Beyond EU 2020 target for energy efficiency: a novel business model to reduce energy consumption in compressed air systems

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Abstract
In a world ever more pressed by natural and societal challenges, increased industrial energy efficiency offers a unique opportunity to reconcile economic competitiveness with sustainable development. The World Economic Forum (WEF) lists a set of barriers to implement energy efficiency measures, including lack of expertise and information, low priority of energy efficiency projects, and access to capital[1]. In this context, online platforms and marketplaces of B2C and C2C services opens new horizons for the development of new business models that promote increased industrial energy efficiency. This paper presents a novel business model named "assisted market place and extended service" for the field of compressed air systems. The novel business model is supported by the development of an online platform that establishes the direct connection between suppliers and machine builders, further allowing for the determination of the most cost-effective drive solutions in the field of compressed air systems (CAS). This novel business model aspired to solve some of the main barriers for the implementation of energy saving measures in industrial automation.

Introduction
Climate protection, energy efficiency and the responsible use of resources have long been a declared goal of the European Union. Under the Energy Efficiency Directive 2012/27/EU, Europe targets a 20 % energy savings by 2020. The industrial sector plays a major role in electricity consumption; for instance, the share of industry in total electricity consumption in Germany in 2018 was around 47 %. The EU aims at boosting domestic energy efficiency investments in energy-intensive industries while investing in industrial energy efficiency. This new Green Deal offers a range of new opportunities to industry, in automation industry, one of the main energy intensive industrial sectors; yet the increased use of over-dimensioned pneumatic drives is a main challenge to industrial energy efficiency. Against this background, science and industrial research have been working for years to develop measures to increase energy efficiency in automation technology. The information about saving potentials is usually described in brochures provided by industrial coalition in countries, for example such as ARTEMA and VDMA. Many of the measures described in the technical report ISO/TR22165[2] can be applied in the same way to electromechanical drive systems. Measures such as "Efficient control and regulation" focus primarily on electric drives. In contrast, little to no attention has been giving to increasing the energy efficiency of pneumatic drives.

Several energy-efficiency solutions are available on the market, ranging from component suppliers and pressure reducers to intelligent systems (e.g. SAFEN[3]) that ensure savings up to

1. WEF (2018). Fostering Effective Energy Transition: A Fact-Based Framework to Support Decision-Making. Technical Report March, World Economic Forum, Cologny, Switzerland.

2. ISO/TR22165: Improvment of the efficiency of compressed air systems. Technical report, Frankfurt.

3. Safen: Fluid and Mechanical Engineering. http://www.safen.it/prodotti/

50 % of the total energy consumption. Moreover, pneumatic audits services are drawing attention of industrial users to the opportunities of optimizing the energy consumption of installed systems and the additional savings of the total cost of energy consumption. However, the cost-effectiveness and long-term financial benefits of these measures are usually not immediately apparent to machine builders when designing a machine. As a result, potential energy efficiency measures are often either not implemented or not absorbed by the market. In this context, not only technical competencies are required, but also a broad market overview on how to create and deliver value to end-users; in other words, a business model that hosts an assisted market place and extended service for promoting energy efficiency in automation industry.

In economics, the lack of perfect information leads to externalities and causes market failures. In automation industry, imperfect and/or asymmetric information translates to the situation where users and/or machine builders do not have all of the necessary information to make an informed decision about the price or quality of a product, leading to s suboptimal solution and inefficient use of resources, including energy. Such problem of the lack of knowledge and understating of sustainable products is also well known in other fields. in practice, customers do not purchase products or services based on environmental attributes alone; instead, they evaluate the trade-offs between the economic and environmental attributes of an offering[4]. Prior research in consumer markets indicates that although customers usually prefer environmentally friendly solutions, they are often reluctant to make the appropriate purchasing decision, since they are uncertain about the potential benefits that such an offering will deliver[5]. In industrial markets, this uncertainty is likely to be higher, since sustainable offerings may involve novel and expensive technologies, high information asymmetry between supplier and buyer, and intangible benefits that are difficult to evaluate.

Patala et al., 2016[6] offer a framework for identifying the key factors for technology suppliers to implement sustainable products into the market by considering three aspects: economical, societal and ecological. In the field of industrial automation, the problematic of increased of energy consumption directly influence all three spheres of sustainability. In the time of raised awareness for the depletion of natural resources, continued innovation and digitalization, the way of implementation of energy saving measures by direct sales of these solution becomes more difficult especially for small and middle producers. High competency and broad market overview require a novel business model to make the increased of energy efficiency available for all producers and to make it a standard practice.

In this paper, a novel business model named assisted marketplace (AM), where customers and suppliers engage in commercial transactions in a marketplace while being assisted by a tailored software and/or consultancy as a service. This novel business model is supported by the development of an online platform that establishes the direct connection between suppliers and machine builders, further allowing for the determination of the most cost-effective drive solutions in the field of compressed air systems (CAS). This novel business model aspires to solve some of the main barriers for the implementation of energy saving measures in industrial automation. The model covers a complete channel starting from the machine design until the end user.

ENERGY SAVING MEASURES IN THE MACHINE DESIGN

To understand how to reduce energy consumption in compressed air industry is necessary to understand the principle of compressed air work. Thermodynamic principles are required to determine the energy consumption, and, thereby, the energy saving potential of pneumatic drives[7]. Some energy saving measures are presented together with their specific savings effect on the pneumatic structure:

- the reduction of the operating pressure
- the reduction of the filling volume
- the limitation of the supplied mass flow
- the use of the exhaust air

The optimization of the design parameters is an effective method to adapt the energy requirements of existing oversized as well as newly designed drive axes with respect to the driving task. The switching and control technology measures include energy-saving circuits. These circuit concepts limit the supplied mass flow or use the exhaust air for the return stroke of the drive via the principle of an air spring.

Methodology

This methodology to find the most cost-effective drive solution while designing a machine starts from the understanding of the thermodynamic behaviour of compressed air system through the assessment of possible energy saving measures and calculation of Life Cycle Cost, ultimately leading to the establishment of EXonomy analysis. The Exonomy analysis has been developed for the comparison and the choice of the most cost-effective drive solution between pneumatic and electro-mechanic technologies. In this paper, the proposed method is applied for pneumatic drives.

The starting point of Exonomy analysis is the choice of the design parameters of the drive. To reach the goal of the correct dimensioning, the exergy-energy balance is used (see Figure 1, step 1). The key of the approach is the adjustment of provided energy by the system to the required energy of the task. In order to calculate generated energy of the cylinder, the energy balance including calculation of maximum available energy or exergy and losses due to friction and damping is analysed. The relation between these values is presented by Sizing Factor (SF). Finally, the analysis of the exergy, SF and the required energy is expressed in one formula for the determination the diameter

4. Ginsberg, J.M. & Bloom, P.N. (2004). Choosing the Right Green Marketing Strategy. MIT Sloan Management Review, 46 (1), 79–84.

5. Rokka, J. & Uusitalo, L. (2008). Preference for green packaging in consumer product choices – Do consumers care? International Journal of Consumer Studies, 32, 516–52.

6. Patala, Samuli & Jalkala, Anne & Keränen, Joona & Väisänen, Sanni & Tuominen, Valtteri & Soukka, Risto. (2016). Sustainable value propositions: Framework and implications for technology suppliers. Industrial Marketing Management. 10.1016/j.indmarman.2016.03.001.

7. E. Rakova, J. Weber. Exonomy analysis for the selection of the most cost-effective drive solution, FPNI 2016.

of the cylinder. Proposed equation includes dynamic and load characteristics of the task and provides the precise calculation of the geometry considering damping and friction forces.

The second step provides the information about the energy consumption and possible energy saving measures. It is realised by the analytical analysis of each system component. Applied approach prioritize biggest consumers of the system, that allows to implement energy saving measures for each part of system.

The third and final step presents the Life Cycle Costs calculation within the operating time and pay-back period for the choice of the optimal cost-effective drive solution. It based on a machine hour rate calculation and includes 4 cost parameters, namely: investment, maintenance, energy, and interest rate. The result is the cost of a cycle or product, or the total cost of machine operation.

Results and Discussion

APPLICATION OF EXONOMY ANALYSIS

In order to demonstrate the capabilities of the Exonomy analysis, a sample application is explained in detail in this section for an example system choice. The sorting of packages was chosen as an example of handling application. The parameters of the task and the standard applied circuit are shown in Figure 2. The task of the drive is the push of package with the weight of 2.5 kg in 250 mm in 0.6 sec.

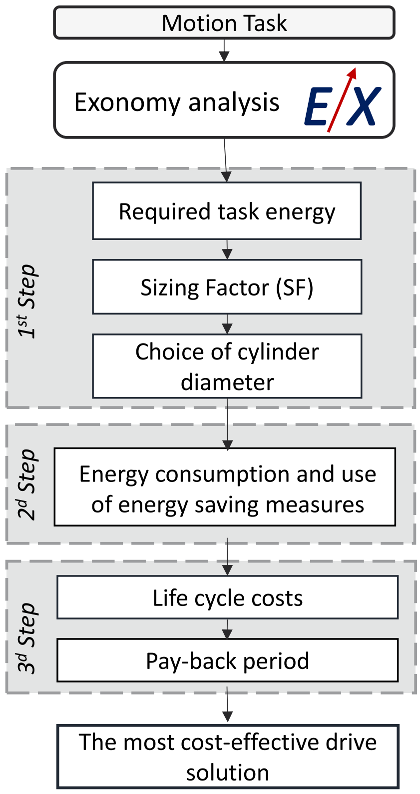

Figure 1. Flow chart of the Exonomy approach.

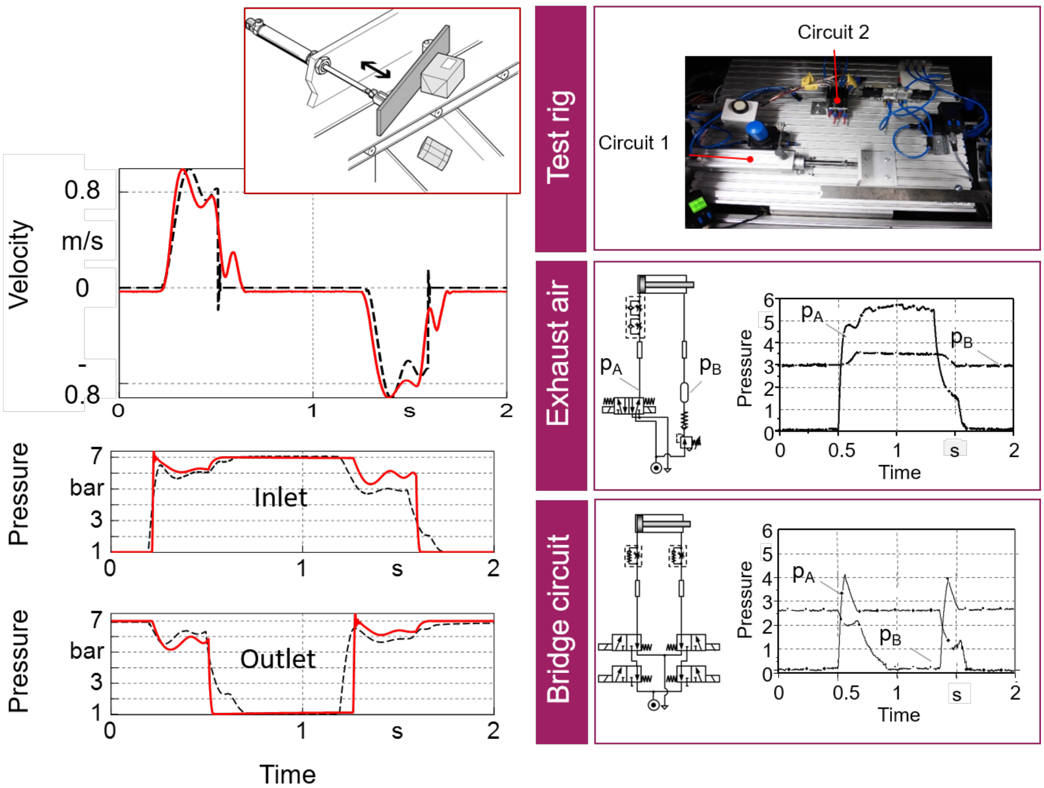

Figure 2. Studied system and measurement and simulation results of standard and energy saving circuits.

According to the Exonomy analysis, the first step is the determination of the cylinder diameter. The chosen cylinder has 32 mm piston diameter. The test results are presented in Figure 2. To determine the throttle parameters, the same equations are applied with an assumption of friction loss coefficient and pressure loss at the throttle. The calculated nominal flow for this system is 211 L/min, while the closest value from the technical data is 320 L/min; hence, 320 L/min is the maximum value of the flow rate.

The use of the bridge circuit and the premature disconnection of the compressed air supply from the pneumatic actuator make the energy savings potential particularly evident in comparison to the standard circuit. The bridge circuit consumes only 50.9 % of the amount of compressed air per double stroke in contrast to the standard circuit. The curves of the chamber pressures show that the short-term ventilation time of the cylinder chambers limits the pressure level in the present case to approximately 4 bar. After the movement has started, the chamber pressure drops during extension. This phenomenon occurs because the movement of the piston increases the volume of the chamber, but the compressed air supply is interrupted. The pressure in the end positions is significantly lower than in the standard circuit, whereby a secure holding the position is uncertain. An exhaust air recovery presents a simple air spring set at the certain level, that offers up to 40 % of energy savings. In the practice, cylinders are usually oversized and in this case, the standard software offers diameter 50 mm. The other option is the use of bigger diameter with reduced pressure.

In the last step, the energy savings measures are analysed considering the life cycle cost calculation and their payback period; hence, these are compared with the standard systems according to the force balance equation. The calculation was done for the use period of 5 years. According to the standard calculation, a cylinder with diameter 32 mm is the best choice, or in case of reduced pressure, 50 mm diameter and 4.5 bar pressure level. Other solutions are also presented in Figure 3 considering: exergy based sized cylinder, reduced pressure return, exhaust air recovery and bridge circuit. Figure 4 shows the payback period for the sorting packages application.

As shown in Figure 3 and Figure 4, standard sized cylinder and reduced pressure order offer the highest costs. Bridge circuit enables reduction of energy consumption but increase the investment within components and maintenance due to the more complex control strategy. The calculation of pay-back period shows which solution is the most cost-efficient during the life cycle of the machine. The exhaust air recovery circuit offers no advantage in comparison to the well-sized actuator. In this case, the room for the air reservoir has also to be considered. Moreover, as the payback period diagram shows, within one-year usage the exergy-based sized actuator is the cheapest solution, with a payback period of 1.3 years of operation as well as offering a reduced pressure return solution. In comparison, the bridge circuit requires 3.5 years for pay back. However, the life cycle costs are directly depended on the operation data, energy cost at the factory, and acquisition cost of components. Moreover, each solution offers additional features, like energy monitoring or better cushioning properties. Therefore, these diagrams cannot (and must not) be used as guidelines, but only as an example. To make this method more usable for different applications, a prototype of web-based tool was developed to support a user-friendly and intuitive application of the EXonomy analysis.

Moreover, for the practical use, the methodology has to be accessible for machine builders. It has to include analysis of the efficiency solutions of suppliers within the integration in the machine under economical and functional aspects. This leads to the establishment of a novel business model in the field of efficient solutions in compressed air industry. A platform-based marketplace for efficient system and component solutions with the use of selection and analytical tools with the high competence in energy efficiency is a new step towards digitization, energy efficiency and sustainability.

ONLINE PLATFORM

The novel business model presented in this manuscript consists of a mixture of marketplace and software as a service (SAAS) business models; to the best of our knowledge, this is the first time a marketplace business model is applied in the field of compressed air systems. The software is developed by the company Direktin with the online-based calculation tool based on EXonomy analysis with possible implementation of suppliers' solutions.

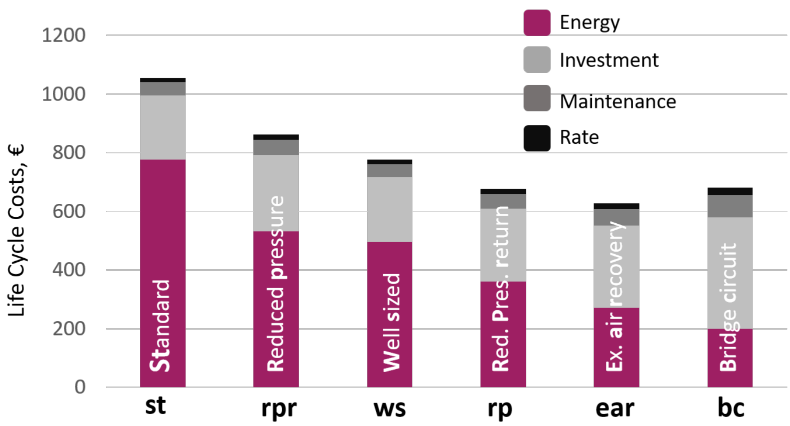

Figure 3. Life Cycle Cost calculation for studied system.

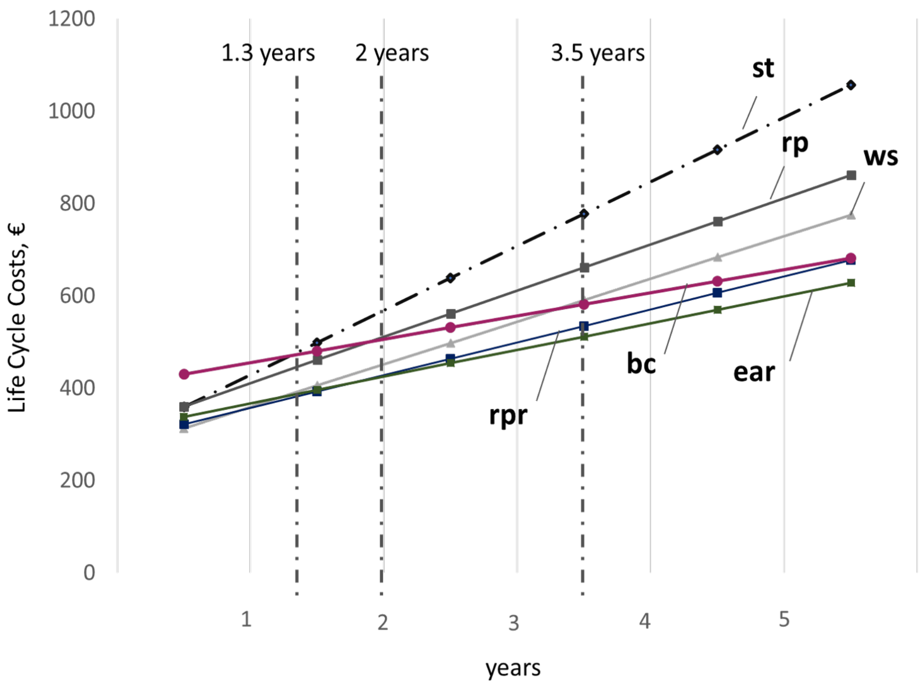

Figure 4. Calculation of payback period for the sorting packages application.

Seven of the ten most valuable companies globally are now based on a platform business model: the creation of digital communities and marketplaces that allow different groups to interact and transact. Companies like Apple, Google, Amazon and Alibaba have used the model to grow exponentially and grab significant market share from established firms[8]. It is no surprise, then, that the platform economy is developing very fast but not only for B2B market places, but also for services and industrial companies representing C2C business models.

The platform economy is reshaping global trade. Global small and medium-sized business trade is on the rise, driven by the growth of platforms such as Alibaba, which allow much smaller enterprises to participate in global trade, without the need to invest in their own supply chains. As these platforms scale, control over trade could shift from countries to these digital platforms. In a world dominated by platform companies that offer ways for customers and companies to connect.

A platform-based approach that offers energy efficient solutions was developed to connect machine builders with component suppliers in a marketplace environment. DIREKTIN promotes the reduction of energy consumption of compressed air in industrial application and, therefore, the optimization of the process of the machine by an engineer. As a result, the machine increase performance and reduce energy consumption, therefore, saves the energy for the end user of the machine. DIREKTIN also differentiates itself by providing a SAAS, free of charge, for the machine builder, supporting the analysis of cost-efficient factors such as pay-back period of investment and total cost of ownership for each solution and propose the best one regarding the technical requirements. In essence, the SAAS promotes the engagement of suppliers and machine builders in a marketplace environment, where DIREKTIN acts both as a facilitator and a provider of expertise; this novel business model is hereinafter defined as assisted marketplace (AM).

DIREKTIN platform model and AM works as follows: increasing easy implementation of energy saving measures will drive component suppliers towards new development of energy efficient solutions and, therefore, the decrease of the price by increasing volume. As a result, the platform provides win-win business model for components suppliers by promoting their solution and increasing their market. Machine builders can optimize their machines in terms of performance and efficiency, and end users decrease the overall energy consumption. AM business model provides intuitive choice of the drive and assets investment of energy efficient solutions. Figure 5 depicts a schematic representation of an AM as considered within DIREKTIN platform model.

The detailed business model is, instead, depicted in Figure 6. The key activities are focused on the continues improvement of energy efficiency of industrial machines by the support of the expertise in this topic. The optimization is possible through the detailed study of each use case by the support of key partners that provide energy efficient solutions. A solid collaboration with them allows continuous sustainable development of machines that contributes ecological goals of industrial and national strategies.

DIREKTIN provides free of charge service of informative workshops for clients about energy efficiency as well as supports the design of pneumatic systems by free online tool that is described further. The function of free service is supported by premium consultancy on a specific cases, analysis and modeling of the machine, and realization of specific customized projects. The revenue stream is based on a potential energy cost saving for each client case, the current defined at the level of 20 % of the first year, wherever customer will be having further

8. The Innovator: The Platform Economy. https://innovator.news/the-platform-economy-3c09439b56

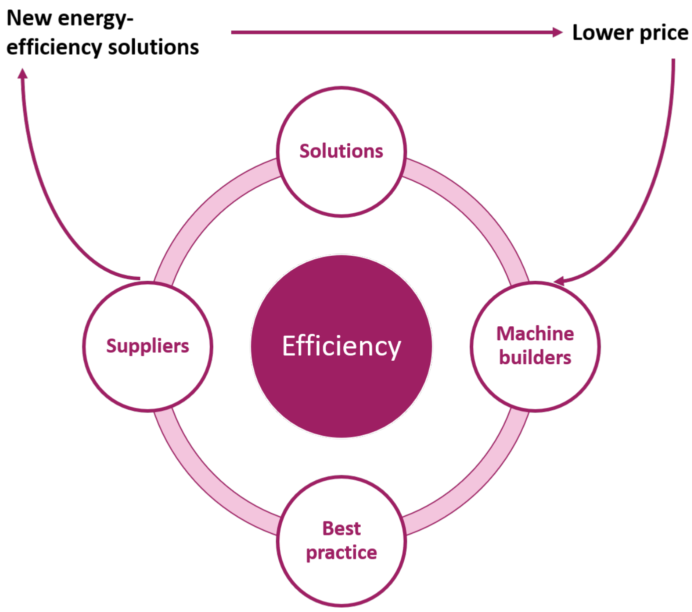

Figure 5. Schematic representation of an AM as considered within DIREKTIN platform model.

savings each next year. The rest 8 % of each revenue creates a fundament for the cost structure of the company. Free services provides a comprehensive knowledge base as well as an online tool for the choice of cylinders, valve and tube technical parameters, calculation of LCC and first estimation of the use of energy saving measures.

ONLINE TOOL

The program prototype was developed to automatize all steps of the choice of pneumatic drive. It comprise all steps including drives choice, pressure settings, valve and throttle choice. The data is used for further energy consumption calculation as well life cycle cost analysis and finishes with an estimation of possible energy saving measures within calculated use case.

The first developed prototype focuses on the cylinder choice and considers all possible cylinder mounting angels as well as calculates system parameters for both directions. First step is an entry data of technical characteristics of the task such as load parameters, mass of moving parts, etc. It also takes into account dynamic characteristics such as velocity, stroke time, and dynamic load, as well as tube length.

Economy data input implies costs characteristics as well as operational data of the system. All entry data is specific for each user and has a major influence on the result. Main components of cost data are energy cost, that can vary from 0.6 to 6 euro cents for Nm^3 It is estimated as 75 % of the energy within 13% of investment for the compressor station, and 12%

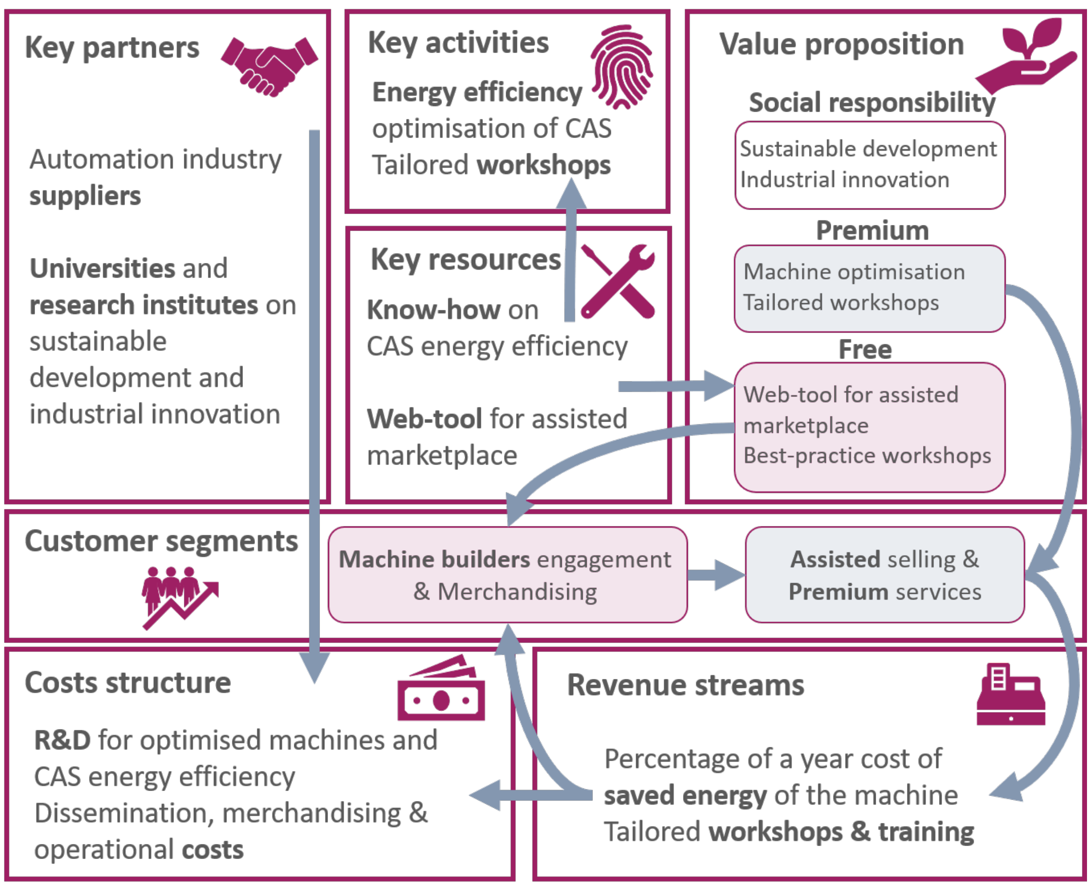

Figure 6. AM business model, as used by DIREKTIN.

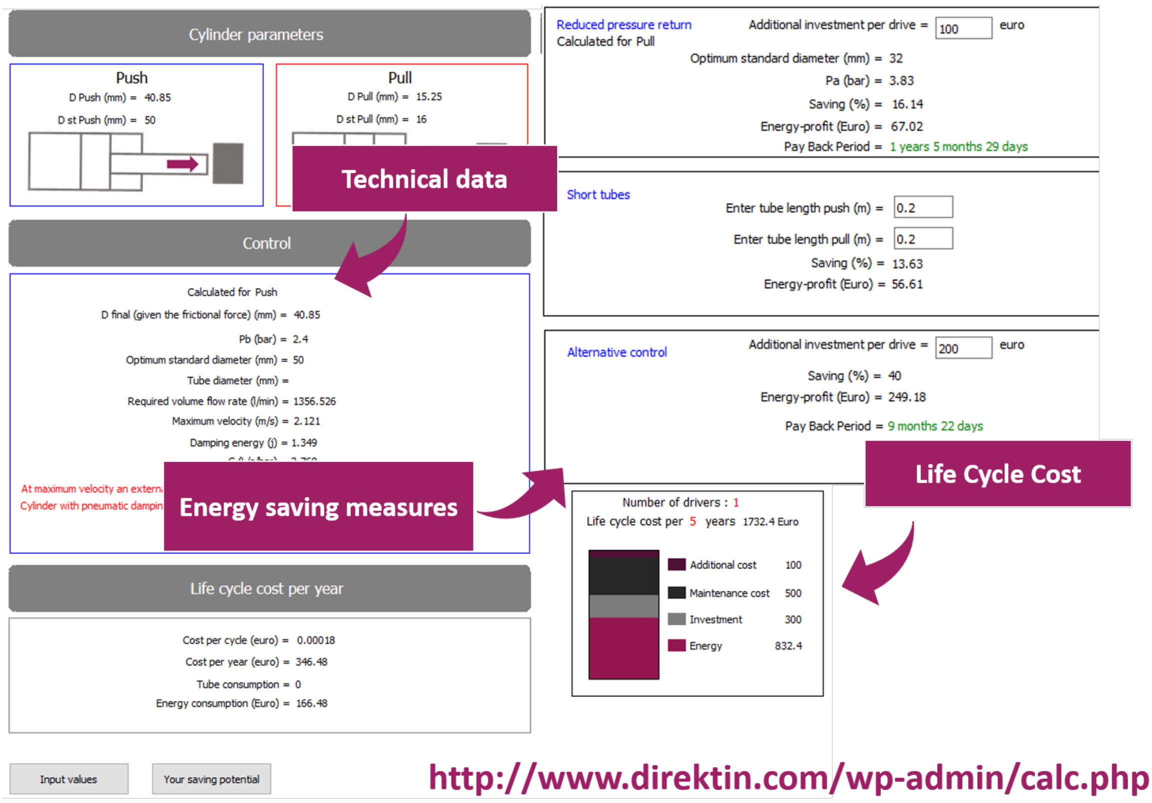

Figure 7. DIREKTIN online Exonomy calculator.

for the maintenance. Investment cost is the one-time purchase, and maintenance cost is yearly purchase. User can also add any additional cost such as personal, room or any other expenses.

Results of the calculation provides an information about cylinder diameter, it dependency on the back pressure in the form of the diagram as well as all necessary data for the choice of the throttle and valves, as well suggestions on the use cushioning system. Economical result shows all cost over the calculated period as well as cycle cost, that in many cases can be interpreted as product cost. The final step is the evaluation of saving potential available for the system. In current version, there are four possible saving potential are available: reduced pressure return; usage of alternative diameter; tubes shortage and use of alternative control. Reduced pressure return is based on the calculation from a previous example for the case when load forces are different for push and pull directions. Figure 7 displays the looks of the online tool provided free of charge by DIREKTIN for performing Exonomy calculations.

Several component suppliers produce cylinders with not standard diameters, that allows to save energy and avoid oversized actuators. The program calculates this opportunity and chose cylinder from an alternative diameters row. Unnecessary long tubing is a frequent problem of machine builder, recalculating of its length shows a total saving potential for the system. Last, but least, alternative control integration considers bridge circuit integration. All solution are analyzed considering their pay-back period in regard to their additional cost. In the future, a comparative analysis with electro-mechanical drives has to be integrated as well as further options of energy-saving measures for more complex systems. Current development is focused on the implementation of supplier's solutions.

Conclusions

Presented novel business model of an assisted market place DIREKTIN in the field of CAS shows economic and competitiveness gains of cost-efficient solutions, while at the same time raising awareness of the importance of increased energy efficiency in automation technology. Even though an enormous work has been done by researches, governmental organizations and industry to increase the energy efficiency by implementing various measures, the adoption of it as a standard practice is very hard due to the technical and economic barriers. Inspired by online market places from B2C and C2C markets DIREKTIN propose an assisted B2B market place supported by unique expertise in the field of energy efficiency of CAS. The platform offers free services such as online tool for the most cost-efficient drive choice of the machine at the design phase as well as, it provides a link between suppliers of efficient solutions and machine builders. The structure of the business model provides a fundament for the continues development of sustainable products in industrial automation.