloads/epa_datacenter_report_congress_final1.pdf), August
- [19] Murugesan, S. (2008): Harnessing Green IT: Principles and Practices. IT Professional 10, 1, 24-33.
- [20] Hilty, L. M. (2008): Information Technology and Sustainability. Essays on the Relationship between ICT and Sustainable Development Books on demand, ISBN: 9783837019704)
- [21] [http://re.jrc.ec.europa.eu/energyefficiency/pdf/Datacenter\\_CodeOfConduct\\_Introductory\\_Guide.pdf](http://re.jrc.ec.europa.eu/energyefficiency/pdf/Datacenter_CodeOfConduct_Introductory_Guide.pdf)
- [22] [http://ec.europa.eu/information\\_society/activities/sustainable\\_growth/docs/broadband\\_eq\\_code-conduct.pdf](http://ec.europa.eu/information_society/activities/sustainable_growth/docs/broadband_eq_code-conduct.pdf)
- [23] Garud, R. (1997): On the Distinction between Know-How, Know-Why, and Know-What, in Advances in Strategic Management, Volume 14, p 81-101
- [24] <http://www.coolemall.eu>

# DO YOU FEAR TELEWORK?

## Understanding the “petrify effect”

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### ABSTRACT

Telework is a chance to improve social, economic and environmental sustainability through the use of ICT. However the take up of telework has, up to now, been very slow: on average in the EU-teleworkers account for only 1.7% of the total labor force. The article focuses on the cultural barriers visible in employees' and employers' attitudes to telework. Hence, the article applies the theory of social institutionalization of Berger and Luckmann (1966) to the on-site working paradigm in order to understand how it produces a set of values opposed to the adoption of telework. To systematize and generalize how these barriers arise, the article introduces a new heuristic concept, the *petrifying effect* and examines its emergence through an ongoing case study, in which 20 employees of Turin's municipality spend 80% of their time teleworking.

### KEYWORDS

Telework Social Implication, social institutions, cultural gap, petrifying effect, ICT and sustainability, smart city.

## 1. SOCIAL AND TECHNOLOGICAL CHANGE

Making sustainability possible faces two main challenges. The first challenge is to address the ways in which technological development can combine economic efficiency, environmental health and a better quality of life for the present as well as future generations.

However, technologies are never free from social consequences, indeed, there often needs to be a fundamental change in the way relevant institutions are organized before they can introduce sustainable technologies, while the potential for new technologies to weaken or strengthen the institution can act as either barrier or incentive to implementation. This leads to the second challenge: how to overcome the different kinds of barriers that can impede the dissemination of new and more sustainable technological solutions.

The organization of labour is a privileged point of view from which to observe the dialectic between social and technological change. Not by chance is the history of labour organization rich with examples of material improvements delayed by their social and cultural implications.

For example, the first watermill was designed by the Roman architect Vitruvio around 40 BC, but only came into common use 1000 thousand years later, when the poor availability of beasts of burden and slaves required a new organizational solution for food production (De Masi 1999).

This article is about a new social practice, the telework. The term telework can be broadly conceived as the ability to carry out a job through the use of ICT without the need to travel to a specific workplace.

While many jobs utilising ICT are not reliant on a particular location, such as in the field of research, communication and advertising, most of the labour market is still characterized by the need for on-site organization. It is within these workplaces that Telework represents considerable opportunities for strong innovation while also raising the possibility of resistance to such measures rising from the concerns and suspicions of the impact of its implementation.

The focus of this article is on the cultural barriers visible in employers' and employees' attitudes to telework. To better explain how these barriers arise, the article introduces a new heuristic concept: the petrifying effect, and examines its emergence through an empirical case study. The contribution provides a theoretical benchmark through which to propose a framework analysis valid for further empirical study. By exploring the mechanism of social institutionalization this article looks to develop a new sociological perspective on the relationship between ICT and the organization of labour. It focuses on the role of the cultural habits that have the effect of slowing down the implementation of telework despite the advanced level of ICT. It is heuristic because it points out the necessity for policy makers as well as for academic scholars, to move away from technological determinism in order to give more attention to the societal aspects of the ICT paradigm evolution.

The main hypothesis is that cultural barriers have the "petrifying effect" of changing the organization of labour, in at least two ways:

- By spreading a negative attitude among employees, who should be actively involved with specific telework projects, and also amongst employers, who should be allowing this engagement with telework to take place;

- By concealing even the possibility of the usefulness of telework as a productivity and quality of life improvement;

In order to analyze the *petrifying effect*, this article proposes to conceive the labour organization as a social institution. Hence, it applies the theory of the social institutionalization of Berger and Luckman (1966) to the on-site working paradigm, in order to understand how it produces a set of values opposed to the adoption of telework. In order to provide empirical evidence of the petrifying effect, the paper will introduce an on-going case study of 20 examples of telework reserved specifically for women in the municipality of Turin - Italy. Through an analysis of in-depth interviews with workers, trade unionists and managers, the paper will outline some key research findings relating to the prejudices, fears and confusion arising when starting a telework experience. Since the focus of the article concerns the urgency of implementing telework to improve sustainability, the initial analysis will briefly examine the

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controversial relationship between sustainability and telework. The challenge of making sustainability possible also includes the overcoming of any form of technological determinism.

### 1.2 *Telework and Sustainability: a controversial relationship*

In the policy arena and academic literature, telework is considered a strategic resource to improve social, economic and environmental sustainability through the use of ICT.

According to the "telework saving calculator", a quantitative model adopted by the United States Government, the 2,3% of teleworkers within the overall workforce saves the United States 390 million gallons of gas, preventing 3,6 million tons of Co<sub>2</sub>. If those with compatible jobs worked at home at least 50% of the time, the US would save 51 million tons of Co<sub>2</sub> - the equivalent of the entire New York workforce off the roads - and would save 900 billion dollars while cutting the amount of oil purchased from the Persian Gulf by 46 % (Lister and Harnish 2011).

The implications of Telework for quality of life have also been highlighted by a number of qualitative references. Di Nicola (1999) proposed a typology of benefits on the basis of the actors involved: for employers telework could be a resource helping to increase productivity; for employees, it would reduce transport charges while eliminating the stress of travelling to work; for the social context, telework both cuts the emissions of greenhouse gases while providing opportunities for making urban development less centralized

Nevertheless, there is large body of empirical research that explains the presence of an important "*rebound effect*" in many applications of telework. Derived from neoclassical economics theory, the *rebound effect*, in the case of the sustainable implications of telework, concerns the counter-effects that may result from telework - for instance reducing the vehicle mileage of commuters but -consequently- increasing their energy consumption at home (Moos et al. 2007).

Recently, the benefits for social life resulting from home-telework have been criticized by a number of authors, because of the "genderization" of domestic work for women (Holloway 2007) and conflicts around the possession of domestic space (Mallett 2012).

There is a commonality between these two different interpretations: telework is too poorly implemented to understand its real impact for sustainability.

According to research by Eurofound, in Germany full time teleworkers make up just 1.7% of the total labour force, France 1.4%, United Kingdom 2.3 and Italy 0.5%. On average in EU teleworkers account for only 1, 7% of the total labour forces (Eurofound 2010). Even though its adoption has increased by 64% in the last three years, the OECD declared that the adoption of telework, especially in public services, is moving too slowly.

An interesting research avenue is the elaboration of a complete barriers' typology, since the obstacles that can inhibit the expansion of telework have different characteristics - be they economic, technological or cultural - and consequently- different solutions.

This article focuses on the cultural characteristics of these barriers, requiring a sociological analysis rather than simply a technological one. Indeed, in order to understand why the implementation of telework is often considered with suspicion by employers and spreads fear among employees, it is necessary to answer a sociological question. How does a specific organization of labour produce culture?

## 2. LABOR AS A SOCIAL CONSTRUCTION

The theory of social institutionalization, elaborated by Berger and Luckmann (1966), can be useful for observing how a particular kind of organization of labour, the on-site working one, succeeds in creating a petrifying *effect* in the implementation of telework.

At the centre of the theory is the argument that the formation of self, as well as the biological development of the instinctual structures in humans, is determined by the influence of the socio-cultural environment. It entails that the social order influences, on the one hand, attitudes, behaviour and values, on the other, needs and ways to express desires.

It is not a choice, but a necessity: the inherent instability of human organisms, induced by its under-developed instinctual organization, makes it imperative that people themselves provide a stable environment for their conduct. This environment is composed of social institutions, where humans share social practices and produce a structured social order. This is the reason why Berger and Luckmann attempt to understand the causes of the emergence, maintenance and transmission of the social order, undertaking an analysis that concludes in a theory of social institutionalization.

To summarize the complex analysis proposed by Berger and Luckmann, the process of institutionalization is composed by three moments: exteriorization, objectification, interiorization.

A community has different permanent needs it has to answer to: this is the reason why they create social institutions. The first permanent need of the community is to crystallize solutions found in a complex of habits, in order to reduce uncertainty and to allow our limited attention span to focus on a number of things at the same time. This is what Berger and Luckmann call "exteriorization": people create an external reality through the sharing and standardization of their actions. Moreover, the standardization also concerns the actors that can or must carry out a particular action. Through the typification of practices and rules, a social institution controls the behaviour of individuals.

However, particularly in a complex society, where different kind of needs require a growing specialization of social roles, institutions have to communicate a model of collective behaviour to individuals through more refined forms than simply the mutual observation.

Language is the first and most important form of objectification: the exteriorization is represented through the use and shared symbol system. Objectification is not always abstract: it could also be tangible, as when institutions create specific places in which actions have to be carried out. The most important aspect of the objectification is that any institution, to conserve its structure needs to be perceived as an objective reality through the sharing of a code.

The reality - socially construed by the exteriorization process and socially shared by the objectification process - becomes socially reified thanks to a third process: the interiorization. An institution succeeds in becoming heuristic when its human fundament is forgotten by the subject and is instead perceived as a matter of fact. It happens when institutions succeed in their historical development for which their legitimation needs to be transmitted to new generations the legitimation is constituted according to the institutional explanations and justification of its necessity, through dissemination and control of cognition and values. The legitimation of the institution follows different strategies relying on the dominant symbolic universe: from mythology to rationalism. Each symbolic universe provides a

more or less solid defence which consists of, on the one hand, the “annihilation” of other competitive symbolic universes and on the other, the therapy of the internal “heretical” exteriorization. A social institution succeeds in becoming a symbolic universe when its internal structure or functioning dynamics influence those of other social institutions.

### 2.1 The values embodied by the on-site working organization

This theoretical model can be applied to our thesis, if we conceive the on-site working organization as a social institution. The modern organization of labour is a social institution because it answers to the permanent social needs of goods and services’ production. It is exteriorized through the typification of practices and roles that take the form of the specialization of the tasks - the social division of labour - and the construction of a defined hierarchy for which control, planning and action are consensually shared (Figure 1).

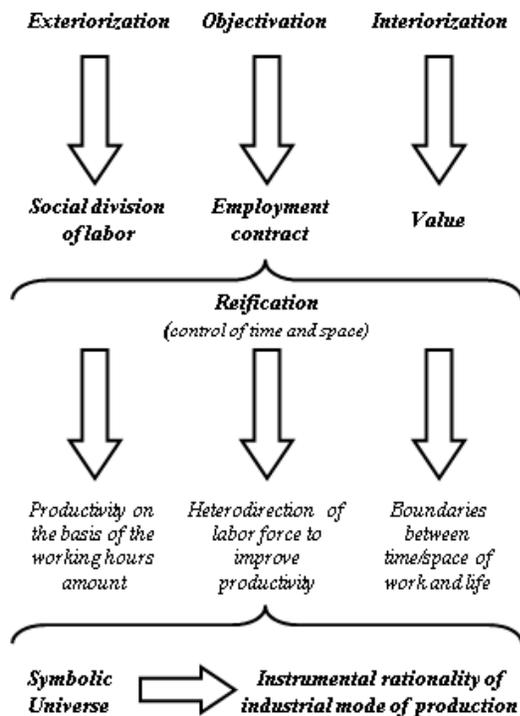


Figure 1: On-site working organization as a social institution

Tasks and hierarchies are objectified through the employment contract that foresees the respect of a system of rules. The rule that differentiate more than others the on-site working organization is the definition of a specific configuration of time and space for the employees.

To control the persons’ dimension of time and space, at least 5 days per week for 8 hours a day on average, is not innocent. As Foucault wrote (1972), what disciplines bodies and makes them domesticated is the practice of the “always unvaried” that is imposed with a top down dynamic. To always do the same things, go to the same places, it is not a simple inoculation of hobbies, but produces within the subject, the intimate conviction that all this is unavoidable or properly right.

This is the first step of the interiorization: conceiving an institutional solution. There is no alternative to follow, or, if there is, it is just for a minority of cases. The basic value on which the reification of the on-site working paradigm is based is the instrumental rationality, which is the mentality produced by the functioning necessities of the industrialization process (De Masi 1999).

Industry has created a particular symbolic universe that has influenced the organization of the whole of society for many decades: around the necessities of industry has been developed urban planning, the habits of consumption, geographical mobility and also the internal organization of the public sector, even though its’ good’s production is often oriented to services rather than products.

The key concepts of the instrumental rationality applied to the on-site working paradigm are:

- The evaluation of productivity on the basis of the working hour’s amount;
- The hetero-direction of the labour force in order to improve its productivity;
- Rigid boundaries between time/space of work and life;

Each of these aspects has a rational explanation in the symbolic universe of the industrial society and is reciprocally connected. The production in series, to which corresponds the idea that the time work takes and quantity of outputs are correlated, is rational in an economy in which the demand for goods is always superior to the supply.

The production line, derived from the necessity of efficiency in the series production, makes rational the standardization of the employees’ actions, and therefore, their hetero-direction in the “scientific” model of Taylorism, for which they can improve their productivity only by respecting the application of a protocol regarding their movements during the productive process. The necessity to produce a huge number of outputs in order to maximize reductions in costs makes concentrating each section of the production chain in the same place, where the mass of workers work for the same length of time, to the same rhythms of the production process, a rational decision.

The modern levels of ICT, for different jobs, in particular in the service sector, overcome the necessity for the physical presence of the worker. The worker needs a computer rather than an “office” to input data, to carry out research, to evaluate a request for building a house, etc... If the worker needs to coordinate their work with others, they can use modern communication networks: from emails to teleconferences. If they want, they can autonomously create their own community environment, or meet their colleagues periodically, transforming their telework contract from full to part-time. Like De Masi argued in his work on the future of labour’s organization, ICT finally allows us to bring information to people and not the contrary (1999).

The application of ICT in each phase of the industrial process moves the repetitive tasks from the human to the digital resource, faster, more punctual and economical. The use of ICT in industrial production allows a greater differentiation of products that fits with an increasing personalized demand. Therefore, factories need a reduced workforce consisting of more specialized workers, able to control and direct complex systems and to be flexible in their tasks. If the hetero-direction of the labour force is always less a rational value for the industrial processes, in the services economy it never made sense. Even though there are many attempts to standardize these activities, it is impossible to define a “scientific procedure” to write a good article, to carry out interesting research, to be a

stimulating teacher, to develop an effective website, even to carry out administrative tasks.

In the same manner, the correlation between working hours and productivity has no rational evidence or the information economy. Research into Telework (Ruth 2008) has shown that the same tasks carried out in eight hours in the office have been carried out in three hours at home, because of fewer distractions and a greater determination to save time for leisure. The industrial, symbolic universe still pervades the information one where the greater part of employment contracts in public administration, even the short-terms ones, calculates income on the basis of the numbers of hours in the office.

Therefore, for many jobs, especially in the information economy, the traditional dimension of time and space required by the old organizations of labour has lost its rationality for the production process. Although, its cultural necessity overcomes its technical legitimization. Here lies an institutional gap.

## *2.2 Telework and institutional gap*

When a social change has not been followed by an institutional change, there is a gap between the demands of a social system and its capacity to respond and consequently to maintain the social order (Strassoldo 1993). It happens when a symbolic universe is de-reified by a new one able to be competitive in disseminating new values, new technologies and new social practices.

