Actors for Innovation in Green IT

Christina Herzog, Laurent Lefèvre and Jean-Marc Pierson

Abstract Green IT is a mandatory process required for energy consumption reduction and sustainable development. Many actors are involved in the development and adoption of Green IT, ranging from individual persons to research groups, companies, governments, and countries. This chapter identifies actors for innovation in the field of Green IT, explores, and defines them. Their interactions are detailed and their influence on the Green IT landscape is pointed out. A definition of Green IT is given as a common understanding to form a basis for all further investigations of this sector. Then we detail the different actors of innovation in Green IT and outline their relationships to understand the keys for better development and adoption of Green IT.

Keywords Green IT · Standardization · Innovation

1 Introduction

Greening IT is a process required for reducing the consumption of energy and scarce materials used in IT. Green IT is a factor of innovation which can be considered as a large potential impacting contributor in terms of employment and societal improvements.

C. Herzog · J.-M. Pierson (✉)
IRIT, University of Toulouse, Toulouse, France
e-mail: Pierson@irit.fr

C. Herzog
e-mail: Herzog@irit.fr

L. Lefèvre
INRIA, Laboratoire LIP, Ecole Normale Supérieure de Lyon, Université de Lyon, Lyon, France
e-mail: Laurent.Lefevre@inria.fr

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This domain is being explored by a large number of academic and industrial research groups through the world. To be more impactive, it requires formalized links and support from various bodies (funding agencies, standardization bodies, technology transfer offices (TTO), etc.). It is crucial to understand the interactions between these entities in order to improve Green IT adoption and advancements. This chapter proposes to define the set of actors involved in innovation in Green IT: standardization bodies, influential groups, funding agencies, universities and academic research institutes, companies, technology transfer offices, and business angels.

We will explore involved actors using a standardized canvas which consists of defining the actors, giving some illustrative examples, analyzing the leverages for Green IT development and focusing on their potential for boosting it or slowing it down. This canvas will be also used for analyzing the links between selected actors in given scenarios.

While describing actors and their links in a formal model is fundamental, we have also investigated the implementation of such a model in a multi-agent system. We will briefly introduce this aspect so as to explain how the consideration of this chapter can be eventually concretized in a simulator.

The organization of this chapter is as follows: It will quickly revisit the definition of Green IT in Sect. 2. The formalized actors developing innovation in Green IT will be considered in Sect. 3, and in Sect. 4 actors supporting Green IT advances will be described. Section 5 will carefully select and analyze some scenarios in order to illustrate links and interactions between subsets of actors. Section 6 will present models for innovation and briefly describe our methodology for implementing a simulator of the complex system, and Sect. 7 will conclude this chapter.

2 Green IT

A large number of definitions of Green IT exist in the scientific and public press, in the scientific community, and in general discussions. These definitions take several aspects into account, such as optimizing cooling, optimizing server placement in data centers, shutting down unused devices from screens to complete servers, etc. They are more or less general. Some definitions also deal with economic aspects, while others focus mainly on energy management.

In our work, we use the life-cycle view given by Hilty [1]. Green IT must be involved in every phase, not only the use phase, but also production and end of life. Green IT helps to decrease the ecological damages which we all have to pay. Unfortunately the real costs for production and the "costs" for our environment are often not taken into account while we still will have to pay for them: hardware producing and recycling, with the societal aspects of people living in these areas where raw materials came from or are dismantled. Murugesan defines the field of green computing in [2] as "the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems—such as monitors, printers, storage devices, and networking and communication systems—efficiently and effectively with minimal or no impact on the environment". Many such slightly different definitions of Green IT exist due to the youth of this research field. Energy consumption awareness, the impacts of hardware production on the environment, recycling of IT equipment, etc. have become important public topics only during recent years. Previously, these issues were less discussed in IT and not at all in IT research.

Based on various definitions and motivations for Green IT, a basis for this work is stated: "Green IT is the effort to reduce resource consumption and environmental impact in IT. The reason for using Green IT may arise from economic, social, or ecological interests. Actions can affect the whole life cycle of IT—from construction via utilization through to disposal".

In the following, the actors for innovation in Green IT are considered, following the above definition. In some cases, actors may push more in the ecological dimension, some others in the economical dimension, and yet others in societal dimensions. It is idealistic (and not reasonable) to state that one actor drives in just one direction, hence every actor will have a mix of interests in Green IT, viewed from these three dimensions. These different interests may boost innovation differently.

