Environmental Issues in Internet of Things: Challenges and Solutions

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Abstract: The Internet of Things (IoT) is an emerging technology which extends the boundaries of Internet to include a wide variety of devices. However, the technologies that facilitate its implementation come with some challenges. Its effect on the environment is one of these. To reflect the interest in this field, the paradigm of green IoT is used in research and practice. In this paper, we survey state-of-the-art technologies and applications in this new area. According to previous research, the IoT is a suite of technologies that enables a connection between millions of devices and sensors. These technologies mean that more resources are used and that there is more e-waste; however, it also leads to new possibilities to help the environment and society through natural disaster prevention. Each IoT technology brings benefits by reducing the negative effects of the activities for which it is used, and by using it directly in environmental protection. We investigate the challenges of and the solutions brought about by the essential components of the IoT on the environment, in accordance with these two fields of interest.

Keywords: Internet of things; environment protection; energy efficiency; e-waste management

JEL Classification: Q55; O33

1. Introduction

The Internet of Things (IoT) is an extension of the Internet and consists of a very large number of computing devices communicating with each other to perform various tasks. The first use of the concept was in 1998, by Kevin Ashton. He said that: "The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so". (Ashton, 2009) The IoT has seen a steady growth in last decades due to the evolution of information and communication technologies (ICT). The World Wide Web has evolved rapidly from Web 1.0 to Web 2.0 and Web 3.0. However, the last generation has been one of transition to Web 4.0, which is IoT. Web 4.0 is *open and intelligent* and is about *the ultra-intelligent electronic agent.* (Fowler & Rodd, 2016) According to Perera et al. (2013), the IoT has not revolutionized people's lives or the field of computing; it is

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just another step in the evolution of the Internet. However, IoT comes with a wide variety of challenges. It is a world full of smart objects that promises to improve business processes and human lives, but it brings with it serious threats that must be solved and technical challenges that must be overcome. (Whitmore et al., 2015) Most of these challenges are in the field of data security and confidentiality. (Georgescu & Popescul, 2016) According to Miorandi et al. (2012), from a conceptual point of view, the IoT is based on *three pillars, related to the ability of smart objects to: (i) be identifiable (anything identifies itself), (ii) to communicate (anything communicates) and (iii) to interact (anything interacts) – either among themselves, building networks of interconnected objects, or with end-users or other entities in the network*. Unlike the traditional Internet, where the main producers and consumers of data and information are people, in the IoT objects generate and use the largest amount of data and information. These objects are highly varied and have different complexities. Some are small devices with limited computation capabilities, such as Radio Frequency Identification tags (RFIDs); others are very complex, such as smartphones, smart appliances and smart vehicles. Each relevant component has the potential to become proactive and self-managing. In IoT, objects are able to understand the objects in the physical world and to respond promptly to events outside of themselves.

The aim of this paper is to identify the main research challenges for the positive and negative influence of the IoT on the environment. The rest of this paper is organized as follows. Section 2 reviews the IoT, both present and future. In Section 3, the problem statement is presented. The positive and negative effects of the IoT"s development and its effect on the environment are presented in Section 4. Finally, Section 5 concludes the study.

2. Related Work

The IoT is the next step in the evolution of the Internet. People are excited about the opportunities and changes brought about by these technologies, such as smart cities, smart power grids, smart wearables, smart supply chain, etc. The development of IoT has been favoured by technological advances and by a reduction in the cost of production and the use of ICT. Its implementation involves billions of online objects that communicate and change their status according to users' preferences and environmental changes. Like any complex and growing technology, the IoT has been defined by different authors in many different ways depending on the component under consideration. Atzori et al. (2010) identified three different visions for the IoT: "Internet oriented" (middleware), "things oriented" (sensors) and "semantic oriented" (knowledge). Different definitions of the IoT, and the main technologies, concepts and standards according to these paradigms, are presented in Table 2.

