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Chapter 12
A Decision-Making Model for Adopting Green ICT Strategies

Qing Gu, Patricia Lago, and Paolo Bozzelli

12.1 Introduction

The interest of organisations in becoming more environmentally sustainable by adopting *Green ICT solutions* is constantly growing. More and more initiatives have been proposed on energy efficiency computing, ranging from hardware to software solutions [9]. Accordingly, energy efficiency has become an important issue for the industry due to the fact that the energy consumption of ICT systems is rapidly growing and the reduction of the related energy footprint is highly demanded to realise financial savings while decreasing the environmental impact of their systems—in terms of, for example, greenhouse gas emissions, e-waste and heat generation [8].

An impediment for organisations to become more environmentally sustainable is that decision makers lack sufficient or necessary information, and hence knowledge, about which Green ICT solutions can or should be adopted. They need suitable tools to guide them in deciding where to invest. This work aims at providing such a tool, that is, addressing the following two issues so that decision makers can easily decide on the most promising Green ICT investment areas (IAs):

1. Improve the knowledge of decision makers about Green ICT investment areas.
2. Provide a tool that helps decision makers decide on Green ICT investment areas.

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12.2   The Decision-Making Model

In our previous work, we have defined an ontological model for Green ICT strategies [3]. Through a number of case studies and collaborations with the industry and public administrations, we validated and refined the model [2]. Our main motivation for defining a model for Green ICT strategies was to offer a semantic structure for the essential elements that define a strategy, for the sake of, for example, reuse, comparison and selection. Accordingly, it was natural to use the elements of this model as a starting point for defining our decision-making model, as presented in this chapter.

12.2.1   The Metamodel

To address the two issues mentioned above, a decision-making model should capture the knowledge necessary to reason about where to invest and should support the reasoning process. To cover these two aspects, we carried out a systematic study of the literature (details are available in [1]) discussing two main artefacts: the *investment areas* that are already claimed in the green and sustainable ICT community and the best practices, or *strategies*, claimed by companies and organisations. Obviously, strategies act in one or multiple investment areas. Hence, the two artefacts are linked. Accordingly, our Green ICT strategy model has been extended to cover this dependency.

Furthermore, strategies naturally need economic investments and bring in economic benefits. In the same vein, they have (positive and/or negative) environmental effects. While economic impacts and environmental effects are elements of our original strategy model, they should also be linked to the investment areas where such impacts/effects may occur. In other words, decision making needs to cluster strategies, and their dependencies, within the scope of investment areas, and investment areas need to be related to the potential economic impacts and environmental effects.

12.2.2   Model Elements

Figure 12.1 shows our decision-making metamodel extending the Green ICT strategy model from our previous work.

A decision-making model would consist of the following key elements:

- **Goals** are objectives that an organisation sets itself to achieve.
- **Green investment areas** are a portion of business assets in which companies spend capitals to achieve green/sustainable goals in terms of green strategies.
- **Green strategies** are clusters of green practices that address common environmental concerns.
- **Dependencies** are defined as relations between strategies.

    For example, in the figure, green strategy a and green strategy b are linked by dependency x (i.e. one strategy may *require* the other).
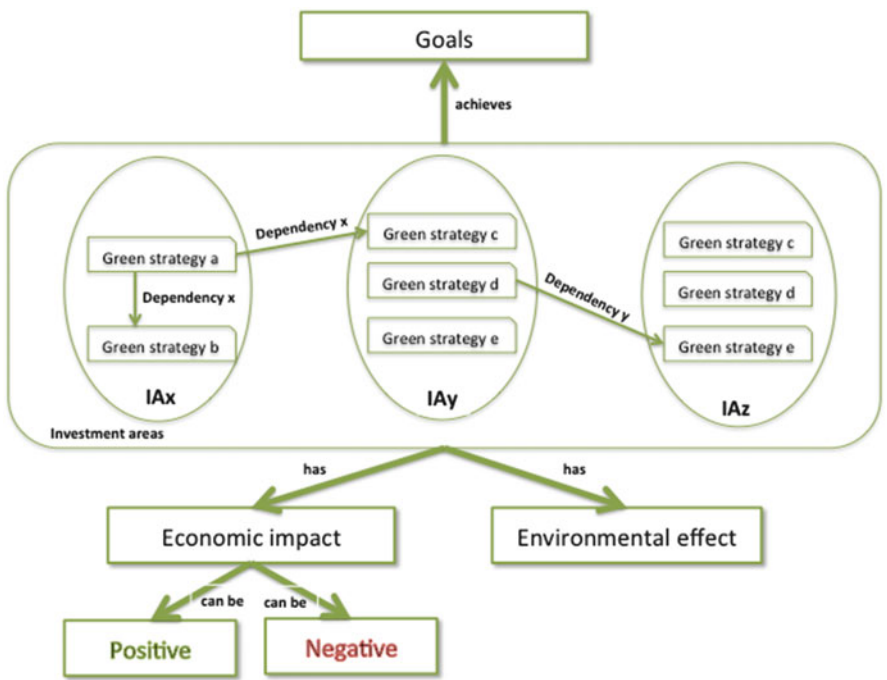
Fig. 12.1 The decision-making metamodel

