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ORIGINAL ARTICLE

A system dynamics approach to analyse the impact of energy efficiency policy on ESCO ventures in European Union countries: a case study of Portugal

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Abstract The development of a competitive and sustainable market for energy performance contracting (EPC) projects supplied by energy service companies (ESCO) may contribute to realising the existent potential of energy savings. Nevertheless, in different countries, like Portugal, this market is still immature and remains far below its promised potential. Different from the existent research that assumes factors operate independently and focusses on how to remove barriers to the adoption of EPC, this study provides insights into how delayed impacts from interdependent policies affect the business processes of an energy service business venture. To understand the relationships beneath the dynamics of those small and developing ESCO markets in the European Union (EU), a system dynamics model of an ESCO venture was developed. The model simulation provides a powerful tool to improve understanding and accelerate learning of the policies that critically impact venture performance. The base case simulation shows an unattractive market value added (MVA) and a high probability of a firm's failure. The demand simulation is quite sensitive to the word-of-mouth (WOM) parameter, and simultaneous initiatives to positively intensify it with incentive public policies such as low interest rate and demonstration projects significantly increased the MVA, reduced the probability of the firm's failure, and consequently increased the widespread adoption of EPC.

Keywords Energy service company (ESCO) · Energy efficiency · Energy policy · Business simulation · System dynamics

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Introduction

Energy efficiency projects based on energy performance contracting (EPC) consist of the implementation of measures that enhance energy efficiency. EPC is an agreement between the facility user or owner and the supplier, also known as energy service company (ESCO). Under EPC, the ESCO designs and puts together a set of measures to improve energy efficiency, or a green energy project, and utilises the stream of gain flows from energy cut-backs, or the renewable energy produced, to repay the investment project, including the initial outflow (Bertoldi et al. 2006). This kind of agreement aims at running-over financial restrictions of energy efficiency projects by replacing upfront costs with future savings consequential from decreased energy expenditures. According to many energy efficiency advocates, the development of a competitive EPC market may contribute to realising the existent potential of energy savings.

However, in different European countries, this market is yet to be developed and remains far below its awaited potential. An important question remains: what policies, including public ones, might increase the success of ESCO ventures? Regardless of the considerable number of studies on the factors affecting the ESCO market (e.g. Bertoldi et al. 2006, 2014; Hansen 2011; Kindström et al. 2017; Marino et al. 2010; Patari and Sinkkonen 2014; Soroye and Nilsson 2010; Vine 2005), there has been little attention to analysing the business processes involved in an energy service business venture. Previous research has generally focussed on what policies remove barriers to the adoption of EPC, and many of them assuming that factors operate independently and have linear and noncircular causality. The critical issue is to comprehend the key factors surrounding the early stages of an ESCO venture and the dynamic interactions among them, as they act interdependently and some impacts are delayed. Once identified, it is expected that more effective policies that drive the economic success of a business venture will be implemented to increase the widespread adoption of EPCs.

To gather insight into this issue, a system dynamics model was developed representing the entrepreneurial processes of an ESCO venture in Portugal, as a representative of a small and developing ESCO market in a European Union (EU) country.

The model simulation provides a powerful tool to improve understanding and accelerate learning regarding the policies that critically impact venture performance. Its algebraic structure of interlinked variables allows the prospective analyses through simulation of the behaviour of some key business variables when several policy measures are implemented.

The remainder of the paper is organised as follows: The following section relates the energy efficiency gap to the development of ESCO markets, presents some specific aspects of EPC and ESCO, describes market failures and barriers limiting the growth in EU ESCO market, and gives an overview of the current status of the ESCO market in Portugal. Section 'Objectives and methodology' presents the goals and methods of the present study. Section 'Model development' describes the development of the system dynamics model representing an ESCO venture. The following section discusses the results of model simulation and analyses the performance impact of certain government policies. Finally, the main conclusions, limitations, and further work are presented.

Closing the energy efficiency gap through ESCOs

Energy efficiency gap and ESCOs

Many countries around the world have implemented policies to improve energy efficiency. Regardless of the advancement in energy efficiency throughout times, there is still a huge room for supplementary energy savings in several business industries (Deng et al. 2012; Worrell et al. 2009) through the implementation of public policies that remove previously identified barriers to energy efficiency (Sardinou 2008; Thollander and Ottosson 2008; Trianni et al. 2013). According to the opinions of different energy efficiency scholars and policy makers, a significant amount of the potential for improving energy efficiency would be successfully realised through the development of a competitive and sustainable ESCO market (Steinberger et al. 2009; Painuly et al. 2003; Bertoldi et al. 2006; Soroye and Nilsson 2010). Previous studies provide support that ESCOs reduce energy use (Fang et al. 2012), and Heiskanen et al. (2011) analysed the role that entrepreneurial firms, such as ESCOs, play in establishing diffusion paths to foster more energy efficient technologies. Okay and Akman (2010) investigated the relationships among the ESCO indicators and the country indicators and observed that either the ineffectiveness of ESCOs or the lack of saturation of ESCO markets may limit the improvement of energy efficiency in the majority of the countries examined.

Nature of EPC and ESCOs

In a typical energy efficiency project supported by an EPC, the ESCO may (a) perform energy audits, project design, and engineering; (b) install new energy conversion, distribution, and/or control equipment at the client site; (c) finance this investment or assist in obtaining financing for the client; (d) operate and control some equipment and monitor and verify performance in terms of energy efficiency; (e) guarantee a particular level of savings in energy consumption or energy costs; and (f) take on the majority of the risks related to the performance of the energy efficiency project, including equipment performance risk and credit risk.

Financing an energy efficiency project through EPC relates to the funding sources for energy conversion and equipment control. Generally speaking, one could mention three wide financing solutions for supporting EPC energy efficiency projects: energy client financing, ESCO financing, and third-party financing (Thumann and Woodroof 2009). The current research considers ESCO financing, as this option is considered to be a proper solution in developing markets where clients take no financial risk (Dreessen 2003). Under an EPC contract, the energy gains are divided according to a prearranged rate. This percentage depends on the cost of the project, the length of the contract, and the risks taken by the ESCO and the consumer. In this arrangement, the ESCO takes on the majority of risks related to the performance of the efficiency project provision in addition to the credit risk.

The ESCO market in the EU

The application of the EPC mechanism for energy efficiency improvements has not been as widespread as expected, however, and many investment opportunities still remain unexploited (e.g. Brown 2001; Hannon et al. 2013; Kindström et al. 2017; Kostka and Shin 2013; Limaye and Limaye 2011; Patari and Sinkkonen 2014; Patari et al. 2016). Researchers describe various market failures and internal and external barriers limiting EPC adoption and the growth in ESCO market. Although each country and sector is different, several common factors impeding ESCO business have been reported. Poor economic attractiveness of ESCO projects due to decreasing availability of highly cost-effective projects (Goldman et al. 2005), heavy capital needs, long payback periods, long project cycles (Deng et al. 2014; Taylor et al. 2008), uncertain energy savings due to efficiency performance variation and energy price fluctuation (Deng et al. 2015), and high transaction costs (Patari et al. 2016). Clients devote low priority to energy efficiency projects and economic incentive depends upon external factors such as the energy price (Bertoldi et al. 2006; Vine 2005); non-compatible legal frameworks, public procurement and accounting rules (e.g. Bertoldi and Boza-Kissb 2017; Marino et al. 2010; Roshchanka and Evans 2016; Vine 2005); lack of appropriate forms of finance (e.g. Bertoldi et al. 2006; Hansen 2011); short track record and low awareness of the EPC concept among customers and financial institutions (e.g. Backlund and Eidenskog 2013; Kindström et al. 2017; Marino et al. 2010; Patari and Sinkkonen 2014; Soroye and Nilsson 2010); lack of accepted and standardised measurement and verification procedures for determining project savings (e.g. Marino et al. 2010; Mills et al. 2006); and lack of technical, business, market, financial, and management skills (Okay and Akman 2010; Taylor et al. 2008).

According to Marino et al. (2011), the ESCO market in the EU and bordering countries still has far to go in order to take advantage of its full capacity, even in countries with a more developed market. Hannon et al. (2013) investigated how ESCOs have progressed within the UK energy sector and concluded that the ESCO business model has not yet managed to reach a relevant stage in that industry. The 2013 ESCO market report (Bertoldi et al. 2014; Bertoldi and Boza-Kissb 2017) provides an up-to-date snapshot of the key developments of the EU markets as well as of some non-EU countries. It concludes that most of the countries have grown since 2010, but only a few have demonstrated strong growth (e.g. Denmark, France, Ireland, and Spain). According to the report, one or more of the following market qualities had been established between 2010 and 2013 in the process of maturation: (a) the markets are becoming demand driven; (b) policies acknowledge and support the ESCO solution; (c) facilitators (e.g. energy audit companies) exist and are effective; (d) ESCO associations have been set up; (e) model contracts, standards, and/or intensive information dissemination are developed and carried out by third parties/market facilitators; and (f) participation of a wide array of companies, including consultants, ESCOs, utilities, and energy suppliers indicate an open and competitive market.

Nevertheless, ESCO markets in European countries are far from reaching their potential, so it is important to mitigate or remove major barriers that are different for large national markets (e.g. Austria, Germany, and the UK) and small ones (e.g. Portugal, Hungary, the Baltics, and Serbia). In smaller national markets, like Portugal, supportive legislative frameworks and effective incentive policies are lacking, trust between ESCO and clients is low, and financing is quite difficult; however, in the larger markets, the barriers are more related to competition with in-house activities and high transaction costs (Bertoldi et al. 2014).

The ESCO market in Portugal

In May 2008, the Portuguese government published the National Energy Efficiency Action Plan. The objectives were to cut 10% of final energy consumption by 2015 and at the same time create and promote ESCOs. Then, in 2010, the Portuguese National Energy Strategy promoted energy efficiency aiming at a 20% reduction in final energy consumption by 2020. This strategic plan reinforced that the development of the ESCO market was a priority as this would create an energy efficiency industry with long-term relevance.

The situation of the Portuguese ESCO market is described by Bertoldi et al. (2014). The markets for efficient technologies and energy services have been developing since 2008, mainly fostered by the energy efficiency initiatives of the government. Some of those initiatives require industries to perform energy audits and to present and implement energy efficiency projects containing specific measures to reduce energy consumption. However, the main driver for the growth is assumed to be public procurement, given the financial weakness of the private sector and the low awareness and trust of EPC contracts. Thus, in 2011, the Portuguese government established new procurement rules to facilitate long-term EPC agreements between ESCOs and public administration.

The Portuguese ESCO market represents about M€ 10 to 30 and has been growing at a slow rate to a potential estimate of M€ 100 to 200 (Bertoldi and Boza-Kissb 2017). Around 10 firms have declared that they are ESCOs, although other types of non-performance-based contracts are much more frequent (Marino et al. 2010). Only a few firms are members of the National ESCO Association, and most of those companies are very small and reported several difficulties mainly associated with the funding and financing of EPC contracts.

Objectives and methodology

This study explores how to create successful ESCO ventures in small European markets. The main issue is to identify the most crucial factors involved in ESCO processes and understand the dynamic interactions among those factors that will determine long-term firm performance. To provide insight into the research problem, a system dynamics model was developed and simulated, representing an ESCO venture. The main objective is to identify and recommend political initiatives that promote reinforcing mechanisms supporting a viable and sustainable development of ESCOs and the dissemination of EPC as an effective means for enhancing energy efficiency.

The study was conducted in Portugal for convenience, as the authors have knowledge and data of its ESCO market. This market is in a similar development stage as other small EU markets like Hungary and the Baltic countries, and all of them have the same main barriers: lack of supportive legislative framework and effective incentive policies, difficulties in financing projects, and low trust among actors. The common EU legislation, firms' managerial processes, and the existence of similar market barriers support our hope that this research process and its conclusions will offer useful insights to others studying or working in EU countries with small and underdeveloped ESCO markets.

System dynamics modelling

The system dynamics (SD) approach has been used to investigate the dynamic and complex nature of socio-economic systems in various scientific domains (Sterman 2000). Various fields within public policy studies have used this approach to study complex problems. In particular, SD has a valuable track record for studies in the energy sector (for example Dyner et al. 2009; Ford 2008). Miller and Sterman (2007) developed a SD model representing a new clean energy technology venture. More recently, Blumberga et al. (2014) applied SD to explore the impact of different national consumer-oriented energy efficiency policies in Latvia's residential building sector. SD translates the understanding on real world problems into 'glass-box' simulation models, as they make explicit the relations among variables (i.e. the structure of the computational model underlying the simulations), thus providing powerful learning environments for understanding complex problems. By experimenting with this prototype of the system (the real world) at hand, we can relate the perceived structure of a system to its behaviour over time and gain further knowledge about the system.

Several public policy studies have used this methodology to explore complex problems. The pertinence and legitimacy of using SD in such policy studies derives from its faculty to capture dynamical structural elements such as feedback loops, time delays, and accumulation of flows into stocks. These attributes combine to create models with nonlinear and non-intuitive behaviour that can often provide useful insight into the behaviour of the complex problem being modelled (Sterman 2000). SD modelling tries to discover and represent those building blocks, which may be described as follow. The feedback loop occurs when the level of a variable is changed directly or indirectly as a result of some prior change in its level. Feedback loops may have a reinforcing or balancing nature. A loop type may be identified by imagining that the effect of a change in a variable is propagated link-by-link around loop (Morecroft 2015). A reinforcing loop is one where an increase in that variable leads to a further increase in itself. An example of a reinforcing loop is the wage-price spiral. Higher wages leads to higher prices, which in turn increase the wages etc. A balancing loop on the other hand is goal seeking leading to stabilising behaviour. Thus, an increase in that variable leads to a counterbalancing decrease in itself. An example of balancing loop is the central heating system. It ascertains that the room temperature will remain within a certain range. A delay occurs when a given cause leads to an effect, but not immediately. Sometimes the consequences of an action or decision are not apparent until several days, months, or even years after an event has taken place. Such time delays add dynamic complexity because cause and effect is less obvious. Any feedback loop in a SD model contains at least one stock and one flow. A stock represents a system entity that accumulates or depletes over time (e.g. the amount of inventory or the number of employees at a certain point of time) and a flow affects the rate of change in the stock. Dynamic behaviour is the result of flows accumulating in stocks. In other words, stocks are a kind of memory storing the results of past actions (Morecroft 2015). They represent the observed state of the system and their value can only be changed through the actions of flows, but it takes time. A delay is involved in changing any stock, be it inventory or the number of employees. For instance, the number of employees is increased by new employees hired (inflow) and decreased by employees leaving the firm (outflow). The flows can be controlled by decision policies, which in turn are embedded in feedback loops. For example, if desirable workforce (an auxiliary variable) exceeds actual number of employees (the stock), a decision will be made to hire new employees and thus increase the number of employees in the firm, closing the gap between desired and actual workforce (a balancing feedback loop).

