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HACKING FOR SUSTAINABILITY

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ABSTRACT

ICT for Sustainability is a growing research area looking at the potential of information and communication technologies for contributing to sustainability. The existing work in this area can be grouped in four main categories: The optimization of existing systems using ICT, the dematerialization of cultural assets and presence, the use of technology for behavioral change, and the support of sustainability practice and research. Within this research area, this thesis focuses on exploring how new technologies and approaches of working with data, such as APIs, mashups, crowdsourcing, open data, and dynamic visualizations, can be applied to sustainability and sustainability practice.

This thesis follows a research through design method, where applications, prototypes, and events were created and released following an iterative design process. Five different design artifacts or "hacks" are presented and analyzed together as a portfolio. This collection of artifacts is a practical exploration of the research questions and it embodies the results.

Based on the created artifacts, this text argues that the new technologies and paradigms coming from ICT can transform how sustainability work is performed, by changing the way that sustainability data is created, shared and visualized. This new "data-driven" approach is characterized by a bottom-up way of data gathering, automatic data collection and crowdsourcing, a real time orientation, a focus on transparency and openness, dynamic and interactive visualizations, and new approaches to innovation. These characteristics create new opportunities for making sustainability practice more effective and broaden its impact, but they also create new problems and increase existing risks.

Finally it is argued that while information and communication technologies are usually treated as tools, these innovations in ICT for Sustainability are not only technological, but also cultural. The hacker ethic values connected with computer technologies, such as an open way of sharing knowledge, the focus on creativity as a driving force, and a hands-on approach, are key for understanding this research area and an important part of the contribution from ICT to sustainability.

SAMMANFATNING

IKT för hållbarhet är ett nytt forskningsområde som undersöker hur information- och kommunikationsteknologier (IKT) kan bidra till hållbarhet. Befintligt forskning kan kategoriseras inom fyra område: effektivisering, avmaterialisering av medier och fysisk närvaro, beteendeförändring, samt stöd till hållbarhetforskning och praktik. Med detta som utgångspunkt, den här avhandling fokuserar på att utforska hur ny teknik och sätt att jobba med data, såsom API:er, mashups, crowdsourcing, öppna data och nya visualiseringsteknik, kan användas inom hållbarhetsområde. Avhandlingen använder designbaserat forskning som metod i vilken prototyper, tjänster och events skapats i en iterativ designprocess. En portfölj med fem utvalda prototyper eller "hacks" presenteras i texten och ger konkret form till resultat och forskningsfrågorna.

Med resultaten från prototyperna som grund argumenterar texten att nya teknologier och paradigmer från IKT kan påverka hur hållbarhetsarbete utförs, genom att förändra hur hållbarhetsdata skapas, delas och visualiseras. Detta nya sätt karakteriseras av en användning av data baserat på automatiskt datasamling, feedback i realtid, öppenhet, dynamiska och interaktiva visualiseringsverktyg, och öppet innovation. Den här ”datadrivna” sätt ger nya möjligheter att förbättra hållbarhetsarbete, men det också skapar nya problem och kan öka befintliga risker.

Slutligen argumenterar texten att även om IKT behandlas ofta som bara ett verktyg, är innovationer inom IKT för hållbarhet inte bara teknologiska, men också kulturella. Värden kopplade till hackeretiken såsom öppenhet, kreativitet som drivkraft, och fokus på handling, är centrala för att förstå detta forskningsområde och kan ses som ett bidrag från IKT till hållbarhet.

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A PhD dissertation can be seen as a mostly personal and individual work, involving long hours sitting alone, reading and writing (and in this case, also coding and designing). While this is partly true, in reality this dissertation is also the result of the collaboration, inspiration, feedback, support, learning, teaching, interactions, with many persons, to whom I will try to give their well-earned acknowledgements.

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Jorge Luis Zapico, Skärbäck, Sweden, 2013

TABLE OF CONTENTS

ARTICLES

This dissertation is as a blend of a monograph and a compendium. Existing publications have been updated and included as chapters inside the text (the chapters where the publications have been used are written in brackets), instead of being included in their original form as custom in compendium dissertation.

The included articles are

- Zapico, J.L., Turpeinen, M., Brandt, N. (2010). **Greenalytics: A tool for mash-up life cycle assessment of websites**. In Proceedings of the 24th International Conference on Informatics for Environmental Protection. Shaker Verlag, Aachen, Germany. *(Chapter 4A)*
- Zapico, J.L. Turpeinen, M. Guath, M. (2011). **Kilograms or cups of tea: Comparing footprints for better CO_2 understanding**. In PsychNology Journal 9(1), pp.43-54. *(Chapter 4C)*
- Zapico, J.L. Sayan, B. Bonanni, L. Turpeinen, M. Young, S. (2011). **Footprinted.org: Experiences from using linked open data for environmental impact information**. In: Proceedings of 25th EnviroInfo Conference – Innovations in Sharing Environmental Observations and Information. Schaker-Verlag, Aachen, Germany. *(Chapter 4B)*
- Zapico, J.L. Pargman, D. Ebner, H. Eriksson, E. (2013). **Hacking sustainability: Broadening participation through Green Hackathons.** International Workshop on EUD for Supporting Sustainability in Maker Communities. IS EUD 2013, June 11-13, 2013, IT University of Copenhagen, DK. *(Chapter 4E)*

Other previous publications have been used as material throughout the text:

- Zapico, J.L., Turpeinen, M. (2009). **Climate Persuasive Services: Changing behavior towards low-carbon lifestyles**. Proceedings of Persuasive 2009: Fourth International Conference on Persuasive Technology, Claremont, CA, 26-29 April 2009, ACM Digital Library.
- Zapico, J.L., Spikol, D. (2009). **Designing Mobile Persuasion: Using Pervasive Applications to Change Attitudes and Behaviors**. In: Sharing Experiences with Social Mobile Media. Proceedings of the International Workshop in conjunction with MobileHCI 2009, September 15th 2009, Bonn, Germany. Pp 11-16.
- Zapico, J.L., Brandt, N., Turpeinen, M. (2010). **Environmental Metrics: The Main Opportunity from ICT for Industrial Ecology**. Journal of Industrial Ecology 14, 703-706.
- Zapico, J.L. (2012). **ICT and environmental sustainability, friend or foe?** Book review at Journal of Information Technologies in Development 8(3):99-101.
- Zapico, J.L. (2013). **Hacking, openness and sustainability**. Book chapter in: The Open Book, edited by Nissilä, J. Braybrooke, K. and Vuorikivi, T. The Finnish Institute Reaktio Serie #3. London.

Links to full texts of these publications can be found online at: http://jorge.zapi.co/phd

1

INTRODUCTION

Information and communication technologies have transformed society and become a main driver of development (Castells, 1996; Van Dijk, 2012; Ensmenger, 2012). Computers have developed exponentially, from being expensive machines taking up whole rooms and confined to research institutions and companies in the forties, to powerful and affordable laptops and mobile devices. A key component in this revolution has been the transformation from individual computers to connected devices. Internet, the global network connecting computers, has grown to become a global network with more than 2 billion users (ITU, 2011), and in some countries such as Sweden almost all the population has access to internet services. This development has changed both the way we work and how we live our everyday life, from how global markets work, to how we communicate with friends.

At the same time, we are facing global environmental challenges. The concentration of greenhouse gases in the atmosphere is at historical high level due to human activities such as fossil fuel use and land-use changes, driving rapid climate change (IPCC, 2007). Changes in the nitrogen and phosphorus cycles, mainly due the use of artificial fertilizers, are polluting water systems and creating eutrophication problems in oceans and freshwater ecosystems (Rockström et al. 2009). The exploitation of natural resources and land-use changes reducing natural habitat, combined with a changing climate and pollution, is creating a loss of biodiversity as extensive as previous big extinctions (WRI, 2005). These are examples of the growing impact of human activity in the natural environment (Rockström et al, 2009). These environmental challenges, together with the need for reducing poverty, led to the development of sustainability as a political discourse and a research area, as an answer to how society has to change for ensuring the wellbeing of future generations (Brundtland, 1987).

There is a growing amount of research focusing on the interaction between these two developments, the information and communication technologies revolution and the need for sustainability, both exploring the negative impacts of the technologies, and their possible positive impacts. ICT for Sustainability is a research area that focuses on the use of these technologies with a sustainability purpose, looking at how information technologies can have a positive impact in working towards sustainability.

This thesis explores the research area of ICT for Sustainability following a research through design approach, where the ideas for how ICT can work for sustainability are put into practice and tested as software applications. The hacking in the title is a reference to the hacker ethic (Himanen, 2001), which defines a hacker as someone that programs enthusiastically[1]. This thesis follows a "hacker approach", not only discussing the impacts of ICT, but working proactively by developing applications, services and events.

Before continuing, it is needed to briefly explore these previously mentioned terms of sustainability, ICT, hacking, and ICT for

1 Not to be confused with the use of "hacker" in popular media as a computer criminal. More discussion about hackers and the hacker ethic can be found in point 1.3 and in chapter 4E.

Sustainability, and to clarify how they will be used throughout the text.

1.1 SUSTAINABILITY

While it is beyond this text to define and discuss sustainability in depth, it is important to introduce the main concepts and clarify how the term is used in this text.

Sustainability and sustainable development has its roots in the political discussion during the last part of the twentieth century, from the UN Conference on the Human Environment in Stockholm 1972, the Brundtland Commission formed in 1983 and the Earth Summit in Rio in 1992 (for a more detailed description of the history of sustainability see Dresner, 2002). The most cited definition comes from the Brundtland's report for the UN World Commission on Environment and Development: "*development that meets the needs of the present without compromising the ability of future generations to meet their needs*" (Brundtland, 1987). The key point in this definition is bringing together environmental and humanitarian concerns under the concept of equity (between and within generations). It includes the concept of *needs*, human well-being, in particular focusing on the world's poor, and the idea of *limits* on the environment ability to meet these needs. Brundtland's definition also points out the possible ambiguity, mentioning that "*Interpretations may vary, but must share certain general features and must flow from a consensus on the basic concept of sustainable development and on a broad strategic framework for achieving it"* (Ibid).

Sustainable development is a normative and anthropocentric idea. It frames the environmental problems not as something external to human society, but as a basis for our future well-being. It includes the realization that the social and economic systems are not independent of the environment, but embedded in it, and that these systems have to take into account that we live on a limited planet. While sustainability and sustainable development are used many times with equivalent meaning[2], this text uses *sustainability* to indicate that it does not focus directly on questions of development. This work focuses more on the environmental concerns that jeopardize sustainability, such as climate change, resource depletion, human toxicity, land use patterns, and the human activities that creates these concerns such as the use of fossil fuel, waste production, and emissions of toxins to air and water.

In particular this text focuses on climate change, energy use and greenhouse gases emissions. Climate change refers to the global warming induced by the increased greenhouse effect created by human greenhouse gas emissions. This warming is now unequivocal, with increases in global average air and ocean temperatures, melting of snow and ice, and rising average sea level, connected with anthropogenic greenhouse gas emissions from fossil fuel use, agricultural and land-use changes (IPCC, 2007). Carbon dioxide is the most important greenhouse gas and used as the main metric for measuring climate change emissions, in cases where other greenhouse gases are relevant they are usually transformed into CO_2 equivalents as a measure of global warming potential (Ibid). The focus on climate change can be argued both by the urgency and the scale of the possible consequences (Stern, 2007), but also because it is a representative problem for our current sustainability concerns, a problem that is global, distributed, not a result from a failure in the system, but an

2 Dresner (2002, pp 65) points out two different views: the Brundtland report (Brundtland, 1987) and Agenda 21 (UNEP, 1992) argue that is important to avoid making a distinction between the sustainability and sustainable development, while others such as O'Riordan (1988) argue that sustainable development prioritizes development, while sustainability is primarily focused about the environment.

unavoidable result of the current resource use patterns (Allenby, 2006).

In this text, the discipline of Industrial Ecology is used as the main approach for framing the sustainability aspects. Industrial Ecology is a mean to deliberately approach and maintain sustainability (Graedel and Allenby, 2010). It is an interdisciplinary research area, having a strong focus on system studies, and while its origins are in industrial systems, it extends onto more general techno-sociological systems. Industrial Ecology has a proactive approach, not only studying the systems, but with the aim of changing them towards sustainability (Jelinski et al. 1992). It uses ecology as a metaphor for analyzing systems: their use of resources, material and energy metabolism, the impacts and the ways of restructuring and creating symbiosis between different elements for enabling sustainability. One important component of Industrial Ecology is assessing the environmental impacts of products, services, and systems, and there are a variety of tools used such as Life Cycle Assessment (LCA), Material Flow Analysis, Environmental Impacts Assessment, Footprint Analysis, Input-Output Analysis and Cost Benefit Analysis (Finnveden and Moberg, 2004). These tools are used with aims such as supporting decision-making, auditing, policy compliance, and improvement of existing or future systems. This thesis refers many times to LCA as a representative of sustainability practice. LCA is a framework for estimating the environmental impacts of a product or service with a system approach (Baumann and Tillman, 2004). It follows four steps: first it defines the aim and scope, including the functional unit to be studied. The inputs, outputs and processes of the whole life cycle are analyzed, from the raw material extraction to the end-of-life. Then the environmental impacts such as global warming potential, eutrophication, eco-toxicity and human toxicity are calculated, and finally the results are analyzed and discussed. This thesis focuses mostly on the application of ICT to sustainability practice and research, exploring how it can be used for empowering Industrial Ecology work such as environmental impact analysis and LCA.

1.2 ICT

Information and communication technologies (ICT) is an overarching term for the various digital technologies used for manipulating information, such as computers and mobile phones. These technologies allow a radical increase in volume, speed and complexity for processing information (Hilbert and López, 2011), and as mentioned before, they are central parts of the current dominant technological paradigm (Castells, 1996; Van Dijk, 2012). While ICT is a quite generic term, in this text the term is used mainly to refer to computers (including equivalent mobile devices), and internet (including the network infrastructure). Information technologies (IT) or computers are sometimes used in the text as synonyms of ICT.

Much of the work and discussion in this text focuses on internet and the world wide web. Internet is a decentralized global computer network used by billions of users. It connects different networks under a standard internet protocol TCP/IP. It supports different services, from serving hypertext documents, file systems, email to voice (VoIP) or television (IPTV). Internet has its origins in defense oriented research during the 1960s and it became more widespread during the 1980s, lead by academic and research institutions and followed by private networks. Internet has followed a fast growth trend, reaching 2.2 billion users worldwide in 2011 (ITU, 2011). The world wide web, www, or simply the web, is the collection of interconnected hypertext[3] documents

3 Hypertext is a computer document including links connecting to other documents. It may have text and other multimedia content. HTML is markup language used on the web for publishing hypertext documents and HTTP the protocol used for accessing them. A web browser is needed for interpreting the HTML to a human readable format.

accessible through internet[4] using unique addresses. The basic structure for the web, including the HTML and HTTP protocols, the first web server and the first web browser, was created by Tim Berners-Lee at CERN in 1992 (Berners-Lee, 2000). In the last twenty years the web has grown to become one of the most important ICT services, used by billions of users.

It is important to also mention the trend towards mobile computing. Mobile phones have in a short time become the most widespread technological device in human history, with more than 5.6 billion subscribers or 70% of the global population (ITU, 2011). There is an ongoing convergence trend between mobile phones and computers. Mobile phones are getting bigger screens, having more power and capabilities, and they are increasingly used to access internet. Computers are getting smaller and adding mobile connectivity, while tablet computers and other hybrids are also becoming popular. When mentioning "computer", this thesis refers to this variety of connected computer devices.

Computers, internet and mobile computing have transformed how we work with data and information. There are some technologies and trends dealing with how data is created, shared, and visualized, that are needed to be mentioned as they play an important role in this work:

- **Machine-readable data:** Machine-readable data is data intended for, and understandable by, computers[5], in contrast with data that is intended for humans to read. This is important as machine-readable formats enable the automatic processing and reuse of existing information. Web APIs are examples that make machine-readable data

4 It is worth reminding that while many times internet is colloquially used for referring to the web, the web is only a subset of the internet.

5 See for more information: http://www.data.gov/developers/blog/primer-machine-readability-online-documents-and-data

available. API stands for Application Programming Interface and it is an interface of a software program that enables other software to interact with it. It contains routines, data structures, classes and protocols that a developer can use to access services from another software. The popularization in recent years of public APIs in web services have transformed the approach of how applications are created. Linked data is another key concept of how the web is becoming more machine-readable. Linked data[6] is a web publishing standard readable both for human readers and computers[7], which uses RDF[8] to describe data in triples containing subject predicate and object. RDF can then be either accessed by computers, or visualized for human readability.

- **Open Licenses:** Open licenses allow data, content and computer source to be "free to use, reuse and redistribute"[9]. Free/Open source software (F/OSS) is software that allows the user access to the source code, and freedom to copy, modify and improve it[10]. F/OSS software has demonstrated to be a successful model for software development (Lakhani et al 2003) and open software is widely used. For instance F/OSS provide some key components of internet, such as the LAMP[11] web server stack that builds on Linux as operative system, Apache as server, MySQL as database and PHP, and popular web browsers such as Firefox and Chrome[12]. Open data is

6 http://www.w3.org/DesignIssues/LinkedData.html
7 More detailed information about Linked Data can be found in the Footprinted chapter 4B.
8 http://www.w3.org/RDF/
9 See http://opendefinition.org/
10 See http://opensource.org/docs/osd and http://www.fsf.org/about/what-is-free-software
11 See http://onlamp.com/pub/a/onlamp/2001/01/25/lamp.html
12 http://firefox.com and https://www.google.com/intl/en/chrome/browser/

usually applied to non-textual information, for instance statistics. Open data has been embraced by governmental institutions, with initiatives from the EU[13], US[14], UK[15] and the World Bank[16]. Inspired by F/OSS, Creative Commons is an organization that has created a set of copyright licenses that allow the free distribution of cultural knowledge[17] such as books, text, movies, music or photographs. The licenses can have certain limitations such as exclusively for non-commercial use, retribution to the author and the possibilities of modification. For instance, the online photo service Flickr hosts now more than 200 million creative common licensed pictures[18]. While machine readable data simplify the access from a technological point of view, open knowledge licenses work towards the same goal from a juridical one.

- **Pervasive Sensing:** There is a growing distributed network of both dedicated sensors and of embedded sensors in other devices such as mobile phones that allow automatic data gathering. Mobile phones are growingly used for data gathering (sometimes without the users even knowing it[19]). Mobile devices are powerful as pervasive sensors because they are with us all the time, always on, and aware of their context with an increasing number of embedded sensors such as microphones, GPS, accelerometers, camera, etc. Mobile phones can also be

13 EU has a directive (PSI) for the opening of public information. http://ec.europa.eu/information_society/policy/psi

14 http://data.gov

15 http://data.gov.uk

16 http://data.worldbank.org

17 See http://creativecommons.org/ for more information.

18 See http://www.flickr.com/creativecommons/

19 In 2011 it was uncovered that Apple's iPhone saved detailed location data of their users without consent: http://techland.time.com/2011/04/20/hidden-iphone-file-records-your-location-coordinates

enhanced with other external sensors, such as Lapka[20], an add-on that provides sensors for humidity, radiation, electromagnetic fields and traces of synthetic fertilizer.