In the history of western society there are many examples of symbolic universes destroyed rather than deconstructed. Guns, steel and germs have been used to erase cultures and, in doing so, impose an institutional order that in a few generations can fundamentally change the social construction of societies (Diamond 2006). However, in contemporary society characterized by high levels of social differentiation, the relationships between the symbolic universe follow more complex dynamics. It is not just a war between opposites, but a flux between sometimes congenial, at other times conflicting, relationships.

Telework is an application generated by the influence of two different symbolic universes on the organization of labour: the informational universe and the ecological. ICT and sustainability are its respective key concepts.

The informational and ecological symbolic universes affect the material and immaterial level of our culture and are influencing the internal functioning of many social institutions, even the more powerful and conservative ones, such as the market and the State. New technologies arise - such as those to produce renewable energy or to improve the performance of digital networks - in conjunction with corresponding cultural representations - such as environmental risk or the network society. As the article explains in relation to the rebound effect, these two new symbolic universes have controversial relationships although it is not possible to attempt a systematization of their encounters and clashes within the limits of this article.

Nevertheless, its individuation could help to explain, on the one hand, which cultural tendencies belong to the idea of telework, and on the other, which ones are on the on-site working organization. Here lies the deeper level of the resistance to innovation, so evident in telework and likewise in other ICT applications for sustainability: the permanence of an organizational structure produced by the industrial symbolic universe in conflict with the emergence of new social needs, and more and more new, potentially permanent, solutions, given by the informational and ecological symbolic system.

Telework is not compatible with the cultural basis of the industrial symbolic universe, because its implementation involves a different way of conceiving social roles, the power relationships and the sharing of daily tasks between the actors involved in the present organization of labour. Telework, if extended to a relevant part of the labour force, would imply the afterthought of an entire world generated by industry. From the social division of labour to the habits of domestic consumption, from the spatial organization of cities to the logic of public transport services, even different ways of conceiving leisure and our social relationships. Each of these fields is composed of many different social institutions each one with its own defences. It is not a surprise, therefore, that telework runs into a lot of barriers against its expansion.

Reprising the proposal of Berger and Luckmann, there are two strategies of defence that a symbolic universe "besieged" by a process of de-legitimation provides: annihilation, that is to eliminate the heresy, and therapy, that is to incorporate the heresy.

The exposition of the case study still ongoing in the municipality of Torino, facilitates the work of explaining how these strategies are embodied in a provisional typology of fears expressed by employees and employers involved in the project "Telework.To.Com".

## **3. PETRIFYING EFFECT IN TORINO MUNICIPALITY**

The framework of analysis proposed in the previous pages allows us to illustrate the case study, focused on the Torino Municipality, where cultural barriers in implementing telework were expressed both by managers and workers.

The case of telework in Torino is still in progress, and the following analysis concerns just the first phase of the project. Indeed the city of Torino is testing telework on 20 female employees, aiming eventually to extend it to 100 more cases.

The first phase of the project began with a public announcement from the Torino Municipality asking female employees for their availability to take part in telework. The public announcement was sent out after a negative response from the Municipality's steering committee, where the main managers of the City, ignored or openly refused, the request for candidates from their departments. The public announcement selection stipulated multiple criteria: the department's level of teleworkability (De Nicola 1999); the workers' personal situation such as any disabilities; relatives with health problems; distance from the workplace; number of children under the age of eight. In the official request, workers had to include a declaration from their manager certifying their department's teleworkability and proving, with an auto-certificate of their personal situation.

The project schedules each worker's time in the following way: home working 4 days per week and one day (Friday) in the office to brief, with colleagues and managers, the next week. Moreover, each day employers have to give 2 hours of phone availability.

Before starting telework at home there is a period of training in which municipality organizes provide ICT classes, cyber security and work psychology. The teleworker can refuse to continue the trial and decide to go back to the office at any time, giving just two weeks' notice.

Out of more than 3000 potential candidates, just 87, less than 2.5%, answered the call. Looking at the professional profiles of the respondents, 80% came from administrative employees (divided between assistants, instructors and operators), 10%

from welfare officers, 5% from security officers, 5% from cultural – communication services employers.

Before publishing the announcement, the Municipality negotiated with the internal trade unions, and each one of them signed a statement of agreement. Even though the process of training was organized after the selection, the announcement was communicated through an internal department directive. Therefore, such a poor level of participation is not explainable by an insufficient level of information.

Finally, interviews with the employees who responded to the announcement, highlight how they were influenced by the employers' doubts and criticisms of telework, showing that the main reason for the non-participation to the selection resulted from a cultural refusal.

Investigating a social phenomenon - asking where and when it happens - is always better than creating or imagining its development in an experimental or survey context. The concrete opportunity to practice telework provides a more authentic experience than ones created during a survey or even a qualitative interview. Employees and managers reveal their position in the daily social relationships of the workplace: they can express their fears and concerns free from the influence of an external researcher observing them.

Therefore, the methodology utilized in this research is not inspired by quantitative techniques based on empirical evidence. There aren't any measurements of opinion or attitudes of the petrifying effect. (Figure 2)

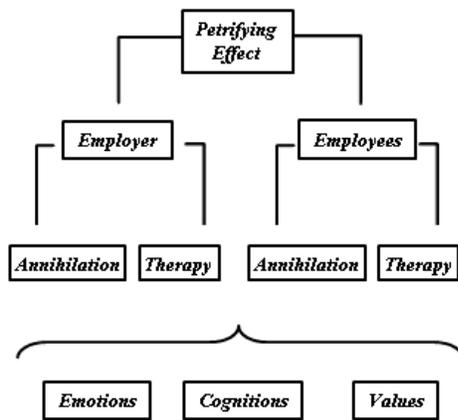


Figure 2: Model of Petrifying Effect in implementation of Telework

The proposed methodology is, both, historical and sociological. I have interviewed a range of key participants involved in the Municipality's telework programme placing their answers within different typologies, following the theoretical analysis described previously.

I divided the managers and employees answers, on the basis of their correspondence with the annihilation/therapy strategy of defence. Therefore, I applied to each matrix the three pillars of each attitude (Cavazza 2005): emotion, cognition and values. Attitudes of emotion were seen through expressions of instinctual feelings like desire or fear; the cognition produced attitudes through the expression of information/disinformation; the value produced attitudes through the cultural belongings interiorized by subjects from social institutions.

The research is still in progress, therefore, the paper at this stage is only able to analyse statements reported by key respondents

during the public announcement, when many of them asked for information and expressed their concerns. These kinds of barriers reveal “annihilation” as the strategy used by employers and managers to keep a distance from telework and “therapy” in order to marginalize telework beyond a minority of cases, or applying to it the cultural categories of the on-site working organization.

If annihilation tries to ignore or to de-legitimate telework, a therapy strategy tries to incorporate telework in actual structures of power derived from the traditional organization of work. Here, telework becomes either a resource to remove problematic employers or a system to improve productivity of marginalized workers. In this perspective telework is always considered a good way to promote employees, but only in particular cases. This is the exception that confirms the rule. It is not by chance that telework is currently promoted as a top-down strategy and that there are only a few cases where employers or workers promote it according to a bottom-up approach.

The “Annihilation” strategy of defence consists, for employees, in:

- **Cognition** - fear of telework's implication for the employment contract: *“It is true that telework entails a lower income? Someone said that maximum wage is 700,00 Euros?”*;
- **Emotion** - fear to change life style habits *“Telework is alienating: after two hours I need to go out of my house. I like my office and my relationships with colleagues”*;
- **Value** - fear of manager's opinions about telework and being disadvantaged/judged as a result verified for results *“I would like to participate but I don't have the courage to ask my manager, because I know that he doesn't want it”* ;

For managers:

- **Cognition** – Correlating better productivity with the physical presence at the workplace *“Telework will definitely allow public dependents to do nothing, not even to go to the office”*;
- **Emotion** - Calibrating own power on the basis of how many employees are under their control *“Ok, I accept offering two of my staff for telework. But I want another two in return!”*;
- **Value** - Excluding teleworkability for specific tasks or for employees because teleworkable would be unworkable even though this is not necessary on technological grounds, *“Here there are no possibilities for telework to be applied. We would like to, but we work in a laboratory every day so...”*;

The “Therapy” strategy of defence consists, for employees of

- **Cognition** - Conceiving telework as a positive resource only for disadvantaged categories of workers: *“Yes I heard about telework: it is good for the disabled, isn't it?”*;
- **Value** - Conceiving telework as a good application but only for people not interested in a career *“If I do telework I renounce to my career: it is impossible to create social networks staying at home”*;

- **Emotion** – Conceiving telework as a way of being marginalized or to be one of the first to be fired *“I would like to apply for telework but if there was a crisis I would be one of the first to be fired”*;

For managers:

- **Cognition** – Regulating a project of telework without any autonomy for the worker; *“Telework could be useful, but it is necessary to regulate daily the tasks of the workers otherwise the productivity drops!”*;

- **Emotion** – Marginalizing telework as a permanent experimentation rather than a systemic solution *“Telework is a*

novelty, it could be productive but we need to observe its implications on a small number of cases”;

- **Value** - Applying to telework the same procedures of control of the on-site working organization “It is necessary to apply some kind of control for teleworkers: for instance, to foresee a required availability with a web cam or by telephone”;

Cultural barriers always reveal fears that individuals are generally not keen to express. The first strategy to prevent them consists of good communication. It is not easy to affect values and emotions, whilst it is different with cognition. This paper is not able to give a complete answer, however, considering the arguments put forward it is possible to make some suggestions that can inform people’s attitudes and opinions regards telework. With this in mind the paper makes ten recommendations:

1. To develop two specific strategies of communication for managers and employers;
  2. To focus each strategy on potential emotional, cognitive and value-based barriers to telework derived by specific organizations where telework is to be implemented;
  3. To communicate to managers first, and later to employers, the advantages and potential risks of telework;
  4. To plan meetings where expert teleworkers introduce their experiences;
  5. To communicate the economic, environmental and social advantages of telework, underlying that it does not entail any change to the contractual aspects of the employment relation;
  6. To communicate how important and productive it is to focus the organization of labour on results rather than on process;
  7. To elaborate specific frameworks, both qualitative and quantitative, to assess the productivity of teleworkers;
  8. To engage trade unions at the beginning of the project in conjunction with political institutions focused on improvements of quality of life for employers;
  9. To introduce telework as a strategic application for Smart City's projects;
  10. To leave to employers the choice full or part time telework, especially in the context of an experimental project;
- There is currently no empirical evidence that shows the role telework plays in relation to improvements in the quality of life of workers. However, telework constitutes an extraordinary opportunity to liberate people from social bonds created by the traditional organization of labour. It does not mean that telework is not able to create other kinds of bonds. For future research the task is to show how telework continues to be alienating and reproduces an unequal social order. For now, a positive result of the research would be to highlight the fact that workers should not fear telework.

## References

[1] Berger, P., Luckmann, T., 1966. *La realtà come costruzione sociale*. Bologna, Il Mulino.

[2] Caragliu A., Del Bo C., and Nijkamp P. 2011. Smart Cities in Europe. *Journal of Urban Technology* 18: 65-82

[3] Cavazza, N. 1995. *Psicologia degli atteggiamenti e delle opinioni*. Bologna, Il Mulino.

[4] De Nicola P. 1998. *Il manuale del telelavoro: nuovi modi di lavorare nella società dell'informazione*, Formello: Seam, 1998.

[5] De Masi D. 1999. *Il futuro del lavoro. Fatica e ozio nella società post-industriale*. Milano, Rizzoli.

[6] Diamond J. 1997. *Armi, Acciaio e Malattie. Breve storia del mondo negli ultimi tredicimila anni*. Torino, Einaudi.

[7] Diana, M. 2001. “*Il telelavoro ci salverà dal traffico?*”, Torino, B-Grande.

[8] Erdmann L. and Hilty M. L. 2009. Scenario Analysis: Exploring the Macroeconomic Impacts of Information and Communication Technologies on Greenhouse Gas Emissions. *Journal for Industry Ecology* 14:5- 824- 841.

[9] Foucault, M. 1993. *Sorvegliare e punire. Nascita della prigione*, Einaudi, Torino.

[10] Hobsbawm, E. J. 1986. *Lavoro, cultura e mentalità nella società industriale*. Laterza. Roma

[11] Holloway, D. 2007. Gender, Telework and the Reconfiguration of the Australian Family Home. In *Continuum*, 21(1), 33 – 44.

[12] Lefebvre, H., 1975. *La produzione dello spazio*. Bologna, Il Mulino.

[13] Lister, K., Harnish T., 2011. *The state of telework in US*. Telework Research Network, San Diego.

[14] Moos M., Audrey J. and Laura C. J. The sustainability of telework: an ecological footprinting approach in *Sustainability. Science, Practice, & Policy* 2:1 (2006): 3-14.

[15] Ruth, S. 2011. The Dark Side of Telecommuting - Is a Tipping Point Approaching? *GMU School of Public Policy Research Paper* No. 2012-02.

[16] Strassoldo, R. 1993. *Le radici dell'erba. Sociologia dei movimenti ambientali*. Napoli. Liguori.

[17] Wapshott, R., Mallett, O. 2012. The spatial implications of homeworking. In *Organization*, January 2012 19: 63-79,

# Towards Automating the Performance Evaluation of Non-Intrusive Load Monitoring Systems

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## ABSTRACT

Non-Intrusive Load Monitoring (NILM) is one of the most well-known techniques used to identify and monitor the energy consumption of individual appliances that co-exist in a building's electrical circuit. However the lack of formal methods to evaluate its performance in realistic scenarios has been delaying the emergence of commercial products. In this paper we discuss the problem and challenges of correctly accessing the performance of these systems and present our hardware-software platform for creating extensive fully labeled datasets for NILM algorithms training, testing and validation where raw electric power consumption and ground-truth consumption data are combined in audio files using the well-known wave format. Towards the end we present our envisioned online framework for enabling the automatic evaluation of NILM algorithms under common sets of performance metrics and consumption data.

## Keywords

Non-intrusive load monitoring, algorithm evaluation, public datasets.

## 1. INTRODUCTION

In the last couple of years Non-Intrusive Load Monitoring has been gaining special attention from the research community playing an important role in the solution of problems related to energy sustainability and smart-grids. However, and despite the fact that NILM is undergoing extensive research towards making it a viable solution for realistic environments, it is evident that there are still some research avenues that need to be explored. For example, most of the existing studies were done in laboratory settings using small and unbalanced datasets without an agreement on what performance metrics should be used, thus making it impossible to generalize results across different scenarios.

This research is a follow up on previous work done at Madeira Interactive Technologies Institute (M-ITI) where we studied the effects of deploying electric energy eco-feedback in households for long periods of time (from 9 up to 58 weeks) [5, 11]. These studies were conducted using a custom made event-based non-intrusive load monitor [13, 14] that we now wish to extend and use to answer two important research questions that we believe have been, for various reasons, largely ignored by both NILM and eco-feedback / HCI research communities: 1) How effective is

NILM in real world scenarios? And 2) what are the best strategies to manually train NILM systems?

In this paper we will be focusing on the first question. We start by introducing NILM and the most relevant literature on this field. We then present the issue of NILM performance evaluation and present some of the existing research initiatives towards viable evaluation solutions. Next we explore the unique characteristics of this kind of systems that make performance evaluation a challenging problem and present our proposed dataset / framework that we believe can play a key role in the ongoing research. We then conclude and outline future work.

## 2. NON-INTRUSIVE LOAD MONITORING

In very broad terms NILM can be defined as a set of techniques used to obtain estimates of the electrical consumption of individual appliances with the application of sophisticated signal processing and machine learning algorithms to Current and / or Voltage measurements, taken at a limited number of locations of the power distribution in a building.

