The importance of additionality in evaluating the economic viability of motor-related energy efficiency measures

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Abstract

The additionality of an energy efficiency (EE) measure is defined as the supplementary impact of a measure beyond standard practices and autonomous changes. The consideration of additionality and the manner of accounting for it may strongly influence the cost-effectiveness of the EE measures and consequently the decision by policy makers. Many studies on energy efficiency improvement potentials fail to provide transparency regarding the methodology and underlying data (discount rate, lifetime etc.) used in their respective cost-benefit analyses for evaluating EE measures. Against this backdrop, this paper discusses various approaches based on US Environmental Protection Agency (EPA) guidelines, using the example of a 45 kW electric motor. We compare the case of disregarding additionality with several other approaches, i.e. only accounting for age (as applied by the Energy Agency for the Swiss Private Sector - EnAW) and other approaches that consider the salvage value as well as differences in investment cost and electricity savings (as applied by the ProKilowatt program, operated by Swiss Federal Office of Energy - SFOE). This study concludes that the chosen method very strongly impacts the results, i.e. by factors and potentially even resulting in opposite findings concerning cost-effectiveness. Choosing full investment costs may lead to the conclusion that the measure is not cost-effective while all other approaches result in the opposite conclusion (economically viable). For slowly expanding manufacturing sectors in an industrialized country like Switzerland (limited growth, mature capital stock) it is found that the additionality approach based exclusively on age overestimates the cost-effectiveness. This study therefore recommends alternative approaches which allow to establish the uncertainty range of cost-effectiveness, while maintaining transparency.

Introduction

The additionality of an energy efficiency (EE) measure is defined as the supplementary impact achieved by the measure beyond standard practices and autonomous changes [1]. Additionality is firmly linked to baseline scenarios, which provide reference points through which one can judge whether an activity is additional or not [2,3]. For example, in the case of replacing an old motor with a more energy efficient one, the baseline scenario would be the standard replacement at the end of the old motor's lifetime, while additionality may refer to the early replacement by a new efficient motor, where the existing (old) motor would otherwise have remained in service until the end of its lifetime. Furthermore, the additionality of an EE measure can be broadly categorized into two components, i.e. additional investment costs and energy savings due to measure implementation. It is notable, however, that both components lack methodological clarity and are not adequately covered in the cost-benefit studies on energy efficiency available in literature.

The consideration of additionality may strongly influence the cost-effectiveness of the EE measures and consequently the decision by policy makers. However, the majority of studies fail to provide transparency regarding the methodology and underlying data (discount rate, lifetime etc.) used in their respective cost-benefit analyses for evaluating EE measures. In particular, it is not typically explained whether additionality has been taken into account and, if so, how. One study that accounts for additionality is that of Jakob (2006) [4], who quantifies the marginal costs of EE investments (including additional insulation, improved window systems and heating and ventilation systems) for the Swiss residential sector. The US Environmental Protection Agency (EPA) outlined an advanced method to account for additionality of EE measures (see EPA metrics) [5], however the application of the method is found limited probably due to the challenges posed by the data unavailability (see discussion in results section).

Zuberi et al. (2017) [6] recently studied a wide range of EE measures for Swiss industrial motor systems and demonstrated that the economic potential for EE improvement increases substantially if additional costs are considered in the cost-benefit analyses. However, due to significant data challenges, the additionality approach applied by the authors only accounts for the age of the replaced equipment (as explained in Section - EnAW method). This raises the question of what is the suitable approach to account for additionality and how it can be adopted. Zuberi et al. [6] recommend the EPA approach as the method of choice. Against this backdrop, this paper discusses various approaches based on EPA guidelines, using the example of a 45 kW electric motor (see Case study: motor retrofit, for details of the choice). We compare the case of disregarding additionality with several other approaches, i.e. only accounting for age (as applied by the Energy Agency for the Swiss Private Sector - EnAW) and other approaches that consider the salvage value as well as differences in investment cost and electricity savings (as applied by the ProKilowatt program operated by Swiss Federal Office of Energy - SFOE).