3 Actors Developing Innovation in Green IT

As in any other technical or scientific field, many actors are involved in the development and adoption of Green IT. These actors are diverse by nature, by interest and motivation, and by means of changing the field. They span from individual persons (e.g., an activist, a researcher, a consultant), research groups in academia (research institutes, universities, academic research networks), companies (developing technologies, advising companies), groups of companies (influential and lobbying groups), governments (through public incentives, laws), to groups of governments (e.g., European Union).

All the actors interact in a kind of microcosm building and feeding each other, influencing and moving forward toward Green IT, at least toward their own view of Green IT. Before discussing their links in Sect. 4, we will oversee here some actors of innovation. The following actors may boost or slow down the development of innovation in Green IT, depending on different factors.

Formally, in this section we will detail some of the actors involved in the development of innovation in Green IT. The methodology we pursue is the following: We first define the actor, give some examples, and name the action leverages this actor can have in developing Green IT. We try to outline the boost this actor is giving to the field, or, conversely, the slowdown the actor may provoke.

In [3] we studied the similarities and differences between academia and industry related to 13 dimensions grouped in 3 categories: the process of research and innovation; the criteria of success and dissemination aspects; the organization. This section can therefore be seen as an extension of this preliminary work as well as its modeling.

We will explore involved actors through a standardized framework which consists in defining the actor (a), giving some examples (b), analyzing the leverages for Green IT development (c) and focusing on the potential boosting or slowing down features (d).

3.1 Standardization Bodies

(a) *Definition*. This section does not aim at giving a full global view of the Green IT standardization initiatives, but rather tries to outline the role and links between and among the standardization bodies [4, 5]. It is based on a study on the standardization bodies in the field of data center energy efficiency [6], complemented with newer developments in standardization efforts.

Standardization bodies can be categorized in two categories: (i) international formal standardization bodies (and their regional and national counterparts); (ii) influential groups and professional bodies. The section will describe category (i) in more detail. Category (ii) is described in the following section (Sect. 3.2).

In Fig. 1, one can see that the first providers of materials and tools that may make their way to actual standards are industry alliances, academic researchers, or both in collaborative projects. Some of the proposed ideas may be presented in one or several standardization bodies to eventually become standards. These standards can in turn be used by governments (at the national, federal, or European levels) as regulations in laws that must (and can) be enforced. Governments can use the materials directly as regulations, recommendations, or labels. While the process for formal standardization takes a long time since a consensus has to be achieved between all members (especially states), the direct link with governments is sometimes more efficient. Finally, it must be noted that some metrics, tools, and methods provided by industry and academia are used directly by final users and may become de facto standards. At the center of the figure is the certification authority whose role is to certify that the measurements claimed by suppliers of technologies actually follow the standards, the labels, or the recommendations.

(b) *Examples of Standardization Bodies*. The ISO (International Standardization Organization), the IEC (International Electrotechnical Commission), the IEEE-SA (Institute of Electrical and Electronics Engineers Standards Association) and the UN ITU (United Nations International Telecommunications Union) are three important bodies in the Green IT landscape.

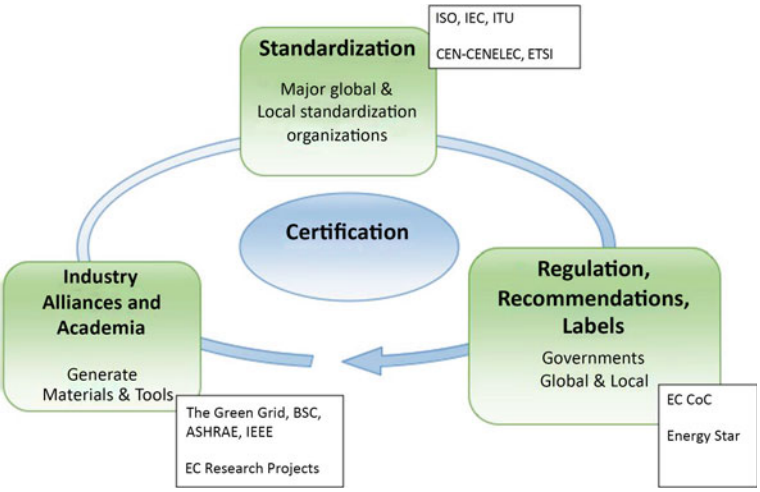

Fig. 1 Standardization stakeholders

(c) *Leverages for Green IT Development*. All three standardization bodies have activities in Green IT in general and in data center energy efficiency in particular. Their action lies in the development of standards, some individually, others in joint groups. The standards range from the design, the production, and the operation, to the recycling of IT services and materials. Some standards may be used directly by stakeholders or by states for regulation.