Attempts to monitor and disaggregate electric power from a single point dates back to the early 1980's and were first introduced by Schweppe and Hart [3] who coined the term Non-Intrusive Load Monitoring. Their main assumption was that every change in the total power consumption in a building would happen in response to an electric device changing its state (e.g. an electric stove going from *off* to *on*), therefore the initial approaches consisted mostly on trying to match the amount of change in power related metrics (e.g. real and reactive power) to different appliance states.

NILM has been subject to some extensive research in the past few years and as of today the existing techniques are normally categorized as belonging to one of two approaches namely: event-based and non-event based. These are two very different approaches but in very broad terms one can safely say that the main difference between both is mostly the fact that the former relies on keeping track of every appliance state transition (by means of event detection and classification assuming that the system was previously trained) [2, 10], while the later normally does not assume previous knowledge of the existing appliances and attempts to disaggregate the individual loads from the total power (normally at low sampling rates) by means of techniques like prior models of general appliance types [12] or temporal motif mining [16]. An extensive review of the existing approaches can be found in [17].

Nevertheless, and despite all the research efforts to the date, some considerable challenges are still present. In one hand researchers have to deal with the problem of identifying the individual loads in the ever-growing complexity of the domestic electric circuits

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where they need to account for very different loads like for example variable, multistate and always on loads. On the other hand there is the problem of not having a formal method to evaluate the performance of the different NILM algorithms, therefore making it impossible to generalize research findings across different problems.

### 3. NILM PERFORMANCE EVALUATION

As said above one of the current challenges of NILM research is the need to properly assess the performance of the existing solutions and it is believed that the main reasons for this are: i) the lack of agreement upon what performance metrics should be used to properly compare algorithm results [17] and ii) the almost inexistence of publicly available datasets like the ones that exist for other machine learning problems like character recognition and spam detection as it was said in [5] and [6].

In an attempt to address this, the research community has turned their attention into finding common metrics [4, 8] as well as towards the development of NILM datasets, and to the best of our knowledge there are currently four publicly available solutions that we briefly describe in the next section.

#### 3.1 Publicly Available Datasets

The Reference Energy Disaggregation Data Set (REDD) [6], which was released for the non-event based approaches, consists of whole-home, individual circuit and device-level consumption data from a number of US houses collected over several months' time. The whole-house data was recorded at high frequency (15 kHz) while the circuit / device data was recorded at 0.5 Hz for the individual circuits and 12 Hz for the single electronics.

The Building-Level fully-labeled dataset for Electricity Disaggregation (BLUED) [7] was, on the other hand, especially tailored for the evaluation of event-based approaches. It consists of one week of whole-house Current and Voltage high frequency measurements (12 kHz) from one US home. Additionally, a list of labels (e.g. timestamp and appliance identifier) is provided for each state transition occurred in the dataset for a total of 43 appliances.

Another public dataset is the UMASS Smart\* Home Data Set [1], that despite not having been specifically created for energy disaggregation, provides power data for three sub metered houses in the US. Power measurements are taken at the main panel and individual circuits with 1 Hz frequency. There is also power data available for individual appliances collected every few seconds.

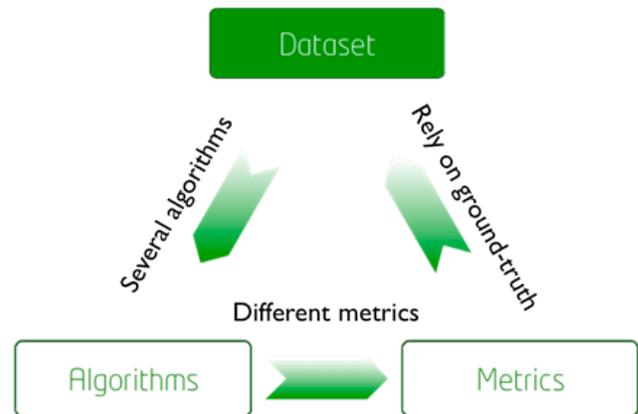
Finally there is also *Tracebase* [14] in which individual appliance consumption data was collected at 1 Hz frequency for 158 appliances instances in a total of 43 different appliance types. The power consumption traces of each individual appliance are stored in individual files.

#### 3.2 Main Challenges

It is our believe that the best way to evaluate the performance of NILM systems is by testing the existing algorithms using the same performance metrics under common datasets that would be faithful representations of real-world scenarios. However it is well known that mimicking real-world scenarios for electric power consumption is not bound to be an easy task especially if we consider all the dynamics of the electric grid in a modern house, for example a proper NILM system will need to account for the presence of unknown and / or malfunctioning appliances, the various operation modes of a single appliance (e.g. a microwave

can be used to make popcorn or to defrost food) as well as the different conditions of operation (e.g. on weekends normally people tend to do the laundry and therefore the system will need to take into consideration the several cycles of the washing machine while the oven might be in use to cook lunch and the vacuum cleaner to clean the car).

In addition to this it is also important to take into consideration the fact that such datasets will need to accommodate several different algorithms and that those algorithms will, on the other hand, require distinct evaluation metrics that can only be calculated using data from the dataset itself. We refer to this as the *NILM Performance Evaluation Loop*, and it is summarized in figure 1.



**Figure 1. The NILM Performance Evaluation Loop: A dataset needs to accommodate several different algorithms that will require their own evaluation metrics which can only be calculated using data from the original dataset.**

Dataset establishments for NILM research have been gaining particular interest in the past few months. In [9] authors introduced what they consider to be the three most important properties of a dataset for NILM research, namely: i) be **informative**, in a sense that the data in it must contain enough information such that it can serve as training and test sets for as much methods as possible; ii) be **diverse**, such that the learning methods are able to capture the dynamics that householders' actions will have on the electric grid; and iii) be **scalable** in a sense that new data (e.g. location of events and steady state areas) can be easily incorporated into an existing dataset.

To these three properties we have added two others that we consider of equal importance: iv) **low overhead and easy access to the data**; and v) **extended ground-truth annotations**. These will be detailed in the next section where we also propose a new kind of dataset for NILM.

#### 3.3 Proposed Dataset

After using the existing datasets for a while it became clear to us that they have a very high footprint, especially when considering the amount of required space in the hard-drive and the volume of code we had to produce in order to interface with the data. Therefore we believe that if a dataset is to be successful it will need to present a low overhead, which can only be achieved by maximizing the *information / file size* ratio and providing easy mechanisms to access the raw waveforms data and the ground-truth annotations.

Furthermore, we also believe that it is of key importance to have as much details of the data as possible. For example, the dataset

should provide extended appliance activity labeling (e.g. which appliance, when and how much energy was used), individual appliance working cycles (it is important to know when cycling appliances like clothes washers or vacuum cleaners are being used as these can strongly affect event detection algorithms). Additionally we also advocate that it would be good to have labels for household activities (e.g. cooking, cleaning or playing) and other sorts of metadata like the weather conditions when the dataset was collected or detailed information about the householders (e.g. how many residents and the number of children).

With this in mind we have decided to build our own public dataset consisting of single appliance consumption data, whole-house plus individual circuit waveforms and extended ground-truth annotations.

### 3.3.1 Single Appliance Dataset

For the appliance-level data collection we have used the Plugwise<sup>1</sup> system (this was also used in [15]), which is a commercially available, distributed sub-metering platform. The system is composed of three main components namely the Circle (also called Module), the Stick and the Source software. Each circle is connected between the appliance being measured and the outlet and the Stick is used to wirelessly (using the ZigBee wireless protocol) interface each deployed circle with a computer that processes and displays the consumption data collected from each individual circle using the source software.

Before displaying consumption information to the users, the measured data is aggregated (by hour, day or month) which is appropriate if the sole purpose is to show the total power consumption of each individual appliance but is far from offering a level of granularity enough to understand in detail the individual behaviors of each appliance, e.g. if it is *On* or *Off* and when these transitions happened. Consequently we had to develop our own Application Programming Interface (API) to provide a more fine access to the consumption data of each individual appliance in the loop.

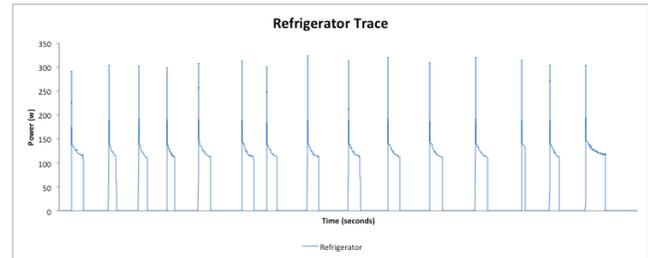
This API is based on the Plugwise Template Engine (PTE), which runs inside a multi-threaded server that is built-in the source software. The PTE works by request, i.e. the clients will request a file with one of the extensions handled by the web-server (we are using XML) and this file will be parsed by the PTE replacing the template tags with the respective values for each plug at the time of request.

Our API follows the event-based software architecture and works by requesting the last known state of the plugged-in modules once every second and dispatching events upon changes in the modules' internal state. The choice of this architecture has proven useful as it offers the possibility of listening and reacting to each module individually according to our needs. From the available events we like to stand out the *AppliancePlugged* / *ApplianceUnplugged* events that are triggered when an appliance is plugged or unplugged from a module and also the *CurrentPowerConsumptionChanged* event that is dispatched whenever there is a change in the power consumption of a given module between two consecutive readings.

Additionally we have also added the possibility of programming custom event detectors for each individual module or groups of modules, which is especially important if we wish to give each

plug the functionality of automatically identifying the appliances that are connected to it.

For the ground-truth collection process we developed an application on top of our API that collects and stores the consumption data of each module in a local database in pre-defined intervals of time (Figure 2 shows the power trace of a refrigerator during 24 hours.). Additionally we also store the aggregated consumption (i.e. the sum of the instantaneous power readings of each individual module) in another table, as this may become important if in the future one wishes to test low-resolution NILM approaches like those mentioned in section 2.



**Figure 2. Partial trace of the refrigerator ground-truth measurements showing that in 24 hours the engine became active 15 times.**

### 3.3.2 Whole-house and Individual Circuit Dataset

For the whole-house data collection we have taken advantage of our custom made Non-Intrusive Load Monitoring framework that is thoroughly described in [13, 14].

The system consists of a netbook that is installed in the main power feed (see Figure 3) covering the entire house consumption and the audio input from the netbook soundcard is used as the data acquisition module using its stereo capabilities (2 channels, one for Current and the other for Voltage).



**Figure 3. Current and Voltage sensors are installed in the main breaker box hence covering the entire house consumption.**

Despite its merits, the soundcard based NILM suffered from a major disadvantage, which resulted from the fact that it only supports two channels. For that reason we have extended the framework such that it would support the usage of a multi-port Data Acquisition board (DAQ).

<sup>1</sup> www.plugwise.com

With this new DAQ (LabJack U6<sup>2</sup>, which offers 14 analog input ports with 16-bit resolution for a maximum sampling rate of 50 kHz) the system gained the capability of monitoring not only the whole-house consumption but also offered the opportunity to monitor the home's individual circuits or even multiple houses (as shown in figure 4).



Figure 4. Six Current sensors installed in the main building breaker box, hence covering the whole-house consumption of six houses from one single location.

### 3.3.3 Putting it All Together

The acquired Current and Voltage waveforms are persisted to the hard-drive in the wave audio format. The main reason behind using such an audio format is its reduced file size (24 hours of Current and Voltage waveforms sampled at 8 kHz with a sample size of 16 bits will take roughly 1.5 GB of disk space) when compared for example with the typical Comma Separated Values (CSV) text format where the same 24 hours of Current and Voltage may take up to 100 GB depending of the used precision.

Another advantage is the possibility of easily adding information about the files through the use of metadata, which can be used to write blocks of text identifying the contents of the file. Additionally, this audio file format also offers the possibility of adding markers directly in the file. These markers are references to positions in the waveforms and can be used to supplement the power measurements with information about individual appliance activity (as shown in figure 5) therefore merging raw waveforms with ground-truth data in one site.

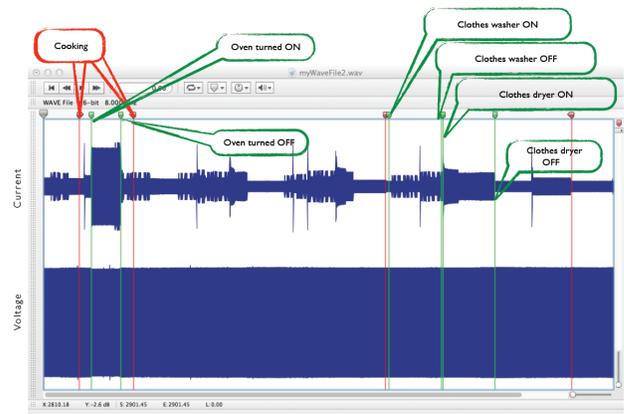


Figure 5. Wave files offer the possibility of embedding markers that can be used to supplement the power measurements with ground-truth data (e.g. appliance and user activities).

## 4. TOWARDS AUTOMATED NILM PERFORMANCE EVALUATION

We are convinced that the ability to merge raw waveforms with ground-truth data is a very important step towards simplifying the process of evaluating different NILM approaches. Moreover, we also believe that to achieve a successful evaluation framework the whole process needs to be straightforward, alleviating researchers from the burden of having to worry about how to access the datasets, what metrics to use and how to compute them. This is why we defined Automated NILM Performance Evaluation as being a four-step process (figure 6).

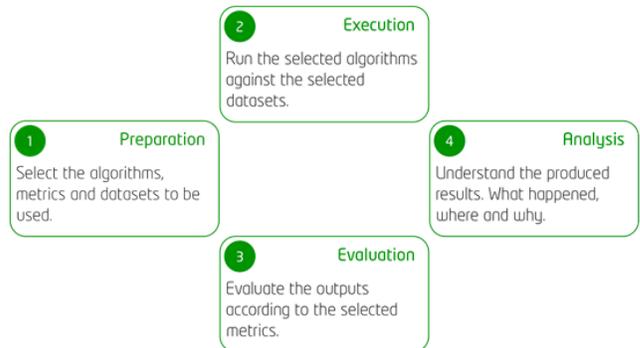


Figure 6. The four steps that encompass the envisioned automated NILM performance evaluation framework.

In the first step (**Preparation**), the researcher will have to select which algorithms will be tested and under which conditions (dataset) and performance metrics that will happen. In the second step (**Execution**) the evaluation framework would take to itself the responsibility of running the algorithms against the datasets selected in the previous step. The same would happen in the third step (**Evaluation**), where the system would compute the metrics selected in the first step and compare them with the results of the execution in step two. Finally in step four (**Analysis**) the researcher would be offered the possibility of looking at the final results thus having the opportunity to understand where and why the algorithms have failed or succeeded.

## 5. CONCLUSIONS

In this paper we have presented the challenges of properly evaluating Non-Intrusive Load Monitoring technology and

<sup>2</sup> www.labjack.com/U6

presented four NILM datasets from which two were specifically created for performance evaluation purposes.

We then discussed in more details the problems behind NILM performance evaluation and introduced our own hardware-software platform for creating NILM datasets. We have also argued that although having proper datasets is of fundamental importance, one can not neglect how these large data sets will be accessed and used by other researchers and presented our vision of a futuristic framework to evaluate NILM algorithms with minimal effort from the researcher.

We are currently planning a long-term deployment of our platform in one or two houses for a couple of weeks in order to obtain some validation. After that we will be looking at ways to automatically annotate the waveforms with data from the individual appliance usage as well as activities from the householders..