- **Crowdsourcing:** Crowdsourcing is a model of participative online activity in which the public voluntarily undertakes a task such as creating or curating content (Estellés-Arolas and González Ladrón de Guevara, 2012). The most well known example is Wikipedia[21], a free online encyclopedia that is collaboratively edited with 24 million articles. It is one of the top ten most visited websites worldwide, and is not supposed to have more errors than the traditional Encyclopaedia Britannica (Giles, 2005).
- **Mashups and remixing:** The availability of machine-readable and open content allows the creation of new data by automatically remixing existing sources. This is known as a "mashup" approach, as it is used in web design context, and it has been one of the defining trends in the so-called web 2.0 (Murugesan, 2007). Mashups can be seen as a paradigm innovation, they are not a technology, but a new way of doing things made possible by the technological affordances[22] created by APIs, and the legal ones created by open licenses. This mashup approach is becoming increasingly relevant, as more and more information connected to the physical world is available in a digital format.
- **Dynamic visualizations:** Visualizations are key for making data understandable (Tufte, 1990;1997;2001), ICT

20 https://mylapka.com/

21 http://en.wikipedia.org/wiki/Wikipedia

22 Affordances of a technology can be understood as the possible actions that it allows the user to perform (Norman, 1988).

allow making these visualizations dynamic, based on real time data, and interactive. Some of the key technologies for visualization of data include new web standards, such as HTML5 with CSS3[23] that allow the creation of advanced graphics natively on websites, and the use of AJAX[24] and jQuery[25], that allow the non-obtrusive modification of the visualization. Libraries such as D3[26] are making the visualization of data easy, transforming web documents using data. Finally, dedicated programming languages such as Processing[27] are being used for generating more complex graphics and interactions.

The technological trends and paradigms presented above, centered around working with data, are the main ones explored throughout this text.

1.3 THE HACKER ETHIC

When looking at the development of information and communication technologies and their impact, it is important to not only look at the technologies themselves, but also to understand the culture and values that foster them. In the core of ICT, hackers and the hacker ethic have been central to its development. Being a hacker is being someone that "programs enthusiastically and who believes that computing and information sharing is a positive good", and that it is "their ethical duty to facilitate access" (Himanen, 2001; Wark, 2006). This is not to be confused with the use of the term in media and popular culture, where it is used

23 Standards by w3c: http://www.w3.org/TR/html5/ and http://www.w3.org/Style/CSS/

24 Using asynchronous Javascript to modify the content of the websites without reloading. http://www.adaptivepath.com/ideas/ajax-new-approach-web-applications

25 A Javascript library for easy development of AJAX applications http://jquery.com/

26 A Javascript library for visualizing data using web standards http://d3js.org/

27 A programming language for creating images and interactions http://processing.org/, also available to use as a Javascript library at http://processingjs.org/

mostly connected to cybercriminals, computer experts that steal credit card numbers and break in to security systems (Nissenbaum, 2004). The hacker ethic originated at MIT and developed in academia during the second half of the twentieth century (See Levy's (1984) historical account and Raymond's (2000) brief history of hackerdom), and it contains a set of values and norms that were embodied in the work of the early hackers[28]:

1. Hands on imperative focusing on practical skills and results.
2. A believe that information should be free.
3. Mistrust in authority and promotion of decentralization.
4. Hackers should be judged by their hacking, not by "bogus" criteria such as degrees, age or race.
5. You can create art and beauty on a computer.
6. Computers can change your life (and the world) for the better.

This is not a uniform set of values shared by all ICT practitioners, nor all “hackers”, and it should not be treated as singular code (Coleman, 2012). But it is an important component of the culture of information technology either implicit or explicit, and the hacker ethic is present in many of the information technologies. Coleman (2012) provides an updated analysis of the contemporary hacker, focusing on the Free/Open Source Software (FOSS) hackers and their connection with legality and intellectual property. While the definition and characteristics of what makes a hacker has changed and evolved, the principles above still capture the main ethical values such as openness, meritocracy and a tinkering and hands-on approach, which Coleman describes in connection with how hackers work in FOSS projects.

During the last years there has been a resurgence of the term hack, using hack and hacker in the sense of sharing information,

28 The hacker Jargon. Available at: http://www.catb.org/~esr/jargon/html/index.html

tweaking, hands-on change, and being used not only to computer related activities, but also to things such as personal development, furniture design or gardening. These communities may not “hack” in the traditional perspective, but they share the principles of openness and creativity of the hacker ethic. The hacker ethic as defined by the jargon file, its master document, does not exclude this, but it welcomes any kind of non computer activity as part of the hacker community, defining a hacker as “an expert or enthusiast of any kind” (See footnote 27).

Pekka Himanen (2001), in his book “The hacker ethic”, argues that the hacker values represents a different work ethic that challenges the dominant protestant work ethic. Himanen discusses the current dominance of the protestant ethic as defined by Weber (1905), tracing its origin to the monastery. In this ethic, work is seen as a duty that must be done for itself, the purpose of the work is not to get something done, but "to humble the worker's soul by making what he is told". Some of the defining characteristics are the emergence of the clock and fixed hours as control, money as the main motive, being busy as a status symbol and playfulness being removed from work. This protestant ethic is now secular and central in the capitalist system. The book defines the hacker work ethic in opposition to this protestant ethic, pointing its origins to the academia. The defining characteristics are being able to organize one's own time, and passion being the main motivation, instead of money. Not working for work's sake but for creating something valuable or just for fun. This work ethic does not oppose work, as Himanen presents the pre-protestant work ethic that was leisure-centric, but abandons the duality of work/leisure, again focusing the motivation around passion, and driven concepts such as openness of information, freedom of speech, privacy, and creativity.

1.4 ICT AND SUSTAINABILITY

The relationship between ICT and environmental sustainability can be roughly classified in two areas, the first-order or direct impacts and the second-order or indirect impacts[29] (Hilty, 2008). The first order impacts of ICT are the negative environmental consequences connected with the production, usage and disposal of the computer equipment itself[30]. There are a growing number of studies looking at these impacts using LCA and other environmental assessment methodologies, as explored by reviews such as Arushanyan et al (2013), Yao et at. (2010) and Teehan and Kandlikar (2010). The results from different studies show quite a big variability and uncertainty (Weber et al, 2010b). This can be explained by the rapid pace of development, the complexity of the systems, lack of available data, and the influence that defining how the products are used has in the results. Even if the results differ, the main impacts in the life cycle (production, use, disposal) of ICT usually point to three areas:

- The energy and resources used during the production of hardware.
- The energy consumed by the equipment, both personal devices, such as computers, and the infrastructure, such as network equipment and servers.
- The toxicity and social impacts of the disposal of electronic waste.

The indirect impacts are the secondary effects that the usage of technology has as it changes the way we interact with each other, the way we work, and the way we organize society. These indirect

29 Hilty (2008) also makes a distinction of third-order, or systemic, impacts pointing out to the more long term impacts of the availability of technologies in society.

30 The studies available focus mostly on the hardware and do not include the software. The design phase of the hardware is not included either.

impacts can be negative or positive, planned or unplanned. Hilty (2008) separates the indirect impacts in three effects:

- Substitution: replacing the use of a product or service using ICT.
- Optimization: ICT used for increasing the efficiency of a system.
- Induction: ICT promoting an increase in use of a service.

As Hilty argues, these three effects are usually interdependent. For instance ICT can substitute the use of paper (by reading in electronic devices), optimize the use of paper (for instance using print by demand) and induce the use of paper (by making printing easier).

This work focuses on *ICT for Sustainability*, the use of information technologies with a sustainability purpose. The important notion is the "*purposefulness*" in the use of technology; ICT is used with a planned attempt to increase sustainability. This text uses ICT for Sustainability or ICT4S as a general term encompassing ongoing research that may use different or more concrete terms such as sustainable HCI, greening through IT, cleanweb, ICT for environmental sustainability and environmental informatics (Hilty et al. 2011). A clarification can be made regarding ICT for development (ICT4D) and GreenIT. ICT4D is an established research area looking at the use of information technologies for social sustainability. It explores using technology as a tool for empowering disadvantaged populations and reducing poverty, focusing on low-income countries. Examples of topics include e-learning, e-agriculture and e-health (Heeks, 2008). While there are many common points and shared interests with ICT4S (see for instance Ospina and Heeks, 2010), the focus of ICT4D is on the development and not on the environmental aspects of sustainability. GreenIT is a term sometimes used with the same meaning as ICT4S, or by specifying “greening by / through IT”. But most generally it is used in the IT industry meaning the work of increasing efficiency and decreasing energy use of IT equipment itself (Murugesan, 2008). These technical aspects of GreenIT, while touched upon by some of the created applications, are not the research focus in this text.

The concept of ICT for sustainability, the state-of-the-art of the research and examples of existing applications will be further presented in the second chapter.

1.5 RESEARCH QUESTIONS

This thesis is an inquiry in the field of ICT for Sustainability, exploring the application of new ICT concepts to sustainability. This thesis explores the use of new technologies and approaches of working with data (crowdsourcing, mashups, machine-readable data, open licenses, pervasive sensing, and data visualization) in a sustainability context, and try to understand how they can transform sustainability practice and research. The main research questions are:

- *How can these new technologies and approaches for working with data be used in ICT for Sustainability and in sustainability practice?*
- *What are the main opportunities and risks in the use of these technologies and approaches for sustainability?*
- *What is the role of the cultural “hacker” values in these opportunities and risks?*

Based on these questions and aims, a research through design approach was followed, developing artifacts or “hacks” (prototypes, events, software applications) to explore the research questions. These artifacts are proofs of concept for specific opportunities or interventions working on a specific area. They work as an exploration of different ICT for Sustainability ideas, and a practical way of identifying opportunities and problems when implementing them. A selected collection of artifacts is presented as a cohesive portfolio that embodies the results from the research inquiry. The results are a contribution to advance ICT for Sustainability as a research area, but also to media technology and human computer interaction, as the technologies and practices coming from these fields are practically applied in the domain of sustainability.

1.6 BACKGROUND

The research presented in this thesis was conducted at the Center for Sustainable Communications (CESC) at KTH The Royal Institute of Technology[31]. CESC is an interdisciplinary research center looking at the relationship between ICT and sustainability, with a team comprising computer scientists, sustainability researchers, sociologists, anthropologists, designers, and urban planners. With undergraduate studies in computer science and a master in sustainable technology I started my research for bridging together these two apparently unrelated fields. This interdisciplinary environment and background is key to understanding the motivation of this thesis and its interdisciplinary research approach. This thesis and the research that lead to it is to be seen as a part of a wider effort at CESC for understanding the effects of ICT in sustainability, studying the possible risks, and exploring the opportunities for making ICT a positive force towards a more sustainable society.

31 A Vinnova Centre of Excellence formed as a collaboration between the departments of MID (Media technology and Interaction Design), and FMS (Environmental Strategies Research), together with a number of industrial, media and societal partners (including Ericsson, TeliaSonera, City of Stockholm and COOP) and other research groups and institutions. More information at http://cesc.kth.se

1.7 STRUCTURE

This thesis is divided in six chapters:

- The first chapter introduces the topic of the thesis, the aim and the structure of the text.
- Chapter two presents an analysis of the current research on information technologies for sustainability.
- Chapter three discusses the research approach and methodological questions.
- Chapter four presents the selected artifacts or “hacks”.
- Chapter five brings together the artifacts as part of a cohesive portfolio and it discusses the opportunities, risks, and the influence of the hacker ethic in ICT for sustainability.
- Chapter six wraps up the final conclusions and proposes further research opportunities.

2

ICT FOR SUSTAINABILITY

ICT for Sustainability can be defined as the planned use of ICT with a sustainability purpose (Hilty, 2011). This is still not a fully consolidated area, as there is different, and sometimes overlapping, research coming from different established disciplines such as Human Computer Interaction (HCI), Industrial Ecology, Geo-informatics, Material Science and Computer Science. Other existing communities and terms in this space, beside ICT for Sustainability, include sustainable HCI or sustainable interaction design (Goodman, 2009; Di Salvo et al, 2010), environmental informatics (Avouris and Page, 1995), greening through IT (Tomlinson, 2010), and cleanweb[32]. Hilty and Lohmann (2013) provide a comprehensive bibliography of the existing conceptual frameworks that span across the different communities. This text does not dwell on the differences and uses ICT for Sustainability (or ICT4S) as a general term encompassing these different research efforts. Even if the perspectives, boundaries and goals may vary between them, many of the topics are common.

This chapter will discuss four of the main topics in this research area:

32 Cleanweb is a non-academic interest group and movement looking at the intersection of web technologies and cleantech, see : http://www.cleanweb.org.uk/manifesto.html

- Efficiency and optimization
- Dematerialization
- Behavioral change
- Tools for sustainability practice.

These four areas are discussed to give an overview of the research in ICT4S and to provide background information for the practical applications and discussion in this thesis.

2.1 EFFICIENCY AND OPTIMIZATION

Efficiency is the relationship between the amount of input and resources needed for producing a result, and optimization is the process of increasing the efficiency of a system. ICT has always been used to increase efficiency, specially time-efficiency, accelerating existing processes (Hilty et al, 2005). This acceleration is the defining characteristic of the impact of ICT in society, and as Castells (1996) argues, one of the pillars of the information society. In the context of ICT for Sustainability, efficiency usually means the use of ICT for optimizing a system or a process with a sustainability purpose, for instance reducing the amount of energy and materials required for delivering a service or the greenhouse gases produced when creating a product.

Efficiency is one of the key concepts that are heavily mentioned in the literature of ICT for Sustainability. Reports such as Smart2020 (Climate Group, 2008), and Greener and Smarter (OECD, 2010), point out efficiency as the most important contribution that ICT can make to sustainability, and even as a central part in achieving a more sustainable society in general. Much of this discussion uses the terms *smart* or *smarter* and argues that ICT can improve and tune existing systems, reducing emissions and resource consumption while maintaining or increasing utility. Examples of this include: smart cities, smart grids, smart appliances, intelligent transport systems and smart logistics.

Smart grid is representative for how ICT is being applied for sustainability related efficiency. Information technologies are used to improve the actual electricity grid system, for instance routing power more efficiently, reducing the need for excess capacity and allowing two-way real time information exchange between producers and customers for real time demand side management. Smart grid has been suggested as the single most important application of ICT for reducing greenhouse gas emissions (Climate Group, 2008).

Intelligent transport systems (ITS) is also a very active research area where the optimization potential of ICT is being explored, including the optimization of storage and transportation of goods (ibid). ICT applications that are suggested to increase efficiency include inventory reduction, eco-driving, route optimization and intermodal shifts. A particular example is the computer models used by Japan National Institute of Informatics for calculating the best possible delivery route between different stores and providers, creating both economical and environmental savings (Satoh, 2008).

Efficiency measures are also being applied to other fields, such as agriculture. For instance ICT based smart irrigation systems to reduce water usage and carbon emissions by context-aware watering schedules, using weather data and/or soil moisture and evapotranspiration sensing (Mutchek and Williams, 2010).

Hilty et al. (2005) problematizes the focus on efficiency, pointing out that the main effect of ICT has been in increasing productivity, meaning that the efficiency gains of time-efficiency has resulted in increasing output, not in reducing input. This is a classical rebound effect (Brookes 1990); a rebound effect is the lost gains in efficiency of technological progress due to that cost reduction generates increased consumption of the same service, and/or increases spending in other areas due to higher income and systemic macro-economic effects (Berkhout et al 2000). This is not exclusive to ICT, but endemic to efficiency. A classical example is provided by Allenby (2006), where he shows how cars have increased in fuel efficiency, but the total impact of cars have grown as cars are bigger and faster, there are many more cars and we drive them more. Hilty argues that using ICT for efficiency measures is not enough precondition for saving resources, and that that measures restricting input and output (aiming for sufficiency[33]) are needed in order to avoid rebound effects (Hilty et al. 2005).

2.2 DEMATERIALIZATION

Dematerialization is a reduction in the quantity of physical material required to provide a service (Berkhout and Hertin, 2004; Fuchs 2006). While from an Industrial Ecology perspective, dematerialization is usually seen as optimization of materials used in production (Gradeel and Allenby, 2003), in the context of using ICT for Sustainability, dematerialization is a more radical change, pointing out the transformation of physical products and services to virtual digital services.

Much of the early discussion about how information technology would transform society and contribute to lessen environmental impact was based on this dematerialization potential of technology, being able to move “bits instead of atoms” (Negroponte, 1995). Based on my observation of existing research, there are two main assets that have been the subject of dematerialization: cultural and knowledge assets, and physical presence.

Culture and knowledge artifacts such as music, books, magazines and journals, have been one of the fastest areas subject to

33 Sufficiency can be seen as a limitation of needs in order to avoid overconsumption, focusing on the total amount that is needed instead of on the efficiency ratio (Princen, 2003).

dematerialization. For instance, music delivery has been transformed during the last decade, with a move from physical devices such as CDs towards purely digital formats downloaded online and listened through dedicated players or general devices such as computers or mobile phones. This decoupling of content from a physical container reduces the energy needed for creating and transporting the product. From an energy and CO_2 perspective, Webber et al (2010) found that digital delivery of music is up to 80% more efficient, after accounting for the emissions of internet and computer usage. Books and printed media are also moving towards digital formats, both using dedicated low-energy electronic devices for reading text with new generation e-ink screens[34], and general use devices such as tablets and mobile phones[35]. While not a straightforward answer, the environmental impact of reading electronically is usually less per book versus reading in paper, as soon as the initial hardware production impact is offset (Moberg et al 2011). It is interesting to note that the environmental impact for e-readers per book decreases with usage, in comparison with paper books where the impact is constant per unit.

Presence dematerialization includes virtual presence, videoconferences, and services such as e-banking or e-government. These can be seen as creating a dissociation of presence and physicality. One everyday example is financial institutions. Bank services have been moving away from paperwork and physical visits to bank offices towards fully electronic interactions. Economical reasons and user's comfort can be seen as the main drivers for this change, but there are environmental impacts too. Dematerialization of banking decreases the need of office space, reduces the clients’ need for traveling to bank offices and

34 For instance Amazon Kindle https://kindle.amazon.com/ or Sony Reader https://ebookstore.sony.com/reader/

35 Such as Apple's ibook application http://www.apple.com/apps/ibooks/ or Readmill http://readmill.com

eliminates the paper and logistics of many transactions. This has a direct impact in reducing environmental impacts. For instance, in Sweden, having electronic invoices instead of physical ones sent by post could halve the carbon impact of the invoicing and reduce a total of around 40,000 ton CO_2 (Moberg et al 2008a).

The use of mediated communications as a substitution for traveling has been pointed out as an opportunity of ICT for reducing greenhouse gas emissions (Climate Group, 2008). One example is the case where a high quality videoconference system for the public employment services was installed in a Swedish rural area, which succeeded in reducing car traveling and emissions (Moberg et al 2008b).

While the energy use, and its connected environmental impact, of creating and moving bits (even if still existing) is usually smaller than the impact of transforming and moving material or people, dematerialization is also effected by rebound effects as explained above. Some classical examples of failed dematerialization due to rebound effects are the increase in paper consumption with the introduction of the computer, instead of the promised paperless office (Sellen and Harper, 2001) and the increase in total distance traveled by teleworkers in some cases as they could live further away (Fuchs, 2006).

