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Techno-economic analysis of energy efficiency improvement in electric motor driven systems in Swiss industry

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HIGHLIGHTS

- Energy efficiency cost curves are developed for Swiss industrial motor systems.
- The economic electricity saving potential is estimated at ~7900 TJ/yr.
- The results of two energy efficiency programs in Switzerland are compared to each other.
- The importance of accounting for additionality is demonstrated.

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ABSTRACT

According to its 'Energy Strategy 2050' (case 'new energy policy') Switzerland aims to reduce its industrial electricity demand by 25% and 35% in 2035 and 2050 respectively compared to 2010. Electric motor driven systems in Swiss industry, which currently account for approximately 69% of the sector's total electricity demand, are expected to contribute significantly to this strategy. This study assesses the potential of electricity savings for electric motor driven systems in industry and its associated specific costs and presents the results in the form of energy efficiency cost curves. For the short term, the economic potential for electricity savings in Swiss industrial electric motor systems is estimated at approximately 17%. The importance of accounting for additionality by using energy-relevant investment instead of total investment for the cost-benefit analysis in order to avoid underestimation of the economic electricity savings potential is demonstrated. The results of this analysis can serve as basis for formulating more effective policies and may also be applicable to other countries with similarly ambitious targets.

1. Introduction

Improving energy efficiency is considered as one of the most important options to reduce energy demand and carbon emissions and strengthen energy security. Electric motor-driven systems (EMDS) account for 60–70% of industrial electricity demand worldwide [1]. According to the Institute of Industrial Productivity (IIP) [2], 30 million new electric motors are sold to industry each year while 300 million motors are already in use for industrial activities. Among these activities, compressed air systems (CAS), pump and fan systems are the most important loads accounting for > 60% of the total energy demand by industrial motors [3]. Being the largest consumer of electricity in industry, EMDS provides major opportunities for energy efficiency improvement, with an estimated potential for reducing global electricity use in motor systems by 20–30% [4]. While standard motors today are already quite efficient (efficiency > 80% over most of the working range, increasing over 90% at full load conditions), the exclusive implementation of well-established energy efficient motors would result in savings of approximately 11–18%, and further energy saving potentials can be leveraged at the systems level [5].

Although there are studies available on the potential of electricity savings in EMDS e.g. [6–9], there is paucity in literature when it comes to the associated costs of these potentials. The economics of energy efficiency in industrial EMDS are generally not well understood and have hardly been covered in publications. Trianni et al. [10] recently presented an overview of empirical studies on barriers to energy efficiency and for EMDS, with the most important ones being lack of information, asymmetries (e.g. split incentives) and hidden costs. Palm and Thollander[11] indicated similar barriers as root cause for the slow diffusion of energy efficient technologies in EMDS. The total investment

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Nomenclature

A	age of the replaced equipment (years)
ANF	annuity factor
B_y	annual benefits of the measure (CHF), i.e. the annual electricity cost savings over lifetime *L* to be achieved from first year after implementation.
$C_{spec,y}$	specific costs of measure *y* (CHF/GJ)
CF_t	annual cash flow for the year *t* respectively at the end of the expected lifetime (15 years) of motor
E_{CAS}	annual electricity demand by electric motors (>15 kW) in compressed air systems (GJ/yr
EI	energy-relevant investment (CHF)
E_i	annual total electricity demand by industry (GJ/yr)
ES_{whr}	annual thermal energy savings potential (GJ/yr))
ES_y	annual potential electricity savings by measure *y* for system *x* (GJ/yr)
$ES_{y,EnAW}$	total electricity saved by measure *y* in EnAW data (GJ)
$ES_{z,EnAW}$	total electricity saved by class *z* in EnAW data (GJ) savings (GJ/yr)
h	recoverable share in the form of heat, i.e. 70% (see Section 3.5)
I_y	initial investment (CHF) required to achieve the ES_y, determined from the dataset using Eq. (8). Its value is zero for all years after base year of implementation.
IR_y	is the investment cost ratio (CHF/GJ per year) unique to each measure *y*
L_y	lifetime of the equipment or measure *y* (years) which motors work efficiently
N	shaft speed (rpm)
NPV_y	net present value of measure *y* for the base year 2015 (CHF)
$O\&M_y$	operation and maintenance cost which is assumed to be identical before and after implementing the energy efficiency measure and hence neglected (CHF)
P	power required by a pump or a fan (kW)
$P_{DH,i,n}$	district heat price for industry in year *n*
$P_{e,h,2010}$	electricity price for household in year 2010 given by Prognos (CHF/GJ)
$P_{e,h,n}$	electricity price for household in year *n* projected by Prognos (CHF/GJ)
$P_{e,i,2010}$	electricity price for industry in year 2010 given by ElCom (CHF/GJ)
$P_{e,i,n}$	electricity price for industry in year *n* (CHF/GJ)
$P_{FO,i,n}$	light fuel oil price for industry in year *n*
$P_{NG,i,n}$	natural gas price for industry in year *n*
$P_{t,i,n}$	thermal energy price for industry in year *n*
r	real discount rate
s	share of E_{CAS} to which the measure is applicable
T	torque (Nm)
TI	total investment (CHF)
$W_{z,y}$	weightage of class *z* in measure category *y*

