Chapter 1
Modelling Technology Transfer in Green IT with Multi-agent System

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Abstract While there is a tremendous increase in academic research and collaboration between academia, the results of exchange between industry and science are steady. To understand this complex situation and to propose an improvement for technology transfer between academia and industry, it is necessary to investigate the different partners involved. We present a multi-agent system to model this technology transfer of green IT in order to see the impact on the development of sustainability in our society. We define a sustainability indicator and we study its changes according to the parameters defined in the technology transfer.

Keywords Multi-agent system • Green IT • Technology transfer

Introduction

For the last 5–10 years, research on energy saving is getting more important for industry as well as for academia. Several studies conducted by environmental and international organisations warn about the steady increase of energy consumption in various fields as data centres and cloud computing. In some cases, the operating costs exceed the investment costs, and new methods are needed to reduce costs and environmental impact. New materials are developed by equipment manufacturers to reduce these costs. Only a few basic techniques are available to software and middleware levels.

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In laboratories, some techniques were developed and have promising results in energy savings. Unfortunately, the transfer (or even the creation of awareness of the possibilities in the usage of new technology) of these techniques to industries is limited to project partners, innovative companies or large private research centres.

In order to understand the reasons for problems in this technology transfer, we discuss a model of technology transfer. We define links between actors and their conversion in a multi-agent system. In this system each actor has objectives while interacting with other actors. The generic model is specialised in the field of green computing. Depending on the evolution of the system, the value of a sustainability indicator varies. Finally, this model allows to test several scenarios related to technology transfer and the impact on the participating actors and on the sustainability of the system.

The main contributions of this article are:

- A model of technology transfer between defined actors, their interactions with joint projects
- A formal concept of sustainability and its evolution
- A study of the impact of transfer settings on the evolution of the actors and the sustainability

The article is organised in the following way: firstly, the identification of the problem; secondly, the selection of actors and their links; and thirdly, a definition of sustainability. We present in section “Implementation of the Multi-agent System” the implementation of the model in a multi-agent system using NetLogo. Next, we present some simulation results in section “Experiments”; and finally, we present the state of the art in section “Related Work” with concluding remarks and ideas for future work given in section “Conclusion and Outlook”.

Actors of Technology Transfer

In Herzog (2015) we have reviewed the literature and provided a detailed analysis of responses to a survey sent to colleagues in the field of green IT. Of these colleagues, we studied their motivations and their links with each other in the context of a transfer from academia to industry and vice versa. Our study identified the main players in this transfer, motivations (that turn into goals) and their modes of action. In this article, we devote ourselves to five major (researchers, research centres, enterprises, technology transfer offices and funding agencies) leaving to others future work (standardisation bodies, pressure groups, governments, angel investors). We now present the evidence we have gathered based on our choices for our model to transform these actors’ agent in the multi-agent system. These choices allow us to highlight the critical aspects of transfer and are not intended to be exhaustive. Also, we have chosen to focus only on players in green IT and on their activity.

Researchers

At the heart of technology transfer, researchers produce knowledge through publications that they seek to increase in number (this will be their goal). Publications are related to the researchers' connections which are created at conferences and/or collaborative projects and to the financial budget of the researchers' research centre. More connections lead to more opportunities for publication. Researchers can be either permanent or non-permanent. Both are supervised by permanent research members of the university (whose number is limited) and have a limited duration contract (limited by duration of the project unless the link persists beyond the project).

Research Centres

Research centres bring together researchers. Often attached to a university, they try to contribute to the reputation of the universities and generate funding through participation in collaborative projects (having multiple partners) or direct collaborations (with companies). Research centres will have these targets in our model. Their reputation is based on a moving average of the number of publications and contracts in recent years, while the budget comes from contracts (which represent the majority of researchers' resources). The centres can encourage either more or fewer researchers by funding their research (favouring publications) and can either hire new researchers if resources permit or fire if resources are scarce.

Companies

Companies look to increase their profits by taking a competitive difference (it will be their goal). Participation in a collaborative project increases leadership if the project is successful, but requires human and financial investment that can be lost in the case of failure. They hire new employees to participate in contracts. They initiate direct collaborations with research centres and participate in collaborative projects. They dedicate a portion of their sales to research and development.

Technology Transfer Offices

Technology transfer offices (SATT in France, PSB in Austria) are structures associated with research centres, intended to facilitate and accelerate technology transfer. Their goal is to increase their own turnover (and therefore that of their public shareholders). This turnover is fixed (a percentage or a fixed amount) in the contract signed between research centres and partners. In return they provide names and contact details of potential partners. Due to this database, research centres and businesses can create contracts more easily.