2.3 BEHAVIORAL CHANGE

Another central theme of ICT for sustainability is the use of technology for supporting or triggering behavioral change towards sustainability. This include research on eco-feedback, persuasive technologies, ambient awareness and pervasive and participatory sensing. In sustainable HCI this kind of research is most prominent. Di Salvo et al (2010) in their survey of the research area found that 70% of the publication corpus on sustainable HCI was on persuasive and ambient awareness.

A main concept in research about behavioral change is using technology for “making the invisible visible”. Information technology is used to visualize and communicate data that is relevant for sustainability such as energy use, water use or carbon dioxide emissions (Froehlich, 2000). This is seen as a precondition for acting and increasing sustainability: if it's visible, it's actionable and then it can be made sustainable (Bonanni, Busse et al, 2011).

Some examples of applications and research looking at these topics include:

- *Interactive Institute Energy Studio*: A research group which created pioneer projects making energy visible, such as transparent screens showing a metaphorical tree representing energy consumption, power cords that make electricity consumption visible, and lamps that reward low energy use (Maze, 2008; Broms et al 2008).
- *Show me*: A visualization of water usage at home using a LED lights display in the shower (Kappel, 2009).
- *Good guide*[36]: A service using mobile devices for providing environmental information about consumer products.

Many of the applications do not only present the information in a neutral way, but they have a persuasive intention to change behavior towards sustainability, making use of psychology theories such as the guidelines presented by B.J Fogg (2003) on persuasive technologies. Some of the persuasive techniques used with an environmental purpose include competition, collaboration, goal setting, simulation and facilitation (Zapico et al, 2009).

The focus on using technologies for changing behavior is not free of problems. Brynjardsdóttir et al (2012) present some of the most

36 http://www.goodguide.com/

relevant criticisms, arguing that the persuasive approach used in HCI for sustainability is narrowing too much the concept of sustainability to single metrics, that it focuses mostly on individuals and not on practices or context, and that it assumes rational actions based on the information provided.

2.4 ICT FOR SUSTAINABILITY PRACTICE

Another area where ICT is used for sustainability is in facilitating sustainability practice itself. By sustainability practice it is meant the research and applied work of sustainability as a discipline, such as the work in the Industrial Ecology research area. Information technologies are a main component in sustainability work, allowing the analysis, modeling, control and communication of environmental information. This has been advanced in the research area of environmental informatics (Hilty et al, 2006), which focuses on using technology for the creation and processing of environmental information in traditional environmental disciplines and in institutions such as environmental agencies. Examples of this research include using web technologies for creating customized sustainability reporting (Süpke et al, 2009) or using data warehousing for working with environmental data of companies (Burnmann, 2007).

Another important use of ICT in sustainability practice is in the modeling of environmental impact assessment. Hilty et al (2008) argue that ICT is central to promote life cycle thinking, providing tools for supporting decision making. Complex modeling studies such as life cycle assessments are made possible by the use of computer tools and databases. Modeling software that are widely used for creating environmental impact assessment include SimaPro[37], OpenLCA[38] (Ciroth, 2007) and Umberto[39]. Databases

37 http://www.pre-sustainability.com/simapro-lca-software
38 http://www.openlca.org/

and repositories of environmental information include Ecoinvent[40] and CPM[41]. There are also new tools applying internet technologies to environmental impact assessments, such as Sourcemap[42], a web based visualization of supply chains for products (Bonanni, 2011) which make use of a distributed and crowdsourced way of presenting the life cycle of products.

Finally, the increased availability of freely available tools and data, such as geographic and satellite information, is also allowing other groups than governmental institutions to monitor the environment. Examples include Forest Watchers[43], a citizen science service where the monitoring of land use changes in the Amazon forest is crowdsourced, and Grassroots Mapping[44], where users create maps using DIY[45] balloons with cameras, for instance for tracking and visualizing oil spills[46].

2.5 SUMMARY

The research in ICT for sustainability is still fragmented, with new communities such as Sustainable HCI, that are quite active creating discussion, interventions and applications, converging with older communities such as Environmental Informatics, which has worked with computer-based environmental information since the seventies. In the middle there is a lot of interdisciplinary research coming from other established areas, such as computer science or Industrial Ecology. There is also a growing interest from the government and industry, with a number of reports being published

39 http://umberto.de
40 http://www.ecoinvent.ch/
41 http://cpmdatabase.cpm.chalmers.se/
42 http://sourcemap.com
43 http://forestwatchers.net/
44 http://grassrootsmapping.org
45 Do It Yourself.
46 http://grassrootsmapping.org/gulf-oil-spill

outside academia, such as Smart2020 (Climate Group, 2008), and grass-root initiatives such as cleanweb.

This chapter gave an overview of the existing research and activities, focusing on four areas that give a good overview of the state-of-the-art:

- ICT is being applied to optimizing existing services for saving resources, making existing systems such as transportation, housing, and cities, more efficient.
- ICT is argued as potentially reducing the environmental impact of existing services by dematerializing physical assets such as books, bills, music, and activities that used to require physical presence, such as meetings or visits to the bank office.
- ICT is being used for providing feedback to users by making invisible variables, such as energy use, visible with the aim of increasing awareness and affecting the users behavior.
- ICT is used in the work of sustainability research and practice, being central to the measurement, modeling and analysis of data, for instance when making environmental impact analysis such as LCA.

As presented before, there is also work looking at the risks and possible negative aspects of these areas. The most relevant is the importance of rebound effects, the loss of efficiency gains because the saved resources are invested in making more with the same (or even more) resources, instead than doing the same with fewer resources. This is especially relevant for ICT as these technologies are used for the acceleration and optimization of different systems, and to ICT for Sustainability, where many of the argued opportunities are based on efficiency and dematerialization. The rebound effects may counter the positive effects if there is no sufficiency measure in place to avoid a growth in the total impact.

This overview of the state of the art in this research field provides background information for this thesis. Optimization, efficiency, dematerialization, persuasion, eco-feedback, environmental information systems, rebound effects, etc. are representative terms of the ongoing work in ICT4S and provide the context where the applications created in this thesis are positioned.

3

RESEARCH APPROACH

Both sustainability and information technologies are complex and interdisciplinary fields. The research on ICT for Sustainability, which explores the relationship between the two, creates methodological challenges requiring the understanding and use of different domains, disciplines and methods.

In this thesis, Industrial Ecology[47] provides the frame for discussing sustainability and the domain for the practical work, while interaction design provides the practical tools and the frame for discussing the use of technology in sustainability. Interaction design is the process of deciding and creating the user oriented qualities of *digital artifacts*[48]: structural, functional, ethical and aesthetical (Löwgren and Stolterman, 2004). This interdisciplinary area focus not only on the technology but also on how it is used and its consequences, and it has a practical approach of working with the design and creation of artifacts.

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47 See information and references about Industrial Ecology in the introduction chapter.

48 An artifact means just anything made by humans (Simon, 1969). A digital artifact is one whose core functionality is made possible by information technologies (Löwgren and Stolterman, 2004). "Artifact" is used in design theory as a general term and it is used throughout this text in that sense. Examples of concrete digital artifacts are a piece of software program, a website, a digital photograph, an interactive display, etc.

Research through design is used as the method of inquiry, bringing the different pieces together. Design allows to work in an interdisciplinary way, to have a more holistic and proactive perspective on complex problems such as sustainability, and to create and use artifacts as a way of inquiry.

3.1 RESEARCH THROUGH DESIGN

Research through design (RtD) is a research approach that uses design processes as legitimate method of inquiry (Zimmerman et al. 2007, 2010). Design artifacts (Ulrich, 2011) are used as outcomes to transform the world from its current state to a preferred state (Frayling, 1993), and the artifacts can function as a showcase for this preferred state, or to open up new design and research spaces (Zimmerman et al, 2010). Fallman (2003, 2007) discusses how design is used in interaction design and human computer interaction and makes a distinction between design-oriented research and research-oriented design. In *design-oriented research*, design activities are a mean, while the aim is to produce new knowledge. In *research-oriented design*, research is used for driving a design process, while the aim is the creation of a design artifact. Other areas that relevant to, or share elements with, research through design are *design research* (Buchanan, 2001), which focuses on research about the design process and practice itself, and the *action research* tradition coming from the learning sciences (Brown, 1992; Barab and Squire, 2004), which focuses on the design of practical interventions.

The main characteristics that define research through design (and why they make this method a good fit for this research) are:

- **It focuses on creating**. The design and creation of artifacts is central to the research process. The artifacts work as concrete embodiments of theory. They are used as tools for exploring and moving forward the theories and existing knowledge. In the case of this thesis, the research is conducted by creating innovative digital artifacts (such as software and web services). Artifacts are created in iterative cycles and are used for exploring and developing new knowledge.

- **It has a normative stance**. With the introduction of artifacts with goals and "oughts" (Simon, 1969), RtD wants to affect the world and transform it. This normative approach also changes the focus to research of the future, instead of the present or the past (Zimmerman et al, 2010), and on how to affect it. This thesis has a normative stance where sustainability is acknowledged as a desirable state for the future.
- **It addresses wicked problems**. Wicked problems are problems that contain paradoxes, conflicts, changing requirement, and that cannot be easily modeled by traditional scientific approaches (Rittel and Webber, 1977). Solutions to wicked problems are not right or wrong, but better or worse. This thesis addresses sustainability, probably one of the *wickedest* problem we have right now, or as Levin et al (2009) used referring to climate change, a "Super Wicked" problem. Sustainability involves conflicting interests, it does not have a fixed end, sustainability is not a true or false state but only better or worse, the requirements change with time, and it includes complex interdependencies at a global level. Examples of these problems have already been brought up in the discussion on the previous chapter on rebound effects.

3.2 PROCESS

The research process followed is adapted from Zimmerman et al (2007) and it is a quite generic iterative design process with four different stages: grounding, ideation, iteration, and reflection. The design process starts with grounding the work with the investigation of the problem, gathering different perspectives and exploring the current state of the art. A comprehensive study is important for the design process, as the contribution must constitute a significant invention (Zimmerman et al, 2007). The ideation and iteration phases involve the generation of many possible different solutions based on the grounding stage and a cyclical process of refining the concepts. The design artifacts are iteratively improved, moving from early stages such as paper prototypes or ideas from a brainstorm, to later stages where they become more functional and are even released for public usage. During the different iterations diverse ideas are tested and discarded, different stakeholders may participate in the process, prototypes are released to be tested by users, new challenges are identified, new directions are found. The final process is the reflection on the outcomes of the process, the synthesis of the knowledge created by the designed artifacts and the analysis of the relevance and impact. This reflective action is not only a final stage, but it is part of each iteration as new experiences are gained in the design process.

In this thesis this process of grounding-ideation-iteration-reflection was used both on micro and macro level. Each of the applications created followed this design process:

- *Grounding:* the identified problems were framed and existing literature and relevant projects were reviewed.
- *Ideation:* innovative digital artifacts were developed to explore the problem.
- *Iteration:* the artifacts were developed in an iterative process where they were refined from ideas to being functional software products, that were in most cases released to public use.

- *Reflecting:* the outputs and the process were analyzed and the results published usually in the form of academic publications.

The thesis as a whole can also be seen to follow this process. It starts with an overview of the ICT for Sustainability field for *grounding*. In the *ideation* phase different artifacts and "hacks" are presented, which can be seen as *iterations* that build upon each other. It finishes with a final *reflection* process bringing together all the artifacts, the experiences and knowledge gained in a comprehensive discourse.

The artifacts created are an important result of this thesis, but the main result is the combination of the different artifacts in what can be seen as an *annotated portfolio* (Gaver, 2012). An annotated portfolio consists of individual artifacts that, while they can be seen independently, together "*articulate the ideas and issues that join them and differentiate them*" (ibid). While each individual artifact or hack presented in this thesis embodies an idea or explores a new opportunity in ICT4S, it is in the view of all the artifacts as a whole that the new ideas and results can be presented in a stronger and more articulated way.

3.2 DISCUSSION

Research through design is still an emerging research approach. Zimmerman et al (2010) point out that it can be seen more like an attitude of how to do work than a systematic method, and they discuss some of the challenges of this approach, including a suggestion for more formal development of the method. On the other hand, Gaver (2012) argues that standardization of RtD would go against the strengths of the method, and that we should "*take pride in its aptitute for exploring and speculating, particularizing and diversifying*".

One relevant problem mentioned by Zimmerman et al (2010) is how to document and evaluate the knowledge emerging from this kind of research, as it can be mostly implicitly contained in the created artifacts. As mentioned before, Fallman (2007) discusses that design-oriented research and research-oriented design have different aims and should be evaluated with different perspectives. In research, the generation of knowledge is the important aim while the created artifacts are many times only a mean and usually only developed as prototype that is not fully functional. While this thesis aims also to create knowledge, the process has been a combination between design-oriented research and research-oriented design, where the artifacts are primary contributions and they are developed to a more complete level. Fallman (2007) mentions that trying to do both, a good functional design, and good research on it, may be too much. This thesis tries to handle this tension between the generation of designs and generation of knowledge, presenting the design artifacts as important contributions and annotating them (Gaver, 2012) as a way of bringing forward the embodied knowledge they created.

Finally it is also worth mentioning the similarities between research through design and the aforementioned hacker ethic, and how they are used in this thesis. Both have a clear hands-on approach, focus on creation, and are highly embodied, using the artifacts or hacks as a way of showcasing principles in practice. This text uses research through design as the inquiry method, but it borrows both vocabulary and approaches from the hacker ethic, using terms such as artifacts and hacks as mostly interchangeable in the context of this work.

The next chapter will present the five individual hacks or artifacts, presenting both the process and results. Afterwards, chapter five will discuss all the hacks as a portfolio, exploring the common concepts, opportunities and risks.

4

THE HACKS

This chapter presents the empirical work. As presented in the previous chapter, this thesis follows a practical design methodology and the research takes form in different digital artifacts or "hacks". These are functional proofs of concept exploring the research questions, each one starting with a problem, question or idea, about how working with data coming from ICT could help or transform sustainability practice. The hacks function as both showcases of the possibilities of ICT, and also as practical tests exploring new areas and identifying challenges, barriers and opportunities.

Five artifacts are presented in this text:

- The first one is *Greenalytics.org*. As mentioned in the introduction, machine-readable data and APIs allow creating new information and services using a mashup approach. *Greenalytics* is a proof of concept of how this new approach could be applied for the creation of environmental impact data, in this case by calculating and visualizing the carbon impact of websites based on web analytics data using existing APIs.
- The second one is *Footprinted.org.* Most sustainability data, such as environmental impact analyses, is found in closed databases or in journals, and most times in non-machine

readable formats. This makes it not accessible for the general public and difficult to reuse. *Footprinted* is an online open linked data repository that applies the concepts of openness and machine-readability to environmental impact information.

- The third one is *Carbon.to.* Starting from the problem that quantitative carbon dioxide data is abstract and difficult to understand, *Carbon.to* is a web tool to visualize carbon dioxide information and make it easier to understand and to relate to.

- The fourth case are two prototypes based on the same idea and code: *Webenergy* and *HelsinkiCO*$_2$. Starting from the problem that environmental information is presented statically and that this makes it difficult to show how the results vary depending on different variables, these two web tools are proof-of-concepts of how the visualization of environmental impact and the simulation of different scenarios can be made interactive.

The code and implementation of these applications is one important output of this research. The code is available as open source and there is a link to the source code repository for each one of the applications.

- Finally, a serie of events called *Green Hackathon* is presented as the fifth artifact. Starting from the idea of opening up innovation around ICT for Sustainability outside research and practitioners, these events provide a space where developers meet to create prototypes and digital artifacts with a sustainability purpose during a limited amount of time.

As mentioned before, the following sections in this chapter (with the exception of section D) are based on published articles, which were updated and adapted to create a more cohesive text.

In chapter five, these individual applications and their different results will be analyzed from a holistic perspective as a portfolio.

A

GREENALYTICS

Calculating web carbon emissions using a mash-up approach

http://greenalytics.org

Released: January 2010

Code available at: https://github.com/zapico/greenalytics

Text based on: Zapico, J.L., Turpeinen, M., Brandt, N. 2010. Greenalytics: A tool for mash-up life cycle assessment of websites. In Proceedings of the 24th International Conference on Informatics for Environmental Protection. Shaker Verlag, Aachen, Germany.

A.1 GROUNDING

Environmental impact analyses are mostly manual processes tailor-made for a product or service. Once the analysis is done, the results are static, showing one or several scenarios that the researchers chose for their relevance. It is not possible to adapt the results to new cases without manual input.

The growing availability of data about products and services in machine readable digital formats, opens the possibility of creating dynamic environmental impact assessments using a mashup approach. A mashup in web development, as mentioned in the introduction, is an application that combines data or functionality from two or more external sources usually through APIs, to create a new service that was not intended by those original sources.

Using such an approach for sustainability data could make possible not only to increase the amount of data processed, but also to adapt the analysis to new contexts and scenarios as the same model can be adapted by inputting new data.

Greenalytics was developed as a service that showcases this possibility. It applies the idea of calculating the carbon impact of websites. Websites are interesting as a use case for two main reasons:

- Websites store detailed information about their usage, such as how many people visited the site, for how long, from which place, at what time, etc. This information is easily available for building upon it using APIs. This type of information exists for other products but it is not usually easy to access.
- The total energy use and impact of internet is growing continuously, accounting for 1.4% to 2% of world greenhouse gas emissions (Malmodin, 2010; Climate Group, 2008; WWF and HP, 2008). Understanding and analyzing the environmental impact of a website is not an easy task. There is a growing

amount of projects looking at the life cycle of internet services using methodologies as Life Cycle Assessment (Bauman and Tillman, 2004). However, these are few and usually based on a global scale, not applicable only for a single website. The impact of a site is distributed through multiple hardware networks with a global user base, making the individual impact difficult to pinpoint.

A.2 IDEATION AND ITERATION

Greenalytics is a web application that makes the impact of websites visible, it allows instant analysis of carbon footprint using existing data and presenting it in an understandable and transparent way. As mentioned above, most websites log extensive and detailed information about their usage. For our application we chose to work with Google Analytics[49] (GA), the most used web statistics service worldwide (Metalytics, 2009) provided free by Google. This tool is widely used in both big commercial services and personal websites. Greenalytics combines the data from GA with environmental impact data to automatically generate a calculation of the carbon impact of the website, making possible for anyone to login and calculate the impact of their sites.

This artifact was developed from scratch using Ruby on Rails[50] and released as a public beta version in 2010. The development followed an iterative design approach, releasing prototypes early and often for getting feedback.

The second version of this tool was released one year after the original one, changing from on-the-fly calculation where the results were recalculated each time, to a database-based system, where the information is updated once a day in the background.

49 Google Analytics can be accessed at http://google.com/analytics

50 More info at http://rubyonrails.org

This allows providing a history of emissions and increases the speed as the data is retrieved from the own database.