For instance, ISO 14064-1 is used for reporting on greenhouse gases and makes use of the GHG Protocol, while ISO 14101 addresses the environmental impact of an organization in general. Within IEC, Task Committee 111 is interested in environmental standardization for electrical and electronic products and systems. UN ITU-T Study Group 5 evaluates the effects of ICT on climate change and publishes guidelines for using ICT in an eco-friendly way. It is also responsible for studying design methodologies to reduce environmental effects. ITU-T L.1200 specifies the Direct Current interfaces while ITU-T L.1300 describes best practices to reduce negative impact of datacenters on climate.

Joint Technical Committees (JTC) are established between ISO and IEC in specific areas. JTC 1/SC 39 is the joint sub-committee on “Sustainability for and by Information Technology.” The framework for describing metrics for energy efficiency is in flux and must be considered when developing new metrics for their standardization: standards 30134-1 (General Requirements and Definitions) and 30134-2 (Power-Usage Effectiveness, PUE).

At the regional level, concerning European standardization activities on data centers, ETSI (European Telecommunication Standard Institute) is responsible for the network, CENELEC (European Committee for Electrotechnical Standardisation) for the power infrastructure, CEN for IT management, ASHRAE for cooling (not EU-specific), and CEN/CENELEC for monitoring. The need for having joint and coordinated groups is obvious with so many different actors involved. The establishment of the Coordination Group on Green Data Centers (CEN-CENELEC-ETSI) helps to harmonize initiatives.

(d) *Boosting or slowing down*. Without a doubt, the role of standardization is globally, and in the long term, boosting the adoption of a technology and its dissemination throughout society. However, in the context of Green IT and IT in general, the duration of the standardization process is often not compatible with the pace of innovation. One such example is the TCP/IP protocol stack never standardized but de facto a standard. In Green IT, the same applies to PUE, which is still under development in standardization bodies, while already widely adopted (and sometimes misused) by industry.

3.2 Influential Groups

(a) *Definition*. Complementary to standardization bodies, some influential groups propose to enforce and influence development of Green IT by addressing the issue at various levels. Some are country-based, others interact at the global level. Some are purely industrial or academic, others are a mix of both. Some of these groups can be activated by governments, and some can also propose and defend some standards.

(b) *Examples*. The Green Grid is a non-profit organization, an open industry consortium of IT suppliers, end users, policy-makers, technology providers, and utility companies. Its aim is to unite global industry efforts, to create sets of metrics, and to develop educational tools. There is a strong link with the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), The Chartered Institute for IT (BCS), and the China Communications Standards Association (CCSA).

The Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA) is an organization within the IEEE developing global standards in a broad range of industries. IEEE-SA promotes its own standards for electronic products. In Green IT, it addresses desktop personal computers, laptops, and personal monitors. The standard covers environmental aspects of a product along the entire life cycle.

The GreenTouch initiative is devoted to exploring energy efficiency in networks. The main goal of this large academic and industrial consortium is to support an increase in network energy efficiency by a factor of 1,000 by 2015. This group explores all levels of technology and innovation associated with networks: wired and optical, wireless, routing and switching, services, etc.

(c) *Leverages for Green IT Development*. The influential groups can have a major impact on promoting and developing Green IT. By supporting collaborations and direct links between diversified partners, they enforce the promotion and dissemination of innovation.

(d) *Boosting or slowing down*. Like standardization bodies, influential groups have a large potential to boost Green IT development. But contrary to these bodies, with some disruptive supported approaches (like in GreenTouch), they bypass limitations due to long processes.

3.3 Universities/Academic Institutes

(a) *Definition*. Universities and academic institutes include the groups involved in the development of Green IT through academic research. These groups can be financially supported through a mix of international, European, national, regional, or private funding. Innovation in Green IT can come from permanent or temporary contributors: professors and assistant professors, researchers, postdocs, PhD, graduate, and undergraduate students, engineers.

(b) *Examples*. These actors include purely university research groups and groups at research institutes.

(c) *Leverages for Green IT development*. Academic researchers can have an excellent research overview due to their ongoing exchange with other academic research institutions. This overview allows them to connect various research ideas and to be up-to-date with new developments in research. Due to participation in conferences, collaboration in journals, and other activities together with researchers from other universities, a worldwide network of researchers exists. This community interacts on special issues of well-defined research. This specification leads to a very high level of scientific exchange producing new ideas with the possibility to prove easily whether it makes sense to continue in a particular direction, whether this direction can be considered useful or not, or if this idea has already been investigated—and if so, what are the existing but not yet published results.