Materials and methods

Cost-effectiveness of EE measures

Specific costs

Specific costs ($C_{spec,y}$, also referred to as levelized costs) of EE measures are determined in order to evaluate the economic viability of these measures. Specific costs are calculated by the following equation:

$$C_{spec,y} = \frac{ANF \times NPV_y}{ES_y} \quad (1)$$

where:
NPV_y = net present value of measure for the base year, determined by Equation 2
ANF = annuity factor, determined by Equation 4
ES_y = annual potential energy savings by measure
y = EE measure

$$NPV_y = \sum_{t=2015}^{L} CF_t \times (1+r)^{-t+2015} \quad (2)$$

where:
CF_t = annual cash flow, determined as Equation 3
r = real discount rate, taken as 10.5% (private perspective)
L = lifetime of measure
t = year

$$CF_t = I_y + O\&M_y - B_y \quad (3)$$

where:
I_y = Initial investment required to achieve the 'ES_y'. Its value is zero for all years after base year of implementation.
$O\&M_y$ = Operation and maintenance cost[1]
B_y = Annual benefits of the measure, i.e. the annual electricity cost savings over lifetime to be achieved from first year after implementation.

$$ANF = \frac{(1+r)^L \times r}{(1+r)^L - 1} \quad (4)$$

Since the annual benefits (B_y) in Equation 3 are presented with a negative sign, EE measures with the negative specific costs are considered cost-effective. It is evident from the above equations that

[1] In this study, the O&M cost is assumed to be identical before and after implementing the measure and is hence neglected.

investment costs (I_y) and potential energy savings (ES_y) are the two main drivers for determining the cost-effectiveness of the EE measures. Hence, it is crucial to estimate the two parameters carefully for cranking EE measures in terms of their cost-effectiveness. In order to account for additionality while assessing the cost-effectiveness of the retrofit measures (refer to early replacement in this study) by Equations 1-3, 'I_y' should be replaced with additional costs or energy-relevant investments (EI). Similarly, annual benefits 'B_y' should also be adapted depending on the method of choice. Various approaches to account for additionality are discussed in the following section.

Accounting for additionality

The EnAW method

The Energy Agency of the Swiss Private Sector (Energie-Agentur der Wirtschaft – EnAW) was set up by the private sector in order to offer companies the opportunity to avoid the CO_2 tax introduced by the Swiss government in 2008, under the condition that they reduce their CO_2 emissions. EnAW conducts energy audits in collaboration with private companies, which are obliged to implement the measures with payback period of up to 4 years for industrial processes and 8 years for infrastructure (based on energy-relevant investment costs). Companies committing themselves to these objectives and entering a formal agreement with EnAW are reimbursed with the CO_2 tax paid. In addition, EnAW also partners with Swiss cantons which provide incentives to the individual companies to save electricity (see [7] for an example). EnAW companies can also apply for a refund of the network surcharge (KEV; cost-based compensation given to the renewable energy producers by collecting it from the electricity consumers in Switzerland) through target agreements [8]. More than 3600 companies (mostly large enterprises) have signed up with EnAW [9]. EnAW's criterion for estimating energy-relevant investments (EI) of EE measures is as follows:

$$EI = TI \times \left(1 - \frac{A}{L}\right) \tag{5}$$

where:
TI = Total investment costs (CHF)
A = Age of the replaced equipment (years)
L = Lifetime of the equipment (years).

According to the equation, only the investment costs TI of the new equipment is considered. It is multiplied by a factor unique to each equipment based on its age of the old equipment at the time of replacement. The age of the equipment to be replaced is often unknown. In such cases, companies estimate value for the parameter, which increases the chances of errors and poses challenges for monitoring. Energy savings are determined by the following equation:

$$ES = ED_{old} - ED_{efficient} \tag{6}$$

where:
ES = Energy savings (GJ/yr).
ED_{old} = Annual electricity demand by the old equipment (GJ/yr)
$ED_{efficient}$ = Annual electricity demand by the new or more energy efficient equipment (GJ/yr)