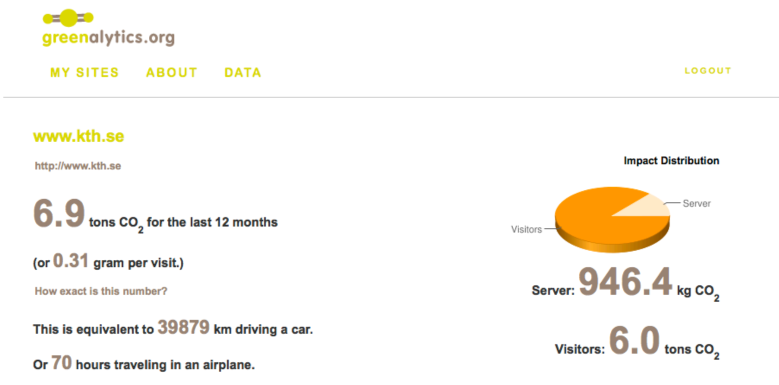

Figure A1: Screenshot of Greenalytics

The calculation is based on the sum of two parts:

- The electricity of the users' computers as they browse the website.
- The electricity use from the server and internet infrastructure.

The user impact of the website is the potential environmental impact generated by the users while browsing the site. In the current version only the electricity consumed by their computer is included. The application makes use of GA detailed information about the users: their exact number, location and duration of visit. The total CO_2 is calculated by aggregating the impact per country, which is the total time visitors from that country spent in the site, multiplied by how much electricity a typical computer consumes, multiplied by the electricity factor (how much carbon dioxide is emitted per electricity unit) of that country. We assume that the users' time is spent exclusively browsing the website, so all the electricity use for that time is allocated to the site. The type of computer and screen size is not possible to specify with the data available. We assume a mix between laptops and desktops: 45 per cent using laptops consuming 19W and 55 per cent using desktops consuming 60W. Electricity consumption information is taken from IVF (2007) and the 45/55 distribution from IDC (2008). The carbon factors for the electricity are taken from Carma[51] through their API. These factors are calculated for a whole year and do not reflect the specific energy mix at the time when the users visited the site. When the country is unknown, the global average is used.

Argentina 46.9 min 18.87 grams CO2. With a factor of 678.69
Australia 73.5 min 85.63 grams CO2. With a factor of 1965.95
Belgium 29.1 min 12.05 grams CO2. With a factor of 698.78
Brazil 0.2 min 0.01 grams CO2. With a factor of 110.74
Canada 5.2 min 1.45 grams CO2. With a factor of 471.06
Chile 2.2 min 1.2 grams CO2. With a factor of 917.15
China 6.2 min 7.02 grams CO2. With a factor of 1910.02
Costa Rica 12.6 min 0.12 grams CO2. With a factor of 15.66
Croatia 34.2 min 14.23 grams CO2. With a factor of 702.33
Czech Republic 3.9 min 3.78 grams CO2. With a factor of 1637.32
Denmark 43.6 min 21.34 grams CO2. With a factor of 825.76
Egypt 3.8 min 1.85 grams CO2. With a factor of 825.22
Finland 45.7 min 5.36 grams CO2. With a factor of 197.97
France 59.6 min 6.83 grams CO2. With a factor of 193.47
Germany 95.2 min 76.19 grams CO2. With a factor of 1350.79
Greece 43.9 min 45.74 grams CO2. With a factor of 1757.29
Hungary 0.8 min 0.31 grams CO2. With a factor of 657.24
India 58.4 min 61.36 grams CO2. With a factor of 1772.7
Indonesia 9.3 min 7.99 grams CO2. With a factor of 1458.33
Iran 4.4 min 2.1 grams CO2. With a factor of 799.01
Ireland 1.7 min 1.34 grams CO2. With a factor of 1308.59
Italy 16.8 min 9.41 grams CO2. With a factor of 947.15
Japan 0.2 min 0.08 grams CO2. With a factor of 802.57

Figure A2: Screenshot from Greenalytics user's impact calculation

The server and infrastructure part is calculated using the total data traffic generated by the site and an approximation of the energy used by internet per data unit. GA doesn't provide a direct way of getting the total data traffic, so an approximation is calculated by aggregating the total traffic per page (the size of the page times the number of visits it has), and multiplying that with an energy use per data unit factor (7 kWh/GB, taken from Taylor and Koomey (2008) and Weber et. al (2010a)). The server location is found out using its IP address and the electricity is converted in CO_2 by multiplying with the location electricity factor.

This calculations has some known problems and limitations:

51 http://carma.org

- The energy factor of 7 kWh/GB is generic and contains itself many assumptions. Weber et. al (2009) argue that this amount is dropping about 30% per year. This would mean that for 2010 the energy use per gigabyte would be closer to 3 or 4 kWh/GB than to the 2008 baseline.
- The data traffic is calculated by the size of the pages, and it doesn't take into account the caching of websites and other factors. Traffic created by dynamic content such as streaming media or AJAX based interactions is not included.
- Hardware production, transport and disposal are not included in this first version.

Greenalytics provides two different functional units: CO_2 per visit and the total CO_2 per month/site. The choice of two units was made for enabling both a regular efficiency value per user and an overview of the total climate impact of the website.

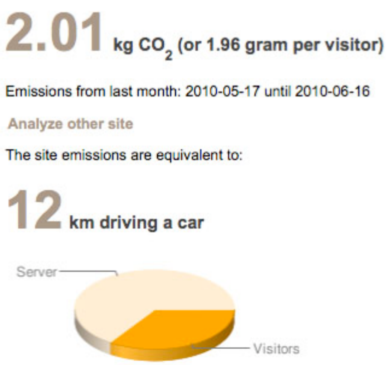

Figure A3: Screenshot of the functional units of Greenalytics

A.3 REFLECTION

Greenalytics served two purposes. The first one is straightforward; to make the carbon impact of websites visible and to increase awareness of this impact. The second one is more theoretical; to show how it is possible to generate environmental impact information using existing sources in an automated way.

a. Internet carbon impact

The impact calculation proved to be successful in some parts and lacking in others. The main problem identified is the carbon footprint calculation of the server and infrastructure. The actual number is still a rough estimate using a general factor for data transfer energy intensity. This approach goes against the mentioned ideas of real time and high granularity. The internet electricity intensity is the other main weak point of the calculation. As presented before, a calculation from Weber et. al (2009) is used. The factor is calculated for 2008 and they argue that the impact is dropping about 30% per year. Rapid technological change adds uncertainties to this calculation. Using data from Google Analytics limits the type of calculations you can do to using average data. A possibility for improving this calculation in the future is using server specific data, requiring the users to either add information about the server, or to create a specific tracker to be included in the server, for instance as a script.

Even if the results are still an approximation of the real environmental impact (focused on the carbon impact), they give a sense of scale of the impact and make it visible. Using a mash-up approach for making the analysis had the benefit of accessing real time data, with a granularity that can surpass traditional life cycle assessments. It also allows users to analyze their own data to check the impact of their website. As the concern about the energy use and the environmental impact of internet is growing, tools as Greenalytics can be key in increasing the visibility and communicating the potential environmental impacts and can be used as a base for action towards minimizing them.

b. A mashup approach to environmental impact analysis

The data available in internet for many products and user behaviors is growing, and with an increasing use of concepts as APIs, Linked Data or Open Data, the creation of mash-ups is realistic. The use of a mash-up approach, as explored in Greenalytics, provide the following opportunities:

Real-time: The results are based on immediate data, the usage data from GA includes visits up to the same day. The carbon factors for the electricity are not static but change with time as information is updated each year.

Better granularity of the data: The use of a programmatic approach allows the gathering and use of bigger data sets as they do not have to be processed by hand. This provides the opportunity to use very detailed information, which would be a tedious or impossible task if done manually. An example is the user impact calculation where the exact time in seconds is taken from each visit and then aggregated by country (See figure A2). This calculation is based on high granularity real use data instead of on assumptions about the usage.

Finally it's worth mentioning that Greenalytics has been well accepted. The release of the public version generated publicity in the press[52], and there was demand from individuals and organizations wanting to use the service for their website and to develop it further.

52 See for instance Computer Sweden: http://computersweden.idg.se/2.2683/1.358420/ny-tjanst-avslojar-miljobovarna-pa-webben and Sweden.se: http://blogs.sweden.se/sustainability/2011/05/16/how-green-is-all-that-surfing/

B

FOOTPRINTED

Sharing environmental impact information

http://footprinted.org

Released: June 2011

Created with: Bianca Sayan, Leonardo Bonanni

Code available at: http://github.com/zapico/footprinted

Text based on: Zapico, J.L. Sayan, B. Bonanni, L. Turpeinen, M. Young, S. 2011. Footprinted.org: Experiences from using linked open data for environmental impact information. In: Pillmann, W., Schade, S., and Smits, P. (Eds.) Proceedings of 25th EnviroInfo Conference. Schaker-Verlag, Aachen, Germany.

B.1 GROUNDING

Sustainability science relies heavily on information (Allenby 2000, 2006). And as sustainability is gaining weight in decision-making, reliant and accessible environmental information is needed (Goleman 2009). This is true both at an institutional level, like when deciding the materials for building a product, and at a personal level, deciding between chicken and salmon at the supermarket. However, most of the environmental information, such as Life Cycle Assessment studies, is closed, based on proprietary software, expensive, and/or in text documents that are only possible to process manually.

Life Cycle Assessment (LCA) is a framework for estimating the environmental impacts of a product or service. It follows a system approach, analyzing all the inputs, outputs and processes of the whole life cycle, starting from the raw material extraction, the manufacturing, distribution, usage and finishing with the disposal or end-of-life. It is also holistic in the environmental aspects analyzed, including global warming potential, eutrophication, eco-toxicity, human toxicity, and other impacts. LCA has a strong base both from research but also from industrial practitioners. Many companies use it as a tool for reporting and improving environmental performance, and the process is well established and standardized by ISO 14040 and 14044 (Finkbeiner et al. 2006).

While LCA is a powerful framework, current LCA practices have several issues that could be improved with new information technologies.

- **Transparency:** LCA studies are usually published without access to the raw data used or to the full inventory data (Murray-Rust, 2008). This can undermine the trust in the results, and it makes difficult or impossible to replicate the study or to adapt it to other contexts.

- **Lack of iteration**: LCA studies are supposed to be iterative, providing a continuing improvement process (ISO, 2006), since they provide an estimation of environmental impacts that can always be improved. But with the current system of publication there is little evidence of existing iterative improvements of the studies (Weidema, 2000)
- **Accessibility**: LCA studies are relevant for the wider public, but the understanding of studies is limited for non-practitioners. This is both because the studies are usually published in scientific journals or specialized databases that are not available freely to the public, and because the results are difficult to read and interpret.

Bringing open data concepts from the web to environmental impact information would make it more transparent, and it would make easier to create new services reusing the existing data (Davis et al, 2010; Zapico et al, 2010). Sayan (2010) provides a more detailed overview of these problems, together with a more extensive literature review and a survey to LCA practitioners around the need of a more open approach to LCA data, which was used during the development of this tool.

B.2 IDEATION AND ITERATION

The ideas presented above were the starting point of Footprinted[53], a web service that is trying to solve the problems of lack of accessibility and transparency by opening up life cycle assessment information using linked data. The key concept for Footprinted is making environmental information open, linked and usable. It is a collaboration between KTH, Sourcemap, and MIT Media Lab[54].

53 Footprinted is still in a beta stage. For more information see http://footprinted.org

54 More info at http://footprinted.org/about/team

Footprinted uses linked data for storing environmental impact information so it can be easily created, presented, shared and reused. The resources in the repository are life cycle assessment (LCA) or other environmental impact analysis methodology (Baumann and Tillman, 2004). For the same product or service there can be different resources, for instance a LCA of leather produced in Brazil for 2010, and another of leather from Spain for 2005. There can even be two different competing results for the same product. The goal of the application is not to provide one correct answer, but a forum to access different answers and a way of selecting and improving the best data. It can be seen as a *bazaar* of LCA instead of a *cathedral* or unique answer approach[55].

The best way of presenting Footprinted is to look at its main functionality:

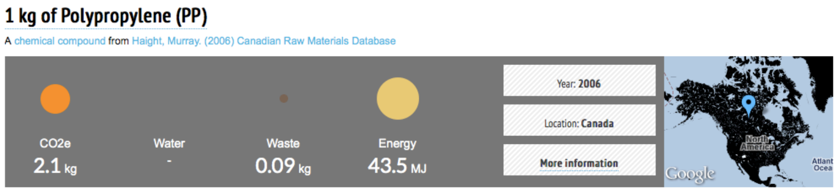

Figure B1: Compact view of resource in homepage

1. Homepage: the start page is designed to present several hand picked life cycle assessments. It aims to awake the interest of casual visitors and direct them to some resources that they can start exploring. It presents the essential information in a compact way: the name, source, main impacts, year, location and category

55 For the origin of this analogy related to open source, see Raymond, 1999.

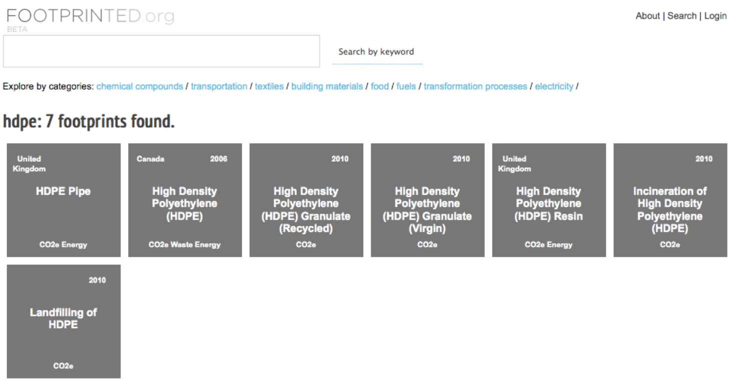

Figure B2: Search results for keyword HDPE

2. Search: the search page[56] is designed for users that are looking for something in particular in the repository. It can be navigated either by keywords or using a category tree. It presents the resource in a minimal way for easy comparison between the results including key data as name, year, location and impacts available for each one.

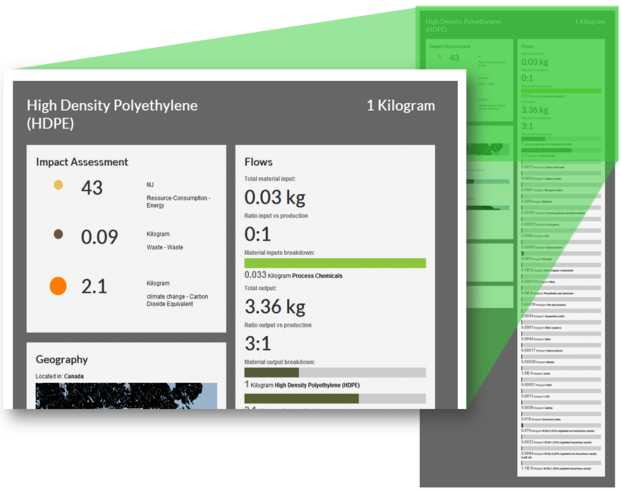

Figure B3: Fact-sheet for a LCA of HDPE with zoom in detail.

56 See: http://footprinted.org/search

3. Fact sheet: the fact-sheet or main view[57] of a resource shows all the existing data connected with it. It has several parts, such as the name and functional unit, impact assessments (such as CO_2, water, energy consumption, toxicity), input and output flows, reference to the original source, year and location of the assessment and extra semantic information such as equivalent concepts. There is also the possibility to comment on the resources and to export them in machine-readable format, either RDF or XML.

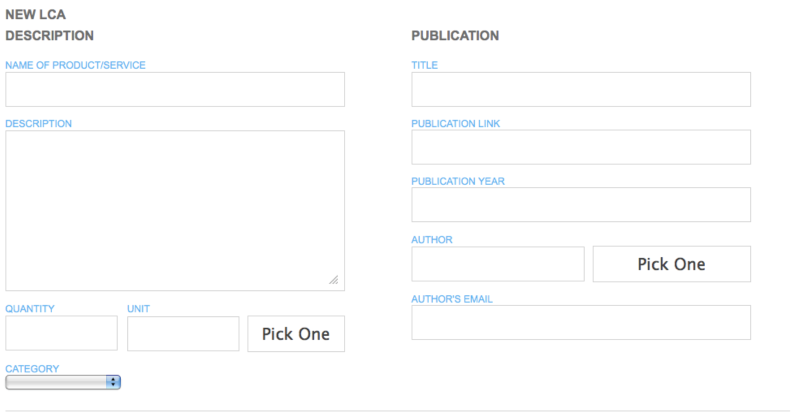

Figure B4: Form for creating new resources.

4. Contributing: there are two ways of contributing data[58] to Footprinted, either manually filling up a form with the required information as in figure B4, or uploading an EcoSpold[59] file that is automatically imported. This functionality is reserved for registered users, focusing mainly on environmental practitioners and researchers.

57 For instance: http://footprinted.org/HighDensityPolyethyleneHDPE40221568
58 More information at http://footprinted.org/about/contribute
59 The format from EcoInvent http://www.ecoinvent.org/ecoinvent-v3/ecospold-v2/

5. API: the Application Programming Interface[60] is the platform that developers use for integrating Footprinted data into other services. It allows to search and retrieve all the information from the repository in machine readable formats such as JSON, XML and RDF.

Footprinted is implemented using linked data[61], a method of publishing data using web standard so it is interlinked and readable both for human readers and computers. The basic concept is:

- Resources are identified by unique internet addresses (HTTP URIs).
- When looking at an URI, people and computers get useful information about that resource in a standard and open format.
- This information is linked to other URIs of related concepts and information.

In Footprinted each resource has a unique and permanent address[62]. When accessing the URI a human will get a fact sheet with the information visualized in a readable format. When a machine (such as another web service) accesses that URI, it will get the information using a machine-readable format such as RDF or JSON so that the data can be easily interpreted and reused without human intervention. The information retrieved contains other URIs for concepts. For instance when presenting the unit Kilogram, it is not just a word, but an URI from Qudt.org that contains a description, abbreviations, conversion rates, etc.

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60 More info at: http://footprinted.org/about/api

61 More info at: 2009. Tim Berners-Lee. Available: http://www.w3.org/DesignIssues/LinkedData.html

62 For example Aluminum ingots has the URI: http://footprinted.org/PrimaryAluminumIngot84706627

Adding semantic information and working with ontologies provides opportunities for disambiguation and machine readability. It also allows Footprinted to use existing information and repositories. The power of linked data can be seen in this simple example:

- We have a resource for Primary Aluminum Ingot: http://footprinted.org/PrimaryAluminumIngot84706627.
- This has the triple "owl:sameAs" indicating that it is equivalent to Aluminum:

  http://sw.opencyc.org/concept/Mx4rvVi2O5wpEbGdrcN5Y29ycA.
- This resource gives extra information about Aluminum, like that it is a Type of Metal.
- It is also linked to http://dbpedia.org/page/Aluminium where we can know that the Japanese name is アルミニウム.
- Putting all things together, an application looking for アルミニウム could get its environmental impact, without any human intervention.

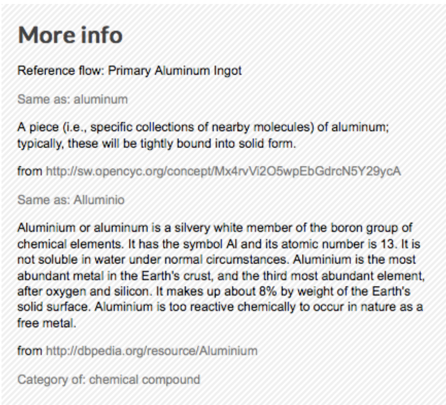


Figure B5. Information gathered via linked data for Primary Aluminum Ingot

Footprinted was developed using Open Source software and standards such as PHP, HTML, SPARQL, JQuery, ARC, RDF, XML and JSON[63]. Footprinted itself is released as Open Source[64], both for contributing to the software community but also as a way of increasing the transparency and openness of the service.