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

- [1] Barker, S. et al. 2012. Smart\*: An open data set and tools for enabling research in sustainable homes. *Proceeding of the SustKDD Workshop on Data Mining Applications in Sustainability*. (Beijing, China, August 12, 2012).
- [2] Berges, M., et al. 2011. User-Centric Non-intrusive electricity load monitoring. *Journal of Computing in Civil Engineering* 25, no. 471-480.
- [3] Hart, G. W. 1992. Nonintrusive appliance load monitoring. *Proceedings of the IEEE* 80, no. 12: 1870 – 1891.
- [4] J. Liang, S. K. K. Ng, G. Kendall, J. W. M. Cheng, “Load Signature Study—Part I: Basic Concept, Structure, and Methodology,” *IEEE Transactions on Power Delivery*, vol. 25, pp. 551-560, 2010.
- [5] Quintal, F., Pereira, L. and Nunes, N.J. 2012. A long-term study of energy eco-feedback using non-intrusive load monitoring. *Adjunct Proceedings of the 7<sup>th</sup> International Conference on Persuasive Technology*. (Linköping, Sweden, June 6-8. 2012)
- [6] Kolter, J.Z. and Johnson, M.J. 2011. REDD: A public data set for energy disaggregation and research. *Proceeding of the SustKDD Workshop on Data Mining Applications in Sustainability*. (San Diego, CA, USA, August 21, 2011).
- [7] Kyle, A. et al. 2012. BLUED: A fully labeled public dataset for event-based non-intrusive load monitoring research. *Proceeding of the SustKDD Workshop on Data Mining Applications in Sustainability*. (Beijing, China, August 12, 2012).
- [8] Kyle, A. et al. 2012. Event Detection for Non Intrusive Load Monitoring. *Proceeding of the 38<sup>th</sup> Annual Conference on IEEE Industrial Electronics Society*. (Montreal, Canada, October 25-28, 2012).
- [9] Lai, P., Trayer, M., Ramakrishna, S and Li, Y. 2012. Database Establishments for Machine Learning in NILM. *Proceedings of the 1<sup>st</sup> International Non-Intrusive Load Monitoring Workshop*. (Pittsburgh, PA, USA, May 7, 2012).
- [10] Norfold, L.K. and Leeb, S.B. 1996. Non-intrusive electrical load monitoring in commercial buildings based on steady state and transient load-detection algorithms. *Energy and Buildings* 24, no. 51-64.
- [11] Nunes, N.J., Pereira, L., Quintal, F. and Berges, M. 2011. Deploying and evaluating the effectiveness of energy eco-feedback through a low-cost NILM solution. *Proceedings of the 6<sup>th</sup> International Conference on Persuasive Technology*. (Columbus, OH, USA, June 2-5, 2011).
- [12] Parson, O. et al. 2012. Non-intrusive load monitoring using prior models of general appliance types. *Proceedings of the 1<sup>st</sup> International Non-Intrusive Load Monitoring Workshop*. (Pittsburgh, PA, USA, May 7, 2012).
- [13] Pereira, L. and Nunes, N.J. 2012. Low cost framework for non-intrusive load monitoring and research. *Proceedings of the 1<sup>st</sup> International Conference on Smart Grids and Green IT Systems*. (Porto, Portugal, April 19-20, 2012).
- [14] Pereira, L., Quintal, F., Nunes, N.J. and Berges, M. 2012. The design of a hardware-software platform for long-term energy eco-feedback research. *Proceedings of the 4<sup>th</sup> ACM SIGCHI Symposium on Engineering Interactive Computing Systems*. (Copenhagen, Denmark, June 25-28, 2012).
- [15] Reinhardt, A. et al. 2012. On the accuracy of appliance identification based on distributed load metering data. *Proceedings of the 2<sup>nd</sup> IFIP Conference on Sustainable Internet and ICT for Sustainability*. (Pisa, Italy, October 4-5, 2012).
- [16] Shao, H., Marwah, M. and Ramakrishnan, N. 2012. A temporal motif mining approach to unsupervised energy disaggregation. *Proceedings of the 1<sup>st</sup> International Non-Intrusive Load Monitoring Workshop*. (Pittsburgh, PA, USA, May 7. 2012).
- [17] Zeifman M., and Kurt, R. 2011. Nonintrusive appliance load monitoring: Review and outlook. *IEEE Transactions on Consumer Electronics* 57, no. 1: 76-84.

# Towards a unified energy efficiency evaluation toolset: an approach and its implementation at Leibniz Supercomputing Centre (LRZ)

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## ABSTRACT

The continuous development of HPC - High Performance Computing systems, which are the key technology for many modern computation-intensive applications, has raised the level of computational capabilities. This performance improvement is going hand in hand with higher electrical power requirements like 20MW target power for exascale systems. Even if a such threshold is met, not many of the current HPC sites could support that. Therefore the optimization and reduction of the energy consumption for HPC systems and supporting infrastructure is an important constituent of pragmatics in efficient energy consumption and a crucial milestone in the roadmap to sustainable multi-peta and exascale computing.

This paper addresses the initial steps in reducing the energy consumption of HPC centers, namely the monitoring and analysis of the energy consumption in a holistic way, combining the HPC systems with the cooling and building infrastructure.

## Keywords

Energy consumption, HPC systems, Energy to Solution, energy measurement, consumption monitoring.

## 1. INTRODUCTION

Recent years have brought a rapid growth in the number of applications requiring high performance computations, which are resolved through the use of supercomputers. Scientific applications like weather forecasting, protein structure prediction, drug design, wind turbine optimization, etc. rely on high performance computers [8, 12]. The performance of computation nodes, which is usually defined as speed of execution measured in Floating Point Operations Per Second (FLOPS), has been the main focus area in High Performance Computing (HPC) for a long time. Table 1

illustrates the current and future tendencies towards high performance system architecture. As can be observed, in order to attain higher performance, the number of nodes and cores per nodes are increasing. This development prediction will not only result in a difference of factor  $O(1000)$  in system peak performance, but also in increase of factor  $O(10)$  in power consumption.

Systems	2010	2012	2015	2018	Difference Today & 2018
System Peak [PF/s]	2	25	200	1000	$O(1000)$
Power [MW]	6	6-20	15-50	20-80	$O(10)$
System Memory [PB]	0.3	0.3-0.5	5	32-64	$O(100)$
GB RAM/Core	0.5-4	0.5-2	0.2-1	0.1-0.5	$-O(10)$
Node Performance [GF/s]	125	160-1000	500-7000	1000-10000	$O(10)-O(100)$
Cores/Node	12	16-32	100-1000	1000-10000	$O(100)-O(1000)$
Node memory BW [GB/s]	40	70	100-1000	400-4000	$O(100)$
Number of nodes	~20.000	10.000-100.000	5000-50.000	100.000-1.000.000	$O(10)-O(50)$

Table 1: Future System Architecture [13]

For example, Japan's K computer, which was the world's fastest supercomputer (according to Top500 June 2011 rankings) reports the highest total power consumption of 12.66 MW, with overall computation rate (energy efficiency) of 830.18 MFLOPS per Watt. The power consumption becomes even a bigger concern in exascale computing, which represents further thousandfold increase in computing capability beyond the currently existing petascale [11], and will be the major challenge in the next decade [2, 4]. An exascale system build on K computer technology would use 1.2 GW of power. Even the former most energy-efficient supercomputer (according to Green500 November 2011 rankings), Blue Gene/Q IBM - Rochester, with an efficiency of 2026.48 MFLOPS per Watt will result in 500MW of power consumption at exascale. Additionally HPC systems require proper and continuous cooling, which consequently further increases operational and maintenance costs. As a result, the energy costs of future systems will start dominating the total cost of ownership (TCO), which is defined as an entirety of costs spent on using and acquiring assets [14]. Besides using energy efficient hardware that would lead to en-

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ergy savings, data centers should also concentrate on building energy aware resource infrastructure, which will monitor the energy consumption of the computing system and the building infrastructure from different sensors and will provide means for further analysis of collected data and optimization of energy consumption.

This paper introduces concepts and an architecture for a unified energy measurement and evaluation system, named power data aggregation monitor (PowerDAM). It allows use of the same tool chain for a variety of computing systems, including clusters, grids and supercomputers. PowerDAM is capable of not only monitoring the HPC systems but any other system, that can be represented in hierarchical tree structure, for example building infrastructure. PowerDAM also provides the ability to extend the monitored system set. It is currently deployed centrally (one deployment collecting all energy data from all monitored systems) but it also can be easily modified to be deployed locally (one instance per monitored system).

Depending on the data collected by PowerDAM, different properties can be tracked and analysed such as the system utilization or the energy consumed by a given application which we call "Energy to Solution" (EtS) and which will be discussed in more detail in Section 3. If system hardware allows to track not only power of nodes but also the power of network equipment, cooling hardware as well as other infrastructure, PowerDAM can split the EtS of a scientific application into those different monitored subsystems.

## 2. BACKGROUND AND PROBLEM STATEMENT

Several institutions and societies are addressing issues related to the efficient energy management of data centers and supercomputers [1, 7]. Most notably, The Green Grid, which is aimed towards creation of common set of metrics and development of technical resources to improve resource efficiency in information technology and data centers. According to them, the efficiency of the energy consumption spent on the HPC system site infrastructure can be quantified using the Power Usage Efficiency (PUE) metric, which is defined as the ratio of the total energy used by the data center site divided by the amount of energy that is consumed for pure computational work:

$$PUE = \frac{E_{Cooling} + E_{Power} + E_{Lighting} + E_{IT}}{E_{IT}} \quad (1)$$

where

- $E_{Cooling}$  - is the energy used by the entire cooling system intrinsic to the data center
- $E_{Power}$  - is the energy lost in the power distribution system through line-loss and other infrastructure inefficiencies
- $E_{Lighting}$  - is the energy used to light the HPC system and support spaces
- $E_{IT}$  - is the energy used by all of the IT equipment in the data center/HPC system

It is worth noticing that nowadays more and more new facilities start to reuse the energy from one part of the facility in another, which means that the mentioned PUE metric won't be able to track this alternate usage of the waste energy. In order to also account the reuse of waste energy, The Green Grid has introduced a new metric, called Energy Reuse Effectiveness (ERE), which is defined as:

$$ERE = \frac{E_{Cooling} + E_{Power} + E_{Lighting} + E_{IT} - E_{Reuse}}{E_{IT}} \quad (2)$$

Additionally, for the detailed energy consumption analysis of the entire HPC system, it is important to not only monitor the compute nodes, interconnect network and storage devices but also the internal infrastructure such as cooling and power components [3]. This will further help to generate (or validate existing) model based descriptions of energy flows and data center thermal topology, whose necessity is also emphasized in [15].

With an eye to reducing energy consumption and thus, also carbon footprint [9] and at the same time maintaining efficiency, reliability and availability, one has to be capable of fulfilling a proper analysis in each of the metric areas, which would not be possible without an appropriate energy monitoring infrastructure. Given a unified monitoring of energy consumption over certain time frames, energy efficient resource utilization possibilities can be spotted and subsequently applied.

A set of related works on energy profiling infrastructure is found in [5], [6], where the proposed measurement infrastructures are a combination of software components and additional external hardware components, for example digital meters.

According to principles of energy efficiency in HPC [3], the energy monitoring infrastructure should be able in addition to storing information about the system's workload and various utilization metrics, (e.g. CPU load, temperature per core; per-node information on the interconnect network load, etc.) to hold information regarding all the jobs that are running on the given system. The latter, will allow to measure the amount of consumed energy of a certain job, which is referred as Energy to Solution (EtS). It is also mentioned in [3], that there is a lack of such unified measuring and monitoring infrastructure, despite the presence of necessary individual components.

Compiling all the mentioned design aspects and issues from the discussion above, the key design goals for a unified energy measurement and evaluation infrastructure/system are:

- preservation of data accuracy and resolution
- breakdown of data collection depending on collected data
- ability to report on energy consumption (EtS) conditioned by given job
- independence of monitored (HPC) systems
- ability to collect data from all desired (HPC) systems

- application transparency - adaptability to new measurement needs
- extensibility - ease of integration of new (HPC) systems
- provision of various reporting options (consumption rate, utilization graphs, etc.)

The energy monitoring infrastructure is specifically essential in collecting and analysing power usage data from different data centers and HPC systems. To the best of our knowledge there is no existing monitoring and measuring tool for HPC systems that covers the requirements above without consideration of any additional external hardware components.

Power Data Aggregation Monitor (PowerDAM) is a unified energy measurement and evaluation infrastructure that is built to address above listed problems. PowerDAM allows the use of the same tool chain for all monitored HPC systems. Currently it is monitoring the CoolMUC linux cluster and the migration system SuperMIG, which is the part of SuperMUC supercomputer deployed at LRZ [10].

CoolMUC is the world's first AMD based direct warm/hot water-cooled Massively Parallel Processing (MPP) cluster with 178 nodes (2x8-core AMD CPU and 16GB RAM per node) and uses Simple Linux Utility for Resource Management (SLURM) as a resource management system. It allows power monitoring for nodes, network equipment and cooling hardware, has closed racks (no dependence on room air conditioning) as well as reuses the waste-heat through a SorTech adsorption chiller.

SuperMUC is one of the fastest supercomputers of the world (according to Top500 June 2012 rankings), with 155.656 processor cores in 9400 compute nodes and a peak performance of 3 PetaFLOPS (= 1015 FLOPS). It uses IBM Loadleveler as a resource management system and a new form of warm water cooling developed by IBM, which makes the system more energy efficient. SuperMUC consists of 18 Thin Node Islands and one Fat Node Island which is also used as the Migration System, called SuperMIG, which enables porting applications to the new programming environment. The Thin Node Islands are equipped with Sandy Bridge-EP processors whereas the SuperMIG migration system and the Fat Node Island are equipped with Westmere-EX processors.

The monitored systems have essential differences in the energy measuring infrastructure and were a good starting point for evaluating PowerDAM's extendibility and analysis capabilities.

### 3. DESIGN AND IMPLEMENTATION OF POWERDAM

PowerDAM takes as input the data fetched from sensors and resource management tools and outputs the information on Energy to Solution, system utilization, etc. It uses scripts deployed on the HPC systems side for fetching the required input data from both sensors and resource management tools. Sensor data is obtained directly from the rack-based power distribution units (PDUs) of the system and hence, the scripts which are deployed on the HPC systems side use system specific commands for receiving this data.

Different HPC systems can have different hardware vendors (Intel, IBM, HP, etc.), and hence the way hardware specific data (as power, load, temperature, etc.) is accessed can vary from system to system. This makes it impossible to have just one generic script for all considered systems. PowerDAM provides the capability to extend the set of monitored systems by requesting a certain output format from the scripts deployed on the HPC system side. The collected data is parsed on the PowerDAM side and put into a database for further analysis and statistics.

The required accuracy and resolution of data depends on the sensors deployed on the HPC system side. For that purpose, PowerDAM collects the data from the sensors (via remote invocation of scripts located on the HPC system side) with the same time resolution (if possible).

PowerDAM starts its monitoring routine with the calculation of EtS [9, 3] for all finished jobs. This value indicates the aggregated energy consumption conditioned as by pure computation of the job as well as by partial sub-system components which were utilized during the run of that job: system networking; system cooling and infrastructure. The latter one can be either system specific or encompass a value for multiple systems. The EtS for a given finished job  $J$  on system  $S$  is calculated iteratively, starting from the monitoring step, whose corresponding timestamp is the "closest", to the initial timestamp of job  $J$  using the following formula:

$$EtS(J, S) = \sum_{i=startIteration}^{endIteration} \Delta t_i \cdot P_i(J, S) \quad (3)$$

where

- $startIteration = \min\{iteration \mid J^{startTime} \leq timestamp_{iteration} \leq J^{endTime}\}$
- $endIteration = \max\{iteration \mid J^{startTime} \leq timestamp_{iteration} \leq J^{endTime}\}$
- $J^{startTime}$  and  $J^{endTime}$  are correspondingly start and end times of job  $J$
- $\Delta t_i = timestamp_i - timestamp_{i-1}$ ,  $timestamp_i$  is the timestamp of  $i$ th iteration

Since system cooling and networking power is shared by all nodes the latter two fractions in (4) can be described as follows. The required cooling can be seen as directly related to the consumed power. Therefore, a job's share of system cooling power is directly related to the proportion of its consumed power and the overall power consumed by all nodes at a given iteration/ timestamp. For calculating a job's share of the overall networking power consumption we assume that the moment the node is active it's networking port is active as well. Thus a job's networking share is related to the proportion of its number of utilized nodes and the overall number of active nodes in the system.

$$P_i(J, S) = P_i^J + \frac{P_i^J \cdot P_i^{S_{cooling}}}{P_i^S} + \frac{P_i^{S_{networking}} \cdot N_i^J}{N_i^S} \quad (4)$$

where

- $P_i^J$  is the power sum of all nodes which were utilized by job  $J$  at  $i^{th}$  iteration of monitoring
- $P_i^S$  is the power sum of all system nodes at  $i^{th}$  iteration of monitoring
- $P_i^{S_{cooling}}$  is the cooling power value of entire system  $S$  at the  $i^{th}$  iteration of the monitoring
- $P_i^{S_{networking}}$  is the networking power value of entire system  $S$  at the  $i^{th}$  iteration of the monitoring
- $N_i^S$  is the number of system active nodes at the  $i^{th}$  iteration of the monitoring
- $N_i^J$  is the number of nodes utilized by job  $J$  at the  $i^{th}$  iteration of the monitoring

Currently, the connector for obtaining building infrastructure sensor data (e.g. cooling pumps, warm and cold water cooling loops, air chillers) is not implemented yet, and hence PowerDAM does not report on those energy consumption rates. Nevertheless, it provides easy means for adaptability to future measurement requirements, including adaptation of building infrastructure reporting.