Greek letters

α	share of total electricity demand by industrial motors (%)
β_x	share of system *x* in total electricity demand by industrial motors (%)
γ_x	share of total electricity demand by system *x* that can be saved (%) (for 'other' systems, the share represents potential electricity savings by only two measures, see Table 2 and Section 4.1.3 for further details)
η_m	efficiency of motor *m* specific to each class
τ_y	share of measure *y* in total electricity demand by system *x* that can be saved (%)

costs of EE measures are the sum of purchase and installation costs. While it is already quite difficult to obtain sales prices from the manufacturers (the price paid depends on the size of the order), the remaining data would be even more difficult to acquire because they are site-specific. Due to lack of data and relevant indicators it is difficult to estimate the costs of EE measures which can discourage end-users to employ more efficient or best available technologies. The raw data used by the authors in this article represent practically implemented EMDS measures in the context of the agreement of Swiss companies with the government or its representatives (see Section 2.1).

Energy efficiency cost curves (EECCs) are a suitable approach for the decision makers to compare the cost-effectiveness and effectiveness (energy savings) of technical measures. EECC is an analytical tool commonly used to present the economic potential of the energy systems at the national and the sectoral levels [12]. While there EECCs have been published for entire industry sectors (e.g. the ones published by Zuberi and Patel [13] for Swiss cement industry, Morrow III et al. [14] for Indian iron and steel industry and Fleiter et al. [15] for German pulp and paper industry etc.), there are hardly any comparable studies for cross-cutting technologies or process groups like electric motor systems. This may be due to the diversity of these systems (unlike cement, steel and paper industries where the products and production steps are more or less standard) which makes it difficult to generalize the costs of the cross-cutting EE measures.

Addressing the issue, the study by McKane and Hasanbeigi [16] was the first step in this direction. They developed EECCs for compressed air, pump and fan systems and each for six different regions including U.S., EU, Canada, Brazil, Thailand and Vietnam. Since the detailed bottom-up data for industrial motor systems at the regional level was not available for developing EECCs, they combined the available data with the expert estimates resulting in substantial uncertainties. Given the differences in industrial structure and cost levels across the globe, it is certainly not imaginable to investigate real costs and all relevant physical data for motor-related EE measures for all parts of the world. It is more appropriate to conduct reliable analyses for specific countries (e.g. Switzerland) which can be adapted to specific other regions in a second step.

In this study, EECCs for different applications of EMDS are developed as a case study for Switzerland for which relatively accurate data was available from the energy efficiency programs. The case of Switzerland can be of interest for the international community because the country has taken very drastic policy measures (more strict than several other countries) in response to different international environmental agreements. With its national 'Energy Strategy 2050', Switzerland aims to substantially reduce final energy demand per capita and gradually withdraw from the use of nuclear energy [17]. While Swiss electricity demand in industry is projected to remain almost same in 2050 compared to 2010 under business as usual scenario, one of the major goals of the "New energy policy" is to reduce electricity demand by nearly 25% and 35% in 2035 and 2050 respectively from the base year 2010 [18].

Industrial motors, which account for 22% of the national electricity demand [6] and an electricity consumption of around 45 PJ as of 2014 are expected to contribute significantly to the national strategy. According to a study commissioned by Swiss Federal Office of Energy (SFOE) [9], the technical energy efficiency improvement potential in Swiss EMDS is estimated at 30% which indicates a significant energy efficiency gap, however without analyzing the attendant cost. This raises the question about the economic energy efficiency potential, which our paper studies. We also address the question of techno-