A detailed review on current status of energy efficiency improvement in the Swiss industry sector

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Abstract

Energy efficiency is considered as key component of national energy policy in many countries including Switzerland. This study assesses the evolution of energy efficiency in the five major Swiss industrial sectors. While quantitative methods for tracking the past evolution of energy efficiency improvement in industry do exist, these cannot be directly applied to all the sectors under investigation due to several data constraints including unavailability of data on physical activity levels in Switzerland. Therefore, a new bottom-up method is developed and tested in this study for estimating the Swiss sectoral physical activity levels. On this basis, sector-specific energy efficiency indices are determined. The results show that during the period 2009-2016, energy efficiency improved most in the paper sector (3.3% p.a.), followed by minerals (2.3% p.a.) and food (1.6% p.a.) sectors while the levels have remained approximately unchanged in chemical and metal sectors. In order to put the results for energy efficiency indices into perspective and evaluate the overall performance of the individual sectors, the annual change in final energy demand was decomposed into changes of production values, changes of price levels and energy efficiency improvement. The analysis leads to the conclusion that only the food sector performed well according to all performance indicators. The detailed analysis of the data on Swiss target agreements has revealed major final energy savings in chemical and food sectors during the period 2000-2016. Among the different categories of energy efficiency measures, process related measures have proven to yield the highest energy savings across all sectors. The results indicate the successful implementation of energy efficiency measures in Swiss industrial sectors, favored by the relatively strict Swiss regulatory framework and its target agreement mechanism. This study is of potential interest for other countries with ambitious targets for energy efficiency improvement in the industrial sector.

Keywords: physical activity levels, energy efficiency index, energy efficiency targets, industry, Switzerland.

Nomenclature:

A_t: Sectoral output (in economic terms, e.g. GVA) in year *t* (kCHF)

CF: Coverage factor

$E_{EnAW,t}$: Final energy demand by EnAW companies (within a sector) in year *t* (GJ)

$E_{i,t}$: Final energy demand for industrial activity *i* in year *t* (GJ)

E_{ref}: Sectoral final energy demand in reference year 2010 (GJ)

E_t: Sectoral final energy demand in year *t* (GJ)

$EEI_{t,EnAW}$: Energy efficiency index based on EnAW approach in year *t* (GJ)

$EEI_{t,PPI}$: Energy efficiency index based on PPI approach in year *t* (GJ)

$EEI_{t,stnd}$: Energy efficiency index based on standard approach in year *t* (GJ)

$ES_{cum,t}$: Cumulative energy savings by EnAW companies (within a sector) from base year until year *t* (GJ)

$SEC_{i,t}$: Specific energy consumption for industrial activity *i* in year *t* (GJ/tonne)

$SEC_{i,ref}$: Reference specific energy consumption for industrial activity *i* in base year 2010 (GJ/tonne)

$m_{CH,i,t}$: Physical production of Swiss industrial activity *i* in year *t* (tonnes)

$m_{CH,i,ref}$: Physical production of Swiss industrial activity *i* in reference year 2010 (tonnes)

m_t: Sectoral weighted physical production in year *t* (tonnes)

$m_{i,t}$: Physical production of industrial activity *i* in year *t* (tonnes)

PLI: Price level index of Switzerland relative to EU

PPI_t: Sectoral physical production index in year *t*, calculated by Equation 8

$Pv_{CH,i,t}$: Production value of the Swiss industrial activity *i* in year *t* (EUR)

Pv_t: Sectoral production value (sales) in year *t* (EUR)

$Uv_{EU,i,t}$: Unit value of the EU industrial activity *i* in year *t* (EUR/tonne)

w_i: Weight of Swiss industrial activity *i* based on typical SECs assumed for reference year 2010

Greek letters

ε_t: Sectoral energy intensity in year *t*

1. Introduction

1.1. Overview

Today, energy efficiency is widely considered as one of the most available, affordable and secure types of energy resources and it has become a key pillar of energy transition strategies across the globe. Many countries aim to further exploit energy efficiency for large-scale benefits, arguably at least cost to the society [1,2]. This is also the case for Switzerland which has incorporated energy efficiency as one of the pillars of its 'Energy Strategy 2050'. According to the strategy, the country is foreseen to reduce its total final energy demand by 22-46% in 2050 compared to the level in 2010 under different policy scenarios [3]. As part of these scenarios, final energy use in industry was projected by Prognos [3] to decrease by 26-39% from 2010 to 2050. The Swiss federal policy on energy efficiency improvement and CO_2 emissions reduction was first enacted in 1998 with the Federal energy law and in 1999 with the CO_2 law, respectively. The set of directives and regulations imposed with the Energy law aimed at promoting and enforcing solutions with higher energy efficiency and the use of renewable sources. Within the CO_2 law, the overall national reduction target for CO_2 emissions was set to 10% by the commitment year 2012 with respect to the reference year 1990, with specific reductions of 15% and 8% for fuel oil and transportation fuel, respectively [4–6].

In 1999, the 'Energy Agency of the Swiss Private Sector' (for ease of notation the German acronym "EnAW", standing for *Energie-Agentur der Wirtschaft*, will be used in the following) was founded as non-profit organization by the Swiss association of private companies. EnAW was mandated to consult both Swiss companies and the federal government to develop strategies and methods to help private companies with the implementation of solutions for national and international compliance with agreements on energy efficiency increase and CO_2 emissions reduction. Starting officially in 2000, EnAW's activities cover most manufacturing and service sectors in Switzerland as well as the transport and agricultural sectors [7]. Until 2007, the Swiss federal regulations relied on voluntary agreements between companies and the regulatory authorities without legally defined tasks and formal obligations. However, the introduction of a CO_2 levy in 2008 (see Section 1.3 for details) encouraged energy efficiency improvement in all sectors of the economy and triggered the introduction of legally binding mechanisms. Hence the case of Switzerland including past development of energy efficiency improvement linked to its policies can be of potential interest for the international community.

1.2. Literature survey

Since the early nineties, in most of the European countries including Switzerland as well as outside Europe, voluntary agreements have been implemented in order to improve energy efficiency in industry and achieve CO_2 emissions reduction targets [8–11]. Various studies have highlighted that the success of negotiated agreements was strongly dependent on the policy mix and supporting framework as well as the sanction mechanism for noncompliance [11,12]. The literature review suggests that among the most important motivations for companies to participate in energy efficiency programs, CO_2 tax rebate and financial incentives play a major role [13,14]. Furthermore, eased access to information on energy efficient technology, energy management and/or energy audit programs promote changes in investment behavior and allow to liberate resources. For example, technological innovation, resource management, equipment optimization, material flow improvement, waste minimization etc. all yielded important results on energy utilization and CO_2 emissions reduction [15]. Moreover, the interaction between companies, government authorities and industrial associations seem to have an impact on how the energy policies are perceived and applied within different industrial contexts: the involvement of national energy agencies or third-party organizations with guiding and consultancy roles or even with full executive control and supervision responsibility has been positively linked with both acceptance of the programs and their effectiveness [8–16]. Finally, energy policy and programs generally targeted energy intensive sectors and large companies with the objective to cover the most energy consuming part of the industrial sectors, except for a few cases targeting specific groups of environmentally-engaged and high-performing companies [10,15].