After the EtS calculation is done, PowerDAM updates the corresponding fields (energy for compute nodes, cooling, networking, infrastructure) for all finished jobs in the database and starts to fetch the actual sensor and job scheduler data from monitored HPC systems. The routine is then repeated (after a configurable amount of waiting time) according to the above description and the workflow illustrated in Figure 1.

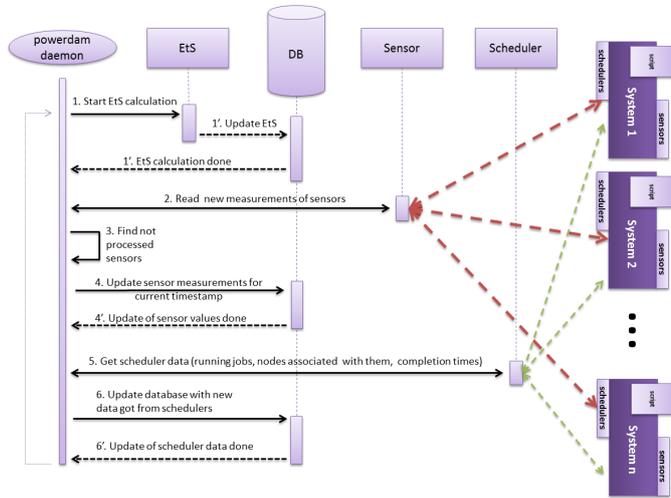


Figure 1: PowerDAM Workflow

Figure 2 illustrates one of the PowerDAM's EtS reporting options: EtS of all finished jobs which were submitted by user *di56biz* on the CoolMUC MPP linux cluster system.

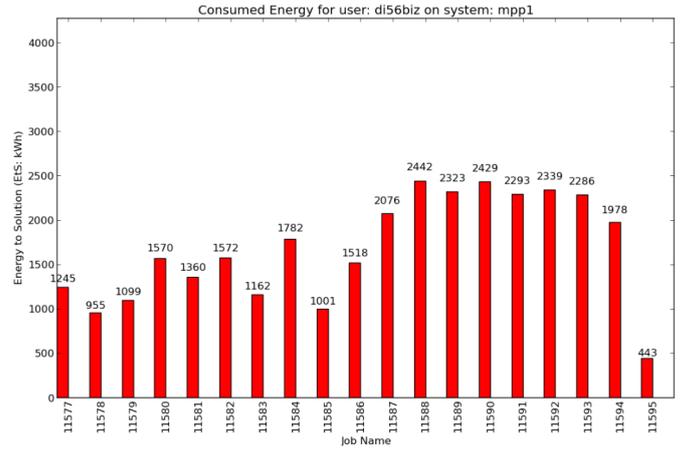


Figure 2: EtS Report For User With Id: di56biz

## 4. POWERDAM FOR COOLMUC AND SUPERMIG

This section presents some PowerDAM output for a job on CoolMUC linux cluster system and SuperMIG migration system. Euroben Kernel for mod2am: dense matrix-matrix multiplication application:

$$C(m, n) = A(m, l) * B(l, n) \quad (5)$$

with  $m = l = n = 200$  was used in our example. Application was compiled with Intel compiler and Intel's MKL (Math Kernel Library). The following subsections present the results for the example application on CoolMUC and SuperMIG systems.

### 4.1 Example Application on CoolMUC

16 OpenMP threads were used for the Euroben mod2am application: 1 thread per core, 16 cores for one node of CoolMUC cluster.

The consumed energy of this application can be queried by

```
./ets -system=SystemName -job=jobID [-trace]
```

command invocation, where the latter *-trace* option, when specified, prints in addition to aggregated EtS also the detailed sensor trace of all the nodes which were utilized by the given job (Figure 3).

It is possible that some sensor measurements are invalid. Therefore in order to minimize the error this invalid data is approximated using linear interpolation. At the end of the considered trace a user is informed on the replacement of source data if any.

As can be observed, the program ran 44 minutes consuming around 0.23 kWh energy. Figure 4 illustrates the power graph of all nodes, which were utilized by the job during its execution.

```

time, sensor, power(Watts)
2012-08-27 15:51:08, mpp1_networking_power:5642.0
2012-08-27 15:51:08, mpp1_cooling_power:3810.1
2012-08-27 15:51:08, mpp1.lxa164_power:235.0
2012-08-27 15:51:08, mpp1.lxa164_load:223.262
2012-08-27 15:51:08, job.mpp1_cooling_power:9.23934355346
2012-08-27 15:51:08, job.mpp1_networking_power:13.6816294398
2012-08-27 15:52:09, mpp1_networking_power:5655.0
2012-08-27 15:52:09, mpp1_cooling_power:3767.4
2012-08-27 15:52:09, mpp1.lxa164_power:235.0
2012-08-27 15:52:09, mpp1.lxa164_load:1572.7
2012-08-27 15:52:09, job.mpp1_cooling_power:35.7341884859
2012-08-27 15:52:09, job.mpp1_networking_power:53.6382746424
...
2012-08-27 16:34:30, mpp1_networking_power:5664.0
2012-08-27 16:34:30, mpp1_cooling_power:3924.9
2012-08-27 16:34:30, mpp1.lxa164_power:242.0
2012-08-27 16:34:30, mpp1.lxa164_load:1572.74
2012-08-27 16:34:30, job.mpp1_cooling_power:37.370066781
2012-08-27 16:34:30, job.mpp1_networking_power:53.9285225733
EtS is: 0.226854 kWh

```

Figure 3: EtS Trace Of The Application On CoolMUC

```

time, sensor, power(Watts)
2012-09-28 14:52:38, SuperMIG.i01r11c02s03_power:379.0
2012-09-28 14:52:38, job.SuperMIG_cooling_power:0.0
2012-09-28 14:52:38, job.SuperMIG_networking_power:0.0
2012-09-28 14:53:38, SuperMIG.i01r11c02s03_power:487.167
2012-09-28 14:53:38, job.SuperMIG_cooling_power:0.0
2012-09-28 14:53:38, job.SuperMIG_networking_power:0.0
2012-09-28 14:54:38, SuperMIG.i01r11c02s03_power:497.0
2012-09-28 14:54:38, job.SuperMIG_cooling_power:0.0
2012-09-28 14:54:38, job.SuperMIG_networking_power:0.0
...
2012-09-28 15:19:41, SuperMIG.i01r11c02s03_power:508.0
2012-09-28 15:19:41, job.SuperMIG_cooling_power:0.0
2012-09-28 15:19:41, job.SuperMIG_networking_power:0.0
2012-09-28 15:20:41, SuperMIG.i01r11c02s03_power:508.0
2012-09-28 15:20:41, job.SuperMIG_cooling_power:0.0
2012-09-28 15:20:41, job.SuperMIG_networking_power:0.0
EtS is: 0.244362 kWh

```

Figure 5: EtS Trace Of The Application On SuperMIG

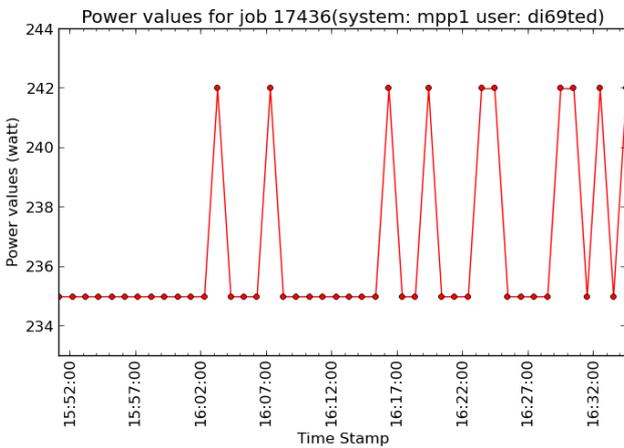


Figure 4: Accumulated Power Values Of Utilized Nodes On CoolMUC

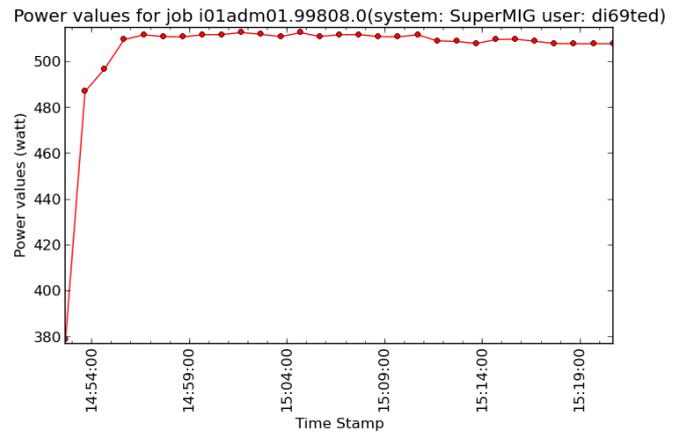


Figure 6: Accumulated Power Values Of Utilized Nodes On SuperMIG

## 4.2 Example Application on SuperMIG

For comparison reasons, the same amount of threads was used for the dense matrix-matrix multiplication application on SuperMIG, even though each node on it has 40 cores.

The application ran 28 minutes on SuperMIG consuming approximately 0.25 kWh energy. Figure 5 illustrates Power-DAM EtS trace. The values for the cooling and networking power are zero, because currently there is no sensor data collected.

Figure 6 illustrates the accumulated power values of all nodes, which were utilized by the job during its execution.

As observed, the maximum node power is higher than the node power from CoolMUC. The most likely reason is the higher number of cores in the SuperMIG node and even though we only used 16 cores in our example, we still need supply power to 24 unused cores. But interestingly enough, SuperMIG had higher performance rate in comparison with the CoolMUC system.

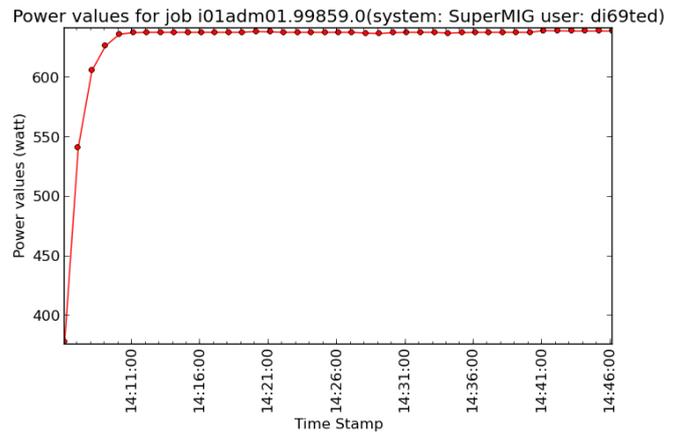
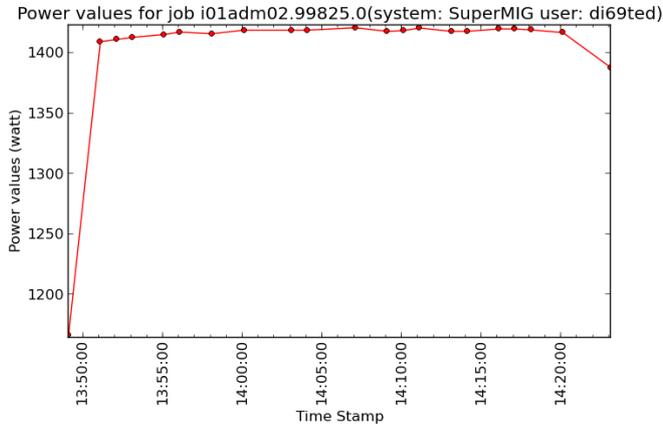


Figure 7: Accumulated Power Values Of Utilized Nodes On SuperMIG In the Case Of 40 Tasks

Figure 7 shows the power values for the case, when SuperMIG's node was full utilized, i.e. 40 OpenMP threads

used, but with problem dimension of  $m = l = n = 250$  and  $iterations = 1500000$ .

Figure 8 illustrates the same dense matrix-matrix multiplication application (with  $m = l = n = 300$ ,  $iterations = 1500000$  problem size) running on two nodes, this time again utilizing all the cores, i.e. 80 tasks, and using MPI. As shown in Figure 9, the program ran approximately 35 minutes consuming around 0.82 kWh energy.



**Figure 8: Accumulated Power Values Of Utilized Nodes On SuperMIG In The Case Of 80 Tasks**

```
time, sensor, power(Watts)
2012-09-29 13:48:04, job.SuperMIG_cooling_power:0.0
2012-09-29 13:48:04, job.SuperMIG_networking_power:0.0
2012-09-29 13:49:04, SuperMIG.i01r01c03s05_power:647.0
2012-09-29 13:49:04, SuperMIG.i01r01c03s09_power:519.2
...
2012-09-29 14:23:07, SuperMIG.i01r01c03s05_power:702.4
2012-09-29 14:23:07, SuperMIG.i01r01c03s09_power:685.6
2012-09-29 14:23:07, job.SuperMIG_cooling_power:0.0
2012-09-29 14:23:07, job.SuperMIG_networking_power:0.0
EtS is: 0.819271 kWh
```

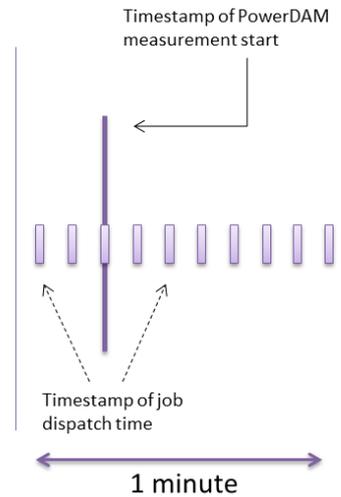
**Figure 9: EtS Trace Of The Benchmark On SuperMIG In The Case Of 80 Tasks**

It is notable that since the monitored PDUs from which the sensor data is obtained in our current system setup deliver measurements in one minute intervals, there is a big probability that the timestamps which correspond to monitoring steps of PowerDAM do not match with exact starting/ending timestamps of jobs (Figure 10). This results in a maximum error of 2 minutes (1 minute for start time detachment and 1 minute for end time detachment) in the measurements. This means that in order to have an error of less than 5% in the measurement, the application has to run a period of at least 40 minutes.

## 5. CONCLUSION AND FUTURE WORK

A new concept for energy efficiency monitoring, architecture and main functionality of a unified energy measurement and evaluation system was introduced and implemented.

The developed energy measurement and evaluation tool will give a thorough description of the power consumption for the entire HPC system including power consumption on a per-job basis and system internal infrastructure if sensor data is



**Figure 10: PowerDAM Measurement Interval and Its Time Error**

available. This allows to evaluate the energy consumption and the energy efficiency of the HPC system and site infrastructure. Additionally the collected data can be used in the future:

- to investigate the power consumption of applications and possibly new algorithms
- to assess the energy saving features of the platform
- to calculate the PUE and ERE of the facility
- to monitor and to optimize the energy consumption of the data center infrastructure
- to support certain schedulers in energy efficient decisions

In the short term, the monitoring system will be extended to collect infrastructure measurements related to power consumption and HPC system, such as cooling pumps, warm and cold water cooling loops, outside temperatures, etc.

In the long term, it is planned to improve the backend infrastructure, to ensure scalability for millions of sensors, expected with next generation data centers and HPC systems. This energy measuring and monitoring infrastructure will form the basis for further investigations regarding energy consumption and energy efficiency optimization at the Leibniz Supercomputing Center (LRZ).

## 6. ACKNOWLEDGMENTS

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## 7. REFERENCES

- [1] ASHRAE TC 9.9 2011. Thermal guidelines for data processing environments - expanded data center classes and usage guidance. <http://tc99.ashraetcs.org/>.
- [2] Tilak Agerwala. Exascale computing: the challenges and opportunities in the next decade. In *Proceedings of the 15th ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming, PPOPP '10*, pages 1–2, New York, NY, USA, 2010. ACM.
- [3] Axel Auweter, Arndt Bode, Matthias Brehm, Herbert Huber, and Dieter Kranzlmüller. Principles of energy efficiency in high performance computing. In *Proceedings of the First international conference on Information and communication on technology for the fight against global warming, ICT-GLOW'11*, pages 18–25, Berlin, Heidelberg, 2011. Springer-Verlag.
- [4] S. Borkar. The exascale challenge. In *VLSI Design Automation and Test (VLSI-DAT), 2010 International Symposium on*, pages 2–3, april 2010.
- [5] G. Da Costa, J.-P. Gelas, Y. Georgiou, L. Lefevre, A.-C. Orgerie, J.-M. Pierson, O. Richard, and K. Sharma. The green-net framework: Energy efficiency in large scale distributed systems. In *Parallel Distributed Processing, 2009. IPDPS 2009. IEEE International Symposium on*, pages 1–8, may 2009.
- [6] Rong Ge, Xizhou Feng, Shuaiwen Song, Hung-Ching Chang, Dong Li, and K.W. Cameron. Powerpack: Energy profiling and analysis of high-performance systems and applications. *Parallel and Distributed Systems, IEEE Transactions on*, 21(5):658–671, may 2010.
- [7] The Green Grid. <http://www.thegreengrid.org>, 2012.
- [8] P. Kogge. The tops in flops. *Spectrum, IEEE*, 48(2):48–54, february 2011.
- [9] T. Minartz, T. Ludwig, M. Knobloch, and B. Mohr. Managing hardware power saving modes for high performance computing. In *Green Computing Conference and Workshops (IGCC), 2011 International*, pages 1–8, july 2011.
- [10] Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities. <http://www.lrz.de/>, 2012.
- [11] Committee on the Potential Impact of High-End Computing on Illustrative Fields of Science and National Research Council Engineering. *The Potential Impact of High-End Capability Computing on Four Illustrative Fields of Science and Engineering*. The National Academies Press, 2008.
- [12] G. Petrone, C. de Nicola, D. Quagliarella, J.A.S. Witteveen, J. Axerio-Cilies, and G. Iaccarino. Wind turbine optimization under uncertainty with high performance computing. In *41st AIAA Fluid Dynamics Conference, Honolulu, Hawaii*, 2011.
- [13] Rick Stevens and Andy White. Exascale prediction. IESP Meeting, Oxford, 2010.
- [14] Marc Wouters, James C. Anderson, and Finn Wynstra. The adoption of total cost of ownership for sourcing decisions—a structural equations analysis. *Accounting, Organizations and Society*, 30(2):167–191, February 2005.
- [15] Rongliang Zhou, Zhikui Wang, C.E. Bash, and A. McReynolds. Data center cooling management and analysis - a model based approach. In *Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2012 28th Annual IEEE*, pages 98–103, march 2012.

# CONFERENCE RECOMMENDATIONS: HOW TO IMPROVE THE CONTRIBUTION OF ICT TO SUSTAINABILITY

## Summary

The speakers and participants of ICT4S 2013 have endorsed a set of recommendations to stakeholders derived from the research results presented and discussed at the conference. Statements provided by the speakers before the conference were compiled to a draft document that was then being discussed in plenary sessions. The main directions of impact of this document can be grouped into three categories with two main issues in each category:

- Sustainability in ICT:
  - There is a large unused potential to save energy by *designing software for energy efficiency*. The power of software should be used more systematically to reduce the energy consumption of hardware.
  - The short service lives of hardware products in combination with the broad variety of scarce material resources used in production lead to material losses and environmental pollution. Efforts are needed to *reduce hardware obsolescence and to close material cycles* at a global scale.
- Sustainability by ICT:
  - ICT offers a high potential for *more intelligent energy management in buildings*, in particular for heating and cooling and in connecting the buildings to smart grids. Smart homes and offices can substantially contribute to sustainability.
  - Urban structures should be planned, managed and further developed in a way taking into account the *structural changes enabled by ICT*, supporting a change towards a sustainable information society that will need less energy and physical transportation.
- Overarching Aspects:
  - ICT applications can and should be used to *create incentives* for more sustainable behaviour and to support people systematically in adopting more sustainable lifestyles.
  - Progress in these areas requires systematic *research and education* in many fields contributing to ICT4S, including systematic interdisciplinary efforts in “ICT for Sustainability”.

These general directions are refined to detailed recommendations addressing specific stakeholders in the long version of this document.

## Preamble

The transformational power of ICT can be used to make our patterns of production and consumption more sustainable. However, the history of technology has shown that increased energy efficiency does not automatically contribute to sustainable development. Only with targeted efforts on the part of politics, industry and consumers will it be possible to unleash the true potential of ICT to create a more sustainable society.

Speakers and participants of ICT4S 2013, the First International Conference on ICT for Sustainability, held February 14-16 in Zurich, Switzerland, have formulated the following recommendations to stakeholders as a result of their research and discussions, grouped in six main themes.

### A. Sustainability in ICT

#### 1. Use the power of software to reduce hardware energy consumption.

Decisions made in systems software and applications software development have important consequences for the hardware load and the resulting energy consumption.

- 1.1 *Software engineers* should become aware of the implications of software structure for energy consumption. The ability to address energy issues, including the automation of energy-efficient behaviour of software systems, should be included in the education of software engineers.
- 1.2 *Researchers* should create more knowledge about the relationship between software structure and energy consumption and how to minimize the latter under practical conditions, including the operation of legacy systems.
- 1.3 *Standardisation bodies* should develop metrics and labels for software energy efficiency based on established and emerging knowledge, *policy makers* should encourage the development of such software energy metrics and standards.
- 1.4 *Organisations providing ICT services* (including cloud computing services) should make the energy consumed in providing a service transparent to their customers.
- 1.5 *Organisations using ICT services* should endorse cloud computing where this clearly leads to net energy savings.
- 1.6 *The ICT Community* should encourage more open sharing of knowledge about software and hardware development.

#### 2. Reduce hardware obsolescence and close material cycles.

Most ICT goods as they are produced, used, and disposed of today are “inherently unsustainable”, both environmentally and socially, from a life cycle perspective.

- 2.1 *Hardware designers and software engineers* should be aware of the consequences of their decisions in terms of hardware obsolescence, decomposability, reusability and recyclability, and strive for intrinsic sustainability.

- 2.2 *Researchers* should create more knowledge about the relationship among hardware architecture, software architecture, ICT business models, and the service life of hardware.
- 2.3 *Standardisation bodies* should define metrics for the life-cycle-wide sustainability of ICT solutions; the metrics should (a) be based on established knowledge, (b) be transparent and (c) be helpful to the final consumer.
- 2.4 *Consumer organisations* should support consumers in demanding and using sustainable ICT solutions and in developing sustainable behaviour in using ICT goods and services.
- 2.5 *ICT manufacturers* should abolish planned obsolescence, declare the resources and CO2 footprint used in production and include informal e-waste recycling in their Corporate Social Responsibility (CSR) policies.
- 2.6 *ICT providers* should shift their business models towards services (in particular: infrastructure as a service) in order to reduce incentives for hardware obsolescence. The technologies used in service-oriented computing should preserve privacy to be acceptable.
- 2.7 *Policy-makers* should make every effort to effectively close the material cycles of the scarce elements used in ICT hardware – e.g., through eco-design, take-back and recycling of hardware.
- 2.8 *Policy-makers* should create better conditions for leasing, renting, and collective/cooperative use of ICT devices.
- 2.9 *International organisations* should develop a global transparency platform for ICT hardware materials, supporting designers and engineers with sustainable data for the hardware's impact on resource consumption and environmental impact.
- 2.10 *Regulators* should effectively prevent that e-waste is exported to poor countries to avoid the cost of the recycling or waste management.

## **B. Sustainability by ICT**

### **3. Enable smart energy use in buildings.**

The energy used in buildings for heating, cooling and the operation of appliances should be reduced and shifted to renewable energy sources, using ICT as an enabling technology.

- 3.1 *ICT innovators* should support the end consumers of energy in shifting from 'demand-' to 'supply-driven' behaviour, changing behaviours towards a more sustainable lifestyle.
- 3.2 *Manufacturers and providers* should increase the energy awareness of the technical systems that provide, store, transmit and use energy.
- 3.3 *Investors and innovators* should create business models that make it easy for real estate owners as customers to purchase increased energy efficiency via innovative use of ICT, in particular ICT-enabled energy rating systems, making the energy infrastructure smarter.

- 3.4 *Public authorities* should create and provide knowledge about energy efficiency potentials of existing buildings through ICT to real estate owners making them “knowledgeable demand shapers”.
- 3.5 *Standardisation bodies and manufacturers* should increase the transparency of any energy consumption of devices in a way that customers understand (i.e. real money); include the whole infrastructure from the sensor up to the display.
- 3.6 *Standardisation bodies* should develop standards for “building operating systems” to enable different systems to communicate with each other to save energy by information sharing and cooperation.
- 3.7 *Standardisation bodies and policy makers* should establish labels (e.g. based on EN 15323) for energy-efficient building automation.
- 3.8 *Professional associations and academia* should establish training programs for professionals in energy-efficient building automation technology.
- 3.9 *Energy industry and interdisciplinary researchers* should develop smarter grids and homes in a way that does not affect the privacy of the users.
- 3.10 *ICT providers* should improve the ways people interact with buildings and encourage sustainable behaviour.

#### **4. Make use of the sustainability potential of the information society in planning and managing urban structures.**

- 4.1 *City planners* should embrace the opportunities of the information society by planning for the reduction of space heating and cooling, for less parking places, for collaborative consumption, for more local work and for other structural changes enabled by ICT.
- 4.2 *City planners* should use ICT solutions supporting the planning process to develop urban structures from an energy consumption perspective.
- 4.3 *Local and regional authorities* should employ experts in *ICT for Sustainability* to include the opportunities of the information society in their planning, regulation and procurement (capacity building in local and regional authorities).
- 4.4 *Public transportation providers and road authorities* should provide travel plans nudging energy-efficient travel with minimal environmental impact.

### **C. Overarching aspects**

#### **5. Create incentives for sustainable behaviour**

- 5.1 *Companies with their own ICT departments* should create incentives for saving energy. Create a green IT-strategy that increases the employee’s awareness of sustainability.
- 5.2 *Utility companies, smart grid researchers and developers* should utilize community based social marketing to enable consumer behavioural change as an integral part of the smart grid, in a privacy-preserving manner.

- 5.3 *Academic research* should develop better metrics for the sustainability of ICT services that are needed as a basis for the creation of incentive systems.
- 5.4 *Regulatory bodies*, when creating incentives for the use of a certain kind of technology, should make the intentions behind the use and promotion of the technology as transparent as possible.
- 5.5 *Academic institutions, non-governmental organisations*: Use social media to improve collective decision-making and encourage sustainable behaviour, bearing in mind the energy consumption issues of the media as well.
- 5.6 *International organisations*: provide a platform to share best practices, promote partnership and encourage cross-sectional collaboration.
- 5.7 *Policy makers, researchers, ICT providers and designers*: Be aware of and try to minimize unintended and indirect sustainability impacts (i.e. rebound effects) of ICT.
- 5.8 *Social scientists* should devise ways to encourage sustainable ICT use by building up peer group pressure and 'nudge' techniques (e.g. behaviour-changing Apps).

## **6. Develop research and education for ICT4S.**

- 6.1 *Academia* should engage in interdisciplinary research about the actual impacts of systems developed to support sustainability.
- 6.2 *Educational institutions* should include cross-disciplinary classes for learning about the relation between ICT-related decisions and sustainability in relevant courses.
- 6.3 Aspects of sustainability should be emphasized in the fields of computer architecture, software engineering and programming.

Zurich, February 15, 2013

*Revised Version of May 23, 2013*

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# AN ANNOTATED BIBLIOGRAPHY OF CONCEPTUAL FRAMEWORKS IN ICT FOR SUSTAINABILITY

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This bibliography covers articles published in journals, conference proceedings or as book chapters that reflect on the role of Information and Communication Technology (ICT) in society's challenge of developing more sustainable patterns of production and consumption. The bibliography is focused on contributions presenting conceptual frameworks intended to structure this interdisciplinary field of research. Some sources not explicitly presenting a conceptual framework were included for their contribution to structuring the research field.

*The earliest frameworks classify ICT applications designed to process environmental data or information. They could be called 'application-oriented' frameworks.*

(1) Radermacher, Riekert et al. (1994) introduce five categories of ICT systems for environmental information processing: (a) specific monitoring and control systems that “interact very closely with environmental objects and processes”, (b) applications of conventional information systems “for input, storage, structuring, integration, retrieval, and presentation of various kinds of environmental information”, (c) specialized evaluation and analysis systems supporting “the processing of environmental data using complex mathematical-statistical analysis methods and modeling techniques”, (d) planning and decision support systems to “support decision makers by offering criteria for the evaluation of alternatives or for justifying decisions”, and (e) “integrated environmental information systems” combining some of the functions (a) – (d) (Radermacher, Riekert et al., 1994, 4-5).

(2) Hilty, Page et al. (1995) extend this approach by relating the five system types to seven computational methodologies, yielding a 5 x 7 matrix that can be used to discuss the relevance of each methodology for each system type. The methodologies are: modelling and simulation, knowledge-based systems, user interface design, computer graphics and visualization, artificial neural networks, and data integration. The paper cites examples for environmental applications of all methodologies and introduces the term “Environmental Informatics” for the systematic application of information processing methodologies in the environmental domain (Hilty, Page et al., 1995, 1). The development of Environmental Informatics is documented in the proceedings of the three main conference series of this community.<sup>1</sup>

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<sup>1</sup> Conference series: Environmental Informatics (EnviroInfo, n.d.), International Symposium on Environmental Software Systems (ISESS, n.d.), International Conference on Information Technologies in Environmental Engineering (ITEE, n.d.). A part of this work can be accessed via the ICT-ENSURE literature information system (ICT-ENSURE, n.d.), a result of the European Commission's support action for building a European Research Area in the field of “ICT for Environmental Sustainability” 2008-2010.

*Some approaches focus on impacts of ICT on the environment instead of environmental applications. These impacts (or effects) can be positive or negative with regard to sustainability goals. This type of framework could be called 'impact-oriented'.*

(3) Berkhout and Hertin (2001) introduce in their OECD report the distinction among first-, second- and third-order effects of ICT, which has been widely used in later literature: (1) “direct environmental effects of the production and use of ICTs”, (2) indirect environmental impacts through the change of “production processes, products, and distribution systems”, and (3) indirect environmental impacts “through impacts on life styles and value systems” (Berkhout and Hertin, 2001, 2). This framework became seminal and has been re-used and re-interpreted many times.