(d) *Boosting or slowing down*. With some "freedom" in exploring new and disruptive fields, this actor can be a major contributor in boosting innovation in Green IT. But researchers may lack links to industry as they are not required to seek out cooperation with industry. This missing link may lead to the fact that the research work and results do not meet the demands of industry.

3.4 Companies

(a) *Definition*. A company can be defined as an "artificial person," invisible, intangible, created by or under law, with a discrete legal entity, perpetual succession, and a company seal. It is an association of individuals (natural or legal persons or a combination of both). Company members share a common purpose, organizing their resources and skills to achieve a well-defined goal.

(b) *Examples*. In this set of actors, we find many different companies, from SMEs to large groups. Their potential influence is related to their size and importance in the field. Besides the large historic companies such as IBM, some newcomers concentrate especially on the field of Green IT (to differentiate their business value) and may become the next generation giant (or be bought by it).

(c) *Leverages for Green IT development*. A customer-company relationship always exists, meaning that the company is close to changes in society, the first one to get to know new trends, hypes, and interests. Companies may react quickly to these changes as a new hype also means a new market for them, hence new business/profit to be made. A company may also create new hypes in proposing new technologies. This relationship holds the impact for developing innovations in Green IT. With society discussing "being green and greener," companies propose greener products with additional features, creating a new hype, which forces competitors to follow this direction and moreover inspires research institutions and funding agencies to take new directions.

(d) *Boosting or slowing down*. On the one hand, companies may boost innovation for Green IT, but on the other hand they also have the possibility to slow Green IT and innovation in general. As a rule, companies are interested in making money, doing business, and staying on the market. If an innovation could decrease their turnover or favor another brand, a company may protect an innovation with the aim of not bringing it to market.

In [3] the different approaches are presented and some are investigated more deeply to show the differences between academia and industry.

4 Actors Supporting Innovation for Green IT

4.1 Funding Agencies

(a) *Definition*. Funding Agencies are organizations providing the mechanisms in which financial incentives are provided to academia or industry individually, or both together. Innovations in Green IT are influenced by funding organizations, as they drive academia in certain directions of research when deciding the topics of open calls.

(b) *Examples*. The European Framework Program 7 and the new Horizon 2020, the French National Agency for Research, and the German FWF (Fonds zur Förderung der wissenschaftlichen Forschung) fall in this category. Countries may have dedicated agencies for Green aspects such the US EPA.

(c) *Leverages for Green IT development*. Before funding agencies publish an open call, experts are invited to give their ideas about new interesting research. Even at this stage, these experts are deciding the direction of research for the upcoming years, as these calls are in general fixed for at least one year. By using money as an incentive, the impact of such open calls on Green IT development is both direct (for the actors benefiting from the grants) and indirect (since these actors will have a societal and economic impact on their own).

(d) *Boosting or slowing down*. A difficulty arises from this situation in that new research ideas, social movements, and upcoming trends cannot be taken into account immediately. Additionally, the high administrative workload creates difficulties for organizations applying for funding. Identifying partners with whom to form a consortium according to the rules of the funding organization takes time, and consortia are not always formed by the requirements of the work packages, but more because partners are needed to respect the rules of the funding organization. Energy and money are wasted because rules for open calls are too strict, and organizations waste time due to burdensome administrative requirements instead of using this time for new research. The advantage of these funding organizations is that they group research ideas and that their research funds are rather large. Funding agencies provide grants for fundamental research, while other actors involved in the innovation process are interested in applied research.

The role of funding organizations will have to change to become a real booster for innovative research. This does not mean that the traditional role has to disappear, but rather that additional roles have to be created.

4.2 Technology Transfer Offices

(a) *Definition*. Technology transfer describes the formal process of transferring rights from scientific research to another party. The aim is to use and commercialize innovative research and results. These rights might be intellectual property (IP) in form of patents, copyrights, or any other form of IP, depending on the product or result of the research. This process involves invention disclosure, licensing, funded research, and also start-up ventures. Research may be sponsored in the form of milestone payments, and it may generate licensing royalties. Most academic and research institutions have now formalized their technology transfer policies. These policies do not always fit with the needs of industry, and TTOs have to find the best way to combine the two sets of interests. TTOs are the interface between industry and research institution. Figure 2 is describing the functioning of TTOs.

(b) *Examples*. In France, the government created a special company status names as SATT, for Technology Transfer. Some universities created their own TTO within this framework, like for instance TTT (Toulouse Technology Transfer).