Larger and consumer-oriented companies are found being early adopters of emission targets and in general, more likely to join energy efficiency initiatives presumably because of the higher visibility to consumers and higher institutional pressure, which facilitated compliance with regulations [17,18]. However, some authors are of the opinion that energy efficiency programs play the role of initiating learning processes especially for small and medium enterprises (SMEs) with limited resources and capabilities and without structured energy management. SMEs can have relatively large potential for energy savings but often suffer from lack of information, which ultimately can prevent implementation [19–21]. The environmental impact of such programs for the SMEs is, in some cases, more significant than for larger companies [21]. Encountering similar challenges, the Swiss energy policy leveraged international experiences and went through learning and adaptive processes, which resulted in the development of a regulatory approach starting in 2004 by the Swiss government by foreseeing the usage of formal commitments.

1.3. Swiss energy efficiency programs

In 2008, a national CO_2 levy [22] and a cantonal law for energy intensive consumers (MuKEn 2008, Art. 1.28 [23]) were introduced that enforced companies with high final energy demand to analyze regularly their energy needs and to explore appropriate measures to reduce CO_2 emissions and enhance energy efficiency in their production facilities [24]. Swiss companies had to sign binding 'Target Agreements', thus formally committing them to CO_2 emissions reduction paths and progress on energy savings implementation. In addition to a regulated energy audit, two types of target agreements were introduced: the 'Cantonal Target Agreements' to be signed directly with cantonal authorities, whereas the 'Universal Target Agreement' could be signed by companies with qualified third parties like EnAW or Cleantech Agency Switzerland (act; similar model like EnAW but with much less participating companies) and had validity across all Swiss cantons [25]. Both the cantonal and the universal target agreements set an indicative target of 2% p.a. for energy efficiency improvement and an agreement of a maximum of 10 years for the first phase (see below for further specifications). For a defined list of industrial activities, companies complying with universal target agreements and with electricity costs of at least 5-10% of their gross value added (GVA) have had the possibility to obtain full or partial refund of the renewable energy network surcharge (KEV) as well as the exemption from the federal CO_2 levy [26].

EnAW was the only qualified agency until 2013 to commission universal target agreements (for the sake of simplicity hitherto referred to as target agreement). In order to address the diverse needs of differently-sized companies, two models were introduced: the 'SME -Model' was designed for small and medium enterprises whereas the 'Energy-Model' targets larger energy intensive companies with higher CO_2 emissions [26]. The binding target agreement within the SME-model obliges companies to comply with the implementation of an agreed list of standard energy efficiency measures, whereas the binding target agreement within the Energy-Model imposes companies to comply with final agreed emissions- and efficiency targets without forcing the implementation of specific measures. The target agreement within the EnAW models is compliant with certain chapters of ISO 50001 and consists, specifically, of four steps: First, the potential energy efficiency measures are identified in collaboration with EnAW consultants/moderators and ranked based on an estimated implementation costs and payback period. Second, EnAW and the company suggest individual targets on energy efficiency improvements and CO_2 emissions reduction based on company's capabilities and the identified potential reduction. These targets have to be approved by the authorities. In a third step, the company decides which measures will be implemented by when and it is responsible for compliance with the agreed targets on CO_2 emissions reductions and energy savings. Finally, EnAW and the Federal Office of Energy (FOEN) regularly monitor compliance with CO_2 reduction and energy saving target results through yearly energy audits [27]. All energy efficiency measures implemented within the agreed target agreement period contribute to the companies' individual targets for energy efficiency improvement (indicative target of 2% p.a.). The bottom-up approach ensures that individual efforts in the past is taken into account by defining a lower target based on the lower remaining potential. EnAW program participants can benefit from subsidies and incentives from utility companies and various foundations, which financially support proactive companies in climate protection [7].

The target agreements have enjoyed a high level of acceptance and as a result, EnAW had over 3'600-member companies in 2016 and 3'800 in 2018, covering most economic sectors in Switzerland. In 2017, about 60% of CO_2 emissions by Swiss economic sectors were covered by target agreements with EnAW [28]. Table 1 presents the cumulative final energy savings and CO_2 emissions reduction of EnAW-affiliated economic sectors within the two commitment phases, i.e. 2000-2012 and 2013-ongoing (the data for the second phase was made available only until 2016). It should be noted that there are also other energy efficiency programs in operation in Switzerland, e.g. ProKilowatt of SFOE or Swiss cantonal or utility-driven initiatives like 'SIG-éco21' in Geneva; however, none of these programs have reached a similarly high company participation as EnAW. In other words, EnAW companies (i.e. companies having a target agreement with EnAW) represent the largest share of total final industrial energy demand and CO_2 emissions (see Section 2.2 for details).

Table 1 EnAW data on cumulative savings of Universal Target Agreements in the two commitment phases [26,29]

Cumulative savings	Phase I 2000-2012	Phase II (ongoing) 2013-2016
Total final energy	22.1 PJ	8.1 PJ
Electricity	4.6 PJ	2.5 PJ
CO_2 emissions	1.4 Mt	0.4 Mt

1.4. Aims and objectives

In this study we analyze the evolution of energy efficiency in the key industrial manufacturing sectors in Switzerland and we discuss the results, thereby considering the boundary conditions. While quantitative methods for tracking the past evolution of energy efficiency improvement in industry do exist (see Section 2.1 for details), these cannot be directly applied to all the sectors under investigation due to several data constraints discussed in the next section. Therefore, a new bottom-up method is developed in this study for estimating the physical activity levels in Swiss industry sectors. Wherever possible, the results will be compared to those generated with commonly used methods for validation. The scope of this paper is to quantify changes in energy efficiency improvement in manufacturing industry and to explain these to the extent possible. This study is currently the only publication of its kind for the Swiss industry and is expected to provide valuable insights on trends and conclusions to policy makers and other stakeholders. As mentioned earlier, the Swiss energy and climate policy is relatively strict and proactive and therefore, this study is potentially interesting for other countries having similar ambitious targets.

2. Materials and methods

2.1. Tracking energy efficiency improvement in industrial sectors

2.1.1. Energy efficiency indicators

An industrial energy efficiency indicator is defined as a metric quantifying the amount of energy required to perform an industrial process. The level of industrial production can either be expressed in economic terms or in physical terms. There is a general consensus that for evaluating energy efficiency developments in the manufacturing industry, physical activity indicators provide better understanding [30]. A very common physical energy efficiency indicator is 'specific energy consumption (SEC)' which is defined as the ratio of the energy demand $E_{i,t}$ and the physical output of the activity $m_{i,t}$:

$$SEC_{i,t} = \frac{E_{i,t}}{m_{i,t}} \quad (1)$$

The effect of energy saving measures can be observed clearly by a decrease in SEC [30]. But since the SEC involves the physical production of industrial activities which is often times difficult to get access to for confidentiality reasons, it cannot always be determined [31]. For the time being it is therefore not possible to analyze SEC in all Swiss industrial sectors. This concerns in particular sectors producing complex, high value-added products.