The ProKilowatt method

ProKilowatt is a sector-wide program initiated by the Swiss Federal Office of Energy (SFOE), subsidizing EE measures that are not economically viable (payback period above 5 years for process measures and 9 years for infrastructure). Energy Service Companies (ESCOs), consultancies and other actors can propose programs and projects to SFOE in a competitive tender call procedure. Once a program or project is accepted, the process of EE measure implementation is monitored. According to the new ProKilowatt approach, effective since January 2016, 40% of the total investment is granted as subsidy for the implementation of the retrofit measure if the age of the replaced equipment is less than 50% of its technical lifetime; and the subsidy amounts to 15% of the total investment if the replaced equipment has exceeded its technical lifetime [10]. ProKilowatt applies the following criteria (Equation 7) to define the subsidy level if the age of the replaced device is equal to or between 50% and 100% of its lifetime. The subsidy that ProKilowatt provides can be understood as the compensation for the additional costs for energy efficiency, i.e. as economic additionality.

$$EI = 40 - 15 \times \left(\frac{A}{0.5 \times L} - 1\right) \quad (7)$$

ProKilowatt estimates energy savings by the following equation:

$$ES = (ED_{old} - ED_{efficient}) \times 0.75 \quad (8)$$

where 0.75 is the reduction factor correcting for the autonomous technological change in future [10].

EPA metrics

The EPA outlines a simple and an advanced method to monitor EE costs and energy savings in case of equipment replacement. The simple method involves total investment costs (sum of purchase cost and installation cost of the new equipment) and energy savings as determined by Equation 6 in the calculation of specific costs. According to the advanced method, the cost difference between the new and the standard equipment should be added to the remaining present value of the existing machine in order to account for the EE (energy-relevant investment costs; see Equation 9). It is clear that the simple method does not single out the additionality effect, while this is the case for the advanced method. We therefore consider the advanced method as the method of choice (if data availability does not represent a constraint).

$$EI = PV_{old} + I_{efficient} - I_{standard} \quad (9)$$

where:
PV_{old} = Remaining present value of the old equipment (CHF)
$I_{efficient}$ = Total investment cost of the efficient equipment (CHF)
$I_{standard}$ = Total investment cost of the standard equipment (CHF)

The advanced method further recommends the sum of Equations 10 and 11 be used for estimating the total energy savings for the retrofit measures (early replacement):

$$ES_{dur} = ED_{old} - ED_{efficient} \quad (10)$$

where:
ES_{dur} = Energy savings by efficient equipment compared to old equipment during the remaining lifetime of the old equipment (lifetime 'L' - current age 'A') (GJ/yr).

$$ES_{aft} = ED_{standard} - ED_{efficient} \quad (11)$$

where:
ES_{aft} = Energy savings after the remaining lifetime of the old equipment (when the new equipment is considered to replace a standard equipment) (GJ/yr).
$ED_{standard}$ = Annual energy demand by the standard equipment (GJ/yr)

In order to calculate the cost-effectiveness of the retrofit measures by Equation 1-3, the annual benefit 'B_y' is calculated as the sum of 'ES_{dur}' and 'ES_{aft}' multiplied by the respective energy prices for the years during which the measure would remain in operation after implementation.

Case study: motor retrofit

Situation

In order to demonstrate the application of the various approaches to account for additionality elucidated above, we selected a case from the database provided by EnAW[2]. The selection was made because most of the required information was available for this particular case only. In the selected case, a 45 kW motor of efficiency class IE2[3] was installed in 2010 for a milling application. The motor operates for 6000 hours per year while the load factor is unknown. In view of the European Commission (EC) directive (No 640/2009), from 2015 onwards all newly installed motors should be of efficiency class IE3 [11], which can be understood as the standard technology today, while the most efficient commercially available motors are of class IE4. In order to show the effect of additionality, a hypothetical case is assumed where a 5 year old IE2 motor (in operation between 2010 and 2015, with a remaining lifetime of 10 years) is to be replaced with the most efficient type, i.e. IE4.