(4) If we restrict our focus to the special case of impacts of telecommunications on transportation, even earlier frameworks should be mentioned, such as the typology introduced by Mokhtarian (1989) and its predecessors in the field. The basic idea is here that telecommunications can decrease the demand for transportation by substituting it, but also increase the demand by stimulating it (inducing new demand). Telecommunications have also an effect on the supply of transportation by optimizing the use of the existing networks. This can lead to rebound effects because the time saved for travel may be used for other trips, and “telecommunications infrastructure and services may lead to long-term changes in land-use patterns (e.g., more dispersed residential and employment locations) that may in turn result in longer trips or more travel in general.” (Mokhtarian, 1989, 235)

(5) Spreng's Triangle (Spreng, 2001) is a framework in the same intellectual tradition. The approach is based on the idea of “substitutional relationships between time, energy, and information” (Spreng, 2001, 83). Spreng's main conclusion from theoretical considerations and case studies is: “Both, IT's potential to do things with less energy input, thus generally more sustainably, and IT's potential to do things faster, i.e. less sustainably, are enormous. Unfortunately, so far, the latter potential has been extensively tapped while the former remains but potential.” (Spreng, 2001, 89) The approach has been recapitulated by Aebischer (2009) and Spreng (2013).

(6) Hilty and Ruddy (2000) combine the distinction among substitution, induction and optimization effects (based on Mokhtarian, 1989) with the application-oriented approach. They structure the applications in public-sector applications (“Environmental Information Systems”, EIS) and private-sector applications (“Environmental Management Information Systems”, EMIS), where both application types are further classified by their objectives: EIS may have the objective of creating “public awareness about the condition of public goods”, fulfilling “prerequisites for political decisions” or just “executing instruments of environmental policy”. EMIS may have the objectives “legal compliance”, “environmental reporting to stakeholders” or “eco-efficiency and material flow management” (Hilty and Ruddy, 2000, 3).

*Several attempts have been made to extend the focus from environmental applications and effects to a broader concept of sustainability.*

(7) Isenmann (2001) proposes to extend Environmental Informatics to “Sustainability Informatics” by adding an ethical dimension that addresses issues of acceptability of ICT solutions to human individuals, to the whole society, and to the global ecosystem. The aim of the ethical dimension is to avoid that “we become ‘information giants’ having huge data bases [...] but ‘knowledge pygmies’ who lack of ethical thinking about ends and guidance.” (Isenmann, 2001, 131)

(8) The Working Group GIANI<sup>2</sup> of the German Informatics Society (GI) presents a roadmap to a “sustainable information society” (Dompke et al., 2004) basically combining the Isenmann (2001) with the Berkhout and Hertin (2001) approach. Sustainability is decomposed into three nested spheres along the line of Isenmann’s acceptability criteria: the human individual, society, and nature.<sup>3</sup> Berkhout and Hertin’s three orders of effect are re-interpreted as “effects of ICT supply” (first order), “effects of ICT use” (second order) and “systemic effects of ICT” (third order). Combining these two dimensions (sustainability aspects and orders of effect) leads to a 3 x 3 matrix, or nine areas of opportunities and risks of ICT with regard to sustainability. The report identifies needs for action for each area and formulates recommendations to academia, politics, business and NGOs. The report concludes: “There is no doubt that ICT offer great potential for sustainable development that has hardly been tapped yet. However, unless the downsides and risks of ICT described above are assessed realistically and discussed openly, the opportunity to reorient our activities towards a sustainable Information Society may be lost.” (Dompke et al., 2004, 11)

(9) Naumann (2008) makes another proposal to extend Environmental Informatics to Sustainability Informatics. He structures the research field into four focal areas: (i) “Analysing the Application Domain” by using ICT to observe, measure, model and simulate phenomena within environment, business, and society; (ii) “Analysing and Classifying the Impacts of ICT” using the framework introduced by Dompke and colleagues (2004) and related approaches; and (iii) “Design of Software Systems” following principles of sustainability, such as using “algorithms which reduce directly or indirectly power consumption and environmental pollution” (Naumann, 2008, 385f.). The last area is called “Sustainable Software Engineering”, which addresses two main issues. The first one is “system-bounded sustainability”, covering quality aspects of the software itself. The second one is “overall sustainability” or “system-unbounded sustainability”, covering the interaction between the software and “ecological, economical, and social systems” (Naumann, 2008, 386).

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<sup>2</sup> GI-Arbeitsgruppe Nachhaltige Informationsgesellschaft. The report was published in German under the title “Memorandum Nachhaltige Informationsgesellschaft” (“Memorandum Sustainable Information Society”) by the Fraunhofer Society, with a one-page summary in English (Dompke et al., 2004, 11).

<sup>3</sup> By decomposing sustainability into three nested spheres, the working group intentionally deviates from the frequently used “three pillars” or “three dimensions” approach to sustainability that puts environment, society, and economy on the same level.

*Life-cycle assessment (LCA) is standard practice for detecting the overall environmental impact of providing a functional unit by following products from cradle to grave.<sup>4</sup> Life-cycle thinking and methodology can be applied to any function provided by any product, including ICT products or products affected by ICT.<sup>5</sup>*

(10) Hilty (2008, Chapter 6) uses the distinction among substitution, induction and optimization inspired by Mokhtarian (1989) to link life cycles of ICT products with life cycles of other products. The links between life cycles thus consist of substitution effects, induction effects, and optimization effects. For example, a service provided by an ICT product can be used to optimize the design, the production, the use, or the end-of-life treatment (e.g., recycling) of another product. The production, use, and end-of-life treatment of the ICT product itself has to be balanced against the intended or actual positive effects of the optimization. The ICT life cycle can also increase or decrease demand for other products (induction or substitution, respectively). This framework (taken up by the OECD Working Party on the Information Economy, OECD, 2010), covers first-order effects (here: environmental impacts of the ICT product life-cycle) and second-order effects (here: environmental impacts of ICT applications), both assessed by an LCA approach. An extension of the framework includes third-order effects, defined here as “adaptive reactions of a society to the stable availability of ICT services”. This includes structural changes of the economy, which assumed to be more sustainable if less material-intensive. In a dematerialized economy, “value-added would depend a lot more than it does today on the creation of structures and not on the churning of material and energy.” (Hilty, 2008, 156)

(11) Naumann, Dick et al. (2011) propose the GREENSOFT reference model, which has a focus on the life-cycle of software products with the aim to improve it with regard to sustainability. The model has four parts: “Life Cycle of Software Products”, “Sustainability Criteria and Metrics”, “Procedure Models”, and “Recommendations and Tools” (Naumann, Dick et al., 2011, 296). The first two parts explicitly borrow from LCA, treating software similar to a material product that goes through a development (or production), a use and an end-of-life phase. The last two parts of the GREENSOFT model aim at improving the processes in each phase of the life-cycle in order to meet the sustainability criteria, which are intended to cover all types of ICT impacts (from first to third order).

(12) Balin, Berthoud et al. (2012) present an approach starting from LCA applied to ICT hardware, which is then extended by the introduction of four additional factors: innovation-related factors, such as software bloat and obsolescence;

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<sup>4</sup> This concept of product life-cycle (as used in the LCA context) should be distinguished from the product life-cycle concept in marketing, which refers to the rise and decline of product sales.

<sup>5</sup> The last stage of the ICT hardware life cycle, electronic waste (e-waste or WEEE, Waste Electrical and Electronic Equipment) and its world-wide impact has stimulated highly specialized activities and publications that would deserve their own bibliography. See Manhart (2011) or Schluep et al. (2013) for the “Best-of-Two-Worlds” approach and Streicher-Porte et al. (2009) for the sustainability assessment of reuse and refurbishing options in education.

behavioural factors such as the addiction of users; organizational factors such as the IT productivity paradox, and structural factors such as the acceleration of economic processes by ICT and the related rebound effects. (Balin, Berthoud et al., 2012, Chapter 4)

(13) Standards and guidelines developed for the assessment of the environmental impacts of ICT based on a life-cycle approach can only briefly be mentioned here because the sources are numerous; the interested reader is referred to the joint activities of the World Resources Institute (WRI), the World Business Council for Sustainable Development (WBCSD), the Carbon Trust and the Global e-Sustainability Initiative (GeSI), described by Stephens and Didden (2013), and the framework developed of the International Telecommunications Union (ITU) (ITU-T, 2012).

*Another set of conceptual frameworks can be grouped under the heading of “Green IT”, a term that became popular around 2008 and has later been complemented by “Green IS”, “Green Software”, “Green Software Engineering” and “Green Computing”.*

(14) Murugesan (2008) defines Green IT as “the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated sub-systems [...] efficiently and effectively with minimal or no impact on the environment.” He identifies the following focus areas: “design for environmental sustainability; energy-efficient computing; power management; data center design, layout, and location; server virtualization; responsible disposal and recycling; regulatory compliance; green metrics, assessment tools, and methodology; environment-related risk mitigation; use of renewable energy sources; and eco-labeling of IT products” (Murugesan, 2008, 26). Besides these focus areas (directed to a reduction of negative first-order effects), he mentions two additional aspects: “Using IT for Environmental Sustainability [...] by offering innovative modeling, simulation, and decision support tools” and “Using IT to Create Green Awareness” by “tools such as environmental Web portals, blogs, wikis, and interactive simulations of the environmental impact of an activity” (Murugesan, 2008, 32f.).

(15) Coroama and Hilty (2009) indicate that the umbrella terms “IT” or “ICT” are not clearly defined and possibly not useful in a “green” context. They suggest “decomposing the ‘ICT monolith’ and look at its (naturally heterogeneous) parts separately.” Coroama and Hilty (2009, 353). They investigate more specific types of digital equipment with regard to the relation between their own energy consumption (first-order effect) and the energy efficiency they enable (second-order effect). The authors found substantial differences, e.g., TV sets and set-top boxes having a high consumption and a low enabling effect on energy efficiency, whereas telecom satellites have a low consumption and a higher enabling potential through the services they provide.

(16) The British Computer Society (BCS, 2010) defines a detailed “Green IT Syllabus” specifying what should be included in the key concepts and “best practice principles of ‘Green IT’” (BCS, 2010, 2). The syllabus shows that Green IT is understood mainly as an approach to minimize the negative first-order effects

of IT (or ICT). In particular, the carbon footprint of an organization is to be minimized by “greening its IT” (BCS, 2010, 4).

(17) Nouredine, Bourdon et al. (2012) define Green IT from a software perspective as a “discipline concerned with the optimization of software solutions with regards to their energy consumption” (Nouredine et al., 2012, 21). Their focus is on the environmental impacts caused by software, mainly CO<sub>2</sub> emissions related to power consumption; the approach is thus restricted to first-order effects. The approach conceptually includes energy models showing the energy use caused by software in hardware resources (in particular processors, working memory and hard disks), power monitoring at runtime, and the use of “power-aware information to adapt applications at runtime based on energy concerns” (Nouredine, Bourdon et al., 2012, 27).

(18) Gu, Lago et al. (2012) develop a “Green Strategy Model” in the IT context that aims to “provide decision makers with the information needed to decide on whether to take green strategies and eventually how to align them with their business strategies” (Gu, Lago et al., 2012, 62). This conceptual model distinguishes among green goals (which an organization decides to achieve), green actions (that should help achieving a green goal), action effects (the ecological effects of the action with regard to the green goal), and economic impacts of the action effects. Green actions are divided into two categories, “greening of IT” and “greening by IT” (Gu, Lago et al., 2012, 65), which can be interpreted as reducing negative first-order effects and increasing positive second-order effects, respectively. The model is explored in a case study with Dutch data centers.

(19) Loeser, Ereik et al. (2012) conceptualize Green IS (Green Information Systems) strategies, where IS is differentiated from IT by including not only technical infrastructure, but also the human activities within an organization. The need for Green IS is justified by their higher transformation potential: Compared to Green IT, “Green IS [...] promise a much greater, organization-wide potential to measure, monitor, report and reduce the firm’s environmental footprint, but the transformation of the business with the help of Green IS requires a holistic long-term strategy.” Green IS strategy is defined as “the organizational perspective on the investment in, deployment, use and management of information systems (IS) in order to minimize the negative environmental impacts of IS, IS-enabled products and services, and business operations.” (Loeser, Ereik et al., 2012, 4)

(20) Ereik, Loeser et al. (2012) present a two-dimensional reference model for “Sustainable Information Systems Management”, which is intended to integrate Green IT and Green IS approaches. One dimension is a re-interpretation of the widespread classification into first- to third-order effects from an organizational perspective: (1) “the fields of action that are associated with corporate sustainability within IT organizations”, (2) “the IT supported business process of a company” (also called “Green through IT”), and (3) “the end products and/or services offered in the market”. The second dimension covers the three levels known from traditional Business Engineering: “strategy (strategic goals), processes (planning tasks) and operational implementation” (Erik, Loeser et al., 2012, 5). This matrix is then used to address the fields of action for a company. For example,

at the operational implementation level of (2) “Green through IT”, the application of Environmental Information Systems (EIS) to calculate, control and optimize resource usage and emissions of the business processes of the company is indicated.<sup>6</sup>

(21) Penzenstadler (2013) discusses concepts of sustainability and interprets them in a software engineering context. She introduces a distinction between “software (engineering) *for* sustainability”, which is aimed at global sustainability goals, and “sustainable software (or sustainability *in* software engineering)”, which is related to the sustainability of the systems that are developed (Penzenstadler, 2013, 1184). Along the software product life cycle, she identifies four aspects in software engineering that should be addressed when discussing sustainability aspects of software: the “Development Process Aspect”, the “Maintenance Process Aspect”, the “System Production Aspect”, and the “System Usage Aspect” (Penzenstadler, 2013, 1184f.).

(22) Malakuti, Lohmann et al. (2013) structure “Green Computing”, introducing the distinction between “Greening in software” and “Greening by software”, where the former “aims to reduce the environmental effect caused by the development, application and retirement of software” and the latter “aims at saving resources by the help of software such as substitution of processes by more efficient processes or by dematerialization.” (Malakuti, Lohmann et al., 2013, 1149)

*Instead of focusing on technology first, a number of approaches are taking a user-oriented perspective, addressing sustainability in design, behaviour, or life styles.*

(23) Blevis (2007) creates a perspective in Human-Computer Interaction (HCI) he calls “Sustainable Interaction Design” (SID), which includes two aspects: “how interactive technologies can be used to promote more sustainable behaviors” and “how sustainability can be applied as a critical lens to the design of interactive systems, themselves.” (Blevis, 2007, 503) He introduces principles that are directed to extending the useful life of embedded materials, either by linking design to end-of-life considerations, by promoting renewal and reuse, or by decoupling ownership and identity to enable sharing for maximal use.

(24) DiSalvo, Sengers et al. (2010) provide an empirical analysis of the emerging structure of Sustainable HCI research. They divide the field in six genres: “Persuasive technology” stimulating desired (sustainable) behaviour; “Ambient awareness” systems making users aware of some aspect of the sustainability of their behaviour, or qualities of the environment associated with issues of sustainability; “Sustainable interaction design”, “Formative user studies”, and “Pervasive and Participatory Sensing”. He identified emerging issues, such as that “we [the Sustainable HCI community] frequently address individual consumers, but now need to find ways to address collectives and regional and national contexts” (DiSalvo, Sengers et al., 2010, 1980).

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<sup>6</sup> EIS for this purpose are usually called EMIS (with “M” for “Management”) in the Environmental Informatics community (e.g., DAAD, 2012; Teuteberg and Marx-Gomez, 2010; Hilty and Rautenstrauch, 1997).

(25) Huang (2011) describes an “initial wave of research” in Sustainable HCI, having shown that “HCI can contribute to solutions to sustainability challenges”, but also that problems of sustainability cannot be “framed purely as problems for HCI or interaction design issues.” (Huang, 2011, 16) Based on this she proposes to build bridges to other fields, namely existing bodies of environmental data (such as LCA data) and related theories, methods and models; to environmental psychology (e.g., when designing eco-feedback systems); and last but not least to real-world situations such as negotiating with a municipality.