The most commonly used economic energy efficiency indicator is ‘energy intensity’. On the national level it is calculated by dividing the country’s total energy demand by the gross domestic product (GDP). For the industry sector or for a subsector it is defined as the ratio of the final energy demand of a sector and its gross value added (GVA) measured in real/constant monetary terms A_t. Mathematically it can be expressed as:

$$\mathcal{E}_t = \frac{E_t}{A_t} \tag{2}$$

In cases where it is not possible to calculate physical indicators or SEC, economic energy efficiency indicators can serve as reasonable alternative since value added figures are readily available from statistics. The value added of different products (e.g. in chemical industry) can be aggregated by simple addition. However, these indicators are relatively weak as they are influenced by all kinds of factors which have no relation to energy efficiency, such as product price fluctuations and sector structure [31]. In this paper, energy intensities are determined for all Swiss industrial sectors under consideration. We express sectoral energy intensity in real prices of 2010, thereby using producer price indices [32] to correct for inflation.

2.1.2. Energy efficiency index

The development of energy efficiency in industrial sectors can be monitored via an indicator called ‘energy efficiency index (EEI)’ which is the ratio of actual final energy demand in a specific year (E_t) to the frozen efficiency energy demand in the base year (see Equation 3) [33,34]. The frozen efficiency energy demand represents the amount of final energy which the industry sector would have used if no energy efficiency improvement had been implemented. It is calculated by multiplying the SEC of each product in the reference year by the production volume of the year studied, corrected by a coverage fraction (CF) (determined for the reference year; see Equation 4).

$$EEI_{t,stnd} = \frac{E_t}{\sum(SEC_{i,ref} \times m_{i,t}) \times CF} = \frac{E_t}{E_{ref} \times CF} \tag{3}$$

$$CF = \frac{E_{ref}}{\sum(SEC_{i,ref} \times m_{i,ref})} \tag{4}$$

In the following, we will refer to this method as *standard EEI approach ($EEI_{t,stnd}$)*. In spite of having been used in several previous publications, this approach cannot be directly applied to all Swiss manufacturing sectors because there are no physical production statistics available (no data on $m_{i,t}$). The method is only applicable to non-metallic minerals, pulp, paper and printing and primary metal sectors[1] where at least some physical production data is available for Switzerland (published annually by FOEN [35]). EnAW faces a similar issue and to track the energy efficiency improvement of target agreements, they use a rather simplified approach: the energy efficiency index in a year is calculated as the ratio of the actual final energy demand in a year $E_{EnAW,t}$ plus cumulative final energy savings until that year $ES_{cum,t}$ (due to implementation of energy efficiency measures) to the actual final energy demand in the same year. It can also be explained as the ratio determined by dividing energy demand under the assumption of frozen efficiency by real energy demand (results in values larger than 1). The method is described in SFOE (2014) [36]. The inverse of this ratio, as defined in Equation 5, represents an energy efficiency index (denoted here as $EEI_{t,EnAW}$) which can be directly compared to

[1] The inverse of coverage fraction expressed as percentage (i.e. % coverage) for non-metallic mineral, pulp, paper and printing and primary metal sectors are found to be 90%, 82% and 54% respectively.

the other approaches applied in this study. However, the method is not applicable to overall Swiss industrial sectors because the energy savings realized by the companies not participating in the EnAW scheme are currently unknown. An alternative method based on physical indicators is hence proposed in this study as a proxy for the detailed analysis (see Section 2.1.3).

$$EEI_{t,EnAW} = \frac{E_{EnAW,t}}{E_{EnAW,t} + ES_{cum,t}} \tag{5}$$

2.1.3. Proposed method for estimating physical activity levels

As mentioned earlier, physical activity indicators are more suitable for evaluating energy efficiency improvement in a sector. However, lack of physical production statistics (in tonnes or kg etc.) can make it impossible to conduct such analyses. To tackle the issue, an alternative approach has been devised in this study which deals with the relationship of physical production and its corresponding sales value in market. In the first step, annual production values (or sales; in euros) of the Swiss economic activities $Pv_{CH,i,t}$ (classified by NACE Rev.2[2]; only available as of 2009) are retrieved from the Eurostat database [39]. From the same database, annual production values (also in euros) and physical production of the same economic activities can also be extracted for the European Union (EU). For the EU, the ratio of the annual production value of an economic sector to the corresponding annual physical production represents the estimated unit value $Uv_{EU,i,t}$ (EUR/unit) of that activity. In order to adapt the unit values to Switzerland, the EU values are multiplied by the annual price level indices (PLI), likewise taken from the Eurostat database [39]. The following equation can be used to estimate the physical production volumes by Swiss industrial sectors.

$$m_{CH,i,t} = \frac{Pv_{CH,i,t}}{Uv_{EU,i,t} \times PLI} \tag{6}$$

Where PLI is the price level index of Switzerland relative to EU determined as the ratio of the purchasing power parity to the nominal exchange rate [40]. It should be noted that after the first step, some irregularities were found in the overall production trends of some products. For these products, sharp changes (increase and/or decrease) in physical activity in subsequent years were observed. In some cases, one of the possible reasons could be a drastic change in prices due to unknown factors which might have falsely influenced the estimation of physical volume in a year. This phenomenon cannot be explained without understanding the dynamics of the affected sub-sectors and detailed analysis for which not enough information is currently available (except for secondary steel production where the trend could be verified with the actual statistics). As pragmatic solution, the estimated data points corresponding to a change of at least +/-20% in physical volume from the previous year were eliminated. In the following step, the missing data points were filled by time series interpolation and/or extrapolation.

Using Equations 1 and 3 and assuming the products considered to be representative for the sector as a whole, the equation for energy efficiency index can be rewritten as Equation 7.[3] It implies dividing the sectoral annual final energy demand given by SFOE [41] by the corresponding physical production index (PPI; dimensionless trend). We will therefore refer to this EEI as *PPI approach* from now onwards

$$EEI_{t,PPI} = \frac{E_t}{E_{ref} \times PPI_t} \tag{7}$$

In order to calculate $EEI_{t,PPI}$, the energy-weighted physical production index PPI is required which is calculated as follows:

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[2] NACE is the classification of economic activities in EU. From January 1, 2008, NACE Rev. 2 is used for statistics referring to the EU economic activities [37]. In Switzerland all economic activities are classified under the Nomenclature Générale des Activités économiques (NOGA) [38]. The last revision i.e. NOGA 2008 is now fully aligned with NACE Rev.2.

[3] In Equation 3 the factor CF is needed for scaling. In contrast, no coverage fraction is included in Equation 7 because PPI_t is a dimensionless quantity (index value) which is assumed to be representative for the sector as a whole.

$$PPI_t = \frac{\sum(m_{CH,i,t} \times w_i)}{\sum(m_{CH,i,ref} \times w_i)} \quad (8)$$

Where w_i is the weighting factor of the Swiss industrial activity *i* based on typical SECs of sector-specific products assumed to be valid for base year 2010. For example, in the food sector, the weighting factor of meat production is equal to the SEC of meat production. The SECs for different activities are taken from the international literature [34,42–54].

For validation, the results from the application of standard approach ($EEI_{t,stnd}$) for the three sectors can be compared to the PPI approach ($EEI_{t,PPI}$). In addition, the energy efficiency indicators for Switzerland published by Odyssee-Mure project (ODEX) [55] can also be used to verify the results, where possible. For further details on ODEX methodology, please refer to the following references [55,56].