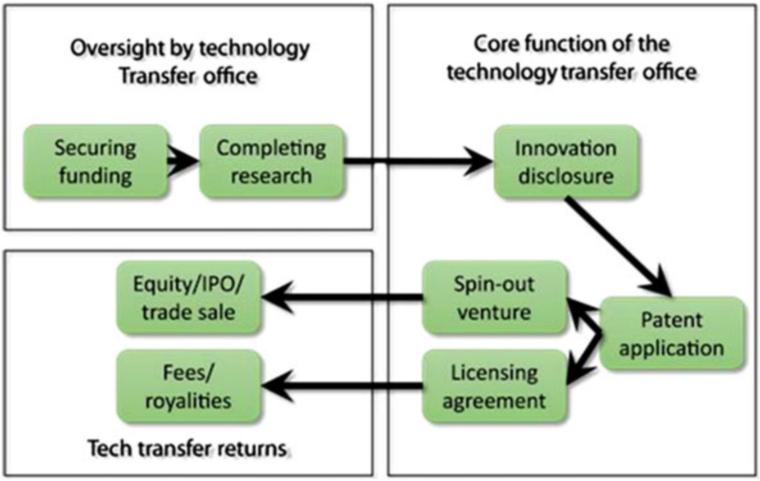

Fig. 2 Technology Transfer Offices' roles in innovation transfer

(c) *Leverages for Green IT development*. Technology transfer may be divided into 4 phases:

- The TTO has a relationship with the research institution. This relationship might be with one specific researcher, with the entire research staff, or with the whole institution. The TTO monitors ongoing research and provides links to commercial partners to fund ongoing research.
- Once the researcher files an invention disclosure with the institution, the TTO evaluates the commercial perspectives and possibilities. If the invention has potential, the TTO will pursue the patent application.
- Once the patent application is filed, the TTO will actively pursue commercial partners for license agreements or other forms of alliances.
- Fees and royalties emerging from commercialization will be paid. The TTO has the aim to become financially self-sufficient, but the research institution has different aims, such as societal benefit or enhancing its own reputation.

(d) *Boosting or slowing down*. TTOs boost new research, as they observe ongoing research as well as industry and the market and can quickly give feedback whether the research may be accepted on the market and meets the needs of industry. But TTOs are interested in financial independence, and it might be the case that they only see the financial return and not the innovation for society. Generally speaking, TTOs are rather new in some countries, and it remains to be seen whether they will become important actors.

4.3 Business Angels

(a) *Definition*. A business angel is an individual providing capital, but also knowledge and contact data, for a business start-up in a very early stage of its creation. Business angels are generally successful managers with more experience than the founder of a company.

(b) *Examples*. The World Business Angel Association is an international organization with the aim of promoting the idea of business angels and stimulating the exchange of knowledge and best practices in angel investing. This not-for-profit organization is based in Brussels and operates worldwide.

(c) *Leverages for Green IT development*. An obvious leverage of business angels is the money they invest in the Green IT start-up. Besides investing money, business angels also provide their knowledge of the field and their contacts. The start-up will have to pay back the sum invested. This may happen by exchanging convertible debts or ownership equity.

(d) *Boosting or slowing down*. Business Angels have a global overview of the industry in their field. If a start-up needs support in its early stages, business angels may help. They may provide contacts as well as financial support. Especially in Green IT, as a rather young research field, business angels are useful as they are experienced managers who know the markets, and potential partners find them trustworthy.

However, like all other actors, business angels have to be convinced of the idea in Green IT. If the business idea with the innovation were to fail, their reputation (or at least their credibility in the view of banks) would be damaged.

4.4 Governments

(a) *Definition*. At the national or international level, governments can certify, regulate, or enforce the usage of technologies, based on several factors. These factors can be related to Green IT and sustainability.

(b) *Examples*. The Energy Star program is a widely adopted means aimed at offering customers the possibility to buy more efficient products than required by law. In the US, the Department of Energy regularly monitors the compliance of the products with the Energy Star label, which was developed by the Environment Protection Agency (www.energystar.gov). The European Union Code of Conduct (EU CoC) is another such initiative. Its aim is to inform and foster the improvement of energy efficiency in the planning and operation of data centers. It is also a voluntary initiative to help design and operate data centers and to report on their power consumption.

(c) *Leverages for Green IT development*. So far, the above initiatives are not laws and thus cannot be enforced, and their impacts could be considered negligible, while they could help speed up the process of innovation transfer. However, the choice of governments to promote some standards or technologies even without introducing regulations has a direct impact on the visibility and attractiveness of these standards and technologies.