Funding Agencies

Funding agencies will have a role as initiator of projects involving regular funds from which the research centres can start (with success in the particular open call) a collaborative project. Funds are limited, resulting in a selection of projects.

The Concept of Sustainability

Sustainability is a concept defined by the conjunction of three factors: environmental, social and economic. An actor of a system improves its durability if at least one of these factors improves. In the field of green computing, a more recently developed material often consumes less electricity (and therefore less environmental and economic impact), but at the same time the production, transport and purchase of new equipment and the recycling of old equipment have a negative impact on the environment, as well as negative social and economic impacts.

Our choice was to calculate the sustainability of each player and how to quantify the sustainability of the system as the mean of their sustainability. Thus we see how and by how much the objectives of each player contribute to the sustainability of the system.

Calculating a Sustainability Indicator

The sustainability indicator (SPI, sustainability performance indicator) has three factors, weighted at 33 % each. Each factor is itself dependent on several subfactors. We detail here below these subfactors along with their *relative* weights to its parent factor (W noted below).

The ecological factor is reflected by four values:

- Awareness: awareness of green IT solution. It increases with the number of publications and contracts and decreases as time passes. W = 10 %
- Reduce: the reduction of energy consumption. W = 30 %
- Reuse: reuse of materials. W = 30 %
- Recycling: recycling of materials into new products. W = 30 %

The 3Rs (“reduce”, “reuse”, “recycle”) increase with the number of contracts by probabilities p1, p2, p3, respectively, where p1 + p2 + p3 = 1, indicating that a contract made progress in one of 3Rs in average. They decrease with an increasing number of employees, as each new employee causes more computers.

The social factor is tied with five values that show the role of an actor in society:

- Green-employment: employees recruited to work on green IT contracts. W = 30 %
- Awareness-consumption: knowledge of the consumption of IT in society. It increases with the number of publications and contracts (with more publications than contracts in proportion 80/20, because the society is more impacted by publications) and decreases with time. W = 15 %
- Rethink: the ability of an actor to rethink its green IT strategy. It increases with the number of contacts and researchers because it encourages brainstorming. It decreases as the number of contracts increases because researchers are then occupied for specific projects, with less freedom of thought. W = 20 %
- Image: the image of an actor in society. It increases with the number of publications, contracts and communication strategy and decreases with time. W = 25 %
- Standardisation influence: the influence of a player on the standardisation of organisations. It follows the number of employees and turnover and decreases with time. W = 10 %

The economic factor is reflected by three values:

- Economic impact: the economic impact of green solutions. It tracks the number of successful contracts. W = 20 %
- Turnover: turnover, which increases and decreases through contracts with investment and research funding. W = 50 %
- Attraction: represents the attractiveness of an actor for investors. It increases with the image of the actor and its turnover and decreases with time. W = 30 %

This particular model of composition has the advantage of connecting more elements of the system to a goal of sustainability. The weights above are not completely arbitrary but estimated through our field survey, interviews with colleagues and literature review.

Implementation of the Multi-agent System

Selecting the Framework

We implemented a multi-agent system with NetLogo 5.0.4.[1] It simulates the evolution and interaction of agents in complex worlds. NetLogo was created in 1999 by U. Wilensky and is regularly updated (Wilensky & Rand, 2015). It is used in many scientific fields: social science, economics, psychology, urban traffic, commercial distribution, biology, chemistry, modelling complex behaviours in a population, etc.

[1] http://ccl.northwestern.edu/netlogo/

In NetLogo, agents are *turtles*, *links*, *patches* or *observers*. Each agent operates independently in steps. The turtles represent the players in our world, the links are their connections. Observers collect the information of each agent in the simulation (they are used for statistics). We did not use patches.

Representation of the Actors and Their Evolution

Each agent has its own set of attributes, which change with interactions and time. Here we give the attributes for a researcher.

1	researchers-own [
2	permanent
3	my_contract_number
4	tt]

A researcher may be permanent or not (line 2, true or false). If it is not permanent, it is associated with a contract (line 3) and the length of his contract is given (line 4). This period may be extended in case of successful collaboration. The researchers are members of a research centre. This will be represented by a link between these two actors (see section "Representation of Links and their Evolution").

The main goal for a researcher is to publish and therefore should have an attribute reflecting this. However, this attribute is shared by others, so it is common to all the turtles, like other attributes given below:

1	turtles-own [
2	action_period
3	contract
4	newcontract
5	publication
6	newpublication
7	itr_cooling
8	its_virtual
9	itr_cloud]

Each turtle is active in the system at regular intervals (line 2). For example, a funding agency is active only every 6 months, or a company does a collaboration every 3 months on average. This random value is unique to each actor. Contracts and publications are stored (from the beginning, lines 3 and 5, and only the last iteration, lines 4 and 6). Lines 7–9 represent the interests of the player for three technologies having potential energy reduction in server rooms (and each actor will be different according to its interests).

Research centres have as attributes the amount dedicated to green research, their budget, their research results (the accumulation of publications of its researchers over time) and reputation (sliding value over 3 years accumulating publications and contracts). If a technology transfer office is attached to this research facility (which is not required), it will appear as a link (see section "Representation of Links and their Evolution").

The companies have a turnover and a R&D budget and a number of employees in R&D. Finally, funding agencies were modelled simply by regularly launching funds to create random amounts of projects between two agents.

Developments of all these actors over time are controlled by algorithms invoked every time step. In our model, a time step is equal to 1 day.

We now give the simplified algorithm of the evolution of researchers as agents. At each time step, if it is not a permanent, its ttl (time-to-life) is reduced. If it reaches zero, this researcher is removed from the system. Then, for each of its *regular* neighbours (definition in section "Representation of Links and their Evolution") and if the research centre of this researcher has sufficient funds dedicated to research (1000 in this case), then there is a probability of publishing with a neighbour (on average every 3 months with a probability of 20 % acceptation). In this case, the research centre funds (1000) the publication. Each researcher updates its interests (itr_cooling, itr_virtual, itr_cloud) based on its regular neighbours and its research centre partners ("it is influenced"). Ties with neighbours can disappear (on average every 6 months), but also appear (every 3 months): the survey we conducted has shown that new contacts are 50 % randomly created with other researchers and businesses, but favouring the compatibility of interests, 25 % by the social network (the neighbours of its neighbours), 25 % with the help of technology transfer offices (especially with companies).

The algorithm for a research centre is next. First, it updates its interests (average of those of its researchers), research results and its reputation. And if the budget is critical, it finishes the contract of a non-permanent, and then it updates its budget by paying the non-permanent. Depending on its action period, there is some change: if the budget is comfortable, hiring a non-permanent (for 1 year, to a maximum of 4 times more non-permanents than permanents) and dedicating an incentive as percentage of the budget to research (*incentive* is a parameter that will change in the experiments). Finally, if a funding agency launches a call, it tries to initiate a collaborative project. These are projects that will create technology transfer based on their success. The creation algorithm of such a project is too long to be included here, but it can be summarised by the following: a research centre seeks to form a consortium (between 3 and 6 partners) according to its own links, to the links of its researchers and those of its eventual technology transfer office. The other centres as well as companies can be partners if all their permanent researchers are not already in projects. If the project is accepted (20 %) while research centres and companies receive a share of the funding (a fraction of which is taken as operating costs), research centres hire non-permanents on the project duration (between 24 and 48 months); companies invest what they receive. Finally, links (*project*, see section "Representation of Links and their Evolution") are created between all partners.

For a company, the algorithm of evolution is quite similar to that of a research centre except that it tries to create a direct partnership with a single research centre (links *partnership*).

Representation of Links and Their Evolution

In NetLogo links are also agents. We have defined several types of links:

- *Regular*: contacts between researchers (research centres and companies)
- *Project*: the relationship between a research centre and the project consortium
- *Partnership*: the relationship between a company and a research centre
- *Belong-to* and *tto-link*: the relationship between a research centre and its researchers and technology transfer office.

The *project* or *partnership* links refer to the characteristics of the collaboration (original investment for companies, strength of collaboration linked to the compatibility between the ends of the link, number of contracts and turnover generated by the link, lifetime of the link, number of researchers in research centre and business sides and finally contract number). For the other links, only the lifetime will have meaning.

Like all agents, links evolve step by step. For non-permanent links, the lifetime is reduced by one each time step. When the lifetime is zero:

- If it is a project, it is finished and each partner finds again its researchers available, but above all, as a function of conversion (conversion is success or failure of a project), he gains a profit up to four times the initial cumulative investment.
- If it is a partnership, the principle is the same except that only one company and one research centre are affected, and moreover the partnership will be extended if it was positive (favouring the efficient partnerships).
- Other links will disappear.

Integration of SPI in the Evolution of the System

There are two possibilities with respect to the SPI indicator: either the system observes its evolution passively or it is activated based on this value. To compare the two situations, we integrate the SPI in the behaviour of the actors:

- When a scientist creates a new contact, he uses the SPI rather than compatibility. Other researchers and companies with a higher value SPI will be promoted.
- When a research centre creates a new project, it prefers partners with a higher SPI value.
- When a company creates a new partnership, it prefers partners with a higher SPI value and invests more in R&D if it has a smaller relative value.
- When a TTO is queried to find partners, it will encourage those with the highest SPI value.

Experiments

Methodology and Objectives of Experiments

The proposed multi-agent system is complex (about 2000 lines of code) and has a large number of parameters to be tested. We looked at the behaviour of the system by varying its main parameters. We give here the results of a representative subset, the others can be found in (1) (a total of 4000 simulations were performed): maximum amount given by funding agencies, conversion rate, incentive rates. We compare the results of the objectives of each player and the SPI value based on these parameters.

The system studied has ten research centres (of which four have a TTO), 50 researchers and 20 companies. Larger experiments were conducted but did not provide more lessons while significantly increasing the simulation time (from 10 min to several hours for each experiment). Also, the studied area (green IT) is limited and larger simulations lose their reality. Regular links are randomly chosen at the beginning, and the social network is built scale-free. Other networks have been tested (random, small-world) but the differences are not significant because the initial network is quickly transformed by the evolution of the system.

Each experiment simulates 7280 days (20 years). We present average values for 50 runs with the same parameters.

Experiments Without Influence of SPI

Impact of the Maximum Amount Financed

Figure 1.1 shows the impact of funding on the average reputation of research centres. More important are the funds and reputation increases, which is logical since when more projects are launched, more researchers are employed and more publications are generated.

On the same case, the impact on total wealth of all the companies is not increased after funding more than 2.5M. Because even if the funding increases, companies do not have enough personnel to participate in the potential projects and in the end it does not benefit from more funding (leaving proportionally more funding to research centres). On publications of permanent researchers, the results show that the impact for them is zero: in fact, once the maximum size of their social network is reached (ten in our experiments), having more projects does not allow them to publish more. You can see by the way that the positive results on the reputation of the centres are largely due to non-permanents hired on projects. Finally, the value of the average SPI for research centres and companies is only slightly influenced positively (1 %).

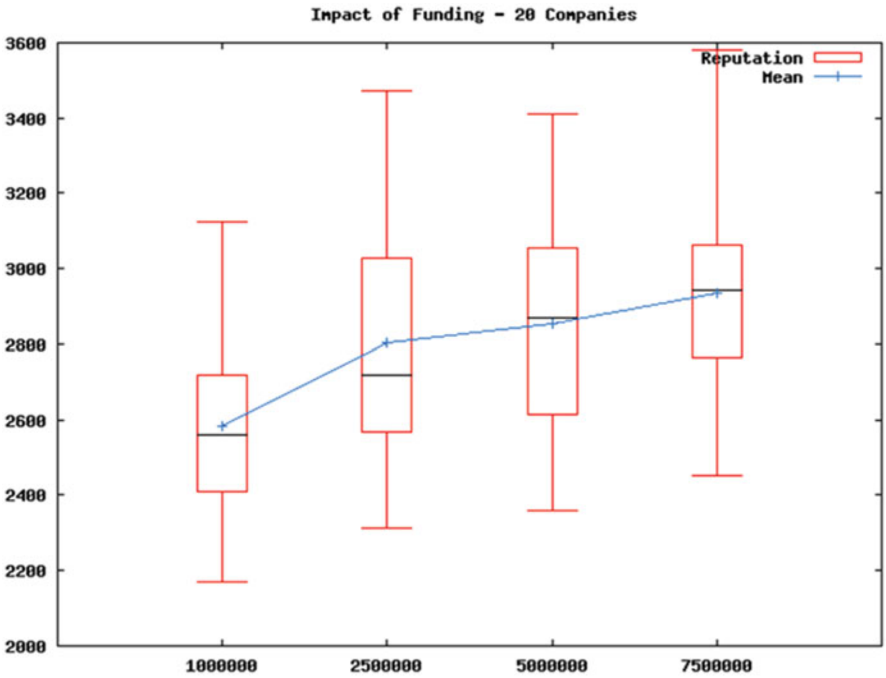

Fig. 1.1 Impact of funding on average reputation of research centres

Impact of the Conversion Rate

This section examines the impact of the conversion rate at the end of a project or partnership. Obviously, the higher it is, the more the profit is high and therefore the combined wealth of companies is high (Fig. 1.2).

This wealth in companies cause more collaborations, and thus research centres have more projects and are also wealthier, allowing them to hire non-permanents who allow to significantly increase the reputation and research results of these centres (+50 % between a rate of 10 and 90 %). For permanent researchers, there are no changes in terms of publication. Finally, the SPI sees its value increase by almost 40 %. Indeed, the calculation of the SPI is related to the number of researchers, either directly (*green-employment*) or indirectly (more people means more *standardisation influence*, more publications, etc.).

Impact of Incentive Rates

On average, every 6 months, research centres reallocate part of their budget to fund research (which has an impact on researchers' publications). This showed a positive effect with an increase of 5 % of the number of publications of permanent researchers between a rate of 10 % and a rate of 90 %. For research centres, this increase is not

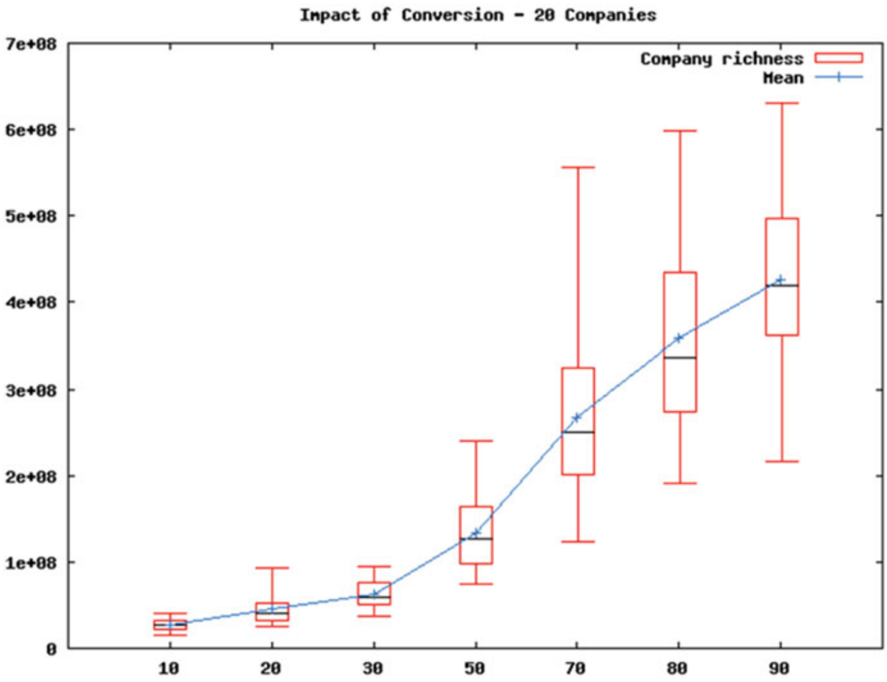

Fig. 1.2 Impact of conversion rate on companies' wealth

observed, and even there is a decrease: indeed, we calculated that these publications contribute around 40 % on research outcome generated in total. In parallel, research centres have fewer resources to hire non-permanents, which therefore generate fewer publications. This also has a negative impact on the SPI (−4 %) for the same reasons (but reversed) as the conversion rate.

Experiments with Influence of SPI

We now compare a situation where agents act, taking account of the value of SPI.

Impact of the Maximum Amount Financed

The first observation in Fig. 1.3 (normalised comparison) is that the situation without consideration of SPI is better than the new situation to corporate wealth when the amount of funding agencies is beyond 1M (up to 14 % more).

The second observation is that this wealth is more stable regardless of the amount of financing. This indicates that the introduction of this new behaviour has no negative effect and that companies are less sensitive to external financing.

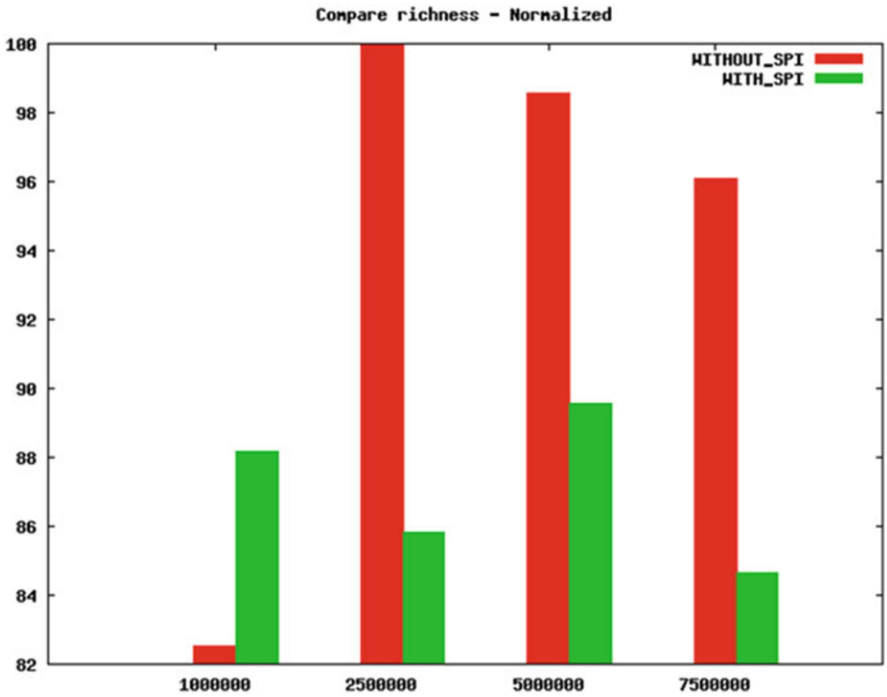

Fig. 1.3 Impact of funding on companies' wealth (*left*, without SPI; *right*, with SPI)

Similarly, publications (for researchers), the results of research and the reputation (for research centres) are not improved (–8 % for publications, –5 % for research results, –6 % for reputation). The difference between the two cases for SPI is only 2 %: the actors with low SPI at an early stage keep this low value (due to low activity), eventually degrading the average value, even if the others increase their value.

Impact of Conversion, Incentive

In almost all experiments, the goals achieved by the actors are very often below the case without SPI. We generally find that our agents do not change their behaviour enough to improve their SPI (and hence their sustainability) in the model. This will be the subject of future work: to change their behaviour or to change the calculation of the SPI.

Discussion

In this work, several simulation parameters were set a priori. Even if they were validated by previous sociological studies of selected players and correlated with a field survey, margin of error is considered in ongoing work.

The choice to project over a 20-year period should also be compared to shorter periods: indeed, that choice of period directly impacted study presented here; only final values of the variables are presented.

Related Work

Few studies have attempted to model technology transfer and the links between actors. A review article (Kiesling, Günter, Stummer, & Wakolbinger, 2012) is interested in multi-agent systems for the diffusion of innovation. Although the setting is a little different (focus towards marketing and customer targeting), it sheds much light. The dominance of the social network in the adoption of innovation is highlighted in (Kuandykov & Sokolov, 2010). The spread in social networks has received much attention in recent years (Jiang, 2009; Jiang & Jiang, 2015; Valente, 1996; Xu, Lu, & Xu, 2012). Dissemination of actors (individuals, groups, organisations), a broadcast medium (diffusion environment, strong and weak links between actors, the network structure) and the content to be broadcast are the three elements of the spread in social networks. This distribution is described as the collective behaviour of a group of social actors interacting in the social network (Jiang & Jiang, 2014). Technology transfer is a kind of diffusion in a social network and thus has inspired our model of linkages between actors.

In the case of a competition for a market, two types of diffusion models are identified (Kempe, Kleinberg, & Tardos, 2003; Libai, Muller, & Peres, 2013): threshold models, where agents adopt if enough neighbours have, and cascade models, where the probability of adoption increases with the number of neighbours who have adopted. In our case, the cascade model was implemented.

The closest work to ours is that of Ning and Qiang (2009) which present a multi-agent model for technology transfer. Their model has two kinds of agents (universities and industry) and four states which range from "doing nothing" to "active part in a collaboration". The transfer is modelled between 0 and 100 for each agent. Their results show that the key to a good transfer costs are to seek information (distance between agents) and the probability of finding a partner. The study is limited, omitting the factors of financing and turnover to influence direction.

Conclusion and Outlook

The ultimate goal of this work is to provide a tool to understand the founts of technology transfer in green IT. We note in passing that the methodology and models developed here can be extended to other areas. Today, the developed model allows the various actors to predict the impact of its decisions on its objectives and on SPI. So, a funding agency can observe the impact of grants and a research centre can understand the interest of an incentive policy, a company the cost-benefit analysis of participation in a collaboration, a researcher the impact of her links with others, and so on.

The main perspectives concern the calculation of the SPI and its weight (a multidisciplinary work with social and environmental sciences), improving the recognition of the SPI for actors and finally the addition of actors in the system.

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