In order to put the results for energy efficiency indices into perspective and evaluate the overall performance of the individual sectors, a factorial decomposition of the annual growth rates of sector-specific final energy demand (E_t) into production value/sales (Pv_t), price levels *(inverse of* m_t/Pv_t*)* and energy efficiency improvement (E_t/m_t) was conducted according to Equation 9. While E_t and Pv_t are readily available from statistics, E_t/m_t is assumed equivalent to the energy efficiency indices based on PPI approach ($EEI_{t,PPI}$). The price levels *(inverse of* m_t/Pv_t*)* can then be calculated from Equation 9 as only unknown variable.

$$E_t = Pv_t \times \frac{m_t}{Pv_t} \times \frac{E_t}{m_t} \quad (9)$$

2.2. Data analysis of Swiss companies with target agreements

Apart from analyzing energy efficiency improvement at the level of Swiss manufacturing sectors, this has also been done for the subgroup of all companies having a target agreement with EnAW (using Equation 5) to comprehend the effectiveness of the program. EnAW provided valuable data on energy efficiency measures implemented within the Energy Model’s binding target agreements in Phase I (2000-2012) and Phase II (2013-2016). It should be noted that Phase II is still ongoing, and data access was given only until 2016. The dataset contains anonymized data on over 14’000 energy efficiency measures implemented in fourteen sectors within almost 500 target agreements. Each EnAW dataset contains complementary information, i.e. on the industrial sector, the year of implementation, the annual final energy savings by energy carrier and in many cases both total and additional investment costs. Utilization of the economic data for analyzing the cost-effectiveness of the implemented measures is outside the scope of this study but can be found in [19,24,51,54,57,58].

It is worth noting that during the data analysis, various data limitations and shortcomings have been observed. First, the comparison of EnAW and SFOE-Eurostat based datasets (see Section 2.1.3) is not possible for all sectors due to differences in sector definitions (e.g. EnAW classification for metals industry also includes metal products). Besides, the cement industry (largely dominating the non-metallic minerals sector in Switzerland) joined EnAW only in 2013 and thus the results before and since their participation could differ substantially. Moreover, the anonymous EnAW dataset does not provide detailed information on individual companies, e.g. number of employees, energy bills, production data or other indicators for them. There are several other reasons (explained later in Section 3.3) which make the comparison between EnAW energy efficiency results and the aforementioned statistical methods challenging.

Figure 1 shows the coverage of EnAW companies in the total final energy demand of different Swiss industrial sectors in 2016. Since textile industry is only around 1% of the total final energy demand of Swiss industry sector (see Figure 2) and machinery and other industries (including wood, rubber and plastics etc.; not shown in Figure 1) are hardly represented in EnAW, the focus is on the remaining five sectors displayed in Figure 1 (see blue bars). As shown in Figure 2, these five sectors consumed nearly 70% of the total final energy demand in Swiss manufacturing industry in 2016. It can be readily observed from Figure 1 that in all five sectors, over 50% of the final energy demand is covered by EnAW target agreements (and even above 70% for all studied sectors except for metals and metal products). Hence, the presented EnAW data can be considered representative for most of the energy use in these industrial sectors.

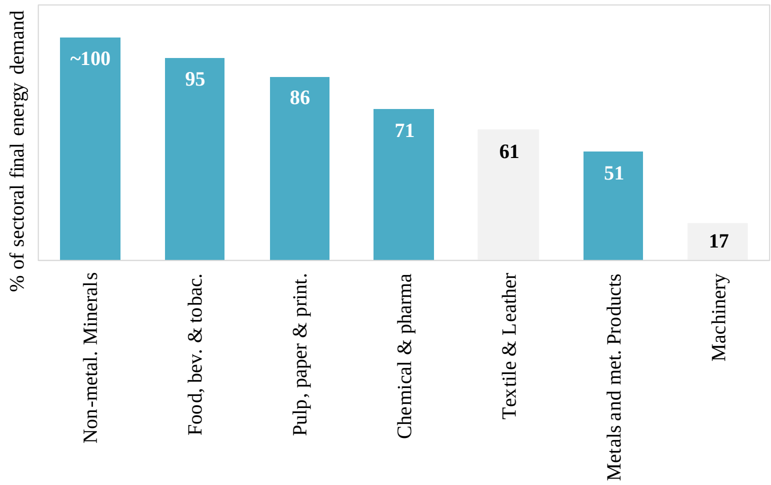

Figure 1 Final energy demand of EnAW companies as percent of total final energy demand of Swiss industrial sectors in 2016; sectors studied in this paper are depicted in blue

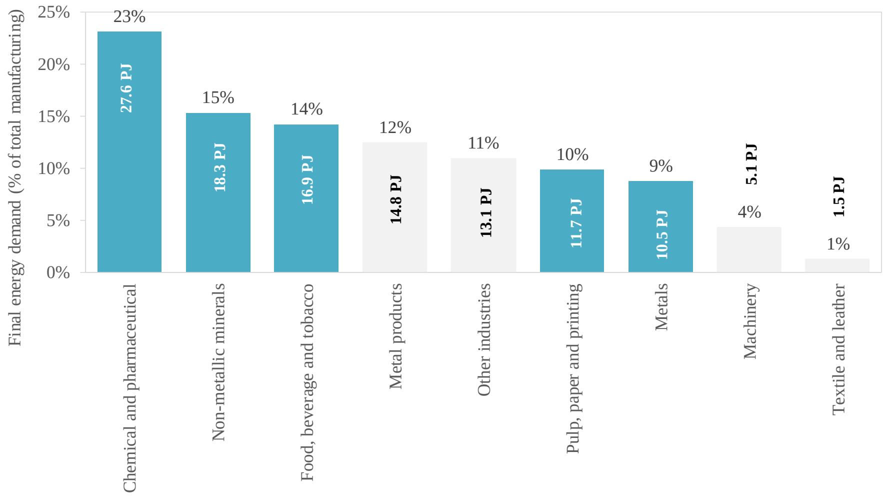

Figure 2 Final energy demand of individual sectors as percent of total final energy demand of Swiss manufacturing industry in 2016; sectors studied in this paper are depicted in blue (Source: SFOE [41])

3. Results and discussion

3.1. Energy efficiency improvement in Swiss industrial sectors

Using Equation 7, energy efficiency indices for the five major Swiss industrial sectors have been determined for the period 2009-2016, refer to Figure 3. As stated, since the data on production value of Swiss manufacturing products is only available from 2009, the level of energy efficiency for the years before 2009 cannot be assessed. Although the time series is relatively short, it provides reasonable insight for the past eight years. Before discussing the results, it should be noted that the results are in good agreement with that of the standard approach (for three sectors only) as well as ODEX hence validating the proposed methodology, refer to Figure 3. The major differences in EEI occur only in 2013 for the chemical and pharmaceutical sector and in 2011 for the primary metals sector. While it is very difficult to pinpoint the reasons, one could link a) the EU economic recession in 2013 to the difference in values for the chemical sector (no recession in Switzerland in 2013; the sector might have been affected more than the other sectors in the EU) and b) the relatively low coverage of the primary metals sector in the standard approach (i.e. 54%, refer to Section 2.1.2; non-ferrous metals, including secondary aluminium which is an energy intensive process, are not well represented) to the difference in values for the metal sector in 2011. From now onwards, the discussion will be based on the results of the proposed method (see Equations 7-8).