Table 1. IoT paradigms

Paradigm	Definition	Technologies, concepts and standards
Internet oriented	"IoT will be deployed by means of a sort of simplification of the current IP to adapt it to any object and make those objects addressable and reachable from any location." (Atzori et al., 2010)	IP for smart objects (IPSO), WoT, Internet Ø
Things oriented	"Things" are "active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information "sensed" about the environment, while reacting autonomously to the "real/physical world" events and influencing it by running processes that trigger actions and create services with or without direct human intervention." (Sundmaeker et al., 2010, p. 43)	RFID, UID, NFC, WSN, Spimes, Smart Items
Semantic oriented	"The Semantic Sensor (&Actuator) Web is an extension of the current Web/Internet in which information is given well-defined meaning, better enabling objects, devices and people to work in co-operation and to also enable autonomous interactions between devices and/or objects." (Barnaghi, 2014)	Semantic Technologies, Reasoning over dynamic data, SEE

Beyond these different approaches, one of the most popular definitions is that given by Vermesan et al. (2011), who stated that the IoT "allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service". Figure 2 represents this approach.

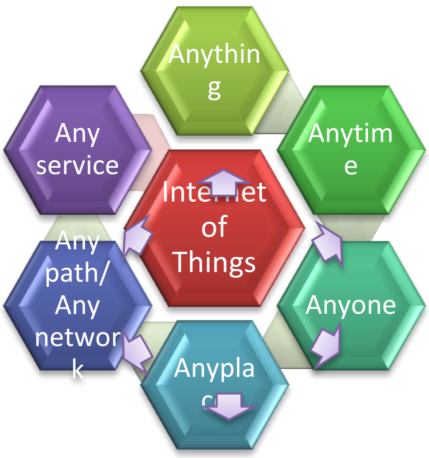

Figure 1. Definition of the IoT
Source: (Vermesan et al., 2011; Perera et al., 2014)

The IoT requires massive investment and significant changes in infrastructure, communications, interfaces, protocols and standards. (Li et al., 2015) At present, the concept is an important subject of political and economic debate, because it is expected to stimulate new business opportunities in the field of ICT and in other industries. (Ardito et al., 2017) The increase in the number of Internet connected devices supports these concerns. According to Rayn and Watson (2017), at present only 0.6% of objects have the potential to be part of the IoT, but the number of devices could be as high as 50 billion by 2020, far greater than the number of human users. Another study made by Gartner points out that the *consumer segment is the largest user of connected things* (Figure 2).

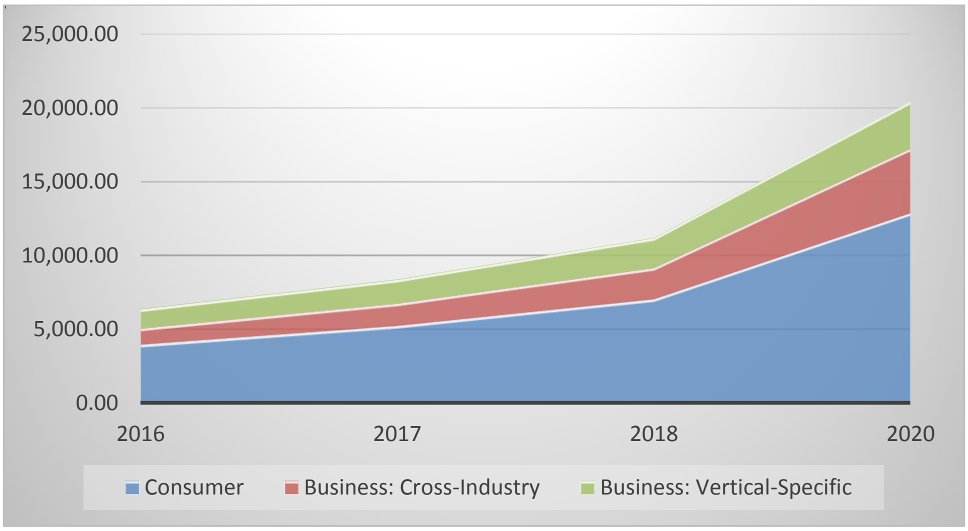

Figure 2. IoT Units Installed Base by Category (Millions of Units)