B.3 REFLECTION

The development of Footprinted.org is in the cutting edge of web technologies, and as the tools have not yet matured the development work encountered different technical challenges:

1. Database performance problems: Footprinted uses ARC[65] and a relational database for storing the linked data triples. This setup worked well for individual resources, but poorly for more complex queries as accessing all resources and their carbon impact. Our solution has been to cache the repository into a relational database containing a summary of each resource (name, link, category, impacts…). Footprinted uses this table for the functions that need complex queries with good performance such as search. The complete information of a resource accessed using the URI is retrieved directly from the triples repository. In the future we see the need of migrating to a native triple repository such as sesame[66].

2. Performance of external repositories: One of the main pillars of linked data is the reuse of existing data repositories. For instance, when using units such as Kilograms, Footprinted uses the existing QUDT ontology[67]. The problem is that when accessing the information of other repositories remotely, the performance of the

63 For more information and links see: http://footprinted.org/about/code

64 The code for Footprinted.org can be found at: https://github.com/zapico/Footprinted under the Affero Gnu Public License (AGPL).

65 ARC is a PHP library to use a regular relational database as a repository for RDF triples. More info at: https://github.com/semsol/arc2/wiki

66 Sesame: http://www.openrdf.org/

67 A ontology coming from NASA, more information at: http://qudt.org/

application suffered, this is particularly true when making queries in big ontologies such as OpenCyc[68]. Our solution has been to duplicate these repositories and accessing them locally. However, we hope that this will change in the future.

3. Semantic errors: The environmental impact information being added to Footprinted does not have semantic information embedded. The data has to be parsed and interpreted for attaching meaning. This can be done automatically in many cases, for instance interpreting kg as the concept kilogram. But in many cases it can go wrong (see Figure B6), or there are unavoidable ambiguities, and manual parsing is needed.

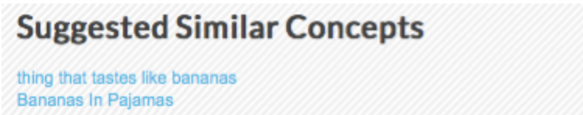


Figure B6: finding similar things to Bananas in the ontology gives back some unexpected results.

Footprinted was designed with different uses in mind:

1. Serving as a repository for external applications: The main aim of Footprinted is to be used as a repository for other applications that need environmental impact information. By using the existing API, other web services can easily add environmental information to their services. The first and original user of Footprinted is Sourcemap.com[69], one of the pioneer web services using internet for sustainability. Sourcemap is a tool for making supply chains transparent. It has been used by organizations and companies for increasing their transparency (Bonanni et al, 2010) with the motto: "people have a right to know where things come from and what they're made of " (Bonanni, 2011) The new version of Sourcemap uses Footprinted as repository for the environmental impact of materials and products, as it can be seen in Figure B7.

68 OpenCyc is used as a general concept ontology

69 More information at http://sourcemap.org and http://sourcemap.com

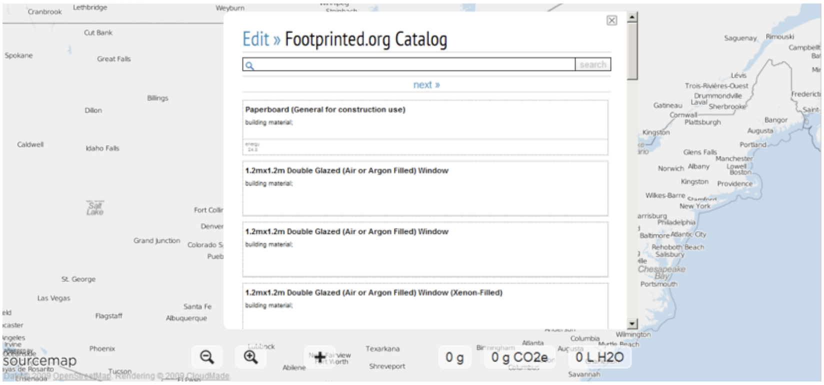


Figure B7: Sourcemap accessing Footprinted

2. Triggering innovation: Opening up the information can empower creators to develop new ideas and applications based on the data. If the data is available and usable for more people than just environmental experts, uses of the data can be crowdsourced. This was explored by the organization of Green Hackathons[70], events where developers gather and in a limited amount of time develop interesting applications and prototypes with a sustainability purpose.

3. Sharing LCAs and community of practitioners: Footprinted is initially populated with a collection of existing datasets[71] but the goal was to have practitioners and researchers directly uploading their results to the website. Social features like comments and ratings are also implemented, with the objective of providing quality assessment and a forum for improvement of the data. This has not been successful at the moment and more work would be needed to increase reach and participation from the sustainability community.

An open approach of linked data can be a powerful tool for environmental impact data. Making this information available for a

70 See chapter 4E.

71 Information about the datasets can be found at http://footprinted.org/about/data

wider audience, easy to understand and use, will hopefully increase public awareness and create new unexpected uses of the data. As previously mentioned, environmental science and sustainability is heavily based on information. The innovations from semantic web and linked data open up new opportunities in the sustainability field, both for practitioners and for other users. Footprinted was a way of exploring the presented ideas of transparency and openness into practice, and also a real service for making use of the existing opportunities.

C

CARBON.TO

Understanding carbon dioxide information

Available at: http://carbon.to

Released: September 2009

Created together with: David Kjelkerud, Henrik Berggren

Code available as open source at:
https://github.com/zapico/carbon

Text based on: Zapico, J.L. Turpeinen, M. Guath, M. 2011. Kilograms or cups of tea: Comparing footprints for better CO_2 understanding. In PsychNology Journal 9(1), pp.43-54.

C.1 GROUNDING

Climate change and carbon dioxide have become commonly used words. In the case of Sweden, it is estimated that hundred percent of the population knows what climate change and global warming is (Naturvårdsverket, 2008), of which seventy percent wants to reduce their climate impact. Organizations and companies have reacted to this and have started providing carbon information about products and activities. Individuals are now presented with information about greenhouse gases in media and in their everyday life. However there seems to be a gap between this increase in the exposure to carbon dioxide information and the public understanding of how to interpret it. Even if individuals are familiar with the concepts of climate change and carbon dioxide emissions, when presented with quantitative carbon dioxide information there is a lack of "carbon literacy", the knowledge to understand the information and assess it in comparison with other activities.

Carbon.to is a digital artifact that explores this problem and tries to increase carbon literacy. The first step in the design process was to explore existing examples of how carbon dioxide information has been represented in different contexts and projects, different efforts and strategies for making the information easier to understand, instead of presenting the quantitative information as it. An observed common strategy is to put the quantitative information in context by using a baseline, against which the data is compared to. This baseline can be a way to improve the readability and to have a sense of scale, for instance in the internet service Dopplr[72], where the individual emissions from travellers are presented graphically in bars.

72 A service (now discontinued) for travelers where the emissions of traveling could be calculated. See http://dopplr.com

The baseline can also be normative, comparing the emissions with an ideal or recommended behavior. One example is the WWF carbon calculator[73] where your emissions are presented in relation to how many planets would be needed if everyone lived like you. There is a recommended goal (living under "one planet" footprint) and the carbon information is presented in relation to it.

Another way to make the information easier to grasp is to translate it into the equivalent of another unit we can relate better to, for instance the hours a light bulb have to be on for emitting the same amount of CO_2. A common representation is translating CO_2 information into the number of trees that would be needed to absorb it. An example can be seen in the polemic around Google search energy use. The Times[74] published in 2009 that two searches using Google accounted for 7 grams of CO_2, as much as boiling water for a cup of tea. Google refuted the story, but the use of the analogy of the cup of tea was a success, making the information much easier to grasp. This success can be seen in the proliferation of stories such as *"A Google or a Cup of Tea: which warms the globe the most?"*[75], and it can be seen as representative of the power of translating abstract information into everyday concepts to which we can relate to. This strategy can also be seen in marketing interventions. For instance, *Jazzcalculator*[76], a web service from Volkswagen, compares the CO_2 emitted by traveling to the number of hours that a jazz band needs to play for emitting that (based on their breathing volume). For example a trip of 200km emits 4,14kg of CO_2 that equals 6:56 hours of jazz jamming. This is used for marketing how little the car emits.

The above examples show a trend to transform carbon dioxide into units that are easier for users to grasp. These alternative

73 http://footprint.wwf.org.uk/

74 http://technology.timesonline.co.uk/tol/news/tech_and_web/article5489134.ece

75 http://www.treehugger.com/files/2009/01/google-global-warming-co2.php

76 Available online at: http://www.jazzcalculator.com/

representations can be seen as a way to get around the fact that most people have poor carbon literacy. By using representations that users can relate to – things and actions encountered in everyday life – a greater understanding of climate impact can be achieved.

C.2 IDEATION AND ITERATION

Based on the problem and the previously explored methods of making carbon information easier to understand, a “hack” was designed and built to test a way of solving the problem and to get user feedback. A web service called Carbon.to[77] was created that allows users to improve their understanding of carbon emissions in a playful way by providing the possibility to convert and compare between different real world units.

Figure C1. Screenshot from application

77 The first version was developed during the Ecomo hackathon in London 2009. The application is available online at: http://carbon.to

The idea is similar to the presented concepts transforming CO_2 information into equivalent representations, but enabling the user to choose the units and quantities for a more dynamic and personal experience. The application was programmed in Ruby on Rails[78] and the source code is available as open source.

When the application starts, it displays 1 kg of CO_2 in a random unit (see fig. C1). The user can add or subtract from the figures to explore the relation between the units. An important aspect is the possibility of comparing all units against each other, not just with CO_2 (see fig. C2). For example it is possible to see how many mobile charges are required to emit the same amount of CO_2 as flying for 5 hours. The application converts between 23 different units[79].

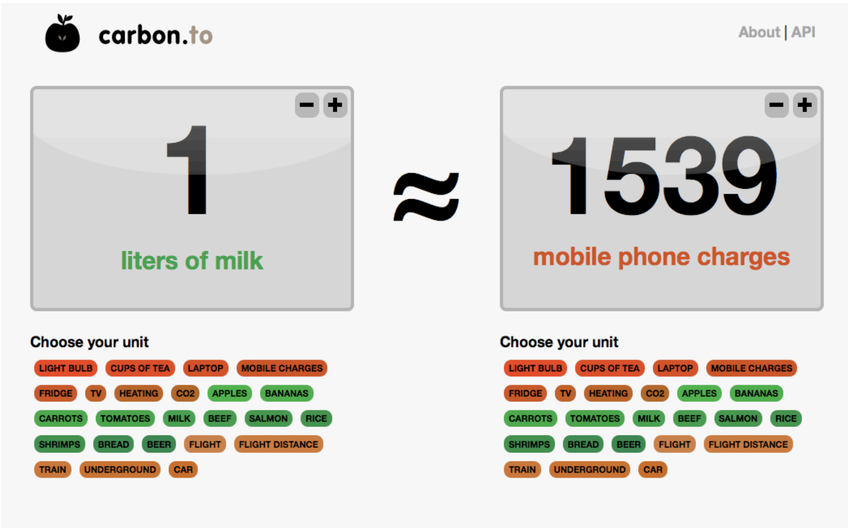


Figure C2. Comparison between two different units

The application is also a tool for other services to translate their carbon dioxide figures into other units through an API (application programming interface).

78 More information at: http://rubyonrails.org

79 The references for the units are publicly available at: http://docs.google.com/View?id=dcqj9r34_206vr9hpqg8

The environmental information used in the application comes from different sources:

- *Food*: Food information as kg of beef or slices of bread comes from life cycle information published at Food and life cycle energy inputs (Carlsson-Kanyama et al, 2003). The data is specific for Swedish consumption.
- *Electricity and appliances*: Data such as watching television or warming cups of tea include the energy use during use (they do not include the rest of the life cycle) and are taken from AMEE80. The electricity carbon factor (for transforming energy to CO_2) is specific for Sweden and also from AMEE.
- *Transport*: Transportation data as km by plane or train is generic data from AMEE and not specific to any country, except the underground which is specific to the London underground.

It is important to understand that there are many uncertainties in these calculations; some data is calculated with a life cycle perspective, while others are limited to the use phase. The uncertainties are made visible by the use of the symbol ≈ instead of equal, and dealt with by being transparent about the calculations and the references used.

The aim of in *carbon.to* is to increase the understanding of carbon emissions through a learning process by simulation. The users compare different choices and different products by playing with the units. This helps to explore the cause-and-effect relationships and it works as a simulation for understanding quantitative carbon dioxide information. The use of computers as simulation tools is one of the key techniques for using computers to change behavior and attitudes (Fogg, 2003). Carbon.to enables experimentation

80 More information at: http://amee.com

without consequences. Users can play comparing different footprints and behaviors while not emitting, and the intervention is designed to show the link between cause (behavior) and effect (CO_2) clearly.

C.3 REFLECTION

Public-wise *Carbon.to* has been successful. From its release in September 2009 it has received more than 19000 visits from 72 different countries, most of them coming from blogs and social media streams such as Twitter[81] and Facebook[82].

A logging system that collected detailed information of the usage of the site, saving each interaction (any time the numbers change, as when changing units or increasing and decreasing the values) in a database, was developed to better understand how the application was being used. Completing data from Google analytics about the users location, time spent and entry points was also used.

The logging system collected more than a thousand interactions per day. After one month running it had 43000 interactions from 1150 users. This can be seen as representative for the normal traffic of the site during the first year when the application was most intensively used. The most compared units (after removing the initial comparison that is randomized) are shown in figure C3.

81 http://twitter.com

82 http://facebook.com

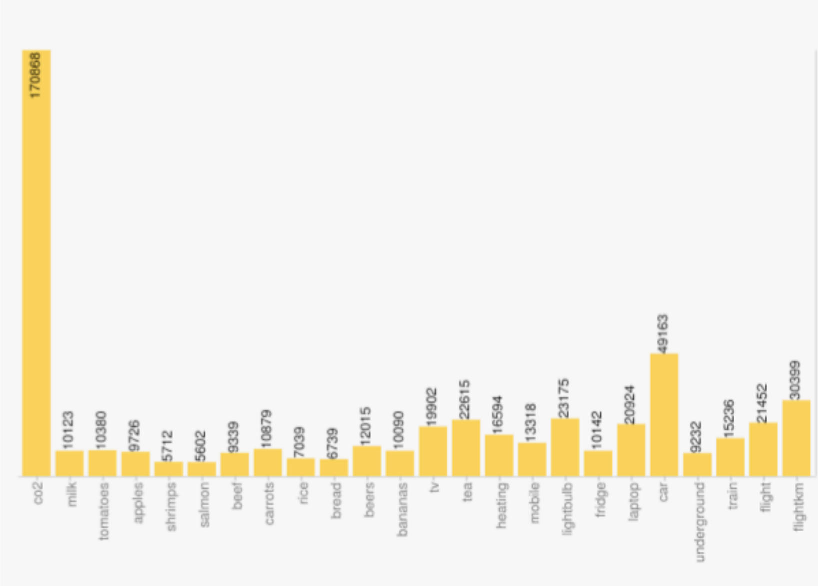


Figure C3. Logs from six months of usage.

From the logs we could get the following conclusions:

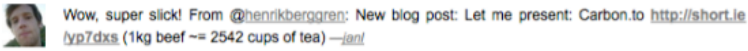
- Users were very active changing units and playing with the numbers. The average number of interactions is nearly 40 per user.
- Most interactions were comparisons between CO_2 and something else, while comparisons between units were less popular.
- Transportation emissions were the most compared ones and "km by car" was the most used unit.

The feedback from social media was useful both for evaluating the effectiveness of the effort and as an input for the next iteration of the design process. Most valuable were the reactions from Twitter. Most responses including a link to the site were mainly a way of people to share the link with the followers, for instance:

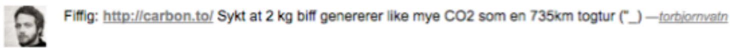

fab Here's an interesting app - http://carbon.to/ - converting carbon into units you might actually understand.... —fairandbare

fairandbare: "Here's an interesting app converting carbon into units you might actually understand…"

There were some comparisons that surprised the users because the big differences in the impacts. For instance beef is known to have a high climate impact, but when comparing with another unit, such as traveling by train, make the size of this impact more graspable. Comments included the following:


Wow, super slick! From @henrikberggren: New blog post: Let me present: Carbon.to http://short.ie/yp7dxs (1kg beef ~= 2542 cups of tea) —janl

jant: "1kg beef ≈ 2542 cups of tea"

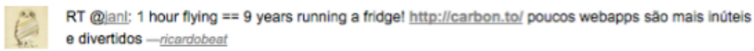

Fiffig: http://carbon.to/ Sykt at 2 kg biff genererer like mye CO2 som en 735km togtur (^_) —torbjornvatn

torbjornvatn: "2 kg beef generates as much CO_2 as 735 km in train"

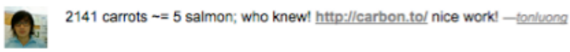

Two hours of flying equals 36kg beef or 13639 carrots in CO2 emissions http://carbon.to/ —frdrk

frdrk: "2 hours flying ≈ 36kg beef ≈ 13639 carrots"

Other activities that had the same effect were salmon and flying with tweets like:

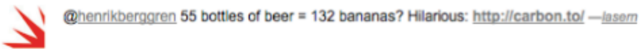

RT @janl: 1 hour flying == 9 years running a fridge! http://carbon.to/ poucos webapps são mais inúteis e divertidos —ricardobeat

ricardobeat: "1 hour flying ≈ 9 years running a fridge!"


2141 carrots ~= 5 salmon; who knew! http://carbon.to/ nice work! —tonluong

tonluong: "2141 carrots ≈ 5kg salmon, who knew!"

Some comparisons were appreciated just as entertainment, for instance:


@henrikberggren 55 bottles of beer = 132 bananas? Hilarious: http://carbon.to/ —lasern

lasern "55 Bottles of beer ≈ 132 bananas? Hilarious"

This feedback provided a general idea of what users thought of the application:

- In general the application was liked and **fun to use**. This "fun" factor was one of the goals from the design process. The different representations explored in the previous review are often tongue-in-cheek. This quality makes the figures less intimidating and more fun, which contributes to making carbon impact less abstract. We tried to include this quality in *carbon.to*, including units such as bottles of beer.

- Some users were **surprised by the relationships between different emissions**, for instance the high impact of beef. We think this had a positive impact in the users' understanding of carbon dioxide information. Not only did they learn or confirmed that beef has a high carbon footprint, but they learned it through their own interaction, not only by reading.

While this feedback is not from controlled sources, nor can be argued to be representative, this method of getting feedback showed to be successful both in providing insight but also in the candid characteristic of the responses. Finally, it can be summed up that the development and the response generated by Carbon.to points towards that new uses of interactive visualizations, creating anchors and context, and allowing simulation, can be powerful techniques for more effective communication of sustainability information.

D

WEBENERGY & HELSINKICO2

Dynamic visualization of environmental impact data.

Webenergy

http://sympact.cs.bris.ac.uk/webenergy/

Released: May 2012

Created together with: Daniel Schien

Code at: http://github.com/dschien/openday

HelsinkiCO2

http://helsinkico2.com

Released: September 2012

Code at: http://github.com/zapico/helsinki

D1. GROUNDING

Traditional environmental impact analysis such as LCAs are static, published in text formats that once published do not allow changes. The results of most LCAs are on the other hand not static, but change depending on different variables. For instance, when making a LCA of a book, even if you know the exact information of the production, the result will still vary: is the reader walking or driving to the city center to buy a book? Would it be bought in a physical shop or in an internet retailer? How many people would read the book? What would happen in the end of life of the book?

LCA practitioners work around this problem by selecting a number of possible scenarios, or using average data. In the previous example for instance there could be a scenario where the book is bought online and delivered by post, other where the book is bought in a store. Then different variables can be based on average data such as the average distance of transportation for books delivered by online stores (Borggren et al 2011).

The problem of this approach is that while it works well for having a good top-down understanding of the impacts, it does not work well when applying the results to individual situations.

Having a dynamic approach using interactive technologies can provide a way of communicating the environmental impact that makes the existing variables visible. This allows the users to create their own scenarios for adapting the results to concrete cases, and to simulate changes in real time.

Based on these ideas two different applications were developed. The first one, *Webenergy*, is an interface to calculate the energy impact of using a website, providing the users the control over different parameters. The second one, *HelsinkiCO2*, is a visualization of the carbon emissions in the city of Helsinki with an interface to test how different changes would affect the result.

These two artifacts are based on the same idea and code, but applied to different domains, so they are presented in this text as an unit.

D2. IDEATION AND ITERATIONS

Webenergy was done in collaboration with Sympact[83] and it was originally created for presenting in situ at The Guardian Open Weekend 2012[84]. It presents the electricity used when browsing The Guardian website and it allows the user to play with different parameters:

- Type of device: mobile phone, tablet, laptop or stationary computer.
- Type of connection: fixed connection using a WiFi router or mobile connection using 3G.
- Type of content: a website with text and images or streaming video.
- How much time is spent in the site: from 1 minute to two hours.

The application responds in real time to the choices changing the results and visualizing the different impacts as bubbles. The area of the bubbles (See fig. D1) represents the energy use and the visualization shows both the total impact in watt hours, and the partial energy use divide between the access device, internet (servers and infrastructure) and the access point (if using WiFi). The visualization provides a translation of the energy use into

83 Sympact is a joint research project between University of Bristol, University of Surrey and Guardian News and Media Ltd, exploring the energy and carbon emissions of digital media technologies. More information at: http://sympact.cs.bris.ac.uk/ .
In this particular project Daniel Schien initiated the work, with collaboration of Heppie Curtis, Stephen Wood and the rest of the Sympact team. I was in charge of the visualization and design.

84 See article in describing the intervention at:
http://www.guardian.co.uk/sustainability/digital-carbon-footprint

carbon dioxide emissions, and also in other units for putting the quantitative information in a context (in the same style that *carbon.to*), such as the number of light bulbs during the same amount of time and distance traveled by car.

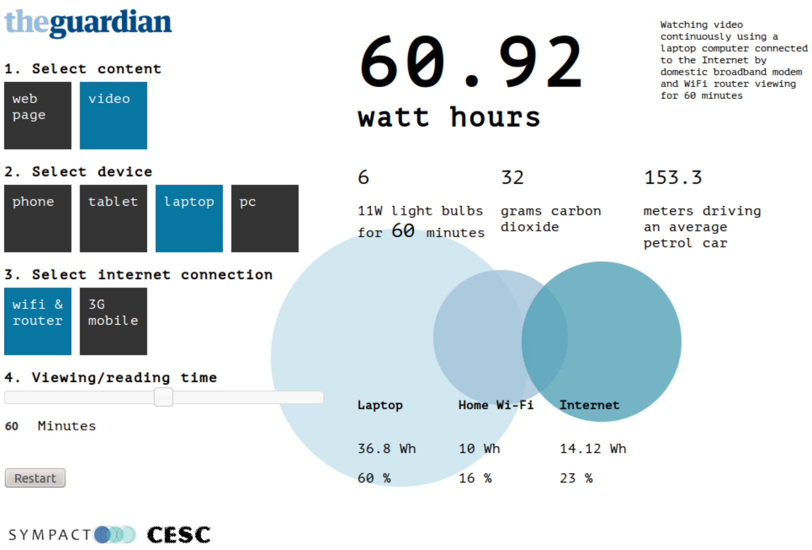


Figure D1. Webenergy start scenario

The visualization is part of a survey to understand people's awareness and knowledge about internet energy use. First, the participants answer some questions about their perceived knowledge and they have to guess the energy use of internet in a scenario. Then they get to play with the visualization and see how the energy impact really was. Finally they get to answer some questions to evaluate how their previous knowledge differed from the real energy consumption. During The Guardian Open Weekend the 24th and 25th of March 2012, visitors answered the survey in place using tablet devices. More surveys are being conducted using the application, investigating the public perception and knowledge about the energy use of internet. A not-branded version of the application is available online for the public.[85]

The visualization is developed using HTML and Jquery, while the survey was built using python and django. The data and model is based on the work being conducted at Sympact in collaboration with The Guardian.

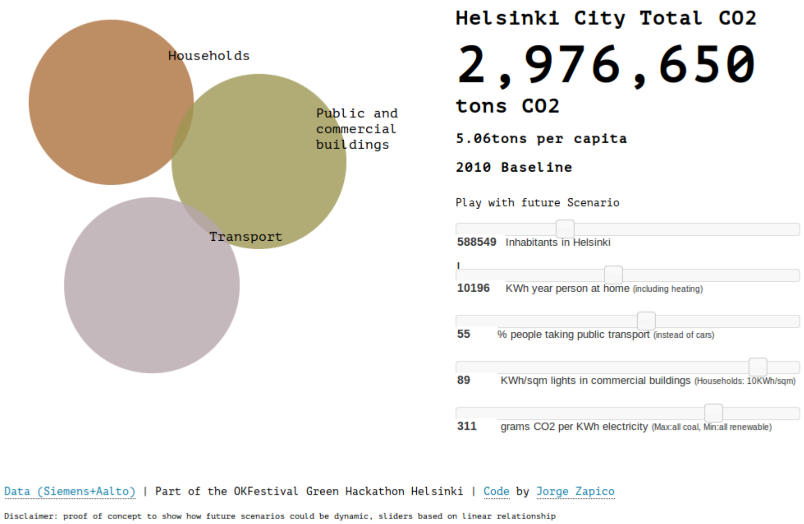


Figure D2. Current baseline showed when starting HelsinkiCO2

Based on the same idea and code, *HelsinkiCO2* was created during the Open Knowledge Festival Green Hackathon in Helsinki[86]. It uses data of the energy and CO_2 emissions for the city of Helsinki compiled by Siemens and Aalto University[87]. This dataset includes information about the energy production, energy consumption by different sectors, and scenario calculations about how the energy use could be decreased. The future scenario in the dataset is based on the application of Siemens smart cities technologies. *HelsinkiCO2* application visualizes the current energy use

85 http://sympact.cs.bris.ac.uk/webenergy/main/app

86 More information about this event in the next section. See: http://okfestival.greenhackathon.com

87 Available as open data at: http://thedatahub.org/dataset/helsinki-siemens

aggregated in the three general categories of the dataset (households, public and commercial buildings, and transportation), using the area of the circle to represent the amount of carbon dioxide.

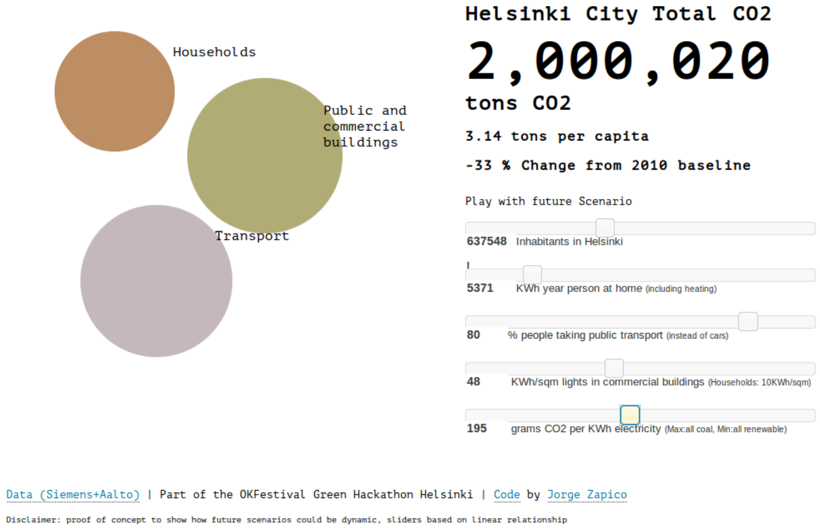


Figure D3. User scenario of a less carbon intensive Helsinki.

Instead of just showing the current situation and a prognosis scenario, the application provides a number of parameters that the user can change, allowing the exploration of different possibilities and learning about the relationships and scales between them. The available parameters are:

- Inhabitants in the city.
- Amount of energy used at home: kilowatt hour per person and year used in households, including heating.
- Percentage of people taking public transportation.
- Energy efficiency for lightning commercial buildings, measured in kilowatt hour per squared meter.
- Carbon intensity of electricity: How much carbon dioxide is emitted for producing electricity, measured in grams of CO2 per

Kwh. It depends on the energy source, from coal that has the higher intensity, to renewables that has the lowest.

The visualization provides the total and per capita amount of CO2 emissions, and the percentage change from the baseline. These values and the size of the bubbles change dynamically when changing the parameters using the sliders.

The different parameters where chosen based on the availability of data and how relevant they were for the final result. The lighting efficiency was included to pinpoint one particular aspect where efficiency gains are possible (the energy use of lighting commercial business was 89 Kwh per sq meter, in comparison with 10 Kwh per sq meter used in households). The sliders allow movement to both sides, having a positive or a negative impact and in the prototype they are a simple linear function.

D.3 REFLECTION

The interactive visualization of environmental impact data allows working with situations where the user's variables greatly affect the result. This is usually the case of ICT, as argued by Weber et al (2010). *Webenergy* corroborate this, as changing the parameters affects the result, both in size, but also the correlation between different components.

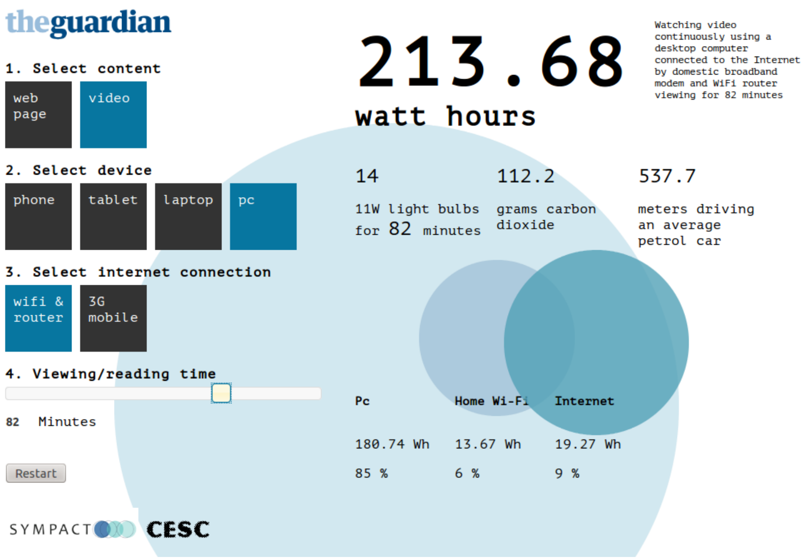


Figure D4. High-impact scenario.

For instance in the scenario shown in figure D4, where the user uses a stationary PC and a WiFi connection to watch video, the energy use is 213 watt-hour and the main impact comes from the user computer. While in figure D5, where the user spends the same amount of time browsing the website with a tablet, the total energy use is one order of magnitude lower (21 watt-hour) and the servers and internet infrastructure become the biggest impact. The graphical interface makes it easier to understand the size relation and the interactivity allows users to tailor the result to the cases relevant to them. It also allows them to be proactive and simulate different scenarios, similar to the approach taken in Carbon.to. This simulation approach, where the user can test different options and get immediate feedback, tends to be a more effective strategy for increasing awareness than static presentations where a certain result is just given to the user (Foggs, 2003).

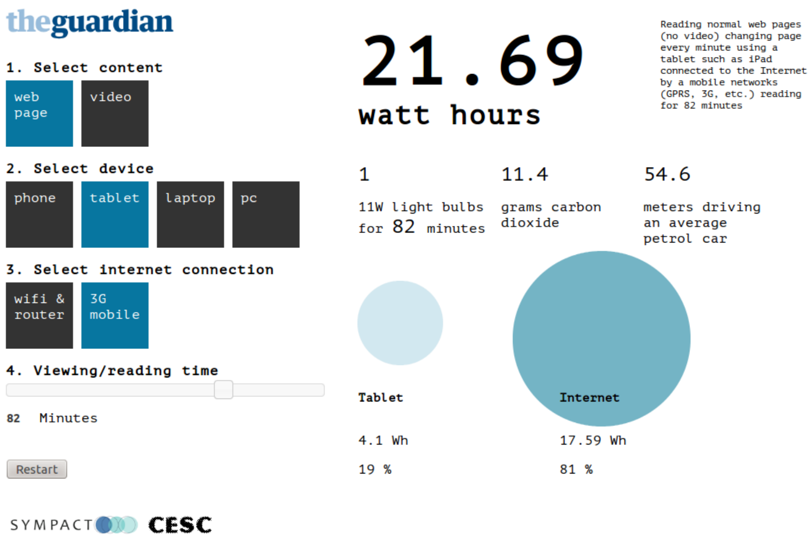


Figure D5. Low-impact scenario.

HelsinkiCO2 presented a similar case, but with the focus on the visualization of how possible future scenarios and actions would affect the city's carbon footprint. The original data is available in a worksheet format, which makes it difficult to understand, and it provides a single possible scenario of the emissions, already set by the data providers, not giving any room for experimentation. Providing a graphical interface to the data helps to understand the relationship between the different impacts in a more intuitive way. Giving the user control over the possible future scenarios and giving real-time feedback as the data changes, allow the user to learn by experimentation the impact of different actions and the size relationship between them. As it was mentioned, the sliders change the result in a linear manner, using percentage change of the baseline data. This is of course not the case in reality, as most relations would not be linear and there are rebound effects, as it is pointed out in the homepage. Höjer et al. (2008) point out also out that prognosis with quantitative data may be counterproductive for future scenarios. The goal of the prototype is not to provide an exact calculation but to show the scale of different emissions and the role of different parameters.

A problem with such approach is that communicating the assumptions behind the visualizations is difficult, and there are normative stances in the choices of which data to visualize or not. In that way using visualization can frame the questions in different ways with the purpose of influencing the users. In the case of HelsinkiCO2, the strategy used was be transparent about the data and assumptions used, just as in Carbon.to or Greenalytics. Since the data is released with an open license, it is easier to achieve transparency.

These two applications can be seen as proof of concepts of how sustainability and Industrial Ecology information, such as life cycle assessment, can be made interactive. This interactivity can help communicating the complexity of LCA data, where there may be multiple scenarios and multiple possibilities that affect the end-result, and that are difficult to communicate using traditional formats.

E

GREENHACKATHON

Hacking events for sustainability

More info at: http://greenhackathon.com

Started on: October 2011

Initiated together with: Hannes Ebner

Text adapted from: Zapico, J.L. Pargman, D. Ebner, H. Eriksson, E. 2013. Hacking sustainability: Broadening participation through Green Hackathons. International Workshop on EUD for Supporting Sustainability in Maker Communities. IS EUD 2013, June 11-13, 2013, IT University of Copenhagen, DK.

E.1 GROUNDING

Hackathons[88] are events where developers, programmers, designers and computer amateurs in general, meet for working intensively on software (or hardware) projects. The word hackathon is a portmanteau of hack and marathon. “Hack” is a reference to the original meaning of a hacker as someone who "programs enthusiastically" (Levy, 1984; Wark 2006; Raymond, 2000), and it reflects the programming and technical focus of the events. The “marathon” part points to the “endurance” side of the events as many hackathons run for extended periods without pauses, not seldom 24 hours or more.

The objective of the hackathons is to work from an idea all the way to a functional solution or a prototype. There are a variety of events, some focus on a particular programming language[89] or company[90], while some focus on a particular field or theme, for example generating business ideas[91], creating music software[92], playing with NASA’s space data[93] or hacking for social change[94]. The organizers of the events have to provide appropriate facilities, connectivity, food and beverages, and take care of practical considerations so the participants can focus on creating[95].

Based on these existing events we created Green Hackathon as a series of events with an environmental profile, where the task is to develop prototypes and demos with a sustainability purpose. The events are defined broadly, the only guidelines are that the focus is

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88 These events can also be called with other names such as hack day, code fest, code camp, app challenge, etc.

89 Rails Hackathon http://railshackathon.net/

90 Yahoo Open Hack Day http://developer.yahoo.com/hackday/

91 24 hours business camp http://www.24hbc.se/

92 Music hack day http://musichackday.org

93 NASA International Space Apps Challenge, http://spaceappschallenge.org/

94 Random Hacks of Kindness, http://rhok.org

95 See the Hack Day Manifesto http://hackdaymanifesto.com/

on sustainability questions (for instance climate change, energy, food, transportation) and the aim is to create functional prototypes. While there has been hardware hacks, web applications and software are the most common form of result, for example applications to help decrease carbon footprint or that visualize sustainability data and information in order to make it more understandable. The Green Hackathon[96] initiative was initiated in Stockholm in 2011 and has since become a series of community events organized locally by different partners in different countries.

One of the main driving forces of Green Hackathon is to use these events to increasing interdisciplinary cooperation. Participation is open to anyone and the events have explicitly invited a wider audience to foster interdisciplinarity and innovation. While most participants had a technical background, like programmers or web developers, in the events there have also been researchers, environmental experts, designers, journalists, farmers, decision-makers and venture capitalists. The Green Hackathon events have thus explicitly attempted to bridge differences between a variety of communities and to foster interdisciplinary collaboration between them.

E.2 IDEATION AND ITERATION

Green Hackathon was started as an open series of events where anyone could organize their own event. The aim of the Green Hackathon was both to create prototypes and to put ideas into practice, but also to bring people together and to foster the ICT for Sustainability community. The first Green Hackathon was organized in Stockholm in October 2011 and has thereafter become an international series of events organized by different partners under the same name; London (January 2012), Helsinki (September 2012), Athens (December 2012) and Zürich (February

96 For more information see http://greenhackathon.com

2013). These events have experimented with a variety of different formats. The Stockholm and London events were 24-hour events where participants were allowed to stay on the premises throughout the event (which many participants did).

Figure E1. Picture from the Stockholm Green Hackathon.