(26) Zapico, Brandt et al. (2010) propose a renewed typology of indirect ICT impacts on the environment, namely “Optimization”, “Dematerialization”, and “Behavioural Change”. Behind these proactive usages of ICT as a tool for mitigating environmental problems is the crosscutting issue of environmental metrics (measuring and accounting of data). Environmental metrics can be expected to improve by ICT as well: “As computers become more pervasive, metrics are getting more accurate, more extensive, and more important in the way the world is viewed and decisions are made.” (Zapico, Brandt et al., 2010, 704)

(27) Kramers, Höjer et al. (2013) present an analytical framework to identify ICT-related opportunities for energy savings and other sustainability issues in private households. The framework is a two-dimensional matrix of household functions and ICT opportunities. The household functions are: personal functions, including “activities such as sleep, clothing, hygiene, recreation, entertainment, certain types of trips and holiday homes” and durable and semi-durable goods; housing, including “the residence and parts of its equipment such as residential service, heating and lighting; furnishings such as furniture, carpets and textiles; and domestic services such as cleaning, maintenance and repair”; food, including “energy use related to food items and the equipment required for storage, purchasing and preparation of food, as well as parts of the restaurant and café visits”; care, including “education, social security and healthcare; common, including “the basic needs of safety and security”; and support, including commuting to work. Each household function can be analysed with regard to the following opportunities provided by ICT: “dematerialization”, “demobilization”, “mass customization”, “intelligent operation”, and “soft transformation” (Kramers, Höjer et al., 2013, 186f.). The framework has been applied to the City of Stockholm.

*Macro-economic developments are the result of interactions of large numbers of agents at the micro-level. Some studies address the problem of linking the two levels or make assumptions about such a link.*

(28) Yi and Thomas (2007) found in their review of research on the “environmental impact of e-business and ICT” that “the currently dominant approach is either a micro-level case study approach or a macro-level statistical approach. It is concluded that a more predictive and empirical model [...] should be more beneficial in the long term.” They address models that are able to simulate the development of a sector, making it possible to assess the potential impacts of changes. They also see a challenge in translating macro-level results back into action: “The challenge of any research is not to just recognise the problem, but to know what can be done, how it can be done, and to choose certain solutions.

It is not enough to know that ICT/e-business has been changing our daily life, economy, transport, air, water, forests, etc., it is not even to understand how it is changing everything, ultimately an approach which can influence the behaviour, say of a company, for example, is desirable.” (Yi and Thomas, 2007, 848)

(29) Grant, Seager et al. (2010) provide a framework for the evaluation of ICT systems designed to support industrial symbiosis, namely the “Designing Industrial Ecosystems Toolkit (DIET)”, the “Industrial Materials Exchange Tool (IME)”, the “Industrial Ecology Planning Tool (IEPT)” and 10 more. Industrial symbiosis is defined as the “mutualistic interaction of different industries for beneficial reuse of waste flows or energy cascading that results in a more resource-efficient production system and fewer adverse environmental impacts.” An industrial symbiosis can be analyzed as a material flow network and a knowledge network at the same time. The evaluation framework includes an industrial symbiosis development process model and a generic description of the functionality of industrial symbiosis ICT tools. The authors observed that “industrial symbioses, compared with traditional commodity exchanges, are characterized by more tacit knowledge flows and application. [...] Put simply, tacit knowledge or know-how cannot be transferred vertically through a hierarchy or to and from a central authority.” (Grant, Seager et al., 2010, 740f.) The study concludes “perhaps the most critical challenge to the systems surveyed was their lack of sociability. This was best illustrated by their focus on connecting inputs and outputs rather than people.” (Grant, Seager et al., 2010, 750)

(30) Laitner (2010) recapitulates studies about the relationship of ICT, energy productivity, and labour markets. He concludes that, in the U.S., “smart policies” could save energy, reduce greenhouse gas emissions and create jobs at the same time. In order to implement such a “semiconductor-enabled efficiency scenario”, substantial investment would be necessary (Laitner, 2010, 694).

(31) Erdmann and Hilty (2010) review 10 studies providing quantitative future scenarios about the future impact of ICT on greenhouse gas emissions at the macro-economic level, analysing their underlying conceptual framework and methodology. A basic distinction is the approach taken, “bottom-up”, “top-down”, or “hybrid”. The result shows that the methods, geographic scopes and time horizons used are diverse and lead to incomparable results. Roughly half of the studies don’t address third-order (systemic) effects, such as rebound effects. Some of the studies are able to break down their results to the level of ICT application areas (such as transport, industrial production, buildings) and to demonstrate which changes to the scenarios imply which effects, making them potentially useful for policy support. The authors conclude that the next generation of ICT impact models should combine the scope of the existing global studies with a “methodology that is able to address effects on all three levels.” They address the interaction between scenario modelling and decision support: “A process that adjusts the scenarios used in such assessments periodically to real-world developments and recalculates the implications could provide opportunities for mutual learning between researchers and decision makers.” (Erdmann and Hilty, 2010, 841)

(32) The participants of ICT4S 2013, the First International Conference on Information and Communication Technologies for Sustainability, have endorsed a set of recommendations under the title “How to Improve the Contribution of ICT to Sustainability” (ICT4S, 2013). The recommendations are structured in three groups: “Sustainability in ICT”, in particular to use the power of software to reduce the energy consumption of hardware and to reduce hardware obsolescence and close material cycles at a global scale; “Sustainability by ICT”, in particular more intelligent energy management in buildings and planning urban structures taking into account the structural changes enabled by ICT, supporting a change towards a sustainable information society; and “Overarching aspects”, in particular ICT applications that create incentives for more sustainable behaviour and support people systematically in adopting more sustainable lifestyles. The detailed recommendations are published on the ICT4S website <http://2013.ict4s.org> and in the proceedings (ICT4S, 2013, this volume).

## References

Aebischer, B. 2009. ICT and Energy: Some Methodological Issues. ERCIM NEWS 79, October 2009. Special theme: Towards Green ICT

Balin, P., Berthoud, F., Bohas, A., Charbuillet, C., Drezet, E., Dubois, J.-D., Gossart, C. and Parry, M. 2012. Les impacts écologiques des technologies de l’information et de la communication. EDP Sciences

BCS. 2010. Green IT Syllabus. Version 2.5. ISEB qualification from BCS

Berkhout, F. and Hertin, J. 2001. Impacts of Information and Communication Technologies on Environmental Sustainability: Speculations and Evidence. Report to the OECD. <http://www.oecd.org/dataoecd/4/6/1897156.pdf>

Blevis, E. 2007. Sustainable Interaction Design: Invention & Disposal, Renewal & Reuse”, Proceedings of CHI 2007, 503-512

Coroama, V. and Hilty, L. M. 2009. Energy Consumed vs. Energy Saved by ICT – A Closer Look. In: Wohlgemuth, V., Page, B. and Voigt, K. (eds.). Environmental Informatics and Industrial Environmental Protection: Concepts, Methods and Tools, 23rd International Conference on Informatics for Environmental Protection, Berlin 2009, 353-361

DAAD 2012. DAAD Alumni Summer School 2012 in Environmental Management Information Systems and Sustainable Development. <http://vlba.informatik.uni-oldenburg.de/en/57635.html>

DiSalvo, C.F., Sengers, P. and Brynjarsdottir, H. 2010. Mapping the landscape of sustainable HCI. Proceedings of CHI 2010: 1975-1984

Dompke, M., von Geibler, J., Göhring, W., Herget, M., Hilty, L. M., Isenmann, R., Kuhndt, M., Naumann, S., Quack, D. and Seifert, E. 2004. Memorandum Nachhaltige Informationsgesellschaft. Fraunhofer IRB, Stuttgart 2004, ISBN: 3-8167-6446-0

- EnviroInfo n.d. Environmental Informatics – International Conference on Informatics for Environmental Protection. <http://www.enviroinfo.eu/de/publication/conference>
- Erdmann, L. and Hilty, L. M. 2010. Scenario Analysis: Exploring the Macroeconomic Impacts of Information and Communication Technologies on Greenhouse Gas Emissions. *Journal of Industrial Ecology* 14 (5) 2010, 824-841
- Erek, K., Loeser, F. and Zarnekow, R. 2012. Reference Model for Sustainable Information Systems Management: Establishing a Holistic Research Agenda. *Sprouts Working Papers on Information Systems*, 12-24
- Grant, G. B., Seager, T. P., Massard, G. and Nies, L. 2010. Information and Communication Technology for Industrial Symbiosis. *Journal of Industrial Ecology* 14 (5) 2010, 740-753
- Gu, Q., Lago, P. and Potenza, S. 2012. Aligning Economic Impact with Environmental Benefits: A Green Strategy Model. *First International Workshop on Green and Sustainable Software (GREENS)*, Zurich, 62-68
- Hilty, L. M., Page, B., Radermacher, F. J. and Riekert, W. F. 1995. Environmental Informatics as a New Discipline of Applied Computer Science. In: Avouris, N. and Page, B. (eds.): *Environmental Informatics – Methodology and Applications of Environmental Information Processing*. Kluwer Academic Publishers, Dordrecht 1995, 1-11
- Hilty, L. M. and Rautenstrauch, C. 1997. Environmental Management Information Systems for Production and Recycling. In: Swayne, D., Denzer, R., Schimak, G. (eds.). *Proceedings ISESS 1997: 2nd International Symposium on Environmental Software Systems (ISESS)*, Whistler (Canada). New York: Chapman & Hall 1997, 21-29
- Hilty, L. M. and Ruddy, T. F. 2000. Towards a Sustainable Information Society. *Informatik-Informatique* 4/2000, 2-7  
<http://graduateinstitute.ch/aspd/wsis/DEVDOT/01573.HTM>
- Hilty, L. M. 2008. *Information Technology and Sustainability. Essays on the Relationship between ICT and Sustainable Development*. Norderstedt: Books on Demand. ISBN: 9783837019704
- Huang, E. M. 2011. Building Outwards from Sustainable HCI. *Interactions*, 18 (3), May-June 2011, ACM Press, 14-17
- ICT4S 2013. Conference Recommendations: How to Improve the Contribution of ICT to Sustainability. In: *ICT4S 2013: Proceedings of the First International Conference on Information and Communication Technologies for Sustainability*, ETH Zurich, February 14-16, 2013, 283-287 <http://2013.ict4s.org>
- ICT-ENSURE n.d. ICT for Environmental Sustainability Research Project, Literature Information System <http://iai-uiserv1.iai.fzk.de/ictensure/site?mod=litdb>
- Isenmann, 2001. Basic Ethical Framework: Guidance for Environmental Informatics towards a Sustainable Information Society. In: Hilty, L. M., Gilgen, P. W. (eds.).

Proceedings EnvirolInfo 2001: Sustainability in the Information Society. Metropolis, Marburg 2001, 127-134 ISBN: 3-89518-370-981-90

ISESS n.d. International Symposium on Environmental Software Systems <http://www.isess2013.org/index.php?pg=home>

ITEE n.d. International Conference on Information Technologies in Environmental Engineering <http://www.itee2013.org/>

ITU-T 2012. Assessment Framework for Environmental Impacts of the ICT Sector (September 2012)  
[http://www.itu.int/dms\\_pub/itu-t/oth/4B/04/T4B0400000B0008PDFE.pdf](http://www.itu.int/dms_pub/itu-t/oth/4B/04/T4B0400000B0008PDFE.pdf)

Kramers, A., Höjer, M., Lövehagen, N. and Wangel, J. 2013. ICT for Sustainable Cities: How ICT Can Support an Environmentally Sustainable Development in Cities. In: ICT4S 2013: Proceedings of the First International Conference on Information and Communication Technologies for Sustainability, ETH Zurich, February 14-16, 2013, 183-188

Laitner, J. A. 2010. Semiconductors and Information Technologies: The Power of Productivity. *Journal of Industrial Ecology* 14 (5) 2010, 692-695

Loeser F., Erek, K. and Zarnekow, R. 2012. Towards a Typology of Green IS Strategies: Insights from Case Study Research. Proceedings Thirty Third International Conference on Information Systems, Orlando 2012

Malakuti, S., Lohmann, W. and Aksit, M. 2013. Editorial Message: Software Engineering Aspects of Green Computing. In: Proceedings of the 28th Annual ACM Symposium on Applied Computing. Coimbra, Portugal. 2013, 1149-1150, The Printing House, Inc

Manhart, A. 2010. International Cooperation for Metal Recycling From Waste Electrical and Electronic Equipment. An Assessment of the “Best-of-Two-Worlds” Approach. *Journal of Industrial Ecology* 15 (1) 2010, 13-30

Mokhtarian, P. L. 1989. A Typology of Relationships between Telecommunications and Transportation. *Transportation Research Part A: General* 24 (3), 231-242

Murugesan, S. 2008. Harnessing Green IT: Principles and Practices. *IT Professional*, Vol. 10, Issue 1, 24-32

Naumann, S. 2008. Sustainability Informatics – A new Subfield of Applied Informatics? Proceedings EnvirolInfo 2008: Environmental Informatics and Industrial Ecology. Shaker, 384-389

Naumann, S., Dick, M., Kern, E. and Johann, T. 2011. The GREENSOFT Model: A reference model for green and sustainable software and its engineering. *Sustainable Computing: Informatics and Systems* 1 (2011) 294-304

Noureddine, A., Bourdon, A., Rouvoy, R. and Seinturier, L. 2012. A Preliminary Study of the Impact of Software Engineering on GreenIT. First International Workshop on Green and Sustainable Software (GREENS), Zurich, 21-27

OECD, 2010, Greener and Smarter – ICTs, the Environment and Climate Change, Report to the Working Party on the Information Economy (WPIE), OECD, Paris

Penzenstadler, B. 2013. Towards a Definition of Sustainability in and for Software Engineering. SAC '13 Proceedings of the 28th Annual ACM Symposium on Applied Computing, 1183-1185

Radermacher, F.-J., Riekert, W.-F., Page, B. and Hilty, L. M. 1994. Trends in Environmental Information Processing. IFIP Transactions A: Computer Science and Technology (A-52) 1994, 597-604

Schluep, M., Müller, E., Hilty, L. M., Ott, D., Widmer, R. and Böni, H. 2013. In: ICT4S 2013: Proceedings of the First International Conference on Information and Communication Technologies for Sustainability, ETH Zurich, February 14-16, 2013, 45-51

Spreng, D. 2001. Does IT have boundless influence on energy consumption? In: Hilty, L. M. and Gilgen, P. W. (eds.): Proceedings EnviroInfo 2001: Sustainability in the Information Society. Metropolis, Marburg 2001, 81-90

Spreng, D. 2013. Interactions between Energy, Information and Growth. In: ICT4S 2013: Proceedings of the First International Conference on Information and Communication Technologies for Sustainability, ETH Zurich, February 14-16, 2013, 6-7

Stephens, A. and Didden, M. 2013. The development of ICT Sector Guidance: rationale, development and outcomes. In: ICT4S 2013: Proceedings of the First International Conference on Information and Communication Technologies for Sustainability, ETH Zurich, February 14-16, 2013, 8-11

Streicher-Porte, M., Marthaler, C., Böni, H., Schluep, M., Camacho, A. and Hilty, L. M. 2009. One Laptop per Child, Local Refurbishment or Overseas Donations? – Sustainability Assessment of Computer Supply Scenarios for Schools in Colombia. Journal of Environmental Management 90, 3498-3511

Teuteberg, F. and Marx-Gomez, J. 2010. Corporate Environmental Management Information Systems: Advancements and Trends. Business Science Reference

Yi, L. and Thomas, H. R. 2007. A review of research on the environmental impact of e-business and ICT. Environment International 33, 841-849

Zapico, J. L., Brandt, N. and Turpeinen, M. 2010. Environmental Metrics: The Main Opportunity from ICT for Industrial Ecology. Journal of Industrial Ecology 14 (5) 2010, 703-706

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The presentations and discussions of the conference are also available as podcasts and visual protocols via the website <http://www.ict4s.org>.