- **Economic impact** captures the financial implications of adopting strategies in a selected investment area. It can be either positive or negative. A positive economic impact can be revenues, gains or returns on investment; a negative economic impact can be expenses required due to the adoption of certain strategies.
- **Environmental effects** capture the ecologic outcomes of adopting strategies in a selected investment area. Examples are the optimisation of energy consumption or the reduction of the company carbon footprint.

As shown in Fig. 12.1, a core part of the decision model is a set of investment areas (IAs). Each investment area has a number of strategies, which have dependencies with other strategies, either within the same IA or different IAs. Each strategy can achieve a number of goals, and as a result, the IA it belongs to can achieve the same goals. Similarly, each strategy can have a number of environmental and economic impacts, and as a result, the IA it belongs to can have the same environmental and economic impacts.

12.2.3   An Instantiation of the Decision-Making Model

Next to the definition of the decision-making model, the systematic literature study presented in [1] also provided quite a rich collection of specific investment areas and information characterising how to address them in various strategies.

We have used these results to instantiate the decision-making model. This instantiation is illustrated by means of two views: the goals view and the dependencies view. The *goals view* (see Fig. 12.3) illustrates which goals are achieved by the investment areas resulting from our studies. The *dependencies view* (see Fig. 12.4) shows dependencies among strategies and defines dependent and independent investment areas.

The notation used in the views is depicted in Fig. 12.2. The thickness of the arrows depicts the *relation strength* (σ) of a dependency. The thicker the arrow, the stronger is the dependency. Furthermore, the views also show which of these dependencies are *critical* or *non-critical*, respectively, depicted as a *red* dependency or a *green* dependency, following the distinction illustrated in Fig. 12.2.

Figure 12.3 depicts the *goals* view in more detail. In this view, only investment areas and their goals are shown. The goals in our study have been extracted from the Green ICT practices. In other words, investment goals correspond to a number of green practices, which are often clustered as green strategies. The thickness of lines in the view denotes the number of practices that have the same goal. In other words, the thicker the line, the higher is the chance to achieve a goal by investing on the related IA. For instance, the number of green practices that can achieve the goal *energy management and good housekeeping* is more in the investment area *IT equipment* than that of *way of working*. This means it is better to invest in *IT equipment* than *way of working* if *energy management and good housekeeping* is the main goal.