The Athens Green Hackathon event was a three-day event, with the first day dedicated to brainstorming ideas, the second day to coding and the third day to presentations. The Zürich Green Hackathon event was a pre-conference activity of ICT for Sustainability (ICT4S[97]) conference and was about 12 hours stretching from early morning to late evening. The Helsinki Green Hackathon event was part of the Open Knowledge Festival[98] and was more of a drop-in event during two days with presentations, collaborative coding and break-out sessions where groups worked together on a specific problem. The number of active participants has varied between 20 and 60 in each event, and usually additional persons dropped by for a limited amount of time or for listening to the final presentations.

97 http://www.ict4s.org/

98 http://okfestival.org/

The work practices during Green Hackathons have been flexible, with most participants working in groups, either formed before the event or in ad-hoc groups created at the hackathon. Some participants have worked by themselves (on a project of their own) or even gone around to help out in different groups. The same patterns could also be seen among non-technical participants, but with some actively looking for coders to help implement an idea of theirs. Switching groups or helping different groups out by providing ad-hoc help based on their expertise was more common among non-developers than among developers.

Figure E2. Picture from the Zürich Green Hackathon.

Almost all events had an element of competition, ending with project presentations and the appointment of “winning hacks”. That decision was taken either by a jury (in Stockholm, London and Athens) or by popular vote (in Zürich). There have been no formal evaluation criteria, but “winning hacks” have excelled through a combination of the quality of the implemented idea from a sustainability point of view and the technical implementation. Working applications (prototypes with running code) were valued over presenting mockups or ideas. Most events have had just a general category, but the London Green Hackathon event had different prize categories for different themes like “the built environment” and “transparency” that were sponsored by specific companies or organizations.

One of the most important results of these hackathons are the applications and prototypes created[99]. Examples of created hacks include:

Carbon Emissions in Minecraft[100]: A mod for the game Minecraft that adds carbon emissions to actions in the game, for instance when burning wood (See fig. E3).

Figure E3. Minecraft carbon mod presentation in Stockholm Green Hackathon

Green Travel[101]: An iPhone application that helps the user commute with public transport and at the same time see how much CO_2 different choices of trips will emit.

99 All the hacks can be found at http://www.greenhackathon.com/category/hacks
100 http://www.greenhackathon.com/blog/2011/hacking-carbon-emissions-into-minecraft/
101 http://www.greenhackathon.com/blog/2011/green-travel/

Kindle energy dashboard[102]**:** A prototype to use an Amazon Kindle to visualize energy data as screensaver when the device is in sleeping mode.

Mastodon[103]**:** A web application that allows selecting the most efficient and sustainable location for cloud computing jobs. It calculates the result depending on the live costs, the current energy mixes at the location and the current temperature (see fig E4).

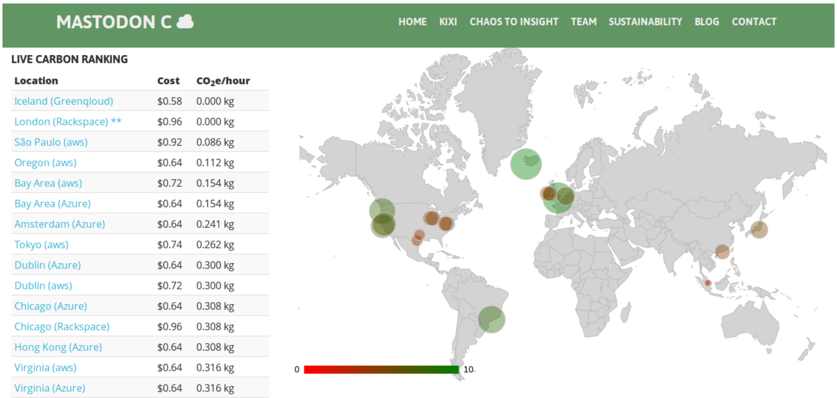

Figure E4. Screenshot of Mastodon C.

Remember Carbon[104]**:** A browser extension that analyzes a travel agency website and inserts CO_2 emission data on the page about each flight (fig E5).

102 http://london.greenhackathon.com/hacks/kindle-energy-dashboard/
103 http://london.greenhackathon.com/hacks/mastodon/
104 http://www.greenhackathon.com/blog/2011/remember-carbon/

Figure E5. Remember Carbon screenshot

Real Time Carbon Emissions[105]: A visualization of the CO_2 emissions from a real boiling kettle shown in real time using open source energy hardware.

Swiss Nuclear Energy[106]: A visualization of the use of nuclear power in Switzerland showing how much it contributes to the energy mix in different Swiss communes (see fig E6)

105 http://london.greenhackathon.com/hacks/real-time-carbon-emissions/

106 http://www.greenhackathon.com/blog/2013/swiss-nuclear-energy-visualization/

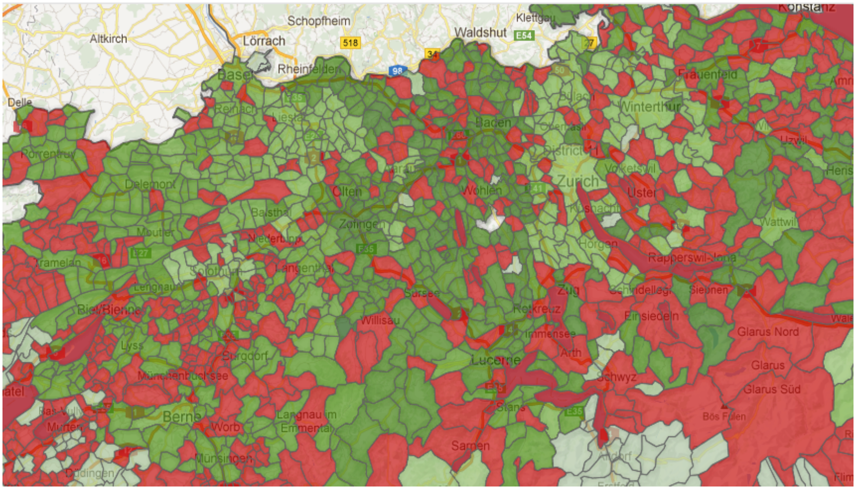

Figure E6. Screenshot of Swiss Nuclear Energy visualization.

One tonne[107]: A visualization that allows user to play with different options of what it can be done with a carbon budget of one tonne of CO_2.

Social impact of supply chains[108]: A modification of Sourcemap where the supply chain information is mashed up with public data from the UN to visualize the likelihood of child labor in each country involved in the manufacturing of a product.

E.3 REFLECTION

The Green Hackathon has grown from one planned event to becoming an ongoing international series of events. The events attracted participants and created a community around the use of internet and open data for sustainability. They have also created press, for example Swedish newspaper Dagens Nyheter wrote a full eight pages report on hackathons based on the Green Hackathon and the 24h Business Camp[109], and the story about

107 http://london.greenhackathon.com/hacks/one-tonne/
108 http://greenhackathon.com/blog/2011/visualizing-the-social-impact-of-supply-chains/
109 http://www.dn.se/livsstil/hackarna-tar-over-finrummen

carbon minecraft mod was published in The Guardian[110], Boing Boing[111] and Italian Wired[112].

The Green Hackathons have been successful in generating prototypes and applications. A key characteristic that makes the hackathon format productive is the combination of providing a long but limited stretch of uninterrupted time to work. The opportunity to work on one task for 24 hours, uninterrupted by meetings or other distractions, is unusual in the current work culture. The hackathon format provides an opportunity of working on a new, exciting project or with an idea that has been around for some time, waiting for an opportunity to be developed. The limited amount of time is also a key factor. Parkinson's law wittingly states that "Work expands so as to fill the time available for its completion." (Parkinson, 1995) where the hackathon "forces" participants to concentrate hard, to produce and to deliver.

This focus on "getting things done" is an important part of the hacker ethic and the computer culture with the focus on hands-on approaches, of "showing results" instead of just "talking about ideas" (Raymond, 1999b). The process of converting an idea into a prototype or a functional application and of practical problem solving is what "makes hackers tick" (Torvalds, 2001) and hackathons embody this with their focus on creating prototypes and working applications (running code). Having good ideas is important, but of little value if you can't show any running code at the end of the event. At these events functional prototypes and running code are valued over good-looking mockups. While getting things to work and showing results is a core hacker culture value, other Green Hackathon aspects are more playful (Danet,

110 http://www.guardian.co.uk/environment/green-living-blog/2011/oct/25/climate-change-strikes-minecraft

111 http://boingboing.net/2011/11/29/hacking-carbon-emissions-into.html

112 http://life.wired.it/news/natura/2011/10/26/co2-minecraft-lucca-comics-games-fate-of-the-world-wakfu-ambiente.html

2001). The competition component is not taken too seriously and the value of the mostly symbolic prizes is puny compared to the economic value of participants' investment in time. The competition is in itself clearly not the main driver for the participants - as apart from other motivations such as doing things together with others and contributing to the community. A key enabler of this hands-on approach is the availability of powerful and easy-to-use web technologies, frameworks, and open data, that can allow hackathon participants to create something useful and original together in just a day or two, and that provides affordances (Norman, 1998) to non-expert programmers to create and extend software.

The Green Hackathon events have also been important physical social events, helping to build a community of interest that bridges different disciplines and that provides face-to-face connections between otherwise distributed or loosely connected individuals. The importance of the social and physical aspect of these types of events has been pointed out by Coleman (2013), Moilanen (2012) and Pargman (2000). Coleman discusses the functions of "hacker con[ventions]" in terms of facilitating contacts between new persons, meeting up with previously exclusively online contacts, reinforcing existing groups and further build up community.

Green Hackathon events have tried to bring together diverse groups such as developers, designers, researchers, sustainability experts and journalists. Examples of interdisciplinary collaborations can be seen in *Mastodon C*, which was created by a programmer, a mathematician, and an anthropology PhD student researching sustainability; and *Swiss Nuclear Energy* visualization, which was created by a journalist with an idea, together with a developer who scraped the data and created the visualization. While the events have explicitly invited a wide audience for fostering interdisciplinarity, the collaborations have been mostly ad-hoc. How to empower and facilitate the collaboration between technical and non-technical expertise is one of the challenges for future events.

The most concrete results of the Green Hackathons are of course the hacks themselves. The hacks are quite heterogeneous within the constraints of creating some kind of technological prototype that has a sustainability purpose. The commercial potential of the ideas has not been a focus at the Green Hackathon events and many of the results are in fact playful, sometimes boisterous internal jokes or smart tweaks, such as *Carbon Minecraft Mod,* that follow from a traditional joyful hacker culture work approach (See Weinberg, 1971/1998, and Torvalds and Diamond, 2001). There has, on the other hand, been hacks created that have become part of existing commercial efforts, and some hacks have been developed further becoming startup companies such as *Mastodon C*[113].

It can be argued that the impact of the applications and prototypes created in the hackathons is limited, and while some applications become new products and keep being used, many of them stay on a prototype stage. But the contribution of the hackathons can be seen to go beyond the impact of individual results. The experimental style of the events helps the cross-pollination of different ideas, the test of new concepts that may mature in the future, and new opportunities as data is opened and made available to people that would not have worked with it before. Finally it can be argued that the hackathons provide a non-technical innovation as they apply hacker ethic values such as openness and hands-on creativity for sustainability, giving an example of how iterative prototyping and hands-on collaboration can be used for moving sustainability ideas to functional applications.

113 See: http://www.theodi.org/case-study/mastodon-c

5

HACKING FOR SUSTAINABILITY

The artifacts presented in the previous chapter have explored how new technologies and approaches in information technologies, such as machine readable data, open data licenses, crowdsourcing, mashups, pervasive sensing, and interactive visualizations, can be applied in ICT4S and, in particular, in sustainability practice. This chapter will analyze the results at a more holistic level, looking at all five artifacts as a cohesive portfolio with common underlying concepts and ideas. This portfolio is used to articulate the discussion around the opportunities and risks of this new area of ICT4S research.

The mentioned trends and technologies are centered on new ways of creating, sharing, visualizing, spreading and remixing data. The artifacts presented in the previous chapter explore their use for working with sustainability data. Sustainability data in this context is meant as data that is relevant for making or evaluating sustainability decisions, for instance energy use, carbon dioxide emissions, water footprint, pollution levels, or material input and output. Data can be seen as the common denominator not only of the artifacts presented in this text, but of many of the applications using ICT for sustainability presented in the background chapter

(See Zapico et al. 2011). Examples of data-centric solutions include smart grids and other efficiency measures, behavioral change interventions based on eco-feedback, and the use of ICT tools in environmental analysis. This centrality of data is not a surprise; information technologies are after all data processing machines, and as mentioned before, Industrial Ecology and sustainability relies heavily on information (Allenby 2000, 2006). But these new technologies and paradigms add new characteristics, opportunities and risks that are more specific to the different ways information and data are created, shared and visualized.

This chapter is divided into three different sections:

- **Data-Driven Sustainability**: an analysis of the common characteristics and the main opportunities of using these new ways of working with data in sustainability practice in contrast with more traditional approaches.
- **Data Blindness**: a discussion pointing out the problems and limitations of the focus on data and dealing with uncertainties.
- **A Hacker Approach:** a discussion on how the previous opportunities are not only technical but also cultural and based on values, and how these are connected to the hacker ethic.

5.1 DATA-DRIVEN SUSTAINABILITY

The presented portfolio of artifacts has explored the use of machine-readable data, open licenses, crowdsourcing, mashups, and dynamic visualizations in the context of working with sustainability data. From the collection of the different artifacts as a portfolio, a number of principles can be outlined to describe the characteristics and changes these new tools and paradigms bring to sustainability practice and to ICT4S:

1. **Bottom up automatic data**

The affordances provided by pervasive sensing, machine-readable data, and open licenses, together with new approaches such as crowdsourcing and mashups, are changing how data is created and collected. These approaches can change how sustainability data is created, from a mostly manual way to a more automated and bottom-up approach, where bigger amounts of data can be processed in a more programmatic style. *Greenalytics* can be seen as a proof of concept of this idea. Instead of making a study of a particular website, making an average of the number of users or where they come from, the application uses existing machine-readable data to calculate the result dynamically based on high definition data of who visited the website, from where, and for how long. This increases the accuracy of the result, but also makes it automatically adaptable to any other website by just changing the data source. The use case of a website is quite straightforward, as data about their usage is already available online and under accessible formats. But with the exponential increase on the world's capacity to store, communicate and compute information (Hilbert and López, 2011) and the increase of data availability connected to the physical world, the same approach could be applied to other products and services.

Crowdsourcing is also relevant in this context, as it changes the way data can be collected to a more social bottom-up approach. Relevant examples using crowdsourcing in a sustainability context include the gathering of weather data (Elevant, 2011), the track of deforestation using satellite pictures[114], or information about supply chains (Bonanni et al. 2010). Pervasive sensing is another technology that can enable the automatic gathering of data. Examples of sustainability-oriented projects exploring this are: PEIR[115], an application from CENS at UCLA that tracks the user's

114 http://forestwatchers.net/

115 I worked with PEIR in a test to implement it in Stockholm which did not continue after the prototype stage.

location and movements using GPS and calculates the CO_2 impact and the exposure to air pollution (Agapie et al, 2008), and Air Quality Egg[116], an open source crowdfunded sensor that can track NO_2 and CO concentrations as indicators of air pollution.

2. Real time and dynamic feedback

Other important characteristic is the use of real time and dynamic feedback that is up to date with the latest data available. This is in contrast with existing Industrial Ecology approaches, such as LCA, where environmental information is mainly collected either in a static, retroactive process or in a prognosis, scenario based approach. A problem with this approach is that the results are based on past data and additional changes to the studied system do not affect the result. In a decision-making process this means that there is no feedback in the possible improvements unless a new study is performed. An example of this is the reporting of a website's carbon footprint from *Greenalytics*, where it is re-calculated everyday. Smart energy meters, that allow real time feedback of electricity consumption, are a representative example of this shift towards real time, and they are one of the key technologies used in many ICT4S behavioral change applications such as in ambient awareness projects (Riche et al 2010; Froehlich et al 2010).

3. Transparency and openness

Much of the existing sustainability data is published in commercial databases or expensive journal articles where the public do not have access to it, and/or written in paper or in a text document where a computer service cannot access it. Applying open licenses and machine-readable formats to sustainability data can make the information more accessible to the general public, and the machine-readability makes possible to easily reuse existing data

116 http://airqualityegg.com/

fostering new innovations. *Footprinted* is a trial to apply the concepts of open licenses and machine readable formats for sustainability data. It aims to make the data more accessible for non-experts and to allow users to create applications on top of the existing data. There are other initiatives working in this direction. Examples include Earthster[117], an upcoming LCA tool with focus on open source and visualization, AMEE[118] a UK company that provide environmental data in a machine-readable API, ELCD[119], a European LCA database that is accessible for free in machine-readable XML format, and OpenLCA, an open source LCA modeling software (Ciroth 2007).

4. Dynamic visualization

The visualization and communication is a key step for making the data understandable and usable (Tufte, 1990), and new technologies are creating new opportunities. New technologies are increasing the possibilities of making the visualization more dynamic and interactive. In traditional LCA and environmental reports the practitioners select a number of representative scenarios of current and future use. This choice may not be relevant to the specific users and in cases where the user parameters are important to the result, such as in the impact of ICT, the result may differ greatly. *Webenergy* and *HelsinkiCO2* explored this space, allowing users to interact with environmental impact analysis. In the case of *Webenergy*, the user can learn about the energy impact of web browsing by changing usage parameters such as time, hardware, and connection type. In the case of *HelsinkiCO2,* the user can explore how future scenarios could look like by changing variables of the energy use at a city level. Both leverage the usage of graphical representations for better communication of quantitative

117 http://www.earthster.org/

118 https://www.amee.com/pages/api

119 http://lca.jrc.ec.europa.eu/lcainfohub/html/datasetsLicense.html

information, and the usage of interaction and simulation for increasing the understanding of cause-and-effect. *Carbon.to* is another example of a purpose-driven visualization. It has the goal to make the data more understandable and it uses an interactive design to engage the user in exploring and playing with the data. Letting the user have a proactive role, experiment and simulate, can be a more effective learning experience than presenting static information (Fogg, 2003).

5. New models of innovation

The affordances of information technologies are broadening innovation (Von Hippel, 2005), and innovation is now driven not only by professionals, but also by end users and amateurs. In the case of sustainability practice, the increasing availability of data in open and machine-readable formats makes it possible to visualize, transform, and remix different datasets, and to generate new innovative usages outside the sustainability practice community. This can be seen in the *Green Hackathon* events, where most new applications and visualizations were based on existing open data, and the participants were mostly from outside the professional sustainability community. Another key difference of this democratization of innovation is the openness of the process, as user innovations are usually freely revealed (Von Hippel, 2005), which makes them easier to spread and to be adopted and adapted. This is not only an ethical choice, but also a pragmatic way for better innovation, as Raymond, (1999a) argues in the case of software projects. The applications in this text are examples of this open approach, and for instance *Greenalytics* have been adapted by other users to further use in their own projects.

A bottom-up automatic way of creating data, real-time orientation, an open approach, dynamic visualization and a more open innovation process. These principles can be seen together as a paradigm change of how work with sustainability data is performed. I call this new way of working "*data-driven sustainability*", and it can be put in contrast with the "traditional" methods of dealing with sustainability information, such as research within Industrial Ecology and practices such as LCA and environmental impact analysis.