An important question is: *how environmental-friendly will these devices be?* The increasing number of devices able to communicate with each other to perform different tasks has both positive and negative effects. For the natural environment, the most important issues are increasing the volume of e-waste, energy consumption and CO_2 emissions. As a result, features like the robustness of devices and energy efficiency are very important for minimizing these influences. On the other side of positive influences, devices for monitoring airborne quality, radiation, water quality, hazardous airborne chemicals and many other environmental indicators bring significant benefits in terms of quality of life. They could be an important source of information for finding sustainable solutions to environmental issues.

3. Problem Statement

All people have a role in reducing the negative impact on the environment in both their personal and professional lives. To fulfil this role, they need to be informed and to have a favourable legal framework provided by regulatory institutions. For this reason, in economically and socially stable countries, the level of interest in environmental protection and citizens' initiatives in this direction are more representative. Neuroscientists have shown that people are addicted to information. Panksepp (2004) mentions that our brain contains a seeking system that promotes the spontaneous capacity to explore or investigate information about our world. (Watson et al., 2011) IoT has all of the features needed to meet this constant need for information and, at the same time, performs certain repetitive activities which therefore leave more time for innovation and creativity. However, the environmental impact of IoT has not received the same level of attention as its impact on social life and manufacturing.

4. Green in IoT vs. Green by IoT

The IoT has brought with it increasing opportunities and challenges for environmental protection. Similar to the relationship between the environment and ICT, the IoT can have both first and second order effects on the environment. (Berkhout & Hertin, 2001, p. 2) A first order effect is the negative impact of ICT production, use and disposal. This effect refers to the physical existence of ICT and the processes it involves. These technologies generate CO_2 emissions, e-waste and the use of harmful substances and non-renewable resources across their entire life cycle. Second order effects are related to the benefits of using ICT to improve the ecologically sustainable development of businesses and society. The contribution of the IoT to environmental protection can be bi-directional: the design and development of energy-efficient IoT devices from recyclable and biodegradable materials and the use of IoT devices to monitor the environment and prevent its degradation. However, the IoT is first and foremost ICT, and ICT has some negative influences on the environment. Nevertheless, by using them in various fields of activity, it helps to reduce the negative effects of human activities on the environment. For example, in supply chains, RFID tags contribute to reducing CO_2 emissions by optimizing flows of perishable goods, ensuring a constant temperature for storing them, tracking the recycling of plastic used by cars, improving waste management, etc. Environmental sensors are used to measure air quality, water quality and radiation level, and to detect the presence of hazardous substances in places in which they would present danger to people or to which they do not have access. The ability to protect the environment must accompany the whole life cycle of IoT technologies through green design, green production, green utilization, and finally, green disposal/recycling so as to have no or very little impact on the environment. (Sathyamoorthy et al., 2015; Zhu et al., 2015)

The most important components and technologies of green IoT are presented in this section. We have identified two perspectives of the relationship of green IoT with the environment, similar those given by Calero and Piattini (2015) to green ICT projects:

Green by IoT are initiatives to reduce the environmental impact of operations using the IoT.

Green in IoT are initiatives to reduce the environmental impact of the IoT.

A *RIFD tag* is a very small microchip with a unique identifier that can be attached to objects, animals or people and can receive and send signals. They use radio waves to exchange information, which is read using RFID readers located at different distances depending on the tag type and the device. In Table 2, the ways in which this technology can support environmental protection are presented.

Table 2. Green by RFID vs. Green in RFID

Green by RFID	Green in RFID
Wildlife monitoring to collect environmental data, track badgers and deliver this information to geologists (Dyo et al., 2009); Waste management: automatic waste sorting into recyclable materials, restricting the access of unauthorized persons to the waste bins and monitoring the volume of waste produced by each person, etc.; Monitoring nature (e.g., trees, animals) and environmental conservations; Predicting natural disasters (e.g., volcanic eruptions).	Minimize tags to reduce the amount of non-degradable resources that they contain; Using biodegradable materials for tags; Developing and using algorithms and protocols to reduce per-tag energy consumption (Qiao et al., 2011), the number of colliding responses from tags (Namboodiri & Gao, 2007) and adjusting transmission power levels dynamically (Zhu, 2015), etc.

Wireless sensor networks (WSN) are spatially distributed autonomous sensors, which communicate with each other to monitor physical or environmental conditions. (Lee & Lee, 2015) The IoT cannot exist without sensor networks because they provide most of the hardware infrastructure support by providing access to sensors and actuators. (Perera et al., 2014) In Table 3, the ways in which WSN can support environmental protection are presented.

Table 3. Green by WSN vs. Green in WSN

Green by WSN	Green in WSN
Integration of the WSN with energy harvesters; Natural environment monitoring and risk identification (floods, tsunami, air pollution, gas, etc.); Energy monitoring in smart buildings; Traffic monitoring; Natural resource management (e.g., water, light) necessary in agriculture.	Energy savings by switching sensors to low-power operation mode when not in use; Reduction of the volume of data by technics, like network coding, compression, aggregation, etc.; Implementing energy-efficient routing protocols.

Near Field Communication (NFC) is "a radio device, on a frequency of 13.56 MHz, which can establish the communication between two objects which are in an area of up to 20 cm". (Popescul & Georgescu, 2013) Table 4 presents how NFC supports environmental protection.

Table 4. Green by NFC vs. Green in NFC

Green by NFC	Green in NFC
Optimizing the use of resources according to the presence or absence of people in a particular place (e.g., home, office, parking garage, etc.); Reducing the amount of paper by using NFC technologies to distribute information to potential consumers; Reducing the number of cards by replacing them with apps available on your smartphone.	Using recycled materials for NFC tags; Minimizing energy consumption for active NFC.

Machine-to-machine (M2M) describes "the technologies that enable computers, embedded processors, smart sensors, actuators and mobile devices to communicate with one another, take measurements and make decisions - often without human intervention". (Watson et al., 2004) Table 5 presents how M2M supports environmental protection.

Table 5. Green by M2M vs. Green in M2M

Green by M2M	Green in M2M
Monitoring energy consumption and gas/oil production; Smart Grid Monitoring in industries; Smart meters for Home Energy Management Systems (Chen, 2011); Monitoring machine health in industry; Monitoring air quality and water treatment and supply; Traffic monitoring.	Harvesting the energy capabilities of the environment; Using an efficient nodes schedule and switching to sleep mode when they are not in use; Using distributed computing techniques and developing algorithms for efficient transmission protocols.

Supervisory control and data acquisition (SCADA) is "a computer-based control system which are used to monitor and control physical processes". (Tsang, 2010) In Table 6, the ways in which this technology contributes to reducing negative impacts on the environment are presented.

Table 6. Green by SCADA vs. Green in SCADA

Green by SCADA	Green in SCADA
Optimizing resources consumed, e.g., energy, water, etc. in all production processes; Managing information on water resources in the case of floods and cleaning up after them; Managing the water reserves necessary for plants in case of drought; Environmental monitoring under extreme temperatures; Monitoring air quality, sound intensity and radiation levels.	Using recyclable materials for programmable logic controllers (PLCs) or remote terminal units (RTUs); Developing and using green software SCADA; Using the most energy-efficient hardware.

Cloud computing is "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (…) that can be rapidly provisioned and released with minimal management effort or service provider interaction". (Mell & Grace, 2009) Table 7 presents how cloud computing supports environmental protection.

Table 7. Green by cloud computing vs. Green in cloud computing

Green by cloud computing	Green in cloud computing
Using clean energy in data centres; Using energy-efficient hardware and software; Efficiently managing hardware and software resources and task schedules; Implementing power saving methods for virtual machine management.	Provides the hardware and software resources necessary for storing, processing and communicating information between the above-mentioned IoT components.

As can be seen from the previous tables, there is a wide range of hardware and software solutions for minimizing the negative effects on the environment of using IoT components. These include low energy consumption, limiting non-renewable or polluting resources in building and infrastructure and optimizing production processes across diverse fields. Considering the exponential increase in the number of connected objects expected over the next few years, the effects of these objects on the environment over their life cycle are very important. But the results of studies in this field are positive. A report done by Ericsson (2015) claims that the IoT, through smart transport (1%), smart buildings (1%), smart travel (2%), smart work (2%), smart agriculture and land use (3%), smart services/smart industry (3%) and smart grids, including smart homes (4%), could help to cut up to 63.5 Gt of GHG emissions by 2030, or a total of up to 15%.

5. The Economic Impact of Green Iot

Green IoT has economic effects both in terms of increasing and decreasing costs and revenues. Some changes can be intuited, while others will emerge in the future. According to data from Cisco Systems, IoT is poised to generate $19 trillion in economic value for businesses and society, as well as cost savings, improved citizen services and increased revenues for governments and other public-sector organizations. (Chambers, 2014) Green IoT creates new sources of revenue for developers and users and has the potential to transform following sectors of the green economy: agriculture, energy supply/renewable energy, fisheries, buildings, forestry, industry/manufacturing, tourism, transport, waste management and water. Businesses will adopt IoT solutions to improve their bottom line by lowering operating costs, increasing productivity and expanding to new markets or developing new product offerings. (Greenough, 2016) But, the IoT is essential for the smart environment. According to Carrino et al. (2016), these technologies allow reliable access to heterogeneous and distributed data and may represent a good solution for the smart cities of the future.

Even without addressing environmental issues directly, the IoT can contribute to protecting the environment through the rigorous monitoring of water and energy consumption, waste management and through intensifying efforts to reduce climate change. The IoT's capacity to increase energy efficiency with smart grids, even if less environmentally-friendly sources are used, leads to cost savings and less CO_2 emissions. In the case of water, the information it provides can help users and different objects to better plan their usage and overall water conservation. In the case of waste management, the IoT helps to measure waste levels in public bins and compact trash, in order to enhance efficiency by planning collection routes where and when pickup is needed. (Adler, 2015) In agriculture, smart farming solutions help farmers to preserve resources and to minimize costs. The IoT has the potential to prevent natural disasters, to support the rational use of water resources, to control the product quality so as not to endanger the health of consumers, etc. All of these are benefits of the IoT. Green IoT, through the development and use of energy-efficient devices, increases these environmental benefits and revenues while decreasing costs. For example, energy-autonomous devices could harvest energy from natural sources and could become energy suppliers for other devices or sub-systems. They could eliminate energy costs for themselves and for other objects.

Increasing the number of IoT devices leads to an increase in the volume of e-waste and to the growth of the e-waste management market. According to a new report from MarketsandMarkets, this market will reach $ 5.04 billion by 2020, which represents an increase of 20.6% between 2015 and 2020, from $ 1.66 million in 2014.

The integration of these objects brings with it many challenges and requires significant investments. The EU is investing €192 million in IoT research and innovation from 2014 to 2017. (European Commission, 2016) According to IDC (2017), global IoT spending will have a compound annual growth rate of 15.6% over the 2015-2020 period, reaching $1.29 trillion in 2020. But this is the price for the more than five billion people and 50 billion things connected (Chambers, 2014) and will bring a compound annual growth rate of at least at 20% over the same period. (Columbus, 2017) Implicitly, a significant percentage of these costs and revenues will lead to environmental protection actions being used for designing and developing green IoT hardware and software. Some of the investments will also be used directly for the production of green IoT devices, which will have a positive impact on the environment.

6. Conclusion

This paper analyses the two faces of green IoT: reducing the negative effects of IoT use in various fields of activity – green by IoT; and minimizing (even eliminating) the negative effects of IoT devices on the environment – green in IoT. We also presented several economic aspects of green IoT. The analysis of those two perspectives showed that the development of green IoT is a natural consequence of IoT evolution. In many cases, as exemplified in this paper, they naturally contribute to enhancing the relationship with the environment through their destinations.

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