Electricity demand by motors and price

In order to apply the aforementioned approaches (see Section: Accounting for additionality), the annual electricity demand of the old (IE2), standard (IE3) and new/efficient (IE4) motor and their respective prices need to be determined. Table 1 presents the annual electricity demand of each motor efficiency class, determined by the following equation:

$$ED_m = \frac{0.0036\ (SZ \times OP \times LF)}{\eta_m} \tag{12}$$

where:
ED_m = Annual electricity demand by motor 'm' (GJ/yr)
SZ = Performance of motor which is 45 kW in this particular case
OP = Annual operating hours which are 6000 in this particular case
LF = Load factor which is assumed 75% at or above which motors work efficiently [12]
η_m = Efficiency of motor specific to each class, taken from [13,14]
0.0036 = Conversion factor from kWh to GJ

Table 1 Annual electricity demand and price of each motor efficiency class

Motor class	**Electricity demand (GJ/yr)[4]**	**Total investment cost (CHF)[5]**
IE2 (old)	783	4605
IE3 (standard)	774	5610
IE4 (efficient)	764	6950

The purchase cost of motors by efficiency class (against the rated power 45 kW) is taken from the data given by 'Topmotors' [15]. For this specific case, total investment (purchase cost + installation costs) from the data is found to be a factor 1.07 higher[6] than the purchase cost. The purchase cost of the IE3 and IE4 motor is multiplied by this factor in order to estimate the total investment cost. Table 1 also presents the total investment costs of each motor efficiency class.

[2] EnAW provides final energy savings and total investment costs, as well as brief descriptions of each implemented measure which are often very general. The description of the selected case was more elaborate, which made it possible to extract the information necessary for this study.
[3] Since 2009, the EE of electric motors is classified according to standard IEC 60034-30-1, which distinguishes between standard (IE1), high (IE2), premium (IE3) and super-premium (IE4) efficiency motors [11].
[4] Based on efficiencies of electric motors (4-pole) according to IEC 60034-30 [13,14].
[5] Installation costs are included.
[6] The factor is specific to this particular case only and does not reflect other cases where the motor replacement can be very complex and expensive, hence resulting in higher installation factors.

Salvage value

Ideally, once a motor has surpassed its projected lifetime, it should be replaced immediately, though this is not always the case in reality. For example, an electric motor energy efficiency program called 'Easy'[7], carried out under the ProKilowatt scheme, revealed that 56% of the analyzed motors (total 4142 motors in 18 industrial and infrastructure facilities) were much older than their expected lifetimes and several had been in operation for nearly double that time [16–18]. This indicates that for the private companies there is some value of the old motor left even after the projected lifetime is over. To account for this, a salvage value (SV) of 15% is assumed as the base case. The value is assumed based on standard ProKilowatt practice, according to which a measure is entitled to not more than 15% subsidy if the age of the old equipment is beyond its expected lifetime [10]. However, the choice of salvage value brings a lot of uncertainty and can largely influence the overall cost-effectiveness of the measure. Since the choice of salvage value is specific to each company and motor, a sensitivity analysis of the specific costs was also done in this study for the possible minimum and maximum salvage value of 5% and 50% respectively.