Traditional	**Data-Driven**
Static presentation	Dynamic presentation
Past Time	Real Time
Top-down	Bottom-up
Manually collected	Sensed, mashuped, crowdsourced
Closed data	Transparency
Closed innovation	Open innovation

Figure 5.1. Data-driven approach against traditional sustainability work.

These can be seen as characteristics, or opportunities, of how the application of new technologies and approaches from ICT can transform (and is already transforming) how data is created, shared and visualized in sustainability practice. As argued through the text above, the artifacts presented in this work have been proofs of concept showcasing some of these characteristics, and they have been used as a way of exploring the opportunities and risks.

5.2 DATA BLINDNESS

After exploring the opportunities of a data-driven approach for working with sustainability, it is necessary to explore the main risks of such an approach, what I group under the name of *data blindness:* trusting *only* or *too much* in data.

As presented in the beginning of this text, we have to remember that sustainability is a wicked problem, not easily reduced to numbers and explicitly normative. One side of this problem is that a data-driven approach focuses de-facto on parts of sustainability that are possible or easy to quantify, while other areas that are more challenging to put numbers on are neglected. This can be seen in the focus on energy and CO_2 emissions in many studies, for instance in the majority of life cycle assessments of ICT (Arushanyan et al, 2013), while other problems such as toxicity do not get the same attention.

The focus on quantitative data and real-time information can create also a kind of time-shortsightedness. The quantitative nature of the data makes it difficult to look at long-term developments concerning the future, as there is no measured data for it. Höjer et al. (2008) argues that this is a common problem for environmental system analysis tools, and that there is a need for more prospective thinking and integrating with future studies. The real-time focus of ICT can accentuate this problem, as data becomes more immediate and there is less room for reflection than in traditional environmental system analysis tools.

Brynjarsdóttir et al. (2012) discuss some of these problems in the context of sustainable HCI, connecting them to the culture of modernism, which “trust that formal, rational methods capture essentially everything that matters about a given situation”. They argue that this axiom of modernism is central to many of the persuasion and behavior change projects in sustainable HCI, and that it narrows the view of sustainability assuming that the users are individuals maximizing utility based on information. They suggest that there should be a shift to more reflection instead of prescription, and to a focus on social and cultural practices instead that on individuals.

Another facet of this problem, which was experienced when developing the presented artifacts, is how to deal with uncertainty. Data such as environmental impact analysis or carbon footprints include many assumptions and modeled data, it has uncertainties and it may not be relevant for the specific case at hand. This is challenging to present and the quantitative data may lead to a false sense of exactness, as it is argued by Koomey et al (2002).

Carbon.to had this problem as it gives exact numbers of comparison like 1kg of CO_2 is equal to 104 hours watching TV. This is of course not an exact calculation, for instance it's based on a generic TV and on an average Swedish electricity mix, and the amount of hours for a particular scenario will be different. It gets even more complicated when comparing two things like watching TV against eating beef, where the methodologies and boundaries of the two calculations may differ quite a bit. *Carbon.to* tried to deal with this problem in different ways. First it focused not on the exact calculation, but on the difference in scale between different actions. For making this clear it used the symbol "more or less equal", instead of equal. The other strategy was to be transparent about where the data comes from, providing all the sources to the data and the assumptions made.

Greenalytics had a similar problem. It provides at first sight a very accurate result in kilograms or tons of CO2 with decimal points. But this result includes many uncertainties and assumptions, and communicating these is a challenge. *Greenalytics* follows a similar approach as *Carbon.to*, with completely transparency about the way the result is calculated, the assumptions, and the sources, and as it is open source, the calculation algorithm can be double checked. It also includes a disclaimer, explaining the uncertainties and how the result is not an accurate value but a best approximation based on the existing data.

From these two examples we can see that transparency and accountability of the results can be seen as a first step for dealing with uncertainty in the data. These uncertainties are not a specific problem of the applications presented above, but a general problem in environmental system analysis such as LCAs, related to poor data quality, use of aggregated data and wrong assumptions (Ross et al, 2002). A data-driven approach using automatic calculation, crowdsourcing, or mashups, lacks the textual space for analysis and discussion available in LCAs published as scientific articles and it produces new challenges that will need to be explored on how to work, calculate and communicate the uncertainties in the results.

The limitations and risks of quantitative data in sustainability have been pointed out before in Industrial Ecology and sustainability research. Finnveden (2000), for instance, discusses the limitations in LCAs and other environmental system analysis tools and how data gaps, uncertainties in data and methodology, and the values embedded, make LCAs limited to provide prescription, for instance in deciding if a product is better than another one. It is suggested that environmental analysis can be a necessary and useful input in decision making, but more as a tool for learning, helping to identify critical points and in general to increase the knowledge of the studied systems. These limitations and the types of problems of trusting only and/or too much in data are specially important to have in mind when implementing ICT for Sustainability applications using data. It is important to identify and work with these specific problems and risks of applying new data-driven approaches, but also to connect to existing research on traditional areas of sustainability research.

5.3 A HACKER APPROACH

While the previous points discussed the results from a pragmatical perspective (which tools are used, how they are used, why they can be useful, what are the risks), this section takes a different perspective and focus instead on the values, cultures and paradigms that are part of ICT and Sustainability, and present in the applications created in this thesis.

As discussed in the first chapter, sustainability is a normative concept, building on ideas such as justice, equity and responsibility, and based on human culture and society (Brundtland, 1987). Sustainability research, and practices such as LCA, that may seem less normative, embed also political ideological and ethical values (Finnveden, 1997). Computers, internet, and the technologies that are central in our network society are not value-free either. They embed normative values and are part of a cultural context, that can be understood both from the historical origins of the technology and the current community around it. But the work looking at computer technologies and sustainability has been oriented towards applications for solving practical problems, and it has mostly overlooked the more normative and ethical perspectives[120]. As explored in the background chapter, most ICT4S research has focused either on understanding the negative direct impacts of hardware such as energy use of internet and the generation of e-waste, or on the applications of using the technologies with a sustainability purpose, such as increasing the efficiency of systems and increasing dematerialization or triggering behavioral change. Computers and internet are treated either as a system to be understood, or as tools that can be used for some purpose.

The previous discussion in this chapter could also be interpreted in this way, using information technologies and data as tools for sustainability. But it is important to point out that many of the

120 Rattle (2010) and Bowers (2001) are examples of critical perspectives pointing out the values of individualism, consumerism and globalization embedded in computer technologies, and their impact in accelerating environmental impacts.

innovations presented are not purely technical. While they require hardware and software, maybe the most important components are cultural ones, as new ways of doing things and new paradigms of how information is dealt with. One example is crowdsourcing and mashups, which while dependent on the technical affordances, the main innovation they provide is a social one: changing the concept of content creation from a central top-down approach to a more distributed bottom-up model. It is also worth mentioning that the social aspect is many times the one that takes the most effort. For tasks such as opening up sustainability information*,* while the technological development is challenging, the main obstacle may be changing the culture of how the information is published and reused.

In the introduction and in the Green Hackathon section, the hacker ethic and the values connected were introduced as key to understanding ICT. Looking at the portfolio of artifacts presented and the data-driven sustainability approach presented above, there are two main concepts and values of the hacker ethic that, I would argue, are the most relevant for the work in ICT for Sustainability: openness and the hands-on approach.

Openness of information is a central part of the hacker ethic. Open source, open knowledge, open data, creative commons, have shown that there are alternative ways of dealing with information based on creating and improving the commons, based on collaboration and community. They have challenged the status quo of the existing business and creation models and also proven in practice to be a more efficient way of working (Lakhani and Wolf, 2003). The hacker ethic in general, and FOSS in particular have provided a “living counterexample” (Coleman, 2012) of how these values of openness and collaboration can work in practice. Those ideas and discourses are being appropriated in other areas, such as architecture[121], education[122], seeds and traditional knowledge (Shiva, 2000), and appropriate technology solutions (Pearce, 2011).

The “Hands-on imperative” is also central to the hacker ethic, hackers focuses on results over ideas. Do you have a good idea? Get your fingers moving and code it. Do you want to defend open source? Shut up and show them the code (Raymond, 1999b). This philosophy is highly visible in hacker communities such as the maker culture, events such as hackathons and code fests, but even in the way internet entrepreneurs and companies work. The Green Hackathon events presented before can be seen as an example of how this hands-on approach works in a practical case with a sustainability purpose. This hands-on approach is quite related to design and the focus on the future and how to affect it. Alan Kay, a researcher at Xerox PARC and creator of the Dynabook concept, forerunner to the modern laptop, famously said:

“The best way to predict the future is to invent it. This is the century in which you can be proactive about the future; you don't have to be reactive. The whole idea of having scientists and technology is that those things you can envision and describe can actually be built.” (Kay, 1989, p5)

The focus on ICT4S has mostly been on the “hard” technological affordances, what computers can do as tools for sustainability, but I argue that these “softer” innovations may be as important. These values from the hacker ethic, such as openness, collaboration, a hands-on approach, a normative stance of transforming the future, are important to have in mind when researching the relationship of ICT and sustainability, and they are key to understanding some of the changes that these new technologies can bring.

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121 See short introduction to open source architecture by Cameron Sinclair at TED 2006: http://www.ted.com/talks/cameron_sinclair_on_open_source_architecture.html

122 See: https://www.edx.org/

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CONCLUSIONS

This thesis has explored the relationship between ICT and sustainability, and the possibilities and risks of using new data technologies and approaches in a sustainability context. After exploring the state of the art of research in the area of ICT for Sustainability, a research through design method was followed to generate a portfolio of artifacts that explored new spaces in this research area. Based on this process and the discussion presented throughout the text, four main contributions can be pointed out:

1. This thesis suggests a topology of the ICT for Sustainability research area categorizing the existing efforts under four main subjects: optimization, dematerialization (culture and presence), behavioral changes and sustainability practice, and it argues that data plays a central role.

2. It analyzes how new ICT technologies change how sustainability data is created, shared and visualized, looking at the possibilities and risks of such a "data-driven sustainability" approach.

3. It argues that the opportunities of using ICT for sustainability are not only technological, but also cultural and connected to the hacker ethic values such as openness and the hands-on imperative.

4. The research through design approach provided an inquiry method that is well suited to the interdisciplinary practical research of ICT4S.

This final chapter will present and discuss these four points and the possibilities for further research.

6.1 CONTRIBUTIONS AND CONCLUSIONS

The starting point of this thesis was that information and communication technologies and sustainability are two important trends of current society, and, while at first sight unrelated, the impact of ICT in sustainability is increasingly important. On one side ICT have a direct negative impact as the technology itself needs energy and resources for the production, it consumes electricity during its use phase and it creates hazardous waste when disposed. At the same time there is a lot of work ongoing in leveraging these technologies for having a positive impact, using ICT for Sustainability (ICT4S).

A review of the state of the art of ICT4S was presented, bringing together research and projects from a variety of fields and communities. In this text these have been organized under four different areas: the use of ICT for *optimization* and increasing efficiency of existing systems, the *dematerialization* of products and services with focus on cultural assets and presence, using computer technologies for *behavioral change*, and the use of *ICT in sustainability practice* itself. As mentioned by Hilty and Lohmann (2013), this classification can be seen as a test of *providing a topology of ICT4S as a research area*, also pointing to the centrality of data in ICT4S (Zapico et al. 2011).

With the research area of ICT for Sustainability as background, this thesis has focused on how a set of technologies and approaches from ICT (machine-readable data, open licenses, crowdsourcing, mashups, pervasive sensing, dynamic visualizations), and the values of the hacker ethic, can change how sustainability data is created, shared and visualized. The main research questions were:

- How can these new technologies and approaches for working with data be used in ICT for Sustainability and in sustainability practice?
- What are the main opportunities and risks in the use of these technologies and approaches in sustainability?
- What is the role of the cultural "hacker" values in these opportunities and risks?

To answer these questions, this thesis followed a *research through design* method where artifacts were created and released following an iterative design process. These design artifacts, or "hacks" had the goals of exploring the research area and being proofs of concepts to open up new research spaces. Five applications and activities were presented in this thesis:

- *Greenalytics,* a web service that calculates the carbon footprint of websites in real time using a mashup approach.
- *Footprinted,* an open repository of environmental impact information that allows the easy reuse and remix of the data.
- *Carbon.to,* a web tool that translates carbon dioxide information into other everyday units, using a playful interface to increase carbon literacy.
- *Webenergy* and *HelsinkiCO2,* web visualizations that allow dynamic interaction with environmental data, respectively the energy use of a website and future scenarios of carbon dioxide emissions at a city level.

- *Green Hackathon,* a series of events where developers work for a limited time, like 24h, to create prototypes and applications with a sustainability purpose.

These applications, websites, and events, explored different aspects of how ICT can be used for sustainability practice, showing new ways of how sustainability data and information can be created, shared and visualized through the application of new technologies and paradigms, such as APIs, open licenses, crowdsourcing, pervasive sensors and mashups. *These technologies add new affordances to sustainability practice and together can be seen as a new data-driven approach of working with sustainability data*. The main characteristics and opportunities of this data-driven sustainability approach are:

- There is a focus on providing real time and dynamic feedback instead of using past static data.
- The data is gathered in an automatic way from the bottom up, instead than top-down approaches, using sensors, mashups and crowdsourcing.
- There is a focus on transparency and openness.
- Data is visualized dynamically and interactively.
- The innovation model is more open and broadened outside the sustainability field.

With these opportunities, there are also new risks and problems that arise or that are accentuated. *Trusting too much, or only, in quantitative data can be misleading when working with a normative problem such as sustainability*, where quantitative data is mostly used as a proxy. The focus on automatic and real time data can hide problem areas that are not easily quantifiable, or discussions in a longer future perspective. The unavoidable uncertainties in the data and calculations also create challenges, as data can be calculated on-the-fly and there is not so much space for reflection as in traditional impact studies. These challenges are not exclusive of ICT for Sustainability or the data-driven applications presented, but the limitations of quantitative data and dealing with uncertainties have been explored and discussed in the Industrial Ecology and sustainability research. Cross-pollination between the new ideas coming from the ICT for Sustainability field and the existing knowledge in more established research areas, such as Industrial Ecology and LCA practice, is needed but these connections are still not well developed.

It is also important to underline that *innovations in ICT4S, are not only technological, but that the values connected with computer technologies are key for the understanding of this research area*. The values of openness and transparency and of hands-on proactive actions and creativity are important components of the hacker ethic and central part of technologies such as the personal computer and internet. The applications presented apply these ideas and values to sustainability beyond the pure technical, working towards openness, collaboration, creativity, and applying a "hands-on" approach of moving ideas forward and implementing solutions. The role of computers in sustainability is more than just the technical applications, and it is not limited to applications like increased efficiency or better communication. The new way of doing things embodied in the hacker ethic presents a challenge to how knowledge is created. In ICT for Sustainability research ICT is mostly treated either as a problem to be studied, or as a tool to be used, but the cultural aspects of computer technologies are an important component for understanding how these technologies can be part of working towards sustainability. The values of passion and creativity, openness and sharing, the creation of commons, the community-oriented thinking, the hands-on approach, can be important values for transforming sustainability practice and in ICT4S.

It is also important to reflect on the use of a research through design approach in an ICT4S context. Zimmerman et al. (2010) mention that the researchers they interviewed believed that research through design can be one of the most important contribution from the design field to the research community. I believe that this can be true in the case of ICT4S, and that research through design can be well suited as a method of inquiry in this area. As mentioned in the method chapter, RtD fits normative wicked problems such as sustainability and it shifts the research focus towards the future and creating preferred states. While not suited to parts of ICT4S that are more analytical, such as assessing environmental impacts, RtD can work, as in this thesis, to explore new options and open up new design spaces. RtD ideas are not alien to the interdisciplinary research in the ICT4S area, and it can work as a bridge between the computer science and interaction design methods, which are familiar with working hands-on and creating digital artifacts, and the sustainability research, which is familiar with working with normative values, wicked problems, and with a focus on the future.

6.2 FURTHER RESEARCH AND FINAL WORDS

How to evaluate the results in a research through design process can be problematic, as the artifacts have a normative intent, besides the theoretical impact. The research value of the different applications has been discussed, but the impact they has as they were used has been more challenging to measure. For example, *Greenalytics* have been used as an example of how sustainability data can be created in real time using a mashup approach. *Greenalytics* has also the visible functionality of providing information of a website. This information has an implicit sustainability goal: to increase the knowledge of web developers about the websites footprint and what it depends on, and with that knowledge to be able to reflect and make better decisions, such as for instance to think about the carbon footprint when deciding the server location. This impact would have been difficult to measure, and in the case of *Greenalytics*, this second aim is only implicit and the impact has not been tried to be measured. While I would argue that it is not the main point of the research, and that the research focused a step behind on how we can work with data in the domain of sustainability, it would be relevant to develop further how the impact is measured. This can be seen as a visible weak point of the applications, and also relevant for other applications in the field of ICT for Sustainability and in RtD. A natural focus of further research can be exploring the next stage of using the data beyond the sustainability research and practice: How can the data affect decision-making at a personal and institutional level? How does the accuracy, real time, visualization, dynamism of the data affect decision-making? These questions have been briefly looked at in this text, but there is a need of more focused studies looking at the specific impacts, and connecting with ongoing research in other areas such as sustainable practices. I would point out that the ideas themselves can be used towards measuring impact. An example of this is the log system built in *Carbon.to*, where the user activity is recorded in real time and then can be combined with focused qualitative studies, or the way *Webenergy* combines a digital questionnaire with the data from the user interactions.

Further research efforts can focus on these question, bringing the ideas forward to a bigger scale and having a more holistic approach of the process, connecting the creation, sharing and visualization of the data with the existing social practices, context and individual behaviors for a better understanding of the effects. There are also many opportunities for further research and activities in the technical aspects presented, from new ways of creating data using sensors, crowdsourcing and mashups, further exploration of how to visualize and communicate the complexity of sustainability data and how to avoid "number blindning", to studying how to deal with uncertainty, concurrent data and data quality when the data is dynamic and decentralized. There are also opportunities for working towards opening up more sustainability data, not only from a technical perspective, but working with organizations, governments and researchers for promoting changes in the policies and traditions of how data is published.

Finally I will emphasize that an important part of this thesis, and in the title itself, is the hacking approach. It was discussed how the hacker values and the cultural part of the computer technologies are important part both to understand the relationship with sustainability, but also a possible key contribution to ICT for Sustainability. This thesis itself embodies these values, taking a proactive research through design approach and creating artifacts as a way of exploring new ideas and spaces, and learning about the possibilities and shortcomings. Openness, hands-on approach, creativity, collaboration, community, transparency, these values represent a new way of working and a new way of innovating, and I believe that they can play an important role in how computer technologies can be used for working towards a more sustainable future.

SOURCE CODE

The prototypes, applications and artifacts created during the research that lead to this dissertation, and their source code, are important contributions from this work.

The source code of all the software is released under open source licenses. For more details about specific licenses please consult the license text in each application.

	Address	Code
Greenalytics	http://greenalytics.org	http://github.com/zapico/greenalytics
Carbon.to	http://carbon.to	http://github.com/zapico/carbon
Footprinted	http://footprinted.org	https://github.com/zapico/Footprinted
HelsinkiCO2	http://helsinkiCO2.com	http://github.com/zapico/helsinki
Webenergy	http://sympact.cs.bris.ac.uk/webenergy/	http://github.com/schien/openday

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