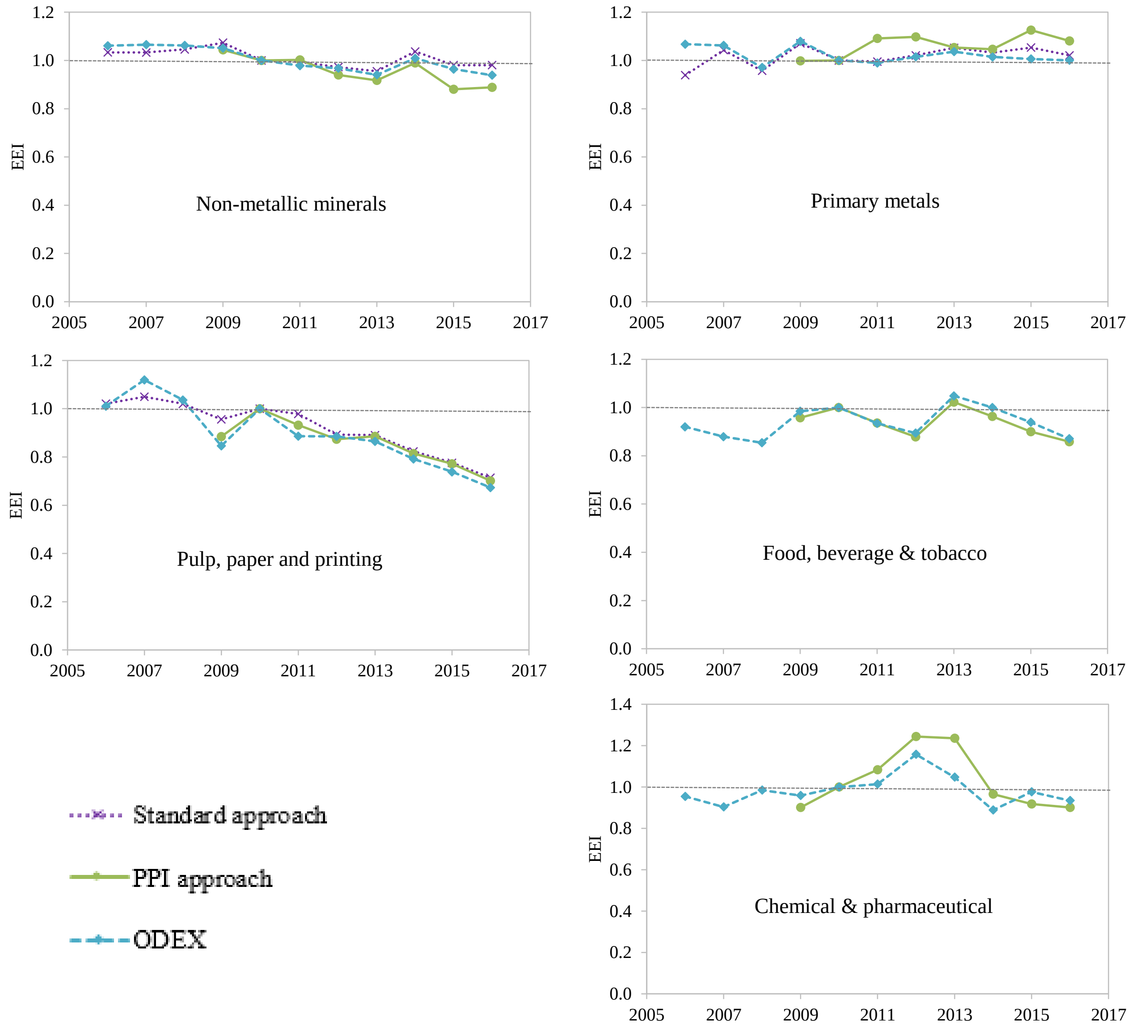

Figure 3 Energy efficiency improvement in Swiss industrial sectors from 2009 to 2016

Figure 3 shows that, during the period 2009-2016, the energy efficiency improved most in pulp, paper and printing industry (3.3% p.a.)[4], followed by non-metallic mineral sector (2.3% p.a.) and the food, beverage and tobacco sector (1.6%). On the other hand, during the same period, energy efficiency remained approximately unchanged according to the chosen indicators in the chemical and pharmaceutical and primary metal sectors[5]. An explanation is that these industries also change the characters of their products. Producing more sophisticated or more lightweight products may compensate efficiency gains. Figure 4 shows the final energy intensities of the Swiss industrial sectors from 2002 to 2016 however, for comparison with Figure 3, we only discuss the results for the period 2009-2016. According to Figure 4 the energy intensities of the chemical sector and the food sector

[4] Calculated as Compound Annual Growth Rate - CAGR $\left(\frac{End\ value}{Initial\ value}\right)^{\frac{1}{\#\ of\ years}} - 1$

[5] From now onwards, the simplified terms ‘food’, ‘paper’, ‘chemical’, ‘mineral’ and ‘metal’ sectors will be used instead of ‘food, beverage and tobacco’, ‘pulp, paper and printing’, ‘chemical and pharmaceutical’, ‘non-metallic mineral’ and ‘primary metal’ sectors respectively.

decreased most, i.e. by 4.1% p.a. and by 3.6% p.a. respectively from 2009 to 2016. While the energy intensities in paper (1.6% p.a.) and mineral sectors (1.1% p.a.) also decreased, an increase by 1.9% p.a. was found for the metal sector. Metal sector in Switzerland is largely dominated by secondary steel production which accounts for 75% of the sector's total final energy demand. In the past few years, secondary steel production has increased in Switzerland causing a higher final energy demand (not at the same rate) while the production of non-ferrous metals has significantly decreased after 2012 [35]. The fact that many high value added products such as alloys and precious metals are included in the non-ferrous metal sector could explain why energy intensity in the overall sector has increased. More detailed information would be needed for further analysis.

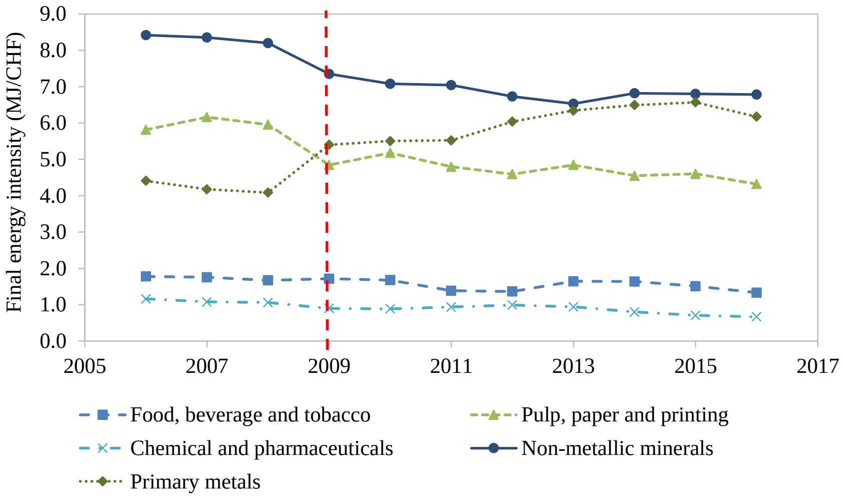

Figure 4 Development of final energy intensities in Swiss industrial sectors from 2002 to 2016

The comparison of the results in Figure 3 and 4 provides somewhat different conclusions. Based on energy intensity as performance indicator, chemical and food sectors have advanced well in the past few years (significant reduction in their energy intensities) while considering energy efficiency index based on physical production, paper and mineral sectors have performed better. The energy intensity of a given sector indicates the energy burden of its economic activity (how much energy is required per unit of GVA). This ratio also provides an indication of how sensitive an economic sector is to changes in energy prices and regulations. For example, the three- to four-fold higher energy intensity values of the paper sector indicate that this sector is significantly more sensitive than chemical and food sectors suggesting a comparatively large challenge to the economic development for the paper sector with increasing energy costs and levels of CO_2 levy[6]. In other words, since chemical and food sectors are producing more sophisticated or high value added products[7] as compared to paper and mineral industries, they are less susceptible to increased energy prices, which may in part explain why these two sectors have improved their level of energy efficiency at a slower rate than the paper and mineral industries. This suggests that the progress made according to economic energy efficiency indicators are influenced by the economic characteristics of an industrial sector.