Causal loop diagrams can be used as visual tools for revealing cause and effect relationships and feedback processes. The basic elements are 'variables' (words or phrases) and 'links' (arrows). A 'variable' represents a condition, situation, action, or decision with can influence, and can be influenced by, other variables. A 'link' (arrow) indicates a causal association between two variables. Causal relationships are indicated by '+' or '−'signs, where '+' means a positive influence, while '−' indicates a negative influence. The notation '| |' on the arrow is used to denote delay in the cause-and-effect relationship. The letter 'R' inside a loop indicates a reinforcing feedback process, and the letter 'B' denotes a balancing loop. At the same time, each loop can be named with a mnemonic for the underlying feedback process. For example, Fig. 1 shows a reinforcing loop called 'R1 - Building awareness and confidence'. That loop includes a positive relationship between 'Prospects interested in EPC' and 'Adoption of EPC'. That link contains a delay symbol '| |', which denotes a time delay. The more prospects are interested in EPC, the more prospects will adopt EPC, but it takes a while (months) for interested prospects to become full EPC adopters.

As dynamic behaviour is the result of flows accumulating into stocks, an essential feature of a SD model is the way in which the system being analysed is described in terms of stocks and flows. Symbols representing stocks, flows, variables (called auxiliaries), constants, and information links are used to create graphical representations of the system's structure in stock and flow diagrams. Stocks are represented by squares and the accompanying flows by double arrows. Flows are controlled by flow rates represented by valves. Auxiliary variables are used to combine or reformulate information and are represented by circles. Auxiliaries are used to model information, so they change with no delay, instantaneously. Flow rates and auxiliaries are defined in the same manner. The difference is that the flow rate is connected to the flow valve and thereby controls the flow directly. Constants variables remain constant over the time period of the simulation. A diamond represents these constants. Connections are made among constants, auxiliaries, flow rates, and stocks by means of information links, which are represented by thin arrows or connectors. They can be inputs to flows, but never directly to stocks, because flows are the only variables that change their associated levels. Stocks, however, can

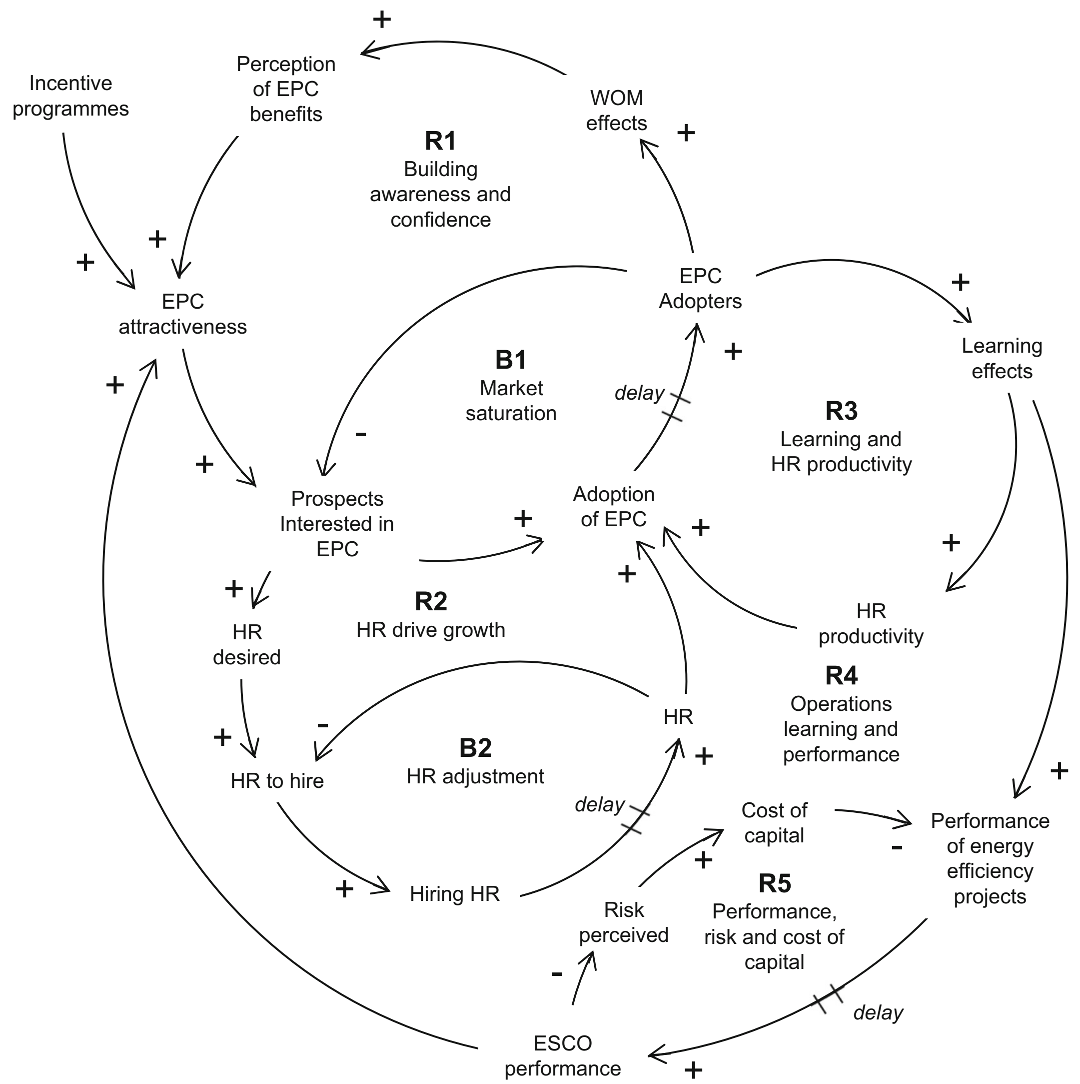


Fig. 1 Causal loop diagram representing the development of an ESCO venture

be inputs to auxiliaries and flow rates. For example, we can observe the diagram presented in Fig. 3. The square 'HR' represents the number (stock) of employees and the valve 'HR Hiring Rate' represents the rate (flow) of new employees hired. The cloud symbols represent the boundaries of the system being modelled (e.g. people/employees arrive from the environment of the defined system and are returned to the environment). The auxiliary variable 'HR to Hire' and the constant 'Average Time to Hire and Train' determine the flow rate 'HR Hiring Rate' which controls the inflow of new employees.

In a SD model, the structure of the system is represented mathematically. Model simulation consists of accumulation (or integration) of the flows that cause the stocks to change. Thus, when creating a stock and flow diagram in a SD computer package, every variable in the model is defined by an equation.

Model development

To provide insight into the research problem, a SD model was developed with the Powersim code representing the market, operations, human resources, and cash flow for an ESCO venture. The simulation model was created according to the process described in Sterman (2000) that includes the following steps: (a) problem articulation (including historical behaviour of the key variables); (b) formulation of a qualitative model (dynamic hypothesis) that explains the dynamics as endogenous consequences of the feedback structure, using causal loop diagrams and stock and flow maps; (c) construction of the quantitative model, specifying the variables, constants, and equations, and estimating the parameters and initial conditions; (d) model testing and validation; and (e) policy design and evaluation.

A literature review, document content analysis, interviews, and a case study were conducted in order to define the structure and assumptions incorporated into the model. A qualitative content analysis on relevant documents was performed, and a set of interviews were conducted to gather insight and practical experience from energy efficiency specialists, energy authorities, ESCO professionals, and energy end-users regarding the creation of an ESCO venture in the Portuguese market. That data were analysed to capture the critical variables and their relationships to build a representation of the problem structure as stock and flow diagrams. Then, the quantitative simulation model was obtained by defining equations, assumptions, and initial values. The reference mode (historical behaviour of the key variables), parameters and initial values definition, and model calibration and validation were performed using data collected from a case study of an ESCO venture.

Causal loop diagram

The initial analysis of the data surveyed suggests some reinforcing (R) and balancing (B) feedbacks that could support the development of an ESCO venture. Figure 1 depicts those loops.

Building awareness and confidence (reinforcing loop R1): As reported in literature reviewed, low awareness and scepticism towards the potential benefits of EPC was one of the most commonly reported barriers to the deployment of EPC projects. Most potential clients are ignorant of the concept or are reluctant to adopt EPC. According to data gathered, the awareness and perception of EPC benefits play an important role in the adoption process. The benefits of EPC offered by the ESCO must be known and understood to improve its attractiveness. The ESCO case study revealed that the power of word-of-mouth (WOM) marketing among clients and government communication initiatives are determining factors to influence the EPC awareness and attractiveness. The building awareness and confidence reinforcing loop is described as follows. As the ESCO launches its services into the market, there exists low interest in EPC due to the unusual underlying business model. As the first prospects implement EPC projects with the ESCO, they may contact other prospects, make them aware, make them interested, and encourage them to engage in EPC projects. As more prospects implement EPC projects, they communicate favourable WOM concerning their energy efficiency impacts, accelerating the diffusion of EPC practices and benefits. The adoption process will be extremely long because prospects need to be moved up through several phases until they become full EPC adopters (this is indicated by the time delay symbol placed in the link between ‘Prospects interested in EPC’ and ‘Adoption of EPC’).

Market saturation (balancing loop B1): Market saturation induces a balancing loop that limits the growth of EPC adopters. The more the EPC adopters in the system, the fewer the potential projects and the lower the expected new profits from EPC.

HR (human resources) drives growth (reinforcing loop R2): As more prospects become interested in implementing EPC projects with the ESCO, the workforce required to be able to capture those business opportunities increases, driving HR adjustment decisions. By hiring new employees, the firm will be able to assign additional HR effort to business operations, and thus more prospects will become EPC adopters.

HR adjustment (balancing loop B2): This balancing loop seeks to adjust the number of employees in the firm. The parameter HR to hire is defined as the difference between desired workforce (HR desired) and existing workforce (HR). The link between Hiring HR and HR includes a delay representing the time needed to recruit, hire, and train new employees.

Learning and HR productivity (reinforcing loop R3) and Operations learning and performance (reinforcing loop R4): Learning effects in increasing EPC capabilities are often mentioned as important drivers for decreasing EPC cost elements and increasing the certainty of the estimated future savings. Thus, one of the most important reinforcing feedbacks is supposed to be the virtuous learning-accumulation of experience loop. This learning process will create and enhance the capabilities of the ESCO for marketing, selling, defining, and implementing EPC projects. As the ESCO employees are engaged in EPC projects they gain further experience and improve their technical, financial, marketing, sales, and management abilities to develop the market, and thus they improve their productivity in all the ESCO activities. Project design and future energy savings are enhanced, and most project processes become more productive and less costly. Higher EPC performance increases EPC attractiveness and encourage further adoption.

Performance, risk, and cost of capital (reinforcing loop R5): Estimating energy savings potential and performance verification involves volatility data, which is an important source of risk. This perceived risk forces lenders to increase the cost of borrowing, which in turn erodes the intrinsic cost-effectiveness of EPC projects and lowers the overall level of available financial resources. As the ESCO improves its capabilities and increases value creation through EPC business, shareholders will start seeing the EPC business as a less risky business or as a promising market niche and will gradually require a lower interest rate.

Incentive programmes: It is assumed that subsidies and government programmes supporting energy efficiency projects and EPC may be useful to foster the initial moves of this industry. Financial incentives and programme deadlines played a powerful role in making EPC attractive for many clients. Beyond providing a source of financing, subsidy programmes presented firm deadlines, which fostered a sense of urgency for action that drives EPC adoption. Some examples are incentive policies to subsidise a part of energy audit costs or the interest rate on debt.

Stock and flow diagrams

This section presents a description of the simulation model. The model includes feedback relationships that represent the previously discussed dynamics. The simulation model is divided into five different sectors that will then be described in more detail: Marketing (prospect chain), HR (human resources), Operations (this sector addresses the assignment of human resources to business activities), Finance, and EVA (Economic Value Added).

Market sector

The market contains commercial buildings that have potential for EPC projects. The model representing the process of market development depicts the adoption cycle as working through a series of stages. This structure is based on Warren (2008, pp. 345–356) and the Bass diffusion model (Bass 1969). Figure 2 presents a stock-flow map of this model sector. Potential prospects are moved up through four stages until they become full EPC adopters: Interested (gaining prospect interest), Audits in Progress (selling and performing energy audit), Projects in Progress (contracting and implementing EPC project), and EPC Adopters.

The Potential stage represents buildings capable of implementing an EPC efficiency project. This stock contains prospects whose managers are not informed or are not interested in EPC. The Interested stock includes those prospects with potential for implementing energy efficiency projects that are informed and interested in adopting EPC. Once prospects have become informed on EPC benefits and adopt a positive attitude towards the EPC model, they move from Potential stock to Interested stock. The rate of that flow is determined by marketing effort and the effect WOM communication between potential prospects and those who already adopted EPC. As described previously, the WOM effect is assumed to be a determining factor in accelerating the dissemination of EPC benefits and building awareness and confidence. The WOM effect is modelled as described by Sterman (2000, p. 333) and Morecroft (2015, pp. 169–181). From this stage forward, the WOM effect is no longer considered significant.

Audits in Progress are prospects that have signed an initial EPC contract for executing an energy audit. Interested prospects move to Audits in Progress as they become involved in an energy audit to develop an EPC project. The Adopt Audit flow rate is determined by HR effort and some attractiveness aspects that are enhanced through experience and learning.

The EPC Adopters stock represents prospects that have implemented an EPC energy efficiency project with the ESCO venture. Once the energy audit and the EPC energy project have been developed, the ESCO offers the client a final EPC agreement. The prospects flow from Audit in Progress to Projects in Progress as they close an EPC and the ESCO starts implementing the energy efficiency project. The Adopt EPC flow rate is determined by HR efforts and some performance aspects that are enhanced through experience and learning. Then, the prospects become EPC Adopters as the ESCO implements the energy efficiency project.

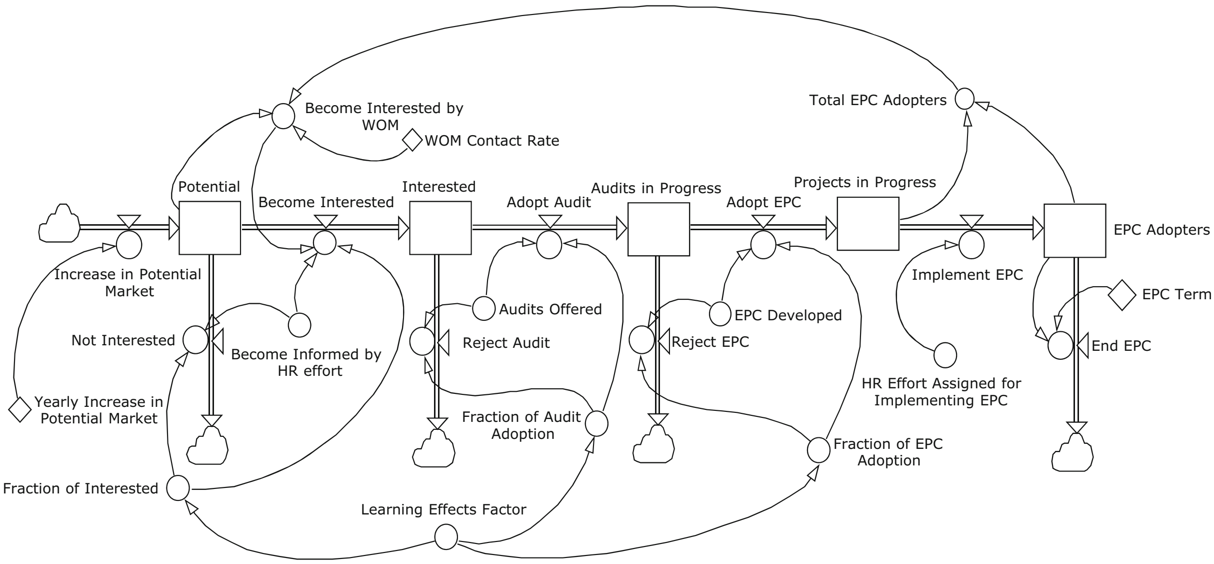


Fig. 2 Sock-flow diagram of the market sector

HR sector

The HR sector of the simulation model (Fig. 3) is supported by Sterman's (2000, p. 758) structure of labour and hiring. The stock labelled HR consists of the number of employees in the firm. They are relevant employees (project managers) with project management responsibilities, including marketing and engineering. The HR Hiring Rate is the flow into the stock HR, and it is diminished by the HR Leaving Rate. The parameter Minimum HR Needed determines the estimation of the HR to Hire, and it is determined by the total HR effort desired for performing ESCO activities that are estimated in the Operations sector of the model.

Learning effects on enhancing ESCO capabilities (marketing, selling, designing, and implementing EPC projects) are important drivers for increasing the performance of energy efficiency projects. As the venture employees are engaged in energy efficiency projects, they acquire additional experience and they enhance their abilities to develop the market. Project energy savings are improved, and EPC business processes become more efficient.

The HR Experience stock accumulates the job experience of employees in terms of number of person-hours. It is assumed that employee experience increases for each EPC that is developed and implemented. The experiences of the employees are incorporated into this model sector using Sterman's (2000, p. 505) labour force co-flow structure and Warren's research (2008, pp. 258–261). The underlying theoretical assumption is that employees learn and accumulate abilities as they are engaged in job activities. New employees bring a certain amount of experience with them, and departing employees take their experience with them. Experience increases with tenure in the job and declines as employees forget relevant knowledge. This co-flow structure provides the average experience of the employee, which influences the variable Learning Effects Factor that reproduces the learning curve for productivity from job experience. This variable is computed using the equation 12–61 from Sterman's work (2000, p. 507). This equation assumes that productivity, starting with an initial reference amount, will increase by a certain value for every doubling of accumulated experience. This is a very important variable as it influences the effectiveness and efficiency of human resources, as well as the revenues and costs regarding the implementation and exploitation of energy efficiency projects. The parameter Minimum HR Desired establishes the initial work force. That initial condition is critical to the success of the venture. The main task of these employees is to develop a market and feed the prospect pipeline. This work force is costly because the firm does not yet have any revenue. As such, this business venture should avoid an overabundance of personnel, as that would drain their cash flow. However, the firm must have enough personnel who must also be sufficiently skilful to effectively sell and develop EPC projects. As clients

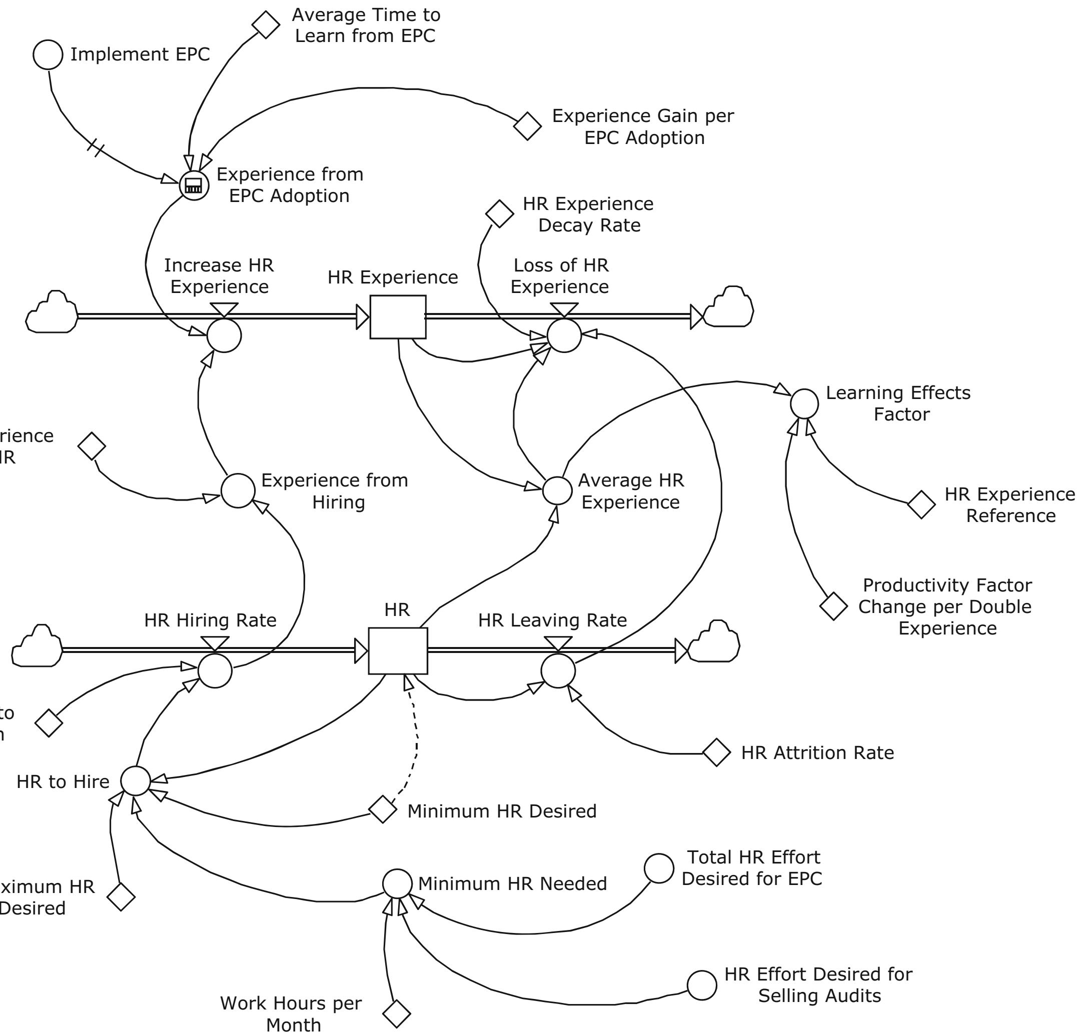


Fig. 3 Stock-flow diagram of the HR sector

begin to adopt EPC, additional employees are needed to implement and run energy projects.

Operations, finance, and EVA sectors

The Operations sector of the model sequences and assigns business operations to employees according to specific operation management practices. The work effort desired for each activity (informing about EPC, selling audits, developing EPC, implementing EPC, and running EPC) determines the employee effort assigned for each one of the ESCO activities, which is limited by the total employee effort available. The effort desired for performing each activity is determined by the stocks EPC Adopters, Projects in Progress, Audits in Progress, Interested, and Potential in the marketing sector (Fig. 1). The work effort is assigned according to the following priorities: first, to perform the activities of developing, implementing, and running EPC; second, to perform the activity of selling audits; and finally, to inform potential prospects about EPC. The variables that represent the unitary work effort to perform the business activities are influenced by the variable Learning Effects Factor (learning curve for productivity from experience) included in HR sector (Fig. 3).

The cash flow and debt of the firm are addressed in the finance sector of the model. The cash flows in from borrowing and through revenues provided by energy savings. The cash flows out to pay the investment in efficiency projects, operating expenses, debt, capital interests, and taxes. The funds are borrowed when the level of cash does not permit the ESCO firm to fund its activities. The cost of debt is a function that increases when the debt to equity ratio increases. The cost of debt determines the value of WACC that is utilised to compute the capital charge and EVA.

The EVA sector describes the process of value creation over time. Some financial parameters such as revenues, costs, capital, and value creation are computed from the accumulation and flow of resources in the ESCO. A stock represents the net capital employed in EPC projects. The inflow is determined by the rate of EPC implementation and the outflow represents the depreciation for the related assets. The parameter EVA (Young and O'Byrne 2000) is computed as net operating profit less amortisations and taxes (NOPLAT) minus Capital Charge (WACC × Capital Employed). The variable MVA (market value added) represents the present value of future EVAs and is determined by summing the discounted EVA, using weighted average cost of capital (WACC) as a discount rate. The net revenues produced by EPC projects are represented by a stock variable. The inflow of that stock is determined by the rate of EPC implementation and the learning effects factor. The outflow represents the reduction of firm revenues due to the termination of EPC term.

Model parameters

A case study of an ESCO venture was carried out during the period of 2009 to 2014. That venture (Galp Energy Solutions) was launched in 2009 by Galp, a Portuguese oil and gas company and one of the largest firms in the country. The services provided included mainly EPC-based projects to improve energy efficiency or produce renewable energy. The projects are financed with internal funds of the ESCO, and the energy savings are split in accordance with a pre-arranged percentage. Data collected from that case study were utilised to represent the reference mode, estimate the parameters and initial values, and validate the behaviour of the simulation model. For instance, the parameters that drive the flows that accumulate the stocks of clients in the adoption cycle were determined from quarterly data available in the ESCO sales reports.

Model validation

This section presents the model validation which focusses on the process of building confidence around the assertion that the developed model is suitable for the purpose; this involves structural and behavioural validation tests (Sterman 2000). Assessing the model structure consists of verifying whether the structure reflects the essential descriptive knowledge of the real problem (Sterman 2000). In order to examine how simulation output replicates the historical behaviour of the real problem, behavioural validation tests are applied (Barlas 1996).

Structure verification

As described in Section 'Stock and flow diagrams', the main model structures are those included in the market and human resources sectors that are derived from system dynamics literature and past research. In the market sector, the series of stocks used as a client choice pipeline has been modelled to represent clients at various stages in the adoption cycle (Miller and Sterman 2007; Warren 2008). The effect of WOM that influences the flows included in the adoption cycle is modelled according to Sterman (2000, p. 333) and Morecroft (2015, pp. 169–181). The co-flow structure applied in the human resources sector is based on Sterman's (2000) structure of labour and hiring (p. 758) and takes into account the experience of the employees (Sterman 2000, p. 505; Miller and Sterman 2007; Warren 2008, pp. 258–261). Thus, it can be assumed that those model structures represent the existing knowledge of the real problem.

Behaviour tests

Behavioural validation tests were used to both calibrate the parameters and assumptions of the model and to examine how simulation outputs replicate the historical behaviour of the real problem. Empirical data gathered from an ESCO venture during the period of 2009 to 2014 (6 years) were utilised to validate the model behaviour. For instance, the client choice pipeline structure attempts to replicate very specific aspects of the ESCO industry. Thus, special attention was paid to the determination of parameters that drive the flows that accumulate the prospect stocks in the client adoption cycle. Those parameters were calibrated in order to minimise the mean deviations between simulation results and observed data.

The simulation results for the stock variables Interested (prospects interested in EPC), Audit in Progress, and EPC Adopters are plotted against the historical data for 6 years to offer a visual comparison. Figure 4 illustrates both the simulation results and the historical data about those stock variables. In order to test the model for its appropriate behaviour, statistical measures of correspondence between model simulation results and observed data can be applied (Sterman 2000). Thus, the simulation results and the empirical data were further used to calculate statistical measures as those presented in Table 1. The results presented in Table 1 do not suggest a perfect fit between simulation results and actual data (e.g. Audits in Progress produces a root mean square deviation of 42%). However, the main purpose of the system dynamics model is to capture the broad dynamic behaviour patterns of the real system, and not provide accurate point predictions. Figure 4 reveals that actual curves exhibit an oscillatory behaviour around simulated data, which, in turn, seem to smooth out historical data. Moreover, the mean absolute deviations found are lower than 1 client/prospect, and the per cent deviations are significant due to the low number of prospects flowing in at this stage of the venture. Therefore, we can conclude that the simulated data match the trend of historical data, thus providing the model with a reasonable appropriateness to reproduce the prospect chain of the venture.

Model simulation

Base case

The ESCO venture launches a new energy service (EPC) into the market. There exist 600 commercial buildings that are capable of implementing EPC-based energy efficiency projects in partnership with the ESCO. The firm possesses €1 M of initial capital invested that is applied to develop the first projects. The initial work force consists of five employees performing marketing and engineering activities. They have no significant experience since they have never been involved in EPC projects. However, since the employees will be engaged in energy efficiency projects, they will enhance their abilities and become progressively more efficient.

Figure 5a–h presents venture performance over the 15-year simulation period. Because of the extremely long adoption cycle, it will take a long time to accumulate a reasonable number of EPC adopters, as it implies that potential adopters have moved up through the stages of the client choice pipeline until they become full EPC adopters. There are no full implemented projects for the first 2 years. The first full EPC adopters are accomplished in the third year. The firm would run 33 projects by year 15 (Fig. 5a). As presented in Fig. 5c, the number of project managers maintains at approximately the minimum level (five employees) until the ninth year. As the flow in the prospect pipeline increases, the employee effort required augments, and the number of project managers is regulated, achieving 13 employees by year 15. The behaviour of the variables Capital Employed, Equity, Debt, Cost of Debt, and WACC is presented in Fig. 5e, f. Before the third year, the firm has no full implemented projects and yet deploys a significant portion of the initial capital (€1 M). The first projects commence to produce the energy savings and corresponding revenues in the third year. Figure 5g–h shows the economic performance over the 15-year simulation period. Accumulated net earnings are negative for the first 6 years and become positive afterwards. For the first 7 years, the business operations of the venture do not add value as the EVA is negative during that period. There is no record of relevant positive EVA flow in the following 4 years. The venture only commences to produce a significant positive EVA after approximately 12 years (a considerably long time for investors). In the first 14 years, the firm produces a negative MVA. That means that the venture only starts adding value in the 15th year. As such, the results indicate that the simulated ESCO is economically viable in the long term. Nevertheless, as presented in Fig. 5h, the MVA (by year 15) of the venture is not relevant (€105 K).

A sensitivity analysis is performed (using the Monte Carlo sampling method provided by Powersim software with 1000 iterations) with respect to the uncertainty of some crucial parameters that are determined according to a normal probability distribution. The procedure took into account the following parameters and corresponding standard deviations: net savings per EPC and investment per EPC, with 10% standard deviation, and time to inform prospects, time to adopt audit, time to develop EPC, and time to implement the project, with 25% standard deviation. This sensitivity analysis varies the values of those parameters to compute a probability

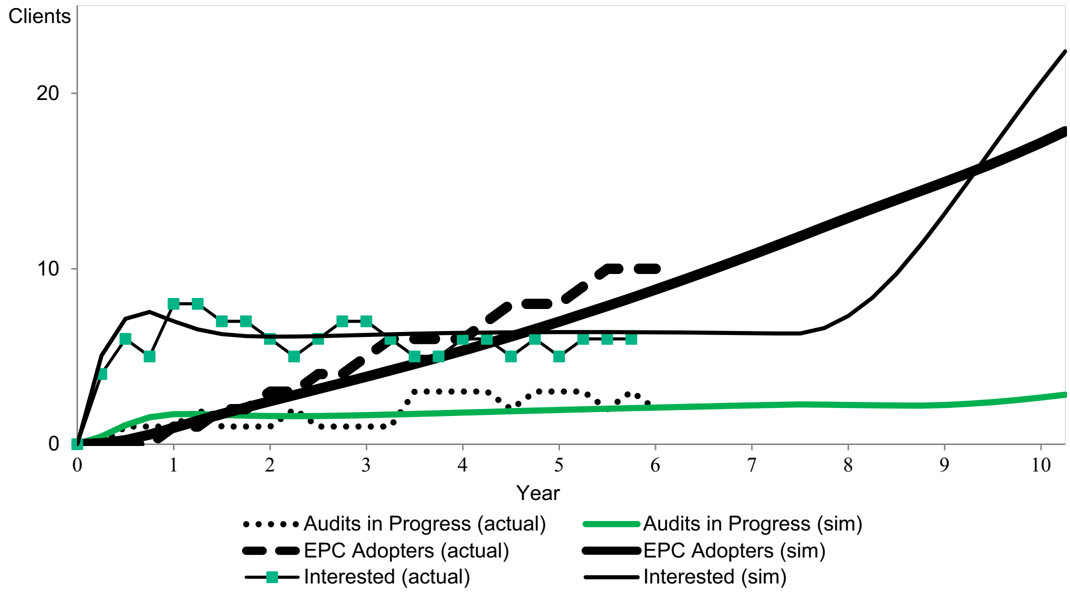


Fig. 4 Base case comparison of observed and simulated values

distribution for the MVA variable. Figure 6 presents the range in which the MVA falls with distinct confidence levels (MVA curves of 10, 25, 50, 75, and 90 percentiles). For example, a value of 75% means that 75% of the simulation runs placed MVA below the 75 percentile curve, also meaning that 25% of the simulation runs placed MVA above the 25 percentile curve, and so on. As presented in Fig. 6, MVA values (by year 15) are not significant and quite sensitive to variations in the assumption parameters, which makes it more strenuous for the venture to succeed. The poor MVA 50 percentile value (€24 K) suggests that the venture has approximately a 50% probability of success (corresponding to a positive MVA).

In summary, supposing that the assumptions considered in this scenario are representative and realistic, the model outcomes indicate that an ESCO firm with appropriate business processes can be viable in the long term. The risk analysis of the simulation model evidences, however, that such a business venture would involve considerable risk as it would have an approximately 50% likelihood of adding value.

Table 1 Statistical measures of deviations between simulation results and observed data

Statistical measure	Model variable		
	Interested (prospects)	Audits in Progress	EPC Adopters
Mean deviation	0.36	− 0.15	− 0.81
Mean deviation (%)	6.08%	− 7.91%	− 16.36%
Mean absolute deviation	0.83	0,67	0.91
Mean absolute deviation (%)	13.87%	36.65%	18.44%
Root mean square deviation	1.00	0.77	1.11
Root mean square deviation (%)	16.67%	42.08%	22.32%

Analysing the sensitivity of the ESCO performance to government policies

The simulation of the present model allows decision makers to analyse the sensitivity of firm performance to certain government policies that may be needed to overcome the barriers to success. The model considers the effect of various policies related to ESCO on the business venture, and includes parameters that allow one to adjust the existence and effect of those policies. The following sections explore the dynamic effects of energy policy on an ESCO business venture. Some government policies recommended in the literature to develop an energy services industry are selected for assessment through simulation, such as initiatives to improve WOM, low interest rates, energy

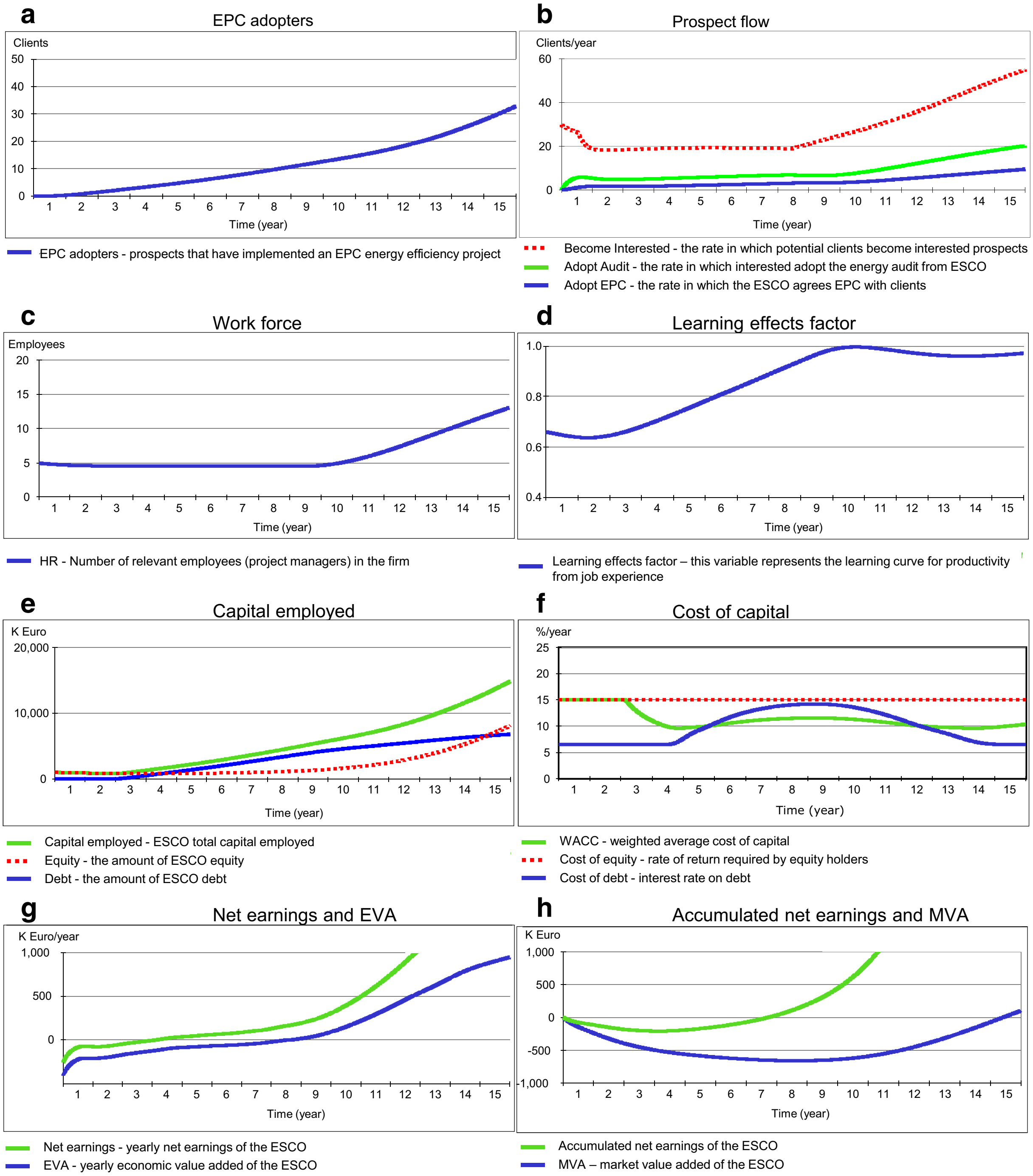


Fig. 5 **a**–**h** Base case performance over 15 years

audit subsidies, public procurement for EPC, and demonstration projects. By generating scenarios over time, the model simulates the performance impacts of those policies.

Effect of WOM initiatives

Prospects will not adopt EPC-based projects unless they are assured of their benefits, eventually from contact

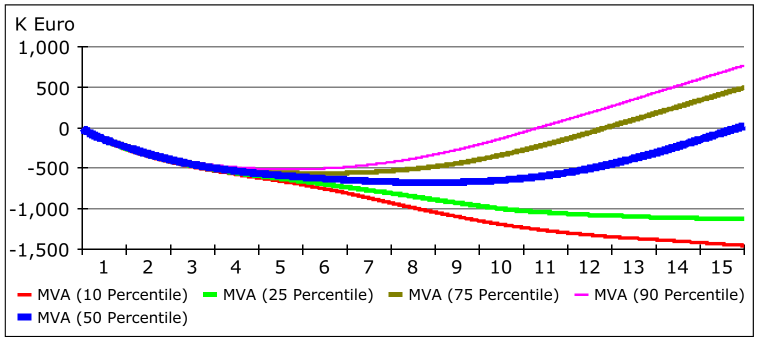


Fig. 6 Base case: MVA sensitivity analysis

with existing adopters. Adversely, it will take a considerably long time to accumulate adopters to diffuse the advantages of EPC projects, as it obliges prospects to have advanced up through stages of the client choice pipeline until they become full EPC adopters. At that phase, to accelerate the business profitability, it is crucial to benefit from the WOM potential.

This scenario assumes that a set of government and ESCO initiatives would induce the WOM mechanism by fostering special events such as workshops and seminars to evidence and disseminate information on the experience regarding successful energy efficiency projects in order to make potential prospects aware of EPC and its benefits. In the base case, the WOM contact rate is assumed to be three prospects per adopter per year. Figure 7a–e illustrates the behaviour of the simulation model as the contact rate parameter is increased by up to nine prospects per adopter per year. Comparing Figs. 5b and 7b, we can observe that the prospect flow rates augment significantly, particularly from year 4 to year 9.

By year 15, the firm will have accumulated approximately 80 projects (Fig. 7a). As presented in Fig. 7c, the number of employees hovers around the minimum capacity (five project managers) until the fourth year. Then, reacting to the augmenting number of clients, the work force is increased by up to 23 employees. Figure 7d, e illustrates the firm's economic performance. For the first 4 years, the variable EVA is negative, after which point the venture commences to produce positive EVA resulting in a reasonable final MVA (€1.2 M); this means that in this case the venture will be economically viable because it will add value in the long term. These outcomes suggest that the simulation model is sensitive to variations in the WOM contact rate assumption. Therefore, effective policies should include initiatives that could accelerate and take advantage of WOM communication among potential prospects and EPC adopters.

Effect of interest rate on debt

As mentioned in the literature review, it is assumed that financial incentives could play an important role in this business venture. A common type of financial incentive policy is to subsidise the interest rate on debt. The result of this policy is to lower the financial cost of the ESCO, enabling higher profits without affecting the costs and attractiveness to the client firms. By benefiting from this incentive, the ESCO avoids the very high interest rates on debt due to the financial stress (high debt to equity ratio) incurred in the base case from year 5 to year 12 (as displayed in Fig. 6f).

Effect of energy audit subsidy

Another common type of policy is to subsidise a portion of the energy audit costs (Bertoldi et al. 2014). The expected result of this policy is to stimulate energy audits to be used as the basis for EPC projects by lowering the upfront costs to the client. It is assumed that a subsidy programme would increase the fraction of energy audit adoption from 20 to 50%. Figure 8a, b presents some simulation results for a case that considers an impact factor of 1.5 (for a 3-year programme).

Effect of public procurement programme

The promotion of public tenders for implementing EPC projects in public buildings could be a supportive policy measure. In this initiative, government energy authorities select certain public buildings for EPC project implementation in partnership with ESCOs. A stock

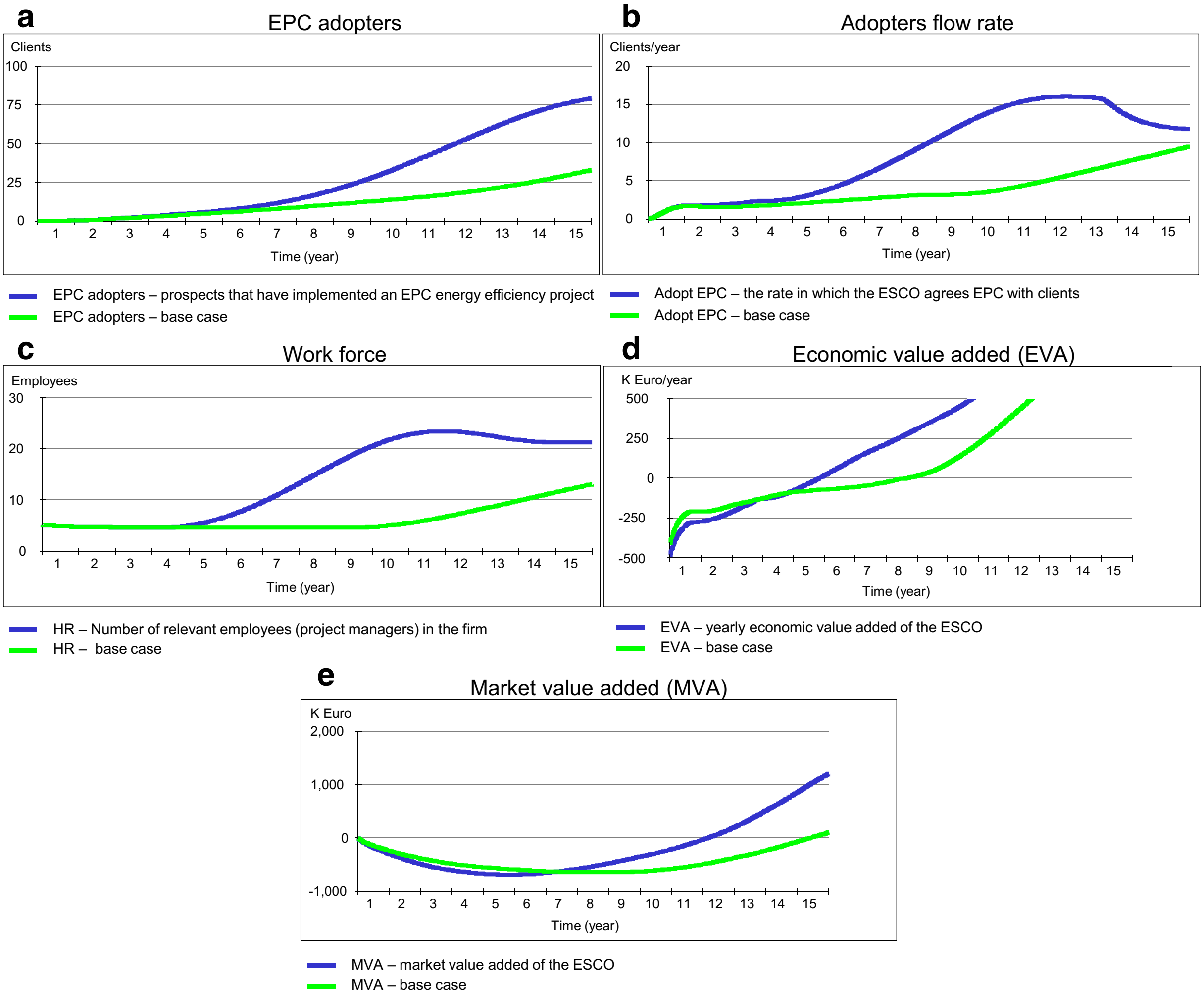


Fig. 7 **a**–**e** Improved WOM case: performance over 15 years

representing those buildings is defined to accommodate that policy measure in the model structure. These buildings will be submitted to energy audits, project development, and EPC agreements. In the present study, a 3-year programme for improving energy efficiency in public buildings is simulated in which ESCOs are called

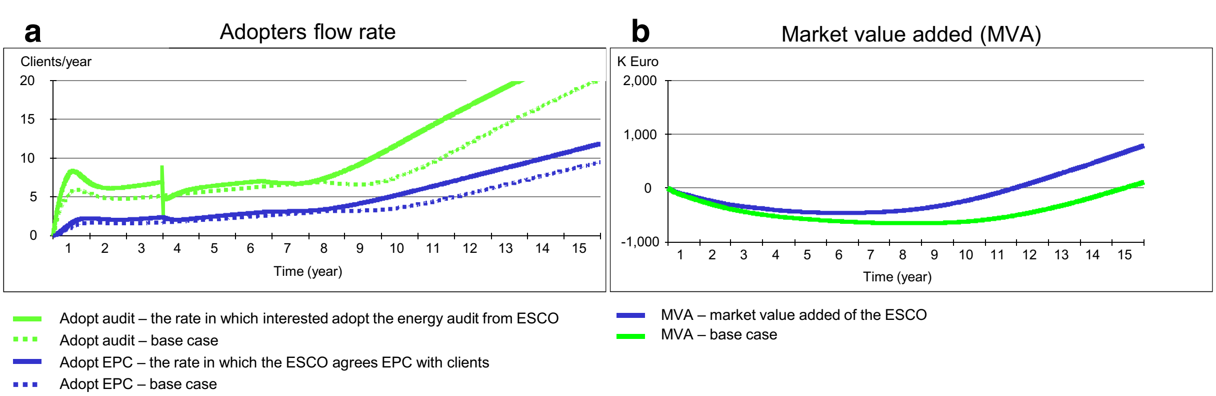


Fig. 8 **a**, **b** Audit subsidy programme case: performance over 15 years

on to propose their energy audit and EPC offers. It is assumed that a certain number of public projects will be available to the startup firm.

Figure 9a–d presents some simulation results for a scenario which considers a calling rate of three buildings per year (for the 3-year program). As shown, this type of policy measure could be very beneficial for an ESCO startup.

Effect of demonstration projects programme

A demonstration programme is another policy measure that could be applied by government authorities to promote ESCOs, particularly in countries where there is a lack of experience and awareness concerning energy services and projects on an EPC basis. In a demonstration programme, ESCOs are called to develop and implement EPC-based projects. Energy authorities select a set of private and public buildings that are suitable to serve as pilot and demonstration projects to display the benefits of energy efficiency projects based on EPC. Those buildings have had energy audits and are capable (legally, economically and technically) of adopting EPC. By engaging in this type of programme, the startup firm has the opportunity to accelerate learning on EPC processes. On the other hand, the results of these learning processes will be disseminated to improve knowledge, awareness, and trust surrounding EPC and ESCOs. The model development considers a stock variable representing those demonstration projects to permit the evaluation of that policy measure.

The present study explores a 3-year demonstration programme. It is assumed that a certain number of demonstration projects will be available to the startup firm. Figure 10a–e presents some simulation results considering a calling rate of three demonstration projects per year (for the 3-year programme). Figure 10e in particular shows the acceleration of the learning processes as the associated effect occurs approximately 3 years before the base case. These results suggest that this type of policy measure can be very effective as it contributes expressly to the success of that business venture.

Effect of combining policies

As revealed by the base case simulation results, an ESCO venture with proper management processes can succeed without government policies in place. The sensitivity analysis of the model shows, however, that such a business venture would have approximately 50% chance of doing so. As each one of the above fostering policies is implemented in the simulation model, the

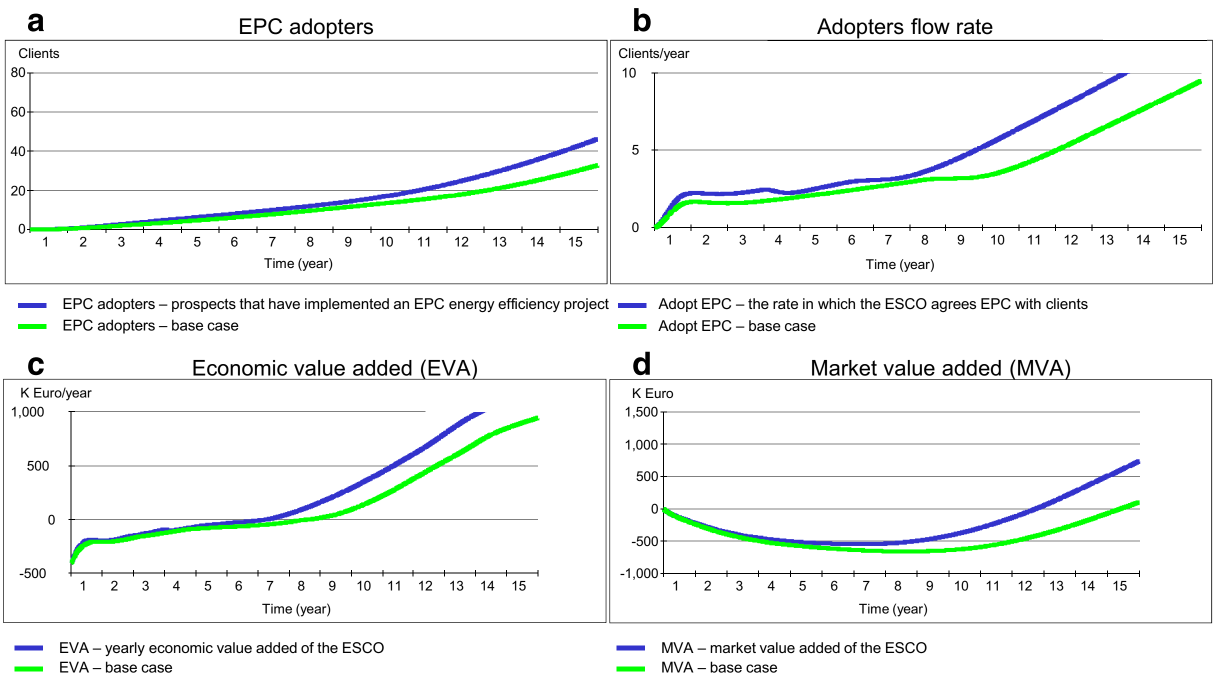


Fig. 9 **a**–**d** Public procurement case: performance over 15 years

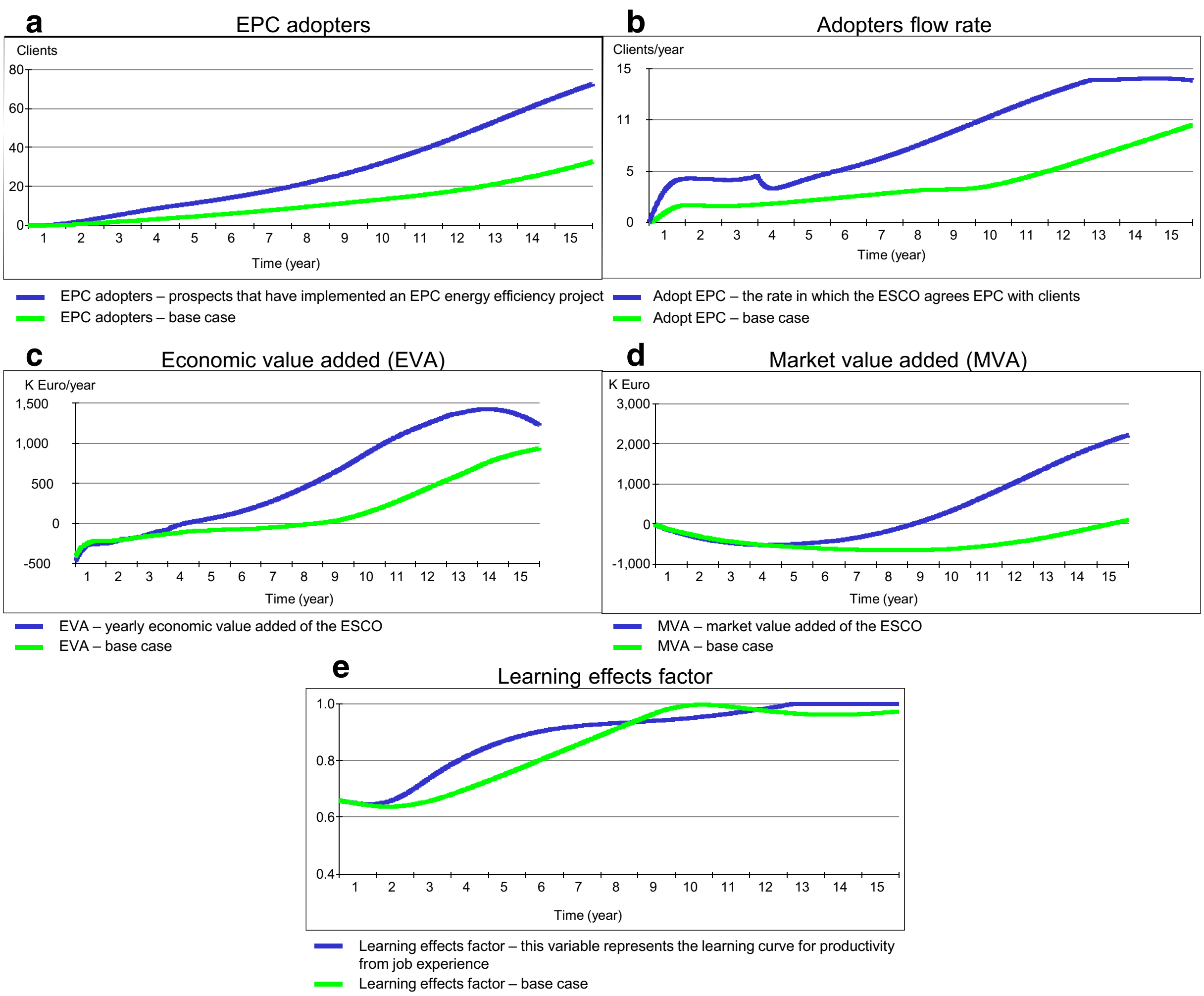


Fig. 10 **a**–**e** Demonstration projects case: performance over 15 years

firm does significantly better than the base case. Thus, supportive government policies would provide the venture a much higher chance of succeeding and achieving wide adoption of EPC. This section analyses and explores the effect of combining the following government policies as described in previous sections:

A. Improved WOM contact rates: it is assumed that the WOM contact rate parameter would be improved from 3 to 6 prospects/adopter/year.
B. Financial incentives: this scenario assumes that the ESCO will benefit from a 2.5%/year interest rate on debt for the first 10 years.
C. Audit subsidies: a 3-year subsidy programme is assumed, during which the fraction of energy audit adoption would increase by 30%.
D. Public EPC projects: it is assumed that on average, two public projects per year would be available to the startup firm for the 3-year programme.
E. Demonstration projects: this scenario assumes that on average, two demonstration projects per year would be available to the startup firm for the 3-year programme.

Table 2 presents a comparison of these five policy measures in terms of MVA to the startup firm. As shown, implementing of any of the policies results in significantly better economic performance than in the base case. The simulated ESCO produces nearly €0.54 M (audit subsidy policy) to €1.658 M (demonstration projects policy) of MVA by year 15. Overall, the firm produces a positive EVA sooner in the presence of

Table 2 Effect of incentive policies on the ESCO performance over 15 years

	Market value added (k€)	Risk analysis							
		MVA (5 perc)	MVA (10 perc)	MVA (25 perc)	MVA (50 perc)	MVA (75 perc)	MVA (90 perc)	MVA (95 perc)	Likelihood of negative MVA (%)
Base case	105	− 1622	− 1454	− 1120	24	500	774	900	49%
A - Improved WOM contact rates	942	− 2036	− 1725	− 694	823	1365	1835	2051	36%
B - Financial incentives	615	− 152	66	360	572	795	988	1089	8%
C - Audit subsidies	743	− 1605	− 1409	− 882	488	859	1145	1287	41%
D - Public EPC projects	540	− 1686	− 1495	− 1056	465	963	1277	1428	42%
E - Demonstration projects	1658	− 2050	− 1715	− 256	1543	2099	2541	2776	29%

Risk analysis: MVA (over 15 years) sensitivity analysis (Monte Carlo sampling method with 1000 iterations) with regards to the variation of the following assumptions (normal distribution with 10% standard deviation): Net Savings per EPC (normal distribution with 10% standard deviation); Investment per EPC (normal distribution with 10% standard deviation); Time to Inform Prospects (normal distribution with 25% standard deviation); Time to Adopt Audit (normal distribution with 25% standard deviation); Time to Develop EPC (normal distribution with 25% standard deviation); Time to Implement Project (normal distribution with 25% standard deviation)

those favourable policies. Most importantly, the venture's probability of failure has been reduced substantially. The MVA figures from risk analysis (5, 10, 25, 50, 75, 90, and 95% percentiles) indicate that those government measures enable the reduction of the likelihood of negative MVA. Unsurprisingly, the interest rate reduction policy produced the better improvement of the simulated firm in terms of risk exposure.

Table 3 shows how the possible combinations of government policies impact the expected market value of the simulated firm. As shown, the maximum performance is achieved by combining all five policy measures (A, B, C, D, and E), producing €5.427 M of MVA by year 15. If just four measures are to be selected, the greatest performance impact comes from the A, B, D, and E policies (€5.171 M of MVA by year 15, corresponding to 95% of maximum MVA). Then, in terms of the three measure combination, the A, B, and E policies provide the best performance (€4.617 M of MVA by year 15, corresponding to 85% of maximum MVA). Concerning the implementation of two policies, the greatest MVA is obtained by combining B and E (€2.602 M of MVA by year 15, corresponding to 48% of maximum MVA). Table 4 presents the impact of the most efficient combinations of policy measures on the ESCO performance. As shown, the greatest

Table 3 Effect of combined policies on the ESCO performance (MVA over 15 years)

	Market value added over 15 years (K€)			
	Base case	A - Improved WOM	B - Financial incentive	A B
A - Improved WOM	942			
B - Financial incentives	615	1826		
C - Audit subsidies	743	1666	1335	2459
D - Public EPC projects	540	1464	1080	2664
E - Demonstration projects	*1658*	2489	*2602*	*4617*
C D	931	1848	1383	3192
C E	1939	2695	2938	4952
D E	1977	2646	3229	*5171*
C D E	2185	2796	3503	*5427*

Italic values represent the maximum performance achieved by combining one to five policy measures

Table 4 Effect of the most efficient combinations of policy measures on the ESCO performance (MVA)

Simulation time (years)	Base case	E	B-E	A-B-E	A-B-D-E	A-B-C-D-E
3 years MVA (k€)	− 494	− 475	− 383	− 350	− 327	− 263
5 years MVA (k€)	− 601	− 496	− 202	− 60	42	149
10 years MVA (k€)	− 588	217	1100	2247	2766	3105
15 years MVA (k€)	105	1658	2602	4617	5171	5427
%/ABCDE 15 years MVA	2%	31%	48%	85%	95%	100%

A - Improved WOM contact rates = 6 prospects/adopter/year. B - Financial incentives - 2.5%/year interest rate on debt for the first 10 years. C - Audit subsidies - 30% increase in fraction of audit adoption for a 3-year subsidy program. D - Public EPC projects - 2/year calling rate for a 3-year programme. E - Demonstration projects - 2/year calling rate for a 3-year programme

performance impact is generated by combining the A - improved WOM measure with the E - demonstration projects initiative.

By interpreting the data from Table 4 using a Pareto analysis, it is interesting to observe that a combination of the three measures A, B, and E produces 85% of maximum performance (corresponding to the five measure combination). Table 5 and Fig. 11a–f illustrate the firm performance over the 15-year duration of the simulation mode under those three policies. The differences between this A-B-E scenario and the base case are immediately identifiable. There is a clear acceleration of the EPC adopters' accumulation process, as seen from the behaviour of the prospects flow rate and stock presented in Fig. 11a, b. There are expected to be approximately 88 EPC-based projects implemented by year 15 (Fig. 11b), in comparison to 33 adopters occurring in the base case. The number of relevant employees increases to up to 23 in the tenth year, whereas in the base case it stays steady around the minimum capacity until the ninth year (Fig. 11c). Equity remains lower than debt until approximately the eleventh year, at which point cash flow from EPC starts to exceed capital expenditures in new projects, which enables debt repayment (Fig. 11d). Figure 11e, f compares the economic performance of the simulated firm ESCO to the A-B-E and base case scenarios. In the base case scenario, the EVA is negative for 7 years, there is no record of significant EVA after 9 years, and the firm begins to develop a reasonable positive EVA flow after only approximately 12 years of simulation time. In the A-B-E scenario, on the other hand, with those government policy measures in place, the investment has strong positive returns (EVA) after 3 years, almost 9 years earlier than the base case (Fig. 11e). With respect to MVA, Fig. 11f shows that the combination of the policies also displays a more favourable behaviour as MVA becomes positive in the fifth year, 10 years earlier than the base case. Figure 12 presents the results of a sensitivity analysis for the A-B-E scenario regarding the uncertainty of some critical assumptions, which is compared to the similar analysis performed for the base case and presented in Fig. 6. As can be observed in Fig. 12, although MVA values (by year 15) are also very sensitive to changes in the considered assumptions, the probability of failure (corresponding to negative MVA) seems to be quite low, which indicates that starting an ESCO venture under these conditions will have a greater chance of success.

Table 5 A-B-E initiatives case: performance over 15 years

Simulation time (years)	Work force (project managers)	Learning effects factor (0–1)	Interested prospects	EPC adopters	Accumulated net earnings (k€)	Market value added (k€)
1	5	0.64	7	0	− 89	− 216
3	6	0.75	25	6	20	− 350
5	11	0.80	45	13	881	− 60
10	23	0.93	55	50	9177	2247
15	23	1.00	39	88	30,739	4317

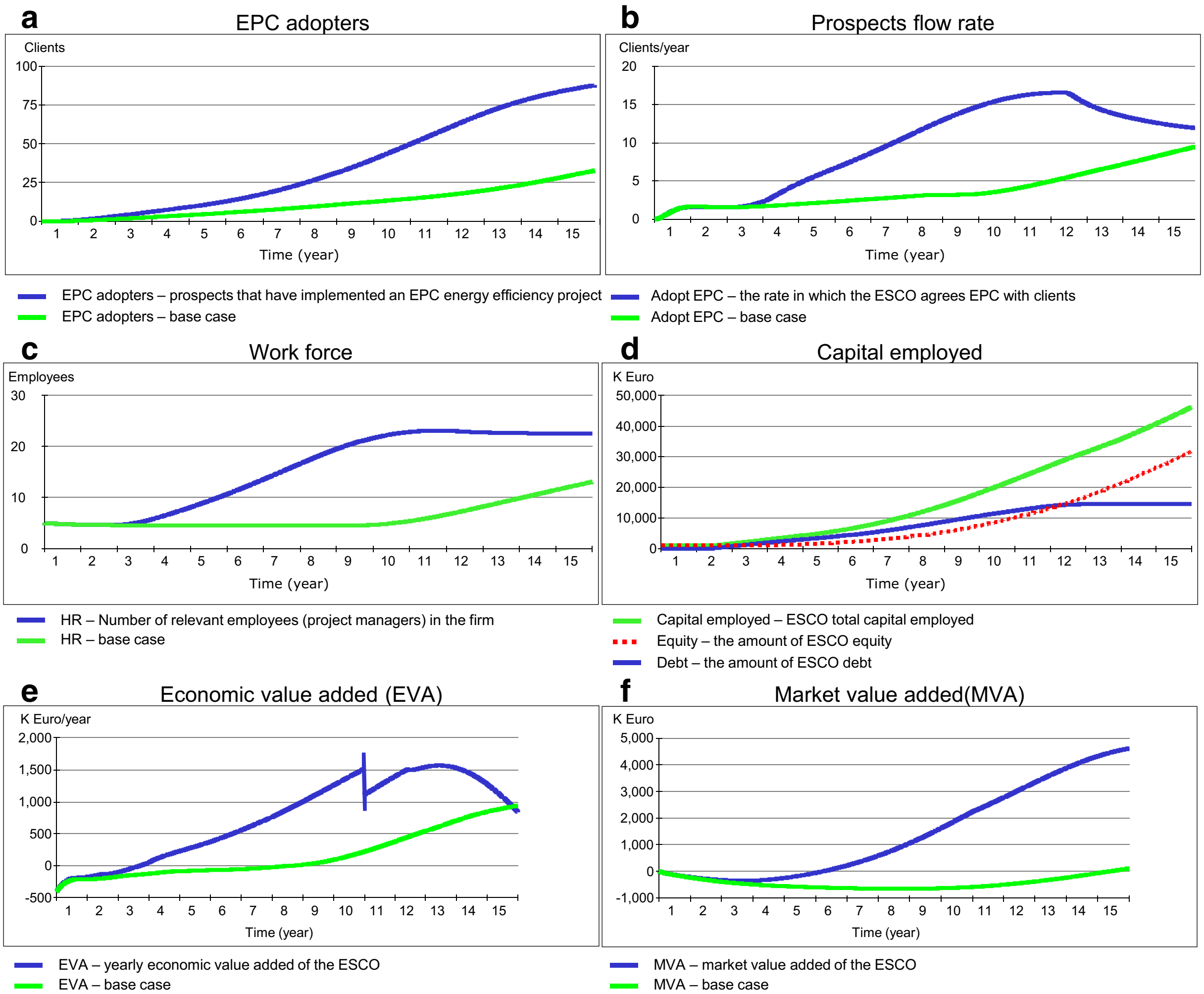
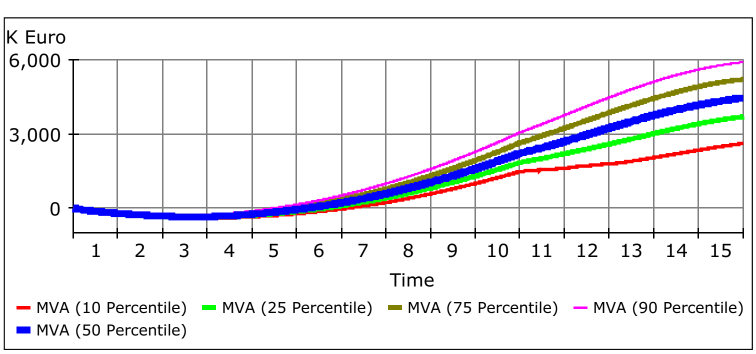


Fig. 11 **a**–**f** A-B-E initiatives case: performance over 15 years

Conclusion

The development of a competitive and sustainable market for EPC projects supplied by ESCOs is considered to be a necessary way to improve energy efficiency. However, against the initial expectations in Portugal, similar to other small European markets, only a few firms are engaged in EPC ventures, and many of those firms

Fig. 12 A-B-E initiatives case: MVA sensitivity analysis



reported several difficulties. To understand why, we conducted this research using Portugal data for convenience.

Our methodological approach was to build an accurate SD model, a set of algebraic equations that interrelated the main causal variables behind the dynamic behaviour of the whole system, which allows computer simulations of different effects.

The simulation of the base case indicated that the overall insignificant MVA and the low probability of success of ESCO result from the long adoption cycle. The length of the cycle stems from the amount of time required to accumulate full adopters in this emergent market and then to build up revenue.

Some simulations examined the sensitivity of ESCO performance to incentive policies. The results revealed that the MVA is sensitive to variations in the WOM contact rate parameter; this indicates that effective policies should include specific initiatives that could accelerate and take advantage of WOM communication among potential prospects and EPC adopters. These simulations also showed that low interest rates, energy audit subsidies, public procurement for EPC projects, and demonstration projects produce a positive EVA sooner than in the base case. Most importantly, the venture's probability of failure is reduced substantially. Unsurprisingly, the interest rate reduction policy produced better improvement of the simulated firm in terms of risk exposure.

Other simulations analysed combinations of the above government policies. The combination of three of the above government policies (improved WOM contact rate, low interest rate on debt, and demonstration projects) seems to provide the most efficient and robust incentive scheme as they may significantly improve the expected market value of the simulated firm and reduce the probability of failure of ESCO ventures. In other words, the simulations show that the most efficient measures are those that can accelerate learning on EPC processes and take advantage of the WOM effect to change the potential adopters' attitudes regarding EPC in a sustained way, along with financial incentives to assure a competitive cost of capital.

Considering the results of the simulated firm, it is valid to ask whether it is rational for private investors to invest in these ventures at all. For the base case venture, which takes 15 years to achieve profitability, the answer is likely no. Too many hazards could occur over that period of time that would cause the ESCO to fail. If adequate management strategies are followed and the referenced government policies are in place, however, then it would be a good decision to invest in an ESCO with attributes similar to the one modelled.

In summary, the simulation model does provide evidence that the combination of certain government policies will significantly reduce the probability of failure of ESCO ventures, improve the value added on investments in these companies, and consequently, increase the odds of success (and the widespread adoption of EPC within a virtuous industry cycle) from what they would have been otherwise.

The contributions of this study include the development of an empirically based SD model for ESCO ventures; an improved comprehension of the challenges and difficulties faced by these firms and the determination and assessment of certain government policies that would improve the probabilities of success of these ventures.

Some potential limitations to the current investigation exist. As regarding to the research field, in terms of economic, demographic, and weather conditions, Portugal might not be considered as a representative EU country for investigating the development of the ESCO markets. During the course of this study, high quality and detailed data was gathered from an ESCO venture. However, parameters and initial values of the simulation model were based mainly on just a single case, thus limiting the model's general validity. With respect to the method (system dynamics modelling and simulation), although data from a real business venture have been used to structure, calibrate, and validate the model, it must be emphasised that the simulation is not reality. The simulation model developed here is meant to be used as a learning tool; it is not predictive. Actual value creation will vary quite widely and be sensitive to factors outside the scope of this business model. It is possible a real ESCO could do better than the simulated one. Further, there are many factors that are not taken into account in the model that could cause a real venture to underperform and to have a higher probability of failure.

The present study focusses on the assessment of certain government policies that would foster the development of ESCO firms; however, additional work will be dedicated to better understand how to improve the odds of this kind of ventures. For instance, the model can be enhanced in order to analyse the effects of other incentive policies and environmental factors. The present simulation model also supports decision makers to explore and learn about the dynamics of managerial processes and strategies as they are able to assess the performance effects of each. For instance, managerial strategies may involve alternative marketing, financial, staff, and operations policies and decisions that will impact and determine that venture success.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Model documentation

The parameters, and correspondent Powersim equations, units, type of variable, and documentation are listed below in alphabetical order.

Acc Net Earnings = INTEGRATE(Net Earnings)

Units: K Eur Variable type: auxiliary

Documentation: Accumulated net earnings of the ESCO

Adopt Audit = Audits Offered * Fraction of Audit Adoption

Units: Clients/year Variable type: auxiliary

Documentation: The rate of persuading interested prospects to purchase and adopt the energy audit from ESCO

Adopt Demo EPC = MIN(Demo Projects/Time to Develop EPC, Total EPC Developed)

Units: Cli/yr Variable type: auxiliary

Documentation: The rate of preforming energy audit, developing project, and agreeing EPC with clients involved in the demonstration programme

Adopt EPC = EPC Developed * Fraction of EPC Adoption

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which the ESCO agrees EPC with clients

Adopt PP Audit = MIN(Public Projects/Time to Adopt Audit, Total Audits Offered)

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which public entities purchase and adopt the energy audit from ESCO

Audit Subsidy Effect = (base case = 0; reference value = 1.3; min = 1.2; max = 1.5)

Units: Dimensionless Variable type: constant

Documentation: This parameter represents the effect of partly subsidising the audit cost on the fraction of audit adoption

Source: Perception of ESCO professionals. From case study ‘Galp Energy Solutions’

Audits in Progress = *dt* * (Adopt Audit + Adopt PP) – *dt* * (Adopt EPC + Reject EPC)

Units: Cli Variable type: level

Documentation: Clients with energy audit in progress.

Audits Offered = Total Audits Offered − Adopt PP Audit

Units: Cli/yr Variable type: auxiliary

Documentation: Number of Audits that can be sold per year to interested prospects

Average Experience of New HR = 300

Units: Whr/Emp Variable type: constant

Documentation: Average experience of new project managers

Source: Perception of ESCO professionals. From case study ‘Galp Energy Solutions’

Average HR Experience = HR Experience/HR

Units: Whr/Emp Variable type: auxiliary

Documentation: Average HR (project managers) experience

Average Time to Hire and Train = 1

Units: yr Variable type: constant

Documentation: Average time to hire and train new project managers

Source: Perception of ESCO professionals. From case study ‘Galp Energy Solutions’

Average Time to Learn from EPC = 2

Units: yr Variable type: constant

Documentation: Average time to learn from EPC project implementation and exploitation.

Source: Perception of ESCO professionals. From case study ‘Galp Energy Solutions’

Become Informed by HR effort = HR Effort Assigned for Informing Prospects/HR Effort per Prospect

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which potential clients become aware and interested prospects from ESCO communication

Become Interested = Become Interested by WOM + Become Informed by HR effort * Fraction of Interested

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which potential clients become interested prospects. Interested prospects are aware and interested in applying EPC in partnership with the ESCO

Source: The effect of WOM is modelled according to Sterman (2000, p. 333) and Morecroft (2015, pp. 166–174)

Become Interested by WOM = Total EPC Adopters * WOM Contact Rate * (Potential/Total Potential Market)

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which potential adopters become interested prospects from word-of-mouth

Source: The effect of WOM is modelled according to Sterman (2000, p. 333) and Morecroft (2015, pp. 166–174)

Borrowing = Borrowing Cash

Units: K Eur/da Variable type: auxiliary

Documentation: Amount of cash borrowed per day.

Borrowing Cash = MAX((Minimum cash level − Cash)/TIMESTEP − Incoming Cash + Outflowing Cash, 0)

Units: K Eur/da Variable type: auxiliary

Documentation: This is cash flowing into the firm via funds borrowed from debt holders.

Capital Charge = Capital Employed * WACC

Units: K Eur/yr Variable type: auxiliary

Documentation: Capital charge is the cost of having the capital charged to the ESCO for use of the capital. The cost of capital is calculated as the weighted average cost of capital (WACC), averaged to a daily rate.

Capital Employed = Cash + Capital in Projects

Units: K Eur Variable type: auxiliary

Documentation: ESCO total capital employed

Capital in Projects = *dt* * (Investing in Projects) – *dt* * (Depreciating Projects)

Units: K Eur Variable type: level

Documentation: Capital in Projects represents the net capital employed in EPC projects

Cash = Initial Cash + *dt* * (Incoming Cash + Borrowing Cash) – *dt* * Outflowing Cash

Units: K Eur Variable type: level

Documentation: Cash available for the ESCO

Cost of Debt = IF(TIME < (STARTTIME + Term of Interest Rate Subsidy), Interest Rate Subsidy, Market Cost of Debt)

Units: %/yr Variable type: auxiliary

Documentation: Interest rate on debt

Cost of Equity = 15%

Units: %/yr Variable type: constant

Documentation: Rate of return required by equity holders

Source: Case study of 'Galp Energy Solutions' venture

Debt = Initial Debt + *dt* * (Borrowing) – *dt* * (Repaying)

Units: K Eur Variable type: level

Documentation: The amount of ESCO debt

Debt Ratio = Debt/(Debt + Equity)

Units: Dimensionless Variable type: Auxiliary

Documentation: Debt ratio of the ESCO

Demo Programme Term = 3

Units: yr Variable type: constant

Documentation: Term of the demonstration projects programme

Demo Projects = *dt* * (Adopt Demo EPC) – *dt* * (DP Calling Rate)

Units: Cli Variable type: level

Documentation: These are firms with buildings selected for EPC demonstration projects. They will be submitted to project development and EPC agreeing. It is assumed that the number of demo projects will be available to the startup firm

Depreciating Projects = Capital in Projects/Projects Depreciation Time

Units: K Eur/da Variable type: auxiliary

Documentation: This is depreciation (and accounting) rate (on daily basis) of the project assets

Desired Rate for Developing EPC = (Audits in Progress + Demo Projects)/Time to Develop EPC

Units: Cli/yr Variable type: auxiliary

Documentation: Desired number of EPCs to be developed per year

Desired Rate for Implementing EPC = Projects in Progress/Time to Implement Project

Units: Cli/yr Variable type: auxiliary

Documentation: Desired number of EPC projects to be implemented per year

Desired Rate for Informing Prospects = Potential/Time to Inform Prospects

Units: Cli/yr Variable type: auxiliary

Documentation: Desired number of prospects to be informed per year

Desired Rate for Selling Audits = (Interested + Public Projects)/Time to Adopt Audit

Units: Cli/yr Variable type: auxiliary

Documentation: Desired number of Audits to be sold per year

DP Call = (base case = 0; reference value = 2; min = 1; max = 3)

Units: Cli/yr Variable type: constant

Documentation: The calling rate for EPC demonstration projects. These are firms with buildings selected for EPC demonstration projects. They will be submitted to project development, and EPC agreeing. It is assumed that that rate of demo projects will be available to the startup firm

Source: Discussion with ESCO professionals

DP Calling Rate = IF(TIME < (STARTTIME + Demo Programme Term), DP Call, 0)

Units: Cli/yr Variable type: auxiliary

Documentation: The calling rate for EPC demonstration projects

EBIT = Revenues − Operating Expenses

Units: K Eur/yr Variable type: auxiliary

Documentation: Yearly earnings before interest and taxes (EBIT) of the ESCO

End EPC = EPC Adopters/EPC Term

Units: Cli/da Variable type: auxiliary

Documentation: The rate in which EPC agreements terminate.

EPC Adopters = *dt* * (Implement EPC) – *dt* * (End EPC)

Units: Cli Variable type: level

Documentation: Clients that are benefitting from energy efficiency projects implemented by ESCO under an EPC agreement

EPC Developed = Total EPC Developed − Adopt Demo EPC

Units: Cli/yr Variable type: auxiliary

Documentation: Number of energy audits (and EPC design) performed per year from prospect base

EPC Net Saving = *dt* * (Saving Variation from EPC adoption) – *dt* * (Saving Variation from EPC Ending)

Units: K Eur/yr Variable type: level

Documentation: This stock represents the yearly net revenues produced by EPC projects

EPC Term = 10

Units: yr Variable type: constant

Documentation: Average term of EPC

Equity = Initial Equity + *dt* * (Equity Var)

Units: K Eur Variable type: level

Documentation: The amount of ESCO equity

Equity Var = Net Earnings

Units: K Eur/yr Variable type: auxiliary

Documentation: Amount of equity variation per day

EVA = NOPLAT − (WACC × Capital in Projects)

Units: K Eur/yr Variable type: auxiliary

Documentation: Yearly EVA of the ESCO. EVA is the economic value added every time period which calculates the value created from the revenues after all costs, including capital charges, have been removed

Expenses per Employee = 50

Units: K Eur/Emp/yr Variable type: constant

Documentation: The yearly salary (and other related expenses) paid to the average employee (project manager)

Experience from EPC Adoption = DELAYINF(Implement EPC, Average Time to Learn from EPC, 1, 0) * Experience Gain per EPC Adoption/2

Units: Whr/da Variable type: auxiliary

Documentation: Amount of experience provided by definition, implementation and exploitation of EPC projects

Experience from Hiring = Average Experience of New HR * HR Hiring Rate

Units: Whr/yr Variable type: auxiliary

Documentation: Experience from Hiring new project managers

Experience Gain per EPC Adoption = 900

Units: Whr/Cli Variable type: constant

Documentation: Amount of experience provided by the definition, implementation and exploitation of each EPC project

Source: Perception of ESCO professionals. From case study 'Galp Energy Solutions' and discussion with ESCO professionals

Fraction of Audit Adoption = Normal Fraction of Audit Adoption * Learning Effects Factor * IF(TIME < (STARTTIME + Term of Audit Subsidy), Audit Subsidy Effect, 1)

Units: % Variable type: auxiliary

Documentation: Fraction of interested prospects that purchase the energy audit

Fraction of EPC Adoption = Normal Fraction of EPC Audit Adoption * Learning Effects Factor

Units: % Variable type: auxiliary

Documentation: Fraction of clients that decide to adopt EPC and implement the energy efficiency project with the ESCO

Fraction of Interested = Normal Fraction of Interested * Learning Effects Factor

Units: % Variable type: auxiliary

Documentation: Fraction of potential prospects that become interested prospects. Interested prospects are aware and interested in applying EPC in partnership with the ESCO

HR = Minimum HR Desired + *dt* * (HR Hiring Rate) − *dt* * (HR Leaving Rate)

Units: Emp Variable type: level

Documentation: Project Managers

HR Attrition Rate = 10

Units: %/yr Variable type: constant

Documentation: The percentage of employees that leave ESCOs each year

HR Effort Assigned for Developing EPC = MIN(1, Total HR Effort Available/Total HR Effort Desired for EPC) * HR Effort Desired For Developing EPC

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per month assigned for Developing and Selling EPC

HR Effort Assigned for Implementing EPC = MIN(1, Total HR Effort Available/Total HR Effort Desired for EPC) * HR Effort Desired For Implementing EPC

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per month assigned for implementing EPC projects

HR Effort Assigned for Informing Prospects = MIN(HR Effort Available For Informing Prospects, HR Effort Desired for Informing Prospects)

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per month assigned for Informing and Persuading Prospects about EPCHR Effort Assigned for Running EPC = MIN(1, Total HR Effort Available/Total HR Effort Desired for EPC) * HR Effort Desired For Running EPC

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per month assigned for managing all the running EPC projects

HR Effort Assigned For Selling Audits = MIN(HR Effort Available For Selling Audits, HR Effort Desired for Selling Audits)

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per month assigned for selling energy audits

HR Effort Available For Informing Prospects = Effort Available For Selling Audits − HR Effort Assigned For Selling Audits

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per month available for informing prospects HR.

HR Effort Available For Selling Audits = Total HR Effort Available − Total HR Effort Assigned For EPC

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort per day available for selling energy audits

HR Effort Desired For Developing EPC = Desired Rate for Developing EPC * HR Effort per EPC Developed

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort desired per month for developing and selling EPC

HR Effort Desired For Implementing EPC = Desired Rate for Implementing EPC * HR Effort per Implemented EPC

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort desired per month for implementing EPC projects

HR Effort Desired for Informing Prospects = Desired Rate for Informing Prospects * HR Effort per Prospect

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort desired per month for informing prospects

HR Effort Desired for Running EPC = EPC Adopters * HR Effort per Running EPC

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort that are desired per month for managing all the running EPC projects

HR Effort Desired for Selling Audits = Desired Rate for Selling Audits * HR Effort per Audit Offered

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort desired per month for selling energy audits

HR Effort per Audit Offered = Normal HR Effort per Audit Offered/Learning Effects Factor

Units: Whr/Cli Variable type: auxiliary

Documentation: Number of person-hours that are needed for selling an energy audit

HR Effort per EPC Developed = Normal HR Effort per EPC Developed/Learning Effects Factor

Units: Whr/Cli Variable type: auxiliary

Documentation: Number of person-hours that are needed for performing each energy audit (including EPC developing, and selling)

HR Effort per Implemented EPC = Normal HR Effort per Implemented EPC/Learning Effects Factor

Units: Whr/Cli Variable type: auxiliary

Documentation: Number of person-hours that are needed for implementing each EPC project

HR Effort per Prospect = Normal HR Effort per Prospect/Learning Effects Factor

Units: Whr/Cli Variable type: auxiliary

Documentation: The number of person-hours of effort needed per prospect

HR Effort per Running EPC = Normal HR Effort per Running EPC/Learning Effects Factor

Units: Whr/yr/Cli Variable type: auxiliary

Documentation: Number of person-hours per year that are needed for managing each running EPC project

HR Expenses = (Expenses per Employee) * HR

Units: K Eur/da Variable type: auxiliary

Documentation: Salaries and other related expenses paid per day to employees (project managers)

HR Experience = Minimum HR Desired * Average Experience of New HR + *dt* * (Increase HR Experience) – *dt* * (Loss of HR Experience)

Units: Whr Variable type: level

Documentation: Cumulative project management, engineering and sales experience of ESCO in terms of number of person-hours

HR Experience Reference = 900

Units: Whr/Emp Variable type: constant

Documentation: Amount of HR experience that will produce normal productivity in all activities

Source: Perception of ESCO professionals. From case study 'Galp Energy Solutions' and discussion with ESCO professionals

HR Fractional Experience Decay Rate = 10

Units: %/yr Variable type: constant

Documentation: Fractional experience decay rate in terms of %/year. It represents the loss of effective experience. Employee knowledge and experience become obsolete because of technological changes

Source: Literature review, case study of 'Galp Energy Solutions' venture, and discussion with ESCO professionals

HR Hiring Rate = HR to Hire/Average Time to Hire and Train

Units: Emp/yr Variable type: auxiliary

Documentation: Hire HR based on how many persons are needed and the average time to get and train them

HR Leaving Rate = HR Attrition Rate * HR

Units: Emp/yr Variable type: auxiliary

Documentation: The number of employees that leave ESCO each day as a result of attrition

HR to Hire = IF(MIN(MAX(Minimum HR Desired, Minimum HR Needed), Maximum HR Desired) − HR > 0, MIN(MAX(Minimum HR Desired, Minimum HR Needed),

Maximum HR Desired) − HR, 0)

Units: Emp Variable type: auxiliary

Documentation: The number of persons to hire

Implement EPC = HR Effort Assigned for Implementing EPC/HR Effort per Implemented EPC

Units: Cli/yr Variable type: auxiliary

Documentation: The rate of project completion

Incoming Cash = Revenues

Units: K Eur/da Variable type: auxiliary

Documentation: This is cash flowing into the ESCO via revenues from clients.

Increase HR Experience = Experience from EPC Adoption + Experience from Hiring

Units: Whr/da Variable type: auxiliary

Documentation: ESCO employees learn from time spent working with EPC-based projects

Increase in Potential Market = Yearly Increase in Potential Market * Total Potential Market

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which potential market (potential adopters) is increased.

Initial Cash = Initial Debt + Initial Equity

Units: K Eur Variable type: constant

Documentation: Initial debt of the ESCO

Initial Debt = 0

Units: K Eur Variable type: constant

Documentation: Initial debt of the ESCO

Source: Case study of 'Galp Energy Solutions' venture

Initial Equity = 1000

Units: K Eur Variable type: constant

Documentation: Initial equity of the ESCO

Source: Case study of 'Galp Energy Solutions' venture

Initial Market = 600

Units: Cli Variable type: constant

Documentation: Initial number of potential EPC adopters

Source: ADENE − National Energy Agency

Interest Expense = Debt * Cost of Debt

Units: K Eur/da Variable type: auxiliary

Documentation: Interest expense on debt

Interest Rate Subsidy = (base case = 0; reference value = 2.5; min = 0; max = 5)

Units: %/yr Variable type: constant

Documentation: This is the subsidised value of the interest rate on debt.

Source: Discussion with ESCO professionals

Interested = *dt* * (Become Interested) − *dt* * (Adopt Audit + Reject Audit)

Units: Cli Variable type: level

Documentation: Number of firms with buildings capable (legal, economically and technically) of adopting EPC that are aware and interested in applying EPC in partnership with the ESCO

Investing in Projects = Investment per EPC * Implement EPC

Units: K Eur/da Variable type: auxiliary

Documentation: This is the financial investment rate (on daily basis) for the energy efficiency projects

Investment per EPC = 450

Units: K Eur/Cli Variable type: constant

Documentation: This is the average investment per EPC project.

Source: Case study of 'Galp Energy Solutions' venture

Learning Effects Factor = (MIN(Average HR Experience/HR Experience Reference, 1))^(LN (1 + Productivity Factor Change per Double Experience)/ LN(2))

Units: Dimensionless Variable type: auxiliary

Documentation: This variable represents the learning curve for productivity from experience.

Source: Formula 12–61 presented in section 12.2 of Sterman (2000, p. 507).

Loss of HR Experience = HR Leaving Rate * Average HR Experience + HR Experience * HR Fractional Experience Decay Rate

Units: Whr/da Variable type: auxiliary

Documentation: This rate represents the loss of employee experience from attrition and knowledge obsolescence.

Lost Prospects = *dt* * (Total Lost Prospects) − *dt* * (Regain Potential)

Units: Cli Variable type: level

Documentation: Potential prospects that are not interested in EPC and decide to implement in-house energy efficiency projects

Market Cost of Debt = GRAPHCURVE(Debt Ratio, 0, 0.05,{0.065, 0.065, 0.065, 0.065, 0.065, 0.065, 0.065, 0.065, 0.065, 0.065, 0.065, 0.07, 0.085, 0.10, 0.12, 0.14, 0.16, 0.18, 0.195, 0.2, 0.2//Min: 0; Max: 0.3//}) * 100

Units: %/yr auxiliary

Documentation: A graphical function of the debt interest rate.

Maximum Cash Level = 200

Units: K Eur Variable type: constant

Documentation: Maximum cash availability in the ESCO

Maximum HR Desired = 30

Units: Emp Variable type: constant

Documentation: Maximum number of employees (project managers)

Source: Case study of 'Galp Energy Solutions' venture

Minimum cash level = 100

Units: K Eur Variable type: constant

Documentation: Minimum cash availability in the ESCO

Minimum HR Desired = 5

Units: Emp Variable type: constant

Documentation: Minimum number of employees (project managers)

Source: Case study of 'Galp Energy Solutions' venture

Minimum HR Needed = (Total HR Effort Desired for EPC + HR Effort Desired for Selling Audits)/Work Hours per Month

Units: Emp Variable type: auxiliary

Documentation: The number of employees (project managers) needed to perform total work effort

MVA = NPV(EVA * TIMESTEP, WACC)

Units: K Eur Variable type: auxiliary

Documentation: MVA (market value added) is the present value of futures EVAs and is estimated by summing the discounted economic value added (EVA)

Net Earnings = EBIT − Interest Expense − Taxes

Units: K Eur/yr Variable type: auxiliary

Documentation: Yearly net earnings of the ESCO

Net Saving per EPC = Normal Net Saving per EPC * Learning Effects Factor

Units: K Eur/yr/Cli Variable type: auxiliary

Documentation: This variable represents the yearly net revenues produced by a new EPC project

Not Interested = Become Informed by HR effort * (1 − Fraction of Interested)

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which potential prospects become no potential prospects as they are no more capable (legal, economically and technically) of adopting EPC, or they are not interested in EPC and decide to implement in-house energy efficiency projects

NOPLAT = EBIT * (1 − Tax Rate)

Units: K Eur/yr Variable type: auxiliary

Documentation: Yearly net operating profit less amortisations and taxes (NOPLAT) of the ESCO

Normal Fraction of Audit Adoption = 40

Units: % Variable type: constant

Documentation: Normal fraction of interested prospects that purchase the energy audit

Source: Sales reports from 'Galp Energy Solutions'

Normal Fraction of EPC Audit Adoption = 50

Units: % Variable type: constant

Documentation: Normal fraction of clients that decide to adopt EPC

Source: Sales reports from 'Galp Energy Solutions'

Normal Fraction of Interested = 30

Units: % Variable type: constant

Documentation: Normal fraction of potential prospects that become interested prospects

Source: Sales reports from 'Galp Energy Solutions'

Normal HR Effort per Audit Offered = 70

Units: Whr/Cli Variable type: constant

Documentation: Normal number of person-hours that are needed for selling an energy audit

Source: Sales reports and time sheets from 'Galp Energy Solutions'

Normal HR Effort per EPC Developed = 300

Units: Whr/Cli Variable type: constant

Documentation: Normal number of person-hours that are needed for performing one energy audit (including EPC developing and selling)

Source: Sales reports and time sheets from 'Galp Energy Solutions'

Normal HR Effort per Implemented EPC = 600

Units: Whr/Cli Variable type: constant

Documentation: Normal number of person-hours that are needed for implementing each EPC project

Source: Sales reports and time sheets from 'Galp Energy Solutions'

Normal HR Effort per Prospect = 21

Units: Whr/Cli Variable type: constant

Documentation: The normal number of person-hours of effort needed per prospect.

Source: Sales reports and time sheets from 'Galp Energy Solutions'

Normal HR Effort per Running EPC = 250

Units: Whr/yr/Cli Variable type: constant

Documentation: Normal number of person-hours per year that are needed for managing each running EPC project

Source: Sales reports and time sheets from 'Galp Energy Solutions'

Normal Net Saving per EPC = 155

Units: K Eur/yr./Cli Variable type: constant

Documentation: Normal yearly net revenues produced by each EPC project.

Source: Sales reports from 'Galp Energy Solutions'

Operating Costs = HR Expenses + Overhead Costs

Units: K Eur/da Variable type: auxiliary

Documentation: Daily operating costs of the ESCO

Operating Expenses = Operating Costs + Depreciating Projects

Units: K Eur/yr Variable type: auxiliary

Documentation: Daily operating expenses of the ESCO

Outflowing Cash = Investing in Projects + Taxes + Operating Costs + Interest Expense + Repaying

Units: K Eur/da Variable type: auxiliary

Documentation: The daily outlay of cash to pay for investments in EPC projects, as well as to pay taxes, operating costs and repay principal on debt

Overhead Costs = 100

Units: K Eur/yr Variable type: constant

Documentation: Yearly overhead costs

Source: Reports from 'Galp Energy Solutions'

Potential = Initial Market + *dt* * (Increase in Potential Market + Regain Potential) – *dt* * (Become Interested + Not Interested)

Units: Cli Variable type: level

Documentation: A number of firms with buildings capable (legal, economically and technically) of adopting EPC that are not aware or are not interested in EPC.

PP Call = 0 (base case = 0; reference value = 2; min = 1; max = 3)

Units: Cli/yr Variable type: constant

Documentation: The calling rate for EPC public projects involved in the public procurement programme. These are public buildings selected for EPC project implementation

Source: Discussion with ESCO professionals

PP Calling Rate = IF(TIME < (STARTTIME+PP Programme Term), PP Call, 0)

Units: Cli/yr Variable type: auxiliary

Documentation: The calling rate for EPC public projects. These are public buildings selected for EPC project implementation

PP Programme Term = 3

Units: yr Variable type: constant

Documentation: Term of the public procurement programme

Productivity Factor Change per Double Experience = 0.3

Units: Dimensionless Variable type: constant

Documentation: Fractional change in HR productivity factor per doubling of their experience. This variable represents the strength of the learning curve

Source: Sterman (2000), Miller and Sterman (2007), and discussion with ESCO professionals

Projects Depreciation Time = 10

Units: yr Variable type: constant

Documentation: Average life time of project equipment

Projects in Progress = *dt* * (Adopt EPC + Adopt Demo EPC) – *dt* * (Implement EPC)

Units: Cli Variable type: level

Documentation: Clients that are implementing energy efficiency projects under an EPC agreement

Public Projects = *dt* * (PP Calling Rate) – *dt* * (Adopt PP Audit)

Units: Cli Variable type: level

Documentation: These public buildings are selected for EPC project implementation as part of a public procurement programme to stimulate ESCO market. These public buildings are capable (legal, economically and technically) of adopting EPC. These building' managers launch a call for implementing EPC project in partnership with an ESCO. These buildings will be submitted to energy audit, project development, and EPC agreeing. It is assumed that that the number of public projects will be available to the startup firm

Regain Potential = Lost Prospects/Time to Regain Potential

Units: Cli/yr. Variable type: auxiliary

Documentation: The rate in which lost prospects become potential clients

Reject Audit = Audits Offered * (1 − Fraction of Audit Adoption)

Units: Cli/mo Variable type: auxiliary

Documentation: The rate in which potential clients reject ESCO offer for performing energy audit. These clients decide to purchase the energy audit from another ESCO or lose interest in EPC and they decide otherwise not to adopt EPC and to implement in-house projects

Reject EPC = EPC Developed * (1 − Fraction of EPC Adoption)

Units: Cli/yr Variable type: auxiliary

Documentation: The rate in which potential clients reject the ESCO offer for EPC. These clients decide to sign the EPC with another ESCO or they decide otherwise not to adopt EPC and to implement in-house projects

Repaying = IF (Debt Ratio > Target Debt Ratio, MIN(MAX(Cash − Maximum Cash Level, 0), Debt − Debt/Debt Ratio * Target Debt Ratio), 0)/TIMESTEP

Units: K Eur/da Variable type: auxiliary

Documentation: Principal is paid on the debt, if the debt to equity ratio is higher than the desired ratio. The amount paid is the lesser of (1) debt over the desired debt level, or (2) available cash. Available cash is the amount over the maximum desired cash level

Revenue per Audit = 40

Units: K Eur/Cli Variable type: constant

Documentation: The average price paid for energy audit and efficiency project design

Source: Reports from 'Galp Energy Solutions'

Revenue per EPC Developed = 20

Units: K Eur/Cli Variable type: constant

Documentation: The average price paid for efficiency project design. This value is applied to public projects and demonstration projects

Revenues = EPC Net Saving + Adopt Audit * Revenue per Audit + (Adopt PP Audit + Adopt Demo EPC) * Revenue per EPC developed

Units: K Eur/yr Variable type: auxiliary

Documentation: Yearly revenues of the ESCO

Saving Variation from EPC adoption = Implement EPC * Net Saving per EPC

Units: K Eur/yr/da Variable type: auxiliary

Documentation: This variable represents the yearly net revenues added per day from new EPC projects

Saving Variation from EPC Ending = End EPC * IF(EPC Net Saving > 0, (EPC Net Saving/EPC Adopters), 0)

Units: K Eur/yr/da Variable type: auxiliary

Documentation: This variable represents the yearly net revenues lost per day from ending EPC projects.

Target Debt Ratio = 0.5

Units: Dimensionless Variable type: constant

Documentation: Desired debt ratio. Debt ratio = debt/(equity + debt)

Tax Rate = 26.5

Units: % Variable type: constant

Documentation: The annual ESCO tax rate is assumed to be 26.5%

Taxes = (EBIT − Interest Expense) * Tax Rate

Units: K Eur/da Variable type: auxiliary

Documentation: Taxes are based on profits before taxes (EBIT − Interest Expense) multiplied by the tax rate

Term of Audit Subsidy = 3

Units: yr Variable type: constant

Documentation: Term to apply the subsidy on cost of energy audit

Term of Interest Rate Subsidy = 10

Units: yr Variable type: constant

Documentation: Time to apply the subsidy on debt interest rate

Source: It is assumed that the subsidy will last for 10 years as this is the term of the first EPC

Time to Adopt Audit = 4

Units: mo Variable type: constant

Documentation: Average time to persuade prospects to adopt energy audit

Source: Reports from 'Galp Energy Solutions'

Time to Develop EPC = 4

Units: mo Variable type: constant

Documentation: Average time to perform audit, design, and sell EPC

Source: Reports from 'Galp Energy Solutions'

Time to Implement Project = 9

Units: mo Variable type: constant

Documentation: Average time to implement an EPC project

Source: Reports from 'Galp Energy Solutions'

Time to Inform Prospects = 4

Units: yr Variable type: constant

Documentation: Average time to inform prospects on EPC

Source: Reports from 'Galp Energy Solutions'

Time to Regain Potential = 10

Units: yr Variable type: constant

Documentation: Average time to regain potential prospects

Total Audits Offered = HR Effort Assigned For Selling Audits/HR Effort per Audit Offered

Units: Cli/yr Variable type: auxiliary

Documentation: Number of energy audits that can be sold per year. It includes energy audits from public programme

Total EPC Adopters = EPC Adopters + Projects in Progress

Units: Cli Variable type: auxiliary

Documentation: Total EPC adopters

Total EPC Developed = HR Effort Assigned for Developing EPC/HR Effort per EPC Developed

Units: Cli/yr Variable type: auxiliary

Documentation: Number of energy audits (including EPC design) performed per year. It includes demonstration projects

Total HR Effort Assigned For EPC = HR Effort Assigned for Developing EPC + HR Effort Assigned for Implementing EPC + HR Effort Assigned for Running EPC

Units: Whr/da Variable type: auxiliary

Documentation: The number of person-hours (HR effort) per day assigned for developing, selling, implementing, and running EPC projects

Total HR Effort Available = HR * Work Hours per Month

Units: Whr/mo Variable type: auxiliary

Documentation: The number of person-hours of effort that are available per day

Total HR Effort Desired for EPC = HR Effort Desired For Developing EPC + HR Effort Desired For Implementing EPC + HR Effort Desired For Running EPC

Units: Whr/da Variable type: auxiliary

Documentation: The number of person-hours of effort per day desired for developing, selling, implementing, and running EPC projects

Total Lost Prospects = Not Interested + Reject Audit + Reject EPC + End EPC

Units: Cli/yr Variable type: auxiliary

Documentation: The total rate in which potential clients reject the ESCO offer for EPC. These clients decide to sign the EPC with another ESCO or they decide otherwise not to adopt EPC and to implement in-house projects

Total Potential Market = Potential + Interested + Audits in Progress + Projects in Progress + EPC Adopters + Lost Prospects

Units: Cli Variable type: auxiliary

Documentation: Total of EPC adopters and potential prospects

WACC = Cost of Equity * (Equity/(Debt + Equity)) + Cost of Debt * (1 − Tax Rate) * (Debt/(Debt + Equity))

Units: %/yr Variable type: auxiliary

Documentation: The weighted average cost of capital (WACC) calculates the weighted average cost of having equity holders and debt holders, who have different rates of return that they require. The WACC is used to calculate the capital charge

WOM Contact Rate = (reference value = 3; min = 3; max = 9)

Units: Cli/Cli/yr Variable type: constant

Documentation: The rate of word-of-mouth contact between adopters and prospects. The number of prospects contacted per adopter per year

Source: Reports from ‘Galp Energy Solutions’ and discussion with ESCO professionals

Work Hours per Month = 160

Units: Whr/Emp/mo Variable type: constant

Documentation: How many hours each employee works per month

Yearly Increase in Potential Market = 1

Units: %/yr Variable type: constant

Documentation: Yearly increase in potential market

Source: It is assumed a rate equivalent to the growth of national economy

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