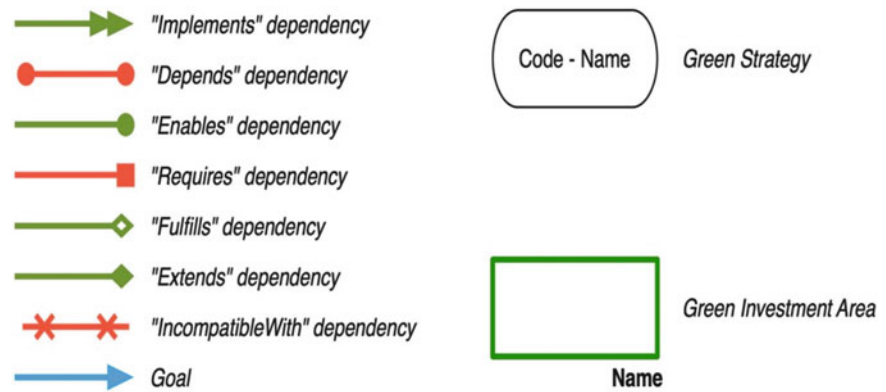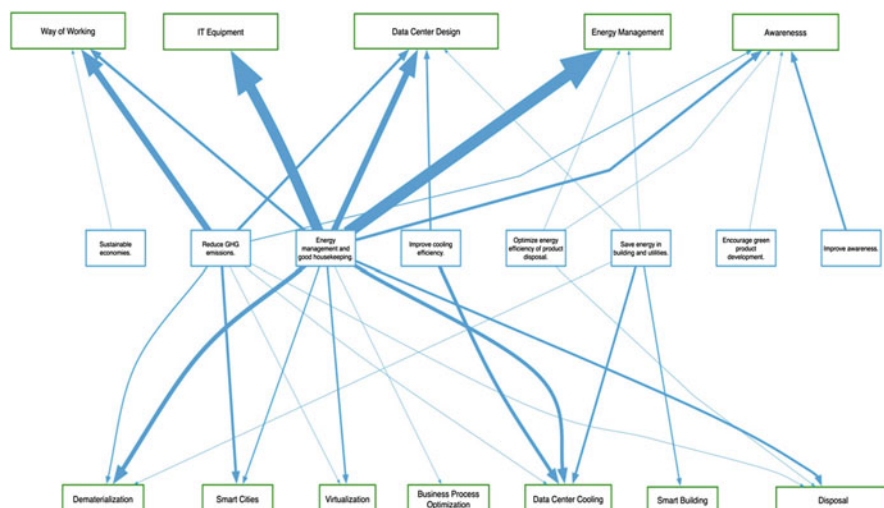**Fig. 12.2** Decision-making model—notation

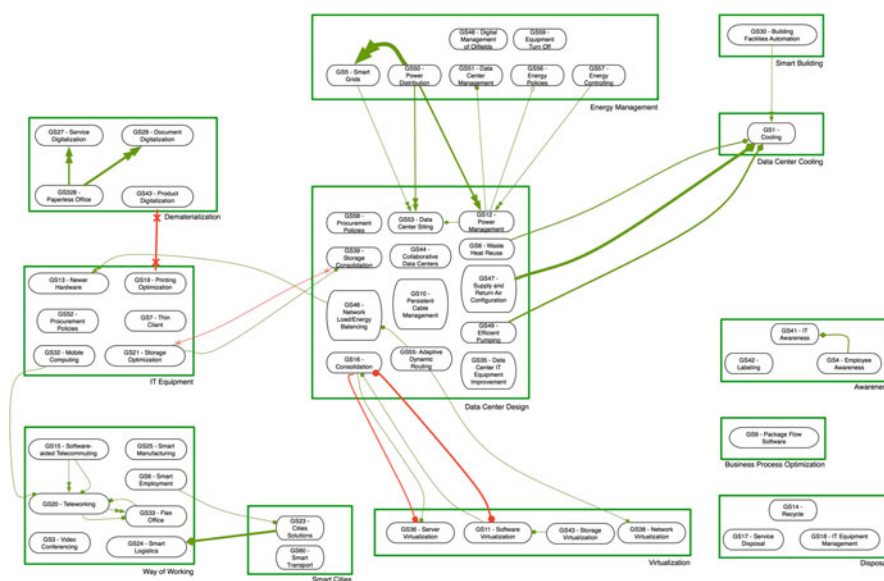**Fig. 12.3** Decision-making model—goals view

Fig. 12.4 Decision-making model—dependencies view

Figure 12.4 represents the *dependencies* view. In this view, investment areas may be divided into two main categories: the *dependent* IAs, which are investment areas containing strategies that are related to strategies of other investment areas,

and the *independent* IAs, which are made up of strategies not related to strategies of other investment areas.

For example, *data centre cooling* and *data centre design* are dependent IAs because three 'extends' dependencies occur among their strategies, while awareness is an independent IA because no dependency is defined between its strategies and strategies of any other investment area. Consequently, the model shows how dependencies occur among strategies, providing a set of arrows with different ends.

12.3 The Decision-Making Process

In this section, we illustrate how decisions on a green investment area should be taken by using our decision-making model. We were able to identify two alternative approaches that depend on what information is available for decision making.

The first approach starts with defining a set of goals that decision makers would like to achieve. Based on the goals, a list of candidate investment areas can be identified. By analysing the expected environmental effects and economic impact of these IAs, decision makers can decide on which area(s) to invest in depending on their specific requirements. We define this approach as the *goal-driven* process.

The second approach assumes that decision makers already have the knowledge of the investment areas they want to target. Starting from these investment areas, the model allows decision makers to check which goals are achieved by addressing those investment areas and to evaluate the related environmental effects and economic impact. We define this approach as the *strategy-driven* process.

12.3.1 *Goal-Driven Process*

First, the decision maker should gather high-level (or user-level) information like the goals one wants to achieve, the drivers motivating the decision-making process towards a certain decision and eventually the challenges, that is, the constraints in place at the company premises, and the decision maker should know upfront on how to pose a reduction in the set of possible final solutions (like initial capital availability). In other words, *goals* will be matched with the ones defined by each green practice. *Drivers* will be used as a rationale to track the motivation that led to the final decision. *Challenges* will be used to constrain the set of possible alternative decisions.

Once the above information has been defined (see Fig. 12.5), it is compared with the possible decisions (e.g. investment areas, strategies and eventual dependencies). Therefore, the investment areas and related strategies matching with the decision maker's requirements are selected.
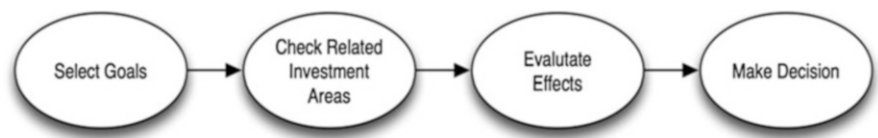
Fig. 12.5 The goal-driven decision-making process

Fig. 12.6 The strategy-driven decision-making process

Therefore, a list of economic and environmental effects for each resulting investment area is provided. As a result, the decision maker can easily decide which investment area provides the most important environmental and economic effects. To aim towards this decision, a set of metrics is provided to quantify the effects, so that decision makers can easily assess the impact of their decision.

After the effects are assessed, decision makers can easily decide on which investment area their company should focus on.

12.3.2   Strategy-Driven Process

Differently from the goal-driven process, the information gathered at the beginning of the *strategy-driven* process (see Fig. 12.6) includes investment areas rather than goals. This approach assumes that decision makers already have the knowledge about some investment areas, and they want to investigate which goals such IAs allow to achieve and which economic impact and environmental effects they bring about. Once one or more investment areas have been identified, decision makers can check which goals are achieved by applying strategies of the selected investment area(s). Furthermore, the model returns a set of environmental and economic effects and provides a set of metrics that allows decision makers to assess the environmental benefits and the economic impact.

As a result, decision makers can check if the resulting goals are compliant with their own goals. Moreover, they make the decision comparing the effect assessment of each selected investment area with their expected effects.

Finally, the investment area that matches with their goals and their expected effects should be decided.

12.4   Usage Scenarios

The following illustrates how each approach works in practice. For each approach, a usage scenario is first defined. Then each step of the approach is applied.

12.4.1   Scenario 1: Goal-Driven Process

Scenario 1: Definition—*CM is a cloud-video surveillance company that is not familiar with Green ICT practices and would like to invest its capital to get economic benefits and to improve the 'greenness' of the company by reducing the environmental impact of its infrastructure. As a starting initiative, its decision makers are investigating a way to reduce the energy consumption generated by the IT equipment of its office.*

12.4.1.1   Step 1: Select Goal

As described in Sect. 12.3.1, the first step is to select the company's goals. CM wants to reduce the energy consumed by its IT equipment, such as workstations, printers, network devices and so on. The goal that CM wants to achieve is:

   G1 Energy management and good housekeeping

12.4.1.2   Step 2: Check Related Investment Areas

Starting from goal G1 takes into account different investment areas. From Fig. 12.3, we can see that the top three investment areas are *IT equipment, data centre design and energy management*. After allaying these three investment areas, the decision makers would like to further focus on *IT equipment* because *data centre design* is about the design and development of more energy-efficient and environment-friendly data centres while *energy management* is about the planning and operation of energy-related provision, which are less relevant to CM.

   Therefore, decision makers investigate for strategies that allow to reduce energy consumption due to IT equipment utilisation.

   IT equipment defines the following strategies:

- Mobile computing: This strategy focuses on the replacement of desktop computers with notebook computers.
- Newer hardware: This strategy includes a set of solutions to improve the energy efficiency of existing IT equipment or to create energy-efficient workplaces.

- Printing optimisation: This strategy includes a set of solutions and policies to reduce paper waste and optimise the utilisation of printers.
- Procurement policies: This strategy suggests to impose requirements on external suppliers with regard to eco-certified hardware.
- Storage optimisation: This strategy suggests solutions such as switching to offline storage or lower storage devices.
- Thin client: This strategy promotes the replacement of desktop computers with thin client computers.

12.4.1.3   Step 3: Evaluate Effects

Assess Environmental Effects
Consequently, decision makers can assess the environmental effects (in Table 12.1) and the positive economic impact (in Table 12.2).

In summary, the environmental effects generated by these strategies are:

- **IT equipment power consumption** allows to measure the power consumption generated by the utilisation of an IT device, such as storage devices, processors and so on. It is calculated as follows:

$$EIT = \sum_{i=0}^{dIT} \varepsilon i$$

where *dIT* is the total number of IT devices and *εi* is the energy consumption of the *i*th IT device. The result of this metrics is expressed in kilowatt (kW). The IT devices to be taken into account in this calculation are printing devices.

Table 12.1 Environmental effects of the strategies

Green strategies	Environmental effects	Metrics
Mobile computing	Reduce power consumption	IT equipment power consumption
Newer hardware	Reduce power consumption	IT equipment power consumption
Printing optimisation	Reduce power consumption, reduce paper waste, reduce cartridge-related pollution	Printouts power consumption, paper waste
Procurement policies	Reduce power consumption	IT equipment power consumption
Storage optimisation	Reduce power consumption	IT equipment power consumption
Thin client	Reduce power consumption	IT equipment power consumption

Table 12.2 Positive economic impact of the strategies

Green strategies	Environmental effects	Metrics
Mobile computing	Reduce energy costs	IT equipment energy cost
Newer hardware	Reduce energy costs	IT equipment energy cost
Printing optimisation	Reduce printing costs	Printouts energy costs, printing costs
Procurement polices	Reduce energy costs	IT equipment energy cost
Storage optimisation	Reduce energy costs	IT equipment energy cost
Thin client	Reduce energy costs	IT equipment energy cost

- Power consumption is also related to the performed printouts. Therefore, decision makers can use the **printouts power consumption**, which measures the power consumption needed to generate printouts. It is calculated as follows:

$$Eprintout = \sum_{i=0}^{p} \varepsilon i + \sum_{j=0}^{po} \varepsilon j$$

where p and po are respectively the number of printers and the number of printouts and εi and εj are respectively the energy consumed by printers and the energy consumed due to printouts.

- The reduction of cartridge-related pollution can be assessed by the **cartridge waste** metrics, which allows to measure the amount of wasted cartridge in terms of kilograms of wasted toner and/or ink. It is calculated as follows:

$$W_{cart} = \sum_{i=0}^{k} Ki$$

where k is the total number of cartridges and Ki is the toner/ink wasted by the ith cartridge. Its result is expressed in kilograms (kg).

- The reduction of the wasted paper can be easily calculated by the **paper waste** metrics, which assesses the waste of paper with respect to the number of installed printers:

$$W_{cart} = \sum_{i=0}^{p} P_i$$

where p is the number of installed printers and P_i is the amount of paper consumed by the ith printer. Its result is expressed in kilograms (kg).

Assess the Positive Economic Impact

In turn, the positive economic impacts generated by these strategies are:

- **IT equipment energy cost** expresses the cost of energy consumed by the IT equipment of a data centre or an office:

$$C_{eIT} = \sum_{i=0}^{d} c_\varepsilon \varepsilon_i$$

where c_ε is the fixed electricity fare, εi is the energy consumed by the ith IT device and d is the number of IT devices in the facility. The IT devices, in this case, are printers in the office.

- The **printing costs** evaluate the cost incurred by the printing tasks. It is calculated with respect to the used amount of paper and cartridge only, as follows:

$$C_{print} = \left(U_{paper} C_{paper} \right) + \left(U_{cart} C_{cart} \right)$$

where U_{paper} and U_{cart} are respectively the amount of used paper and cartridge, while C_{paper} and C_{cart} are respectively the prices of paper and cartridge.

- The **printouts energy cost** metrics calculates the cost of the energy consumed due to printouts. It is calculated as follows:

$$C_{printout} = c_\varepsilon \left(\sum_{i=0}^{p} \varepsilon i + \sum_{j=0}^{po} \varepsilon j \right)$$

where c_ε is the fixed electricity fare, p and po are respectively the number of printers and the number of printouts and εi and εj are respectively the energy consumed by printers and the energy consumed due to printouts.

Assess the Negative Economic Impact

Table 12.3 shows the negative economic impact of each strategy, with the metrics for calculating the impact. Obviously, the strategies *printing optimisation and procurement policies* require the least expenses and investments.

In particular:

- The IT equipment procurement cost metrics performs the calculation as follows:

$$C_{purchase\ IT} = \sum_{i=0}^{d} C_i$$

where C_i is the purchase cost of the ith IT device and d is the number of IT devices in the facility. The number of IT devices is measured, since it suffices to count the IT devices to be replaced or the IT devices to be newly purchased. The cost of IT devices is, for instance, provided by IT reseller catalogues.

Further, the costs of printing equipment depend on the recycling process, the purchase of eco-labelled cartridge and the purchase of multifunctional printers. Consequently:

Table 12.3 Negative economic impact of the strategies

Green strategies	Negative impact	Metrics
Mobile computing	Purchase of new hardware	IT equipment procurement cost
Newer hardware	Purchase of new hardware	IT equipment procurement cost
Printing optimisation	Purchase of printing accessories or new printers	Paper recycling costs, cartridge cost, IT equipment procurement cost
Procurement policies	No	–
Storage optimisation	Purchase of new hardware	IT equipment procurement cost
Thin client	Purchase of new hardware	IT equipment procurement cost

- **The paper recycling cost** metrics allows to calculate the costs incurred by the recycling process as follows:

$$C_{recyle} = p_{crec}$$

where p is the amount of paper to be recycled and $crec$ is the recycling fare. The amount of paper is expressed in kilograms, and it is estimated before delivering the whole amount of paper to the recycling service provider. The recycling fare is set by the recycling service provider, and it is expressed in dollars per kilogram ($/kg).

- The cost of the eco-labelled cartridge is calculated using the **cartridge cost** metrics, which performs the calculation as follows:

$$C_{cart} = \sum_{i=0}^{cart} C_i$$

where C_i is the cost of the ith cartridge and $cart$ is the total amount of purchased cartridges. The cost of the cartridge is provided by the printing equipment reseller. The results are expressed in dollars ($).

- The cost of the multifunctional printers is calculated with the **IT equipment procurement** cost metrics, introduced above. It performs the calculation as follows:

$$C_{purchase\ IT} = \sum_{i=0}^{d} C_i$$

where C_i is the purchase cost of the ith IT device and d is the number of IT devices in the facility. In this case, the IT device is a multifunctional printer. The number of printers is measured, since it suffices to count the printers to be replaced or the

printers to be newly purchased. The cost of printers may be provided by IT reseller catalogues.

12.4.1.4   Step 4: Make a Decision

Once the effects have been assessed, decision makers can decide on which investment area to focus their attention on and which strategies they should apply. Due to the low negative economic impact and promising savings as well as environmental effects, decision makers might choose:

- Decided investment area: **IT equipment**
- Decided strategies: **printing optimisation and procurement policies**

12.4.2   Scenario 2: Strategy-Based Process

Scenario 2: Definition—*The Environmental Department of the Turkish government has been proposed to provide funding for a green initiative, organised by a non-profit association that wants to encourage the department staff to behave in an environment-friendly way. Decision makers of the department are fully acquainted with the initiative, but they would like to know more about its environmental effects. Since it is an initiative organised by a non-profit association, revenues of the initiative are less important, but expenses should be estimated in advance.*

12.4.2.1   Step 1: Select Investment Areas

As described in Sect. 12.3.2, the first step is to identify the starting investment areas. Decision makers have the knowledge about sensitisation of employees regarding environment-friendly behaviour. For this reason, they select the following investment area:

IA1 *Awareness*

The awareness investment area defines the following three strategies:

- GS41 IT awareness: This strategy incentivises the promotion of green awareness by means of software solutions, such as smart metering and sensitisation by sending messages to customers, employees or users.
- GS42 labelling: This strategy is designed to show to consumers the total amount of GHG emissions expected to be produced throughout the product life cycle.
- GS4 *employee awareness*: This strategy is about the promotion of awareness campaigns and the development of green company policies.

In summary, decision makers take into account only the employee awareness strategy, since it is the only one designed to encourage the staff of an organisation to be aware of their energy consumption and take environment-friendly actions.

12.4.2.2 Step 2: Check Achieved Goals

From Fig. 12.3, we can see that the investment area *awareness* would achieve the following goals, sorted by the related strength:

- Improve awareness
- Energy management and good housekeeping
- Reduce GHG emissions
- Optimise energy efficiency of product proposal
- Encourage green product development

The top three goals perfectly match with the goals of the Environmental Department of the Turkish government, and therefore, it is confirmed that the investment area selected is promising.

12.4.2.3 Step 3: Evaluate Effects

To assess the effects of the employee awareness strategy, decision makers can check the list of linked environmental and economic effects (for details, we refer the reader to Appendixes in [1]). Decision makers focus on environmental effects and the negative economic impact.

Assess Environmental Effects
The only environmental effect generated by the employee awareness strategy is the following: increase the environmental awareness of the employees within the company or the organisation.

To assess this environmental effect, decision makers can use the following metrics:

- The **employee environmental awareness coverage** (%), which allows to measure the potential amount of employees that are affected or sensitised by awareness-oriented practices. It is measured as follows:

$$EACemployees = \frac{e_c}{e}$$

where e_c is the number of involved employees and e is the total number of employees. This metrics returns a percentual value (%).
- The **message-bounded employee environmental awareness coverage** (%), which is a particularisation of the *employee environmental awareness coverage* metrics, because it is calculated with respect to the number of messages that are

sent to involve employees in the green awareness initiative. It is measured as follows:

$$MEAC_{employees} = \frac{e_c}{mE}$$

where e_c is the number of involved employees, E is the total number of employees and m is the total number of employees. This metrics returns a percental value (%).

Assess the Negative Economic Impact

The only expense to support the employee awareness strategy will be concerning the rewards that have to be paid to the most active and environment-friendly employees. Therefore, the only negative economic impact will be the following:

- *Extra costs are needed to pay rewards.*
  To quantify and calculate this cost, decision makers can use the following metrics:
- The **reward payment**, which allows to evaluate how much should be spent to reward employees for their awareness about green initiatives. It is calculated as follows:

$$C_{rew} = \sum_{i=0}^{r} C_i$$

where r is the number of rewards and C_i is the amount of money spent for the ith reward.

12.4.2.4   Step 5: Make a Decision

Assuming that the rewards for the best environment-friendly employees should be limited up to some thousands of dollars and that only a limited number of employees (e.g. from 1 to 3) should be rewarded, decision makers can decide to invest in the awareness investment area and, therefore, to support the expenses concerning the green initiative.

In summary, decision makers make the following decisions:

- Decided investment area: a**wareness**
- Decided strategies: **employee awareness**

12.5   Conclusions

In this work, we have presented and instantiated a decision-making model and two alternative decision-making approaches (goal driven and strategy driven) addressing the issues claimed in Sect. 12.1, namely, how to improve the knowledge of decision makers about Green ICT investment areas and how to provide a tool to guide the decision-making process. By means of two usage scenarios, we illustrated the usage of the model as well as the two decision-making approaches.

While promising, major research is required to feed the decision-making model with knowledge about where to invest, how to invest and related implications whenever companies and organisations want to *go green*. This should provide knowledge in rendering energy-aware both the ICT solutions themselves (e.g. [4, 6, 7]) and the exploitation of ICT solutions at the service of energy [5].

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