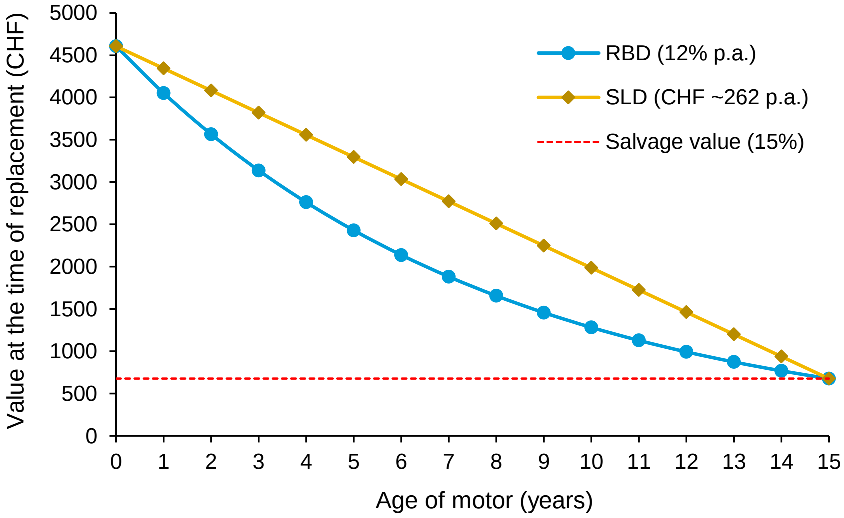

Figure 1 Depreciated and salvage value of the old IE2 efficiency class motor

Remaining value of the motor

Since the value of the motor depreciates with time, its present value (to be used in Equation 9, advanced method) needs to be calculated for the year in which it is replaced. In order to estimate its value, a simplified method of straight-line depreciation (SLD) could be used, according to which a fixed amount is depreciated each year from the initial value of the device at the time of installation [19]. However, it is often argued that the value of the asset, especially for the manufacturing plants, depreciates quickly in the early years compared to the period closer to the end of lifetime (reducing-balance depreciation (RBD) [6]. According to RBD, the value of the device depreciates by a fixed percentage each year instead of a fixed amount [19]. Both approaches were tested in this study. Remaining values of the motor over the years based on both RBD and SLD methods are shown in Figure 1 and are calculated by Equation 13 and 14 respectively.

$$PV_{old} = I_{old} \times \left(1 - \frac{d}{100}\right)^{A} \tag{13}$$

where:

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[7] 'Easy' is a financial incentive program aiming to reduce energy consumption of industrial motor systems used in Switzerland with energy efficiency measures [16–18].

d = Depreciation rate per annum i.e. 18%, 12% and 4% for the salvage value (SV) of 5%, 15% and 50% respectively at the end of the expected lifetime
A = Year of depreciation equivalent to the age of the motor being replaced

$$PV_{old} = I_{old} - (A \times D) \quad (14)$$

where:
D = Fixed amount depreciation per year which is calculated by the following equation

$$D = \frac{I_{old}}{L} \times \left(1 - \frac{SV}{100}\right) \quad (15)$$

Results and discussion

Figure 2 shows the comparison of the specific costs calculated by different approaches for this particular motor retrofit example. If the total investment costs are considered, i.e. not accounting for additionality (simple method), the measure emerges as cost-*in*effective. However if EnAW, ProKilowatt and advanced (base case with salvage value 15%) approaches are applied, the measure becomes economically viable. The comparison clearly shows that the cost-benefit analysis based on total investments leads to underestimation of the economic benefits and has the tendency to mislead decision and/or policy makers. Hence, accounting for additionality is the first step towards correctly estimating the cost-effectiveness of an EE measure.

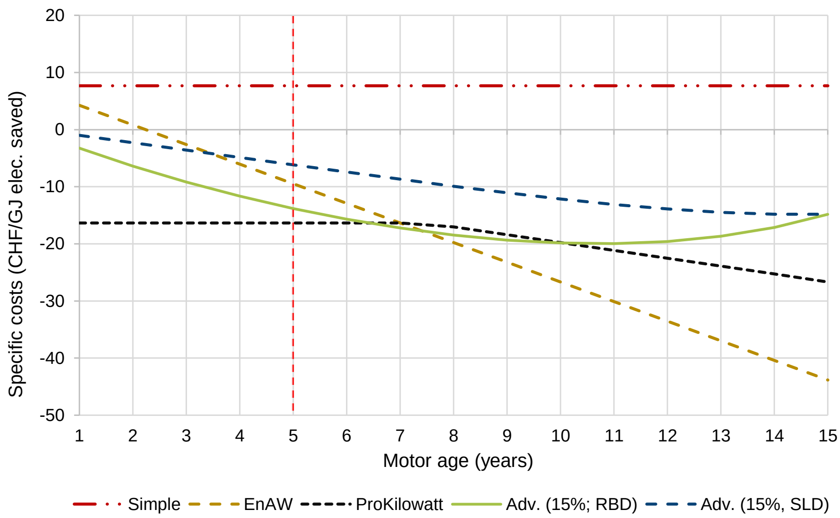

Figure 2 Comparing specific costs of the motor retrofit measure calculated by different approaches (IE2 motor if replaced by IE4 motor after X years of its completed lifetime)