(d) *Boosting or slowing down*. Indirectly, these initiatives have impacts on Green IT development. Customers tend to choose the most efficient products; companies building energy-efficient products promote these labels in their marketing; data centers operating under the EU CoC advertise this fact, publicize their increase in energy efficiency, and use it as a commercial advantage. The direct and indirect social effect must therefore be included in this study.

5 Links and Interactions

As stated before, the different actors interact. These interactions can be of several kinds: between actors of the same group (e.g., between researchers) or between actors from different groups (e.g., researchers and companies). Formally, one should describe all the links between all the actors in Sects. 3 and 4 in detail and study them. We established eight actors, resulting in a potential for 28 links. We argue here that, among all these links, some have greater impacts on the development of Green IT than others, or have the potential to have stronger impacts if such links were to be established.

Following the method used in the previous sections, we detail in this section some of the links by defining them (which actors are involved, what is the nature or the object of the link, which metric could be used to assess the strength of this link), giving some examples, ascertaining what the leverages of this link are for developing innovation in Green IT, and what the impact of this link is for boosting or slowing down the process.

5.1 Link Between Universities

(a) *Definition*. This link is the most common one for researchers. Research is conducted in networks, and this link represents the actual joint research output. It can be assessed by the number of joint publications in Green IT, the number of regular visits, and the number of contracts in which two research groups collaborate. Also, PhD co-supervisions provide evidence of a stronger link.

(b) *Example*. The PhD candidate writing this chapter is co-supervised by and has produced some papers with both research groups. COST (European Cooperation in Science and Technology) Action IC0804 (www.cost804.org) and the new IC1305 are also examples of such networks in the field of energy efficiency in large-scale distributed systems (such as the cloud, HPC, networks, …) and ultrascale computing (up to the exascale).

(c) *Leverages of this link for Green IT*. Each research group in universities has some level of freedom to investigate particular topics, hence Green IT can be one of the topics selected. Also, some funding agencies may choose to favor Green IT if they already see some strong collaboration between partners and high-level publication results in the field. For instance, the COST office decides which actions to fund: The existence of the named funded networks has clearly furthered research in Green IT. Not to be forgotten is the intrinsic scientific reputation of each partner (leading to more or less strong commitment to collaborate).

(d) *Boosting or slowing down factors in Green IT*. While research groups have the capability to collaborate easily, it certainly furthers Green IT research when it is also their choice to do so. However, two factors may limit the impact of this link: The first is obviously the lack of money to hire staff or students to pursue or support the research, meaning that funding is not in line with ambition. The second is that a link may lose importance in one of the research groups independently of the partner, due to a new policy of the university or better opportunity or growing links in other fields: One cannot do everything and interests may change due to the above mentioned freedom.

5.2 Link Between University and Company

(a) *Definition*. This link is probably the oldest besides the one between universities. It is also one of the most controversial. The role of universities has changed during the last decade. Universities are becoming almost an industrial partner in collaborations, even if differences still exist, as explained in [3]. The link represents the contractual interaction between university and company and the value added to both partners through this (close) cooperation.

(b) *Example*. Numerous examples exist, but as these contracts are confidential, it is impossible to mention examples. Possible partners of universities in the field of (Green) IT are IBM, Microsoft, but also energy providers as well as major energy consumers or small SME interested in catching up with a new emerging market.

(c) *Leverages of this link for Green IT*. This link is important for each development in the field of Green IT. Companies are interested in new technologies in order to be the first one to enter the market and earn money. Cooperating with universities may be cheaper than having an research department of their own. However, many large groups already have research departments, some strongly linked with universities or employing former university staff (PhD students, for instance). For universities, it is an advantage to have links with industry: Industry may finance research by paying for students or by paying for results. Overall, it may be a win-win situation.

(d) *Boosting or slowing down*. This link depends is probably most strongly dependent on the contract(s) signed by partners, since they have different interests, as explained in [3]. These differences slow down the impact on Green IT, as it may take a long time to define common interests and goals. Also, links may weaken after the end of the contract, especially when university staff is frequently replaced due to limited contracts. Then, knowledge has to be built again almost from scratch, since only few permanent positions, which could provide for continuity, are available. This may change in the future, as the impact of the newly created TTOs will become apparent in some years. A company may also keep new technologies confidential if they represent a danger for the business. This case does not involve slowing down the innovation, but stopping it. In many cases, the interaction between industry and academia promotes innovation in Green IT.