Table 2 presents the result of the decomposition analysis in the form of rate of change of different parameters (refer to Equation 9) for five sectors during the period 2009 to 2016. Typically, a sector can be considered to have performed well in a period if its energy efficiency improved over time (i.e. decreasing EEI) and its production value or sales/turnover has increased due to increase in physical production and/or increase in production of high value added products (i.e., a decrease of the indicator

[6] The CO_2 levy was 60 CHF/t CO_2 in 2014 and increased to 84 CHF/ t CO_2 in 2016. Since January 2018, the levy amounts to 96 CHF/t CO_2. Moreover, Prognos (2012) [3] assumed the CO_2 levy in Switzerland to be 259 CHF/t CO_2 at maximum under the New Energy Policy (NEP) scenario in 2050.

[7] For example, approx. 90% of the Swiss chemical industry's overall product portfolio are specialties which include drugs and medicines, diagnostics, fine chemicals, vitamins, flavors and fragrances, crop protection agents, pigments and paints and lacquers. The global annual demand of some of these specialties are even below a few metric tons [59].

Physical production/Prod. value). Applying these criteria to Table 2 leads to the conclusion that only the food sector has succeeded to perform well according to all performance indicators. The respectable improvement of physical energy efficiency (Energy/Phys. prod.) seems plausible in view of the high effort made which is reflected in the number of measures implemented (for food sector see below results in Table 3, Section 3.2). While the chemical and pharmaceutical industries have manufactured more high value products, their level of energy efficiency has remained practically unchanged, as also stated above; this hence calls for further investigation. The verdict is also somewhat neutral for paper and mineral sectors because on one hand, the sectors have significantly improved their energy efficiency but on the other hand, their output in value added terms has shrunk and the value added per unit of physical output has deteriorated (increase of the indicator Physical production/Prod. value). For these sectors, the improvement of energy efficiency hence partly seems to be driven by consolidation of the industries. In the metal sector, not only the level of energy efficiency has deteriorated but the value added per unit of physical output has also declined. The results for *Swiss iron and steel industries only* (not displayed in Table 2) show that the level of energy efficiency in the sub-sector has increased. Therefore, the overall metal sector's underperformance in energy efficiency terms seems to be caused to the evolution of non-ferrous metal industries, e.g. if the share of energy intensive products increases at the cost of non-energy intensive products. More detailed data would be required to unravel the underlying reasons.

Table 2 Result of decomposition analysis for five major Swiss industrial sectors from 2009 to 2016

Industrial sector	NOGA code	For overall sectors			
		Energy demand[1]	Prod. value (Pv)[1]	Physical prod./Pv[2]	Energy/Phys. prod. ($EEI_{t,PPI}$)[3]
		% p.a.	% p.a.	% p.a.	% p.a.
Food, beverage & tobacco	10-12	-1.1	3.2	-2.7	-1.6
Pulp, paper & printing	17-18	-5.7	-3.3	0.8	-3.3
Chemical & pharmaceutical	20-21	-0.1	3.5	-3.5	0.0
Non-metallic minerals	23	-1.4	-0.9	1.9	-2.3
Primary metals	24	3.0	1.0	0.8	1.1

Note: Since the background data for the calculation of each parameter come from different sources, this decomposition can hence be regarded as data consistency check. If any of the indicators show implausible behavior, this indicates quality issues with the data used.

[1] *Final energy demand and production value data are readily available from statistics published by SFOE [41] and Eurostat [39] respectively. Production values are expressed in real prices of 2010.*

[2] *Calculated using Equation 9. For comparison, statistics on price indices at sectoral level are not available.*

[3] *Assumed equivalent to the energy efficiency indices based on PPI approach. The results are in agreement with ODEX.*

3.2. Data analysis of measures implemented in Swiss companies with target agreements

The cumulative number of energy efficiency measures implemented and final energy savings achieved by EnAW target agreements in different industrial sectors are shown in Table 3. Food sector exhibits the highest number of measures, with three to four times more measures implemented than in the other sectors. Next to the presence of larger and consumer-oriented companies (see section 1.2) a further reason could be the high number of the food industry sites (i.e. >4200 sites) with relatively low final energy demand (i.e. ~4 TJ per site) which collectively implemented more measures than the rest. In general, the number of measures does reflect the related effort (e.g., investment) and it does not take into account the energy savings per measure, which can differ drastically between the measures. Most final energy savings have been realized in the chemical and the food sector. The reason why chemical sector features high final energy savings despite the lower number of measures compared to the food sector may be explained with the larger size of sites in the chemical industry and the higher final energy demand per chemical site (i.e. ~25 TJ per site) and possibly differences in operation mode (e.g.

continuous vs. batch processes)[8]. For the energy intensive companies in the chemical sector the average final energy savings per measure were hence significantly larger than for the other four sectors, especially compared to the food sector.

Besides, the EnAW datasets also contain detailed data on final energy savings by measure category. The categories are defined by EnAW moderators. Initially in Phase I, the number of categories was somewhat limited with various measures of different nature falling into a single category. For example, measures related to electric motor systems (compressed air, pump, ventilation systems etc.), which themselves can be quite different from each other, were clubbed together with other building and infrastructure technologies, e.g. lighting, steam systems etc. Although the measure categories in the second phase are still rather broad, their number increased substantially from Phase I (9 categories in total) to Phase II (14 categories). Since different EnAW moderators assigned some measures to different categories based on their own criteria and understanding, a few overlaps can be expected. Given that the definitions of the measure categories are not always clear, any changes or reorganization of the original data have nevertheless been avoided. However, these minor differences are unlikely to influence the following conclusions. Figure 5 shows the contribution of each measure category to the sector-specific total final energy savings achieved in the two phases.