The EnAW approach accounts for additionality in a simplified manner, i.e. considering only the age of the old equipment at the time of replacement. The ProKilowatt approach can be considered better than EnAW as it takes into account both the age of the motor and the technological improvement However, the approach does not make a difference in additional costs if the age of the old equipment is less than half of its lifetime and it applies a simple estimate to account for autonomous technological change, i.e. by reducing 25% of the annual energy savings every time (see Section: The ProKilowatt method). This is understandable because ProKilowatt criteria avoid too much detailing for the participants yet accounting for additionality in a rational way.

The comparison in Figure 2 shows that, for the given situation (IE2 motor if replaced by IE4 motor after five years of its completed lifetime; see Situation), the specific costs calculated by the advanced, EnAW and ProKilowatt methods range from -6 to -16 CHF/GJ for a replaced motor aging 5 years. The decision about the method providing the most accurate results at the fifth year also remains inconclusive. We hence find that the differences in specific costs among all the methods become large. The slope of the EnAW approach is found to be relatively steep compared to the other approaches. The ProKilowatt method also shows a gradual decrease in the specific costs after the seventh year (which represents approximately half of the old motor lifetime). On the other hand, advanced methods show the specific costs (after the 7th year) to be more than those calculated by the ProKilowatt and EnAW methods, indicating an over-estimation of the cost-effectiveness by the two programs.

It should be noted that the motor retrofit measure is found to be more expensive for the higher (50%) salvage value (advanced methods), while for the low (5%) salvage value, the measure becomes highly cost-effective (see Figure 3). In other words, salvage value at the end of a motor's lifetime plays a critical role in defining the cost-effectiveness of the motor. Since the parameter is highly influential and, at the same time, very challenging to estimate, it is difficult to conclude whether the ProKilowatt approach is over- or under-estimating the cost-effectiveness of the measure. Moreover, from the datasets received from the EnAW and ProKilowatt programs, it is observed (where possible) that most of the time (nearly 80%), the age of the replaced motors (early replacements) was more than or equal to half of their expected lifetime. This is logical because companies would not replace relatively new motors unless they were damaged or there were substantial benefits associated with the change, e.g. improved operability or advantages due to altered boundary conditions. Since the specific costs calculated by the EnAW approach are the lowest (for motor ages close to the expected lifetime), it is safe to conclude for this case study that the approach taking into account only the age of the replaced motor (e.g. EnAW) over-estimates the cost-effectiveness of the measure in the second half of the lifetime.

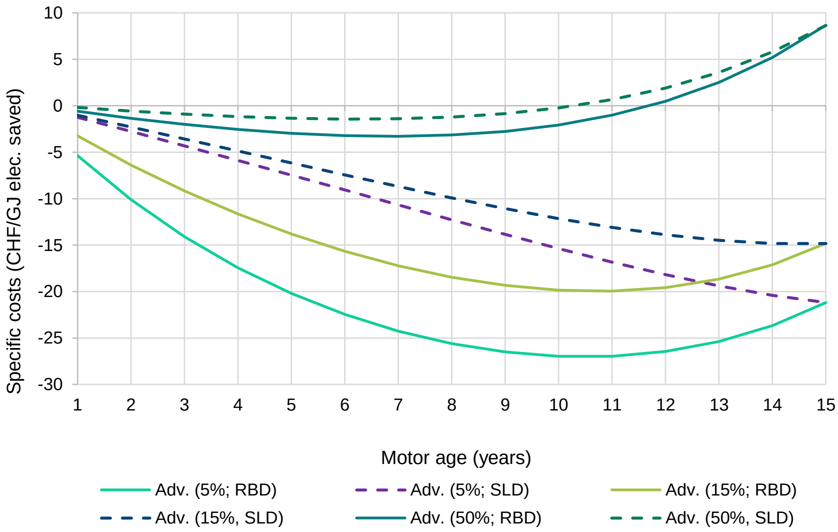

Figure 3 Comparing specific costs of the motor retrofit measure (replacing IE2 by IE4) calculated by advanced methods (RBD and SLD) with different salvage values i.e. 5%, 15% (base case) and 50%

Another interesting feature in Figures 2 and 3 is the curve shape of the advanced methods, especially for RBD. The shape suggests that the specific costs decrease until a certain level is reached after which the costs start increasing, i.e. the measure becomes more expensive (while remaining cost-effective). This is explained with the help of Figure 4. As shown in Figure 4a, the annual discounted cash flows (see Equations 2 and 3) gradually decrease up to a point (red ellipse), after which they drop suddenly and smoothen out again at a low level. The sudden drop occurs due to the large difference in electricity savings during and after the lifetime of the old motor (see Equations 10 and 11) as shown in Figure 4b. This can be explained as follows: the reference technology for the remaining lifetime of the old motor is less efficient than the reference technology for the subsequent period in which the new standard is assumed as reference; this results in smaller energy savings and hence also smaller economic benefits in the second period compared to the first. This holds true for all cases depicted in Figure 3 but it is more visible for RBD than for SLD except for the case with high salvage value (i.e. 50%).

Moreover, the authors find the argument reasonable that the financial value of the manufacturing plant equipment depreciates quickly in the early years as compared to the term closer to the end of lifetime (RBD). Hence RBD can be considered a suitable approach. This leads to the conclusion that, from a company's perspective, it is most profitable to change an old motor with a more energy efficient one once two-thirds of its lifetime has been reached[8]. This may not be true for motors that do not operate on a frequent basis and are in service only for a few hours annually (reflecting on a higher salvage value of the motor compared to motors used more frequently during a given time period; see Figure 3). However, if one considers that the effective lifetime of motors operating less frequently is larger than their projected lifetime, the conclusion may still hold true. The fact that the age of nearly 80% of motors replaced by the EE programs in Switzerland (EnAW) was more than or equal to half of their expected lifetime also partly justifies the conclusion.

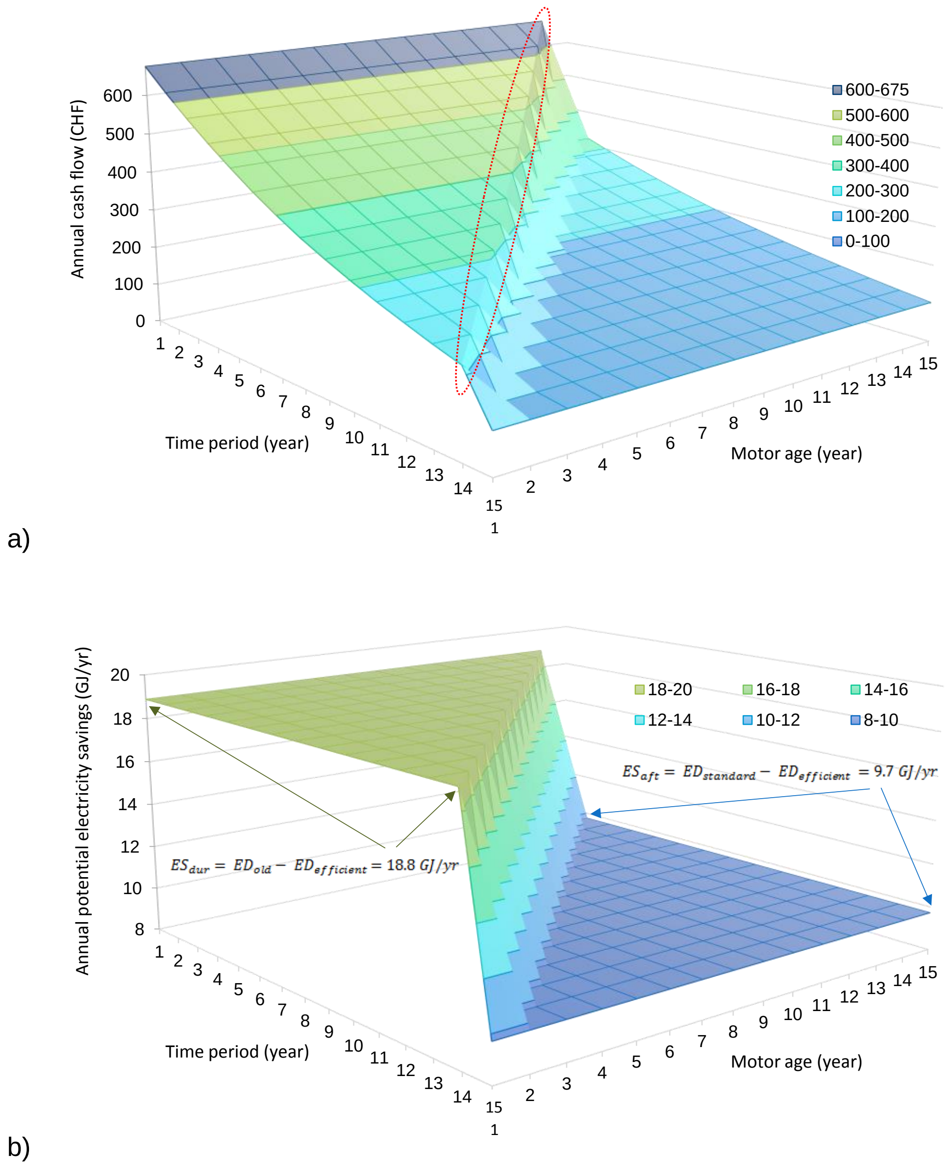

Figure 4 a) Annual discounted cash flows and b) annual electricity savings over the years for different levels of old motor (IE2 in this particular case) age at the time of replacement

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[8] The precise timing at which the motor replacement is most profitable might vary depending upon the old motor efficiency class and its usage.

Although advanced methods are more accurate and provide a better understanding of the EE measure, there are also challenges associated with the methodology that make its applications complicated. The major challenge is to define the reference standard technology for more complex systems such as compressors, pumps, fans etc. For example, compressors used in industry differ in terms of type (e.g. oil-injected or oil-free; with or without variable speed drive), capacity, number of stages, load factors and pressure requirements, which makes it difficult to define a standard equipment for comparison. In contrast, such standards exist for electric motors and could be applied in the case of motor replacement. Simplified methods are, therefore, more popular to account for additionality, however, the method of choice should be advanced retrofit where possible. Identifying standard technologies for electric motor driven systems can be an excellent topic for future research allowing better accountability for economic energy efficiency improvement potentials.

Conclusions

In this paper, a case of 45 kW motor retrofit is studied and the cost-effectiveness of the EE measure is analyzed based on different approaches accounting for additionality. The comparison shows that the chosen method very strongly impacts the results, i.e. by factors and potentially even resulting in opposite findings concerning cost-effectiveness of the EE measure. Choosing total investment costs may lead to the conclusion that the measure is not cost-effective while all other approaches result in the opposite conclusion (economically viable). In other words cost-benefit analysis based on total investments leads to underestimation of the potential and has the tendency to mislead the decision makers.

For slowly expanding manufacturing sectors in an industrialized country like Switzerland (limited growth, mature capital stock), the results show that the additionality approach based on age only overestimates the cost-effectiveness. The authors therefore recommend alternative approaches which allow to establish the uncertainty range of measure cost-effectiveness, while maintaining transparency. We emphasize more specifically on the advanced approach given by EPA for the cost-benefit analysis however, the method may not always be applicable due to several constraints which primarily include the definition of the reference standard technology for diverse systems such as compressors, pumps, fans etc. Finally, it is concluded that the careful estimation of energy-relevant investments and electricity savings and their use in the cost-benefit analysis can reduce the large investment barriers which often limits implementation of EE measures in industry.

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