5.3 Link Between Standardization Bodies and Influential Groups

(a) *Definition*. This link details the relationship existing between standardization bodies and influential groups. The metric for assessing this link can be the ratio of representatives from the various influential groups in each standardization body, in terms of absolute numbers and percentages. This will help to estimate their respective weights in the decision process.

(b) *Example*. One such example is the ISO/IEC Joint Technical Committees. Despite being open to members of the participating countries, there are only a few academic researchers in the formed working groups, for reasons outlined earlier: Motivations for researchers are linked to their scientific reputations and careers, and involvement in such bodies is not key for these. More specifically, the JTC1/39 group mentioned earlier is strongly linked with the GreenGrid in particular for defining the Power Usage Effectiveness (PUE), which was first described by the Green Grid in 2007. The definition of PUE was updated in 2012 [7] and is now being considered for standardization. There is only one academic out of 29 editors of and contributors to the Green Grid reference document, but 20 companies are represented. Only large IT-related groups are present in the list.

(c) *Leverages of this link toward Green IT*. As explained in 3.1 and 4.4, the impact of standardization and governments can be high. The stronger the link between influential groups and standardization bodies, the faster the development can be. Indeed, standardization activities suffer from a long process duration that cannot be followed by individuals, and only structured groups can actually influence decisions.

(d) *Boosting or slowing down*. Mostly driven by company-paid officers, standardization initiatives therefore reflect the interests of companies as well as member states trying to effectively promote their industries. One example involves the metrics for assessing the efficiency of data centers. Each country may participate in the final document for standardization (and eventually vote on it). However, it should be noted that the groups following this work are small in each country, and basically represent the same interests (sometimes they are even the same people). Other examples also discussed in the JTS1/39 group are WUE (Water Usage Effectiveness), CUE (Carbon Usage Effectiveness), and the more controversial GEC (Green Energy Coefficient). This latter promotes the use of green energy (which also has to be defined). Every country, protecting its industry, may behave differently with regard to these metrics. For instance, France's overwhelming electrical power source is nuclear. Data centers located in France benefit from a very good CUE value, but may have a bad GEC value compared to Canada, for instance, where power comes from mainly from hydroelectric plants. The choice of which standard may emerge for regulations (for instance, in EU directives and laws) is therefore a strategic issue for governments and industries.

5.4 Links Between TTOs and Universities

(a) *Definition*. This link is one of the most crucial if universities, researchers, or research groups want to commercialize innovations, results, and research. TTOs (should) monitor ongoing research carefully in order to identify important outcomes immediately. Important outcomes must be considered as to their industrial importance. This link represents the value of a university for industry.

(b) *Example*. Many universities now have a TTO, perhaps under a different name, as e.g., the project service office (PSB) at the University of Innsbruck. In France, the government created SATT, which has the same function as TTOs. As universities are mainly independent now, each may have a different contract with the relevant TTO.

(c) *Leverages of this link toward Green IT*. As TTOs are the interface between universities and industry, their influence on Green IT and new directions of research is rather high. TTOs are aware of new hypes in the industry and may therefore influence academic research due their relationship with the university. TTOs may give advice concerning the direction of the research, so it is their duty to discover new hypes on the markets and to encourage universities to strengthen research for industry.

(d) *Boosting or slowing down*. TTOs and their interaction with universities may boost as well as slow down innovation. The daily business of TTOs is to deal with contracts, Intellectual Properties, and research. Therefore, TTOs and their relationships with universities clearly boost innovations as administration takes less time and people working for the TTOs are up-to-date with research. In the best case, they were researchers before working for TTOs. A close relationship between TTOs and universities is clearly an advantage for collaborating with industry. On the other hand, a TTO is a third party joining, and what was previously a contract between two parties (industry and academia) is now a virtual contract between the TTO, industry, and the university. Even if TTOs represent the university they also have an interest in becoming financially independent. Their interest is to earn money by selling results, and this may slow down the smooth flow of interactions between industry and academia.

6 Models for Innovation

In this section, we outline first steps for modeling technology transfer between researchers and industry and its impact for society. Multi-agent systems (MAS) are well-suited for modeling the interactions in distributed environments, and aiming at optimizing a cost function, either for each individual, or for the community, or both. They have been successfully used in a variety of scenarios, including in Green IT where agents can be pieces of software moving between the physical hosts to find "greener" places, or conversely agents are the hosts trying to minimize their own ecological footprints.

The usage of MAS is not limited to computer science, and social science [8] uses MAS, for instance to model loose and hidden interactions, where non-expected behavior can emerge from a crowd. In this vein, the authors in [9] propose a survey of the usage of multi-agent systems for innovation diffusion. They show that the diffusion of innovations is a contagious process, driven by external influence such as mass media as well as by internal influence (word of mouth). The direct and indirect influences of the actors are derived in terms of mathematics and probability for anyone to adopt a technology. Then aggregate models are derived for communities of potential adopters. Showing the limits of aggregate models, they advocate for individual-level models of innovation diffusion. Agent-based models are shown to outperform aggregate models in a number of dimensions. Each agent is an autonomous decision-making entity interacting with others and its environment through a set of rules. Micro-level interactions between entities (the interactions described in Sect. 4) lead to macro-scale dynamics in an autonomic emergent manner. Thanks to this modeling, the global status of Green IT can be studied and compared for different scenarios of cooperation, funding, and influences between the partners.

We argue that it is feasible to model the innovation patterns in Green IT. In [4] we proposed a first step toward such a model. This study included four kinds of agents: Green IT researcher, IT researcher, general researcher, and society. Building on the methodology described in Sects. 3, 4, and 5, we can develop the agent-based model further.

In this section, we will detail some scenarios using some of the actors and links defined above.

Scenario 1 (*Direct collaboration*). A company contacts a university research group in order to start collaboration. This collaboration will be effective when the contract between the parties is signed, and the TTO acts as an intermediate for determining intellectual property rights, contract details, and the like. The agreement states the amount of money allocated by the company, this is the input of the model. The output of the model can be either a product, a patent, or some publications, depending on the agreement.

Scenario 2 (*Funded project*). This scenario includes four actors. A funding agency publishes a call for proposals in the Green IT area. A consortium is formed between one company and two universities. The chances of being funded are determined based on the quality of the consortium and the research project proposed. If the project is funded, its output will include both industry-related results and academic-related outputs, the effective output depending on the quality of the groups, the size of the company, the researchers' publication history, and other factors.

Scenario 3 (*Standardization activity*). This scenario involves four actors. A research group develops one metric for assessing the energy efficiency of data centers and tries to interact with the appropriate standardization body: This interaction depends on the body and number of academics participating. Then the metric is assessed in the standardization body where influential groups or companies may promote or conversely limit its diffusion, based on their own interests and strategies. Therefore, the interests of companies participating in influential groups and/or standardization bodies are needed for this scenario. The output of this scenario can be nil, or it can lead toward an effective standard in some timeframe, promoted eventually for regulation by a government. The duration of each interaction must therefore also be accounted for.

In these scenarios, different parameters are used as input or decisions patterns by the stakeholders. Building a statistical background from previous observed real-life interactions will help to determine the probabilities of the actors' behavior in general. For instance, in Scenario 1, the amount of money can be computed as the mean of previously observed contracts, and the output can be probabilistically determined as a percentage for each possible output (patent, product, publications, …). It is obvious that, when the model is set, we can observe the impact of increasing the amount of money in a collaboration (scenario 1), changing the grants allocated or the reputation of the partners (scenario 2), or the number of academics involved (scenario 3). The indirect output of one scenario must also be accounted for: For instance when a research group produces a new publication, it increases its societal impact (even though each individual publication may not have a high impact, the sum total of publications may well in the long term), its reputation, its future potential success in contracts, and so on.

Obtaining realistic input for the data at hand is one main difficulty of the modeling effort. Properly building the model requires deep knowledge and precise data analysis from various possible sources. We designed and circulated a survey for the research and industry communities in order to gather input for the models.

We are currently investigating some easy-to-understand metrics in order to assess the impacts of changes with regard to objective functions. These objective functions include a global Green IT innovation impact of each scenario (that can be computed from their outputs, with different weights associated to each output value) that could support decision-making: For instance, one could calculate the global impact of increasing participation in project calls, or the impact of raising funds in funding agencies for Green IT, and so on.

We started to implement the proposed model using the NetLogo framework (version 5) [10], which is widely used in the Agent-Based Modeling community. Even preliminary experiments with few actors showed us the strength and expressiveness of the associated language to properly describe the actors (agents, links) of the system, and the associated tools to calculate some key metrics and objectives to assess.

7 Conclusion and Future Work

In this chapter we analyzed the actors of innovation in Green IT, from the developments in research and technology to influential groups and standardization efforts. While many actors interact with each other, the interplay between them is an important aspect to be taken into consideration when trying to promote Green IT. The future of our work will be to complete the modeling of these actors in terms of agents in a multi-agent system, each actor being an agent pursuing its own interests and motivation, connected to others by a number of valuable links, and to determine quantitatively the main drivers or influential factors for a greener IT society.

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