Table 3 Final energy savings achieved and number of measures implemented in EnAW target agreements from 2000 to 2016

Industrial sector	NOGA code	Phase I (2000-12)		Ongoing Phase II (2013-16)	
		No. of measures	Final energy savings (PJ)	No. of measures	Final energy savings (PJ)
Food, bev. and tobac.	10-12	3037	3.60	2180	1.08
Pulp, paper and print.	17-18	836	2.35	431	0.61
Chemicals and pharma.	20-21	733	4.01	850	0.69
Non-metallic minerals	23	364	0.78	813	0.68
Primary metals and prod.	24-25	738	1.67	731	0.36
Total		5708	12.41	5005	3.42

It can be readily observed that the distribution of final energy savings and of the number of measures differ somewhat across the different categories of the five sectors; this is especially the case for Phase I. It is also evident that the highest final energy savings and the highest number of measures have been realized in the same categories across sectors, i.e. related to production processes (process heat in particular) and utility infrastructure. It is noteworthy in Figure 5 that the number of measures related to production processes in Phase I are on average 30% of the total number of measures implemented in all sectors while their contribution to the overall final energy savings is found nearly 55%. The result is not surprising because energy efficiency measures related to production technologies are generally considered highly effective, particularly in energy intensive processes at high temperatures such as in chemical industries [57,61]. The experience made in Phase I may explain why in the ongoing phase the focus of EnAW and its companies is apparently more on process specific measures (process heat, process cooling etc.) which contributed to more than 70% of the total final energy savings across all sectors, refer to Figure 5.[9] For the five sectors studied, cross-cutting technologies, i.e. ventilation and air conditioning, compressed air systems and other motor systems, jointly contributed almost 12% (on average) of the total saving potential. On average, space heating and improvements of the building envelope jointly contributed only 6% (in spite of the relatively high percentage of measures, i.e. 16%)

[8] Final energy demand per industrial site in food and chemical sectors have been estimated based on the energy use and the number of industrial establishments/sites data published by Swiss Federal Office of Energy (SFOE) and Federal Statistical Office (FSO) [41,60] respectively.

[9] There is also a well-established network within EnAW for pinch analysis. Using tools like PinCH (developed by HSLU with the support of Swiss Federal office of Energy - SFOE), economic measures for process heat integration in industrial plants have been identified and implemented during the period of target agreement.

and lighting had a share of almost 2%. Energy efficiency measures in the remaining categories were implemented less often and resulted in limited savings.

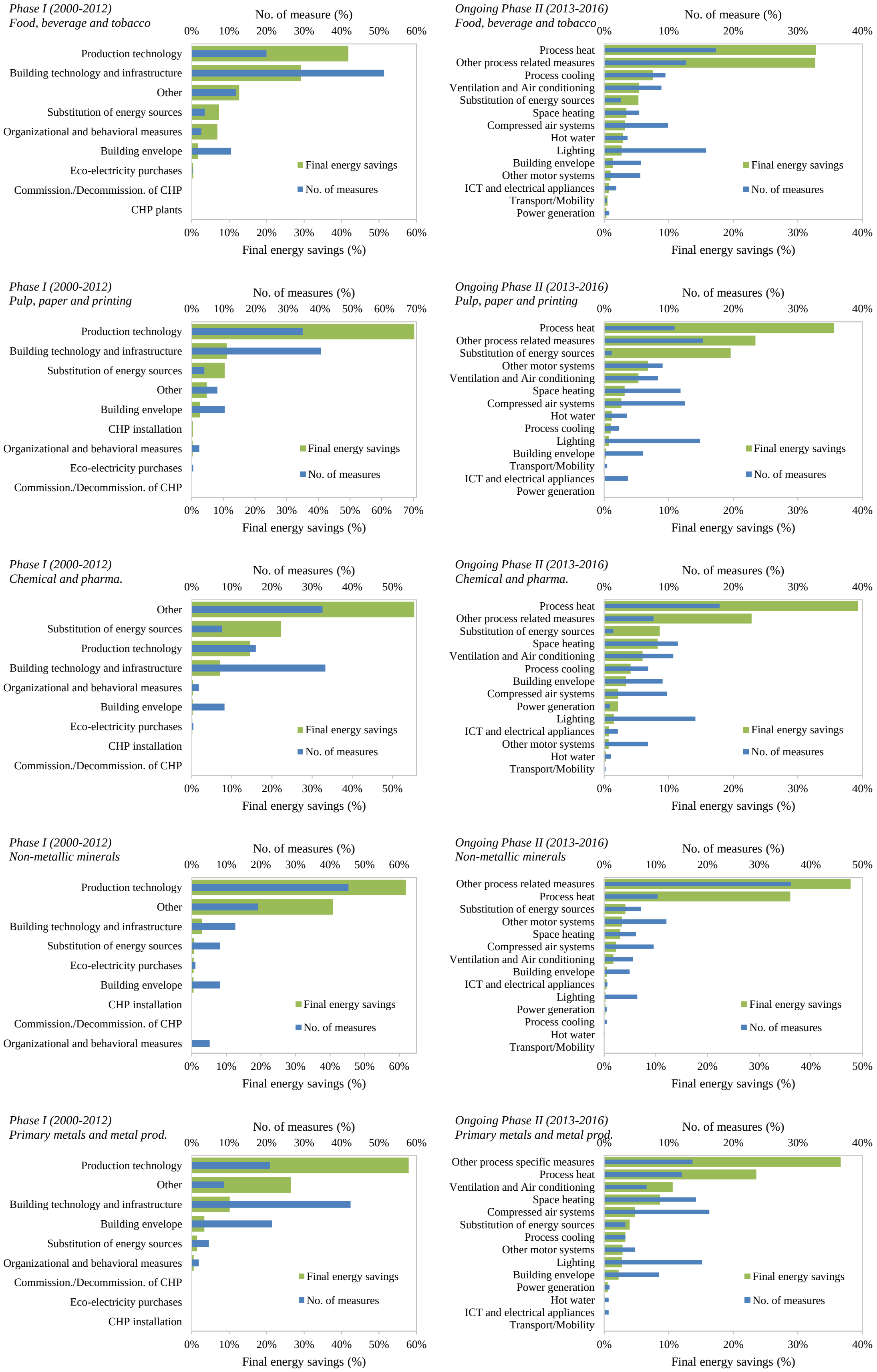

Figure 5 Cumulative final energy savings by measure category in EnAW companies in 2000-2016 (in each graph, the measures are ordered by their contribution to final energy savings)

According to literature [13,62], despite the high potential, changes to the core processes are typically avoided regardless of the industrial sector due to the high effort involved and elevated operational risks, e.g. impacts on product quality and downtimes. Therefore, companies generally limit such changes if they are not considered strategically imperative however, this is not visible from the EnAW dataset. Contrarily, energy efficiency measures in the categories related to utility and infrastructure are facilitated by the fact that substantial reserve capacity is typically available. The energy efficiency measures in these categories typically possess lower energy savings potential but at the same time require fewer resources during implementation [24,57]. The high share of energy savings related to process heat and other process related measures may be related to the fact that that these measures are generally more cost-effective (higher energy savings per unit expenditure). Another possible reason for the EnAW companies to focus primarily on CO_2 saving measures is the rather high level of CO_2 levies in Switzerland (see footnote 6; the reimbursement of the CO_2 levy generally seems to weigh more heavily than the exemption from the renewable energy network surcharge). On the other hand, the exemption from network surcharge was implemented later than the exemption from the CO_2 levy which may partly also explain why the shares of electricity saving measures (e.g. lighting) are rather low.

3.3. Energy efficiency improvement in Swiss companies with target agreements

During the period 2006 to 2016[10], the final energy savings related to sector-specific EnAW target agreements were equivalent to the energy efficiency increase of 2.1% p.a., 2.0% p.a., 1.3% p.a., 1.2% p.a. and 0.4%[11] p.a. in paper, food, metal (including metal products), chemical and mineral sectors respectively (refer to Figure 6; EnAW approach according to Equation 5). It is noteworthy that the rate of energy efficiency increase is highest in the paper sector which might be partially related to the closure of some less efficient production plants and/or processes during the period (manufacture of paper products decreased by approximately 10% both in 2009 and 2011 from the levels in 2008 and 2010 respectively). Cement industries, which are currently dominating the mineral sector, were not part of EnAW in Phase I however, their inclusion in Phase II caused major increase in EEI in 2013 (see top left in Figure 6; highlighted by red line). The increase in EEI in 2013 is clearly due to the sudden increase in the final energy demand in Equation 5 while reporting on the final energy savings in these industries started only in the year 2014. Varying sectoral coverage as a result of new companies signing target agreements in each year can therefore have serious implications on final results calculated by Equation 5. However, if the two phases (i.e. 2006-2012 and 2013-2016) are analyzed separately for the mineral sector, the rate of energy efficiency improvement is more or less same, i.e. 1% p.a. (see later in Table 4). Moreover, since the coverage for the other four sectors has not varied significantly over time, its effects on the overall results are likely to be negligible.

As stated earlier, all measures implemented in the first phase of target agreements (until end of 2012) aimed to contribute to the indicative target of 2% p.a. for energy efficiency increase in a company. While some companies have achieved more than the target, others have fallen short of it (also see Table 4) for various reasons. This shows that it is more challenging for some companies than for others. It also indicates that the target is set at the right level and it demonstrates the advantage of a flexible mechanism. However, for the period 2006-2012, EnAW companies in entirety appear to have improved energy efficiency at a rate of about 2% p.a. in Phase I [27]. In the ongoing Phase II, the improvement rates in EnAW companies have slowed down significantly (compare values for periods 2006-2012 and 2013-2016 in Table 4). A possible argument is the change in policy conditions and the incertitude about future energy laws. So a so-called steering levy (an energy tax which was meant to be redistributed by analogy to the Swiss CO_2 tax [63]) was discussed at that time, but found no political majority. Companies might have preferred not to take action until the future policy conditions

[10] Unfortunately, the data on final energy demand of EnAW companies before 2006 is incomplete. For this reason the energy efficiency increase, which is calculated with respect to the final energy demand in the review year (see Equation 5) can only be calculated from 2006.

[11] Inconclusive because the sectoral coverage increased from 35% to almost 100% in 2013 (due to inclusion of cement plants) resulting in a major shift in the energy efficiency trend (see Figure 6 and later in this paragraph).

were established. A more likely reason for the ‘slow-down’ in the beginning of second phase could be that companies typically start slow on energy efficiency improvement in the first few years of target agreements (budgeting and planning of measures’ implementation usually take time) and accelerate steadily towards the end. The rate of energy efficiency improvement may have increased since the targets were established and the investment-plans of companies were implemented. However, since the data on energy efficiency measures implemented by EnAW companies after 2016 is not available, this hypothesis cannot be tested.

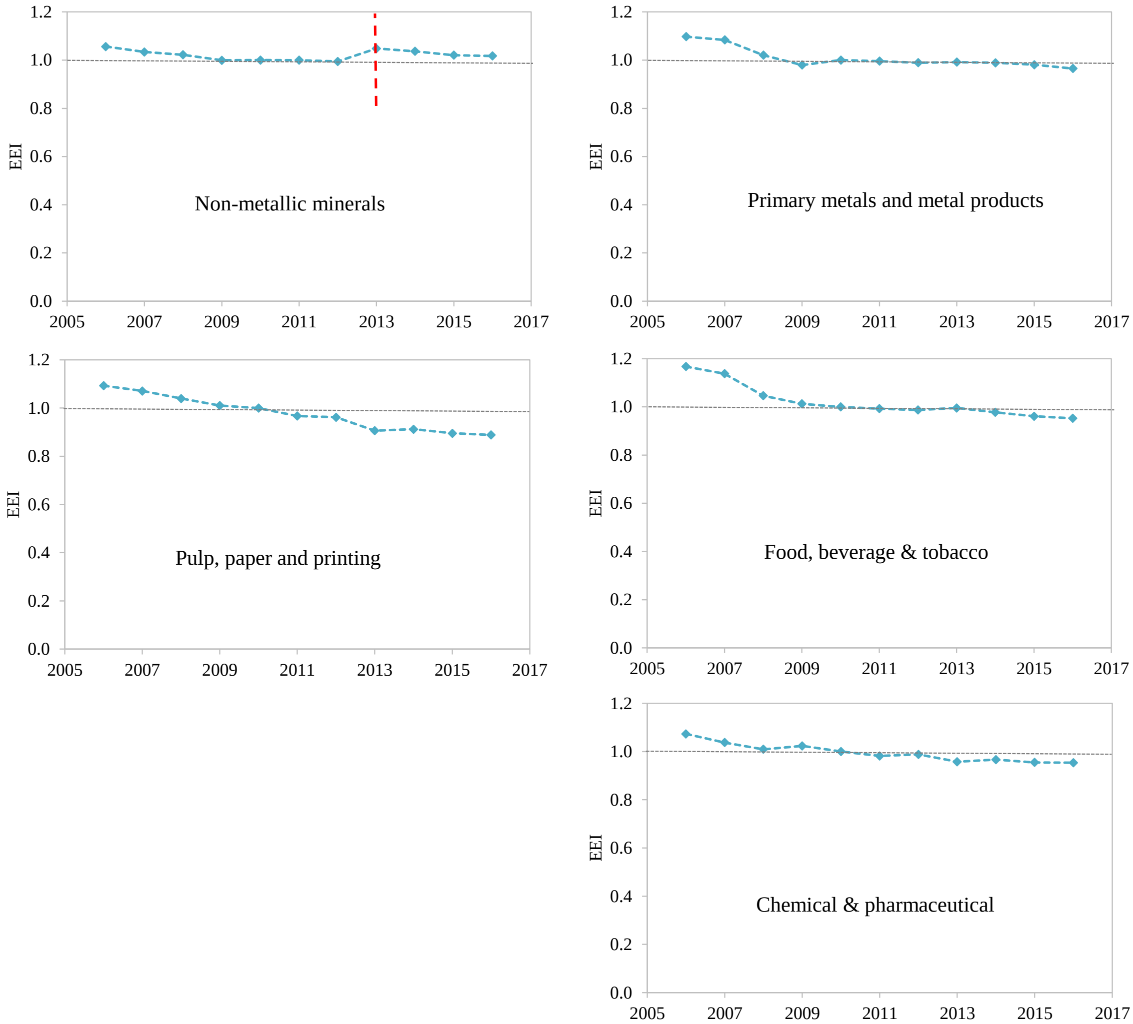

Figure 6 Energy efficiency improvement in EnAW companies from 2006-2016

Since the five sectors’ energy use is dominated by EnAW companies, one would expect a somewhat higher pace of energy efficiency improvement in EnAW companies than the overall sector. However, to confirm the hypothesis, Figures 3 and 6 cannot be compared directly due to following reasons. While PPI measures ex-post results of improvements, EnAW methodology is based on usually conservative ex-ante calculations of measures to be implemented. In the case of large companies, not all implemented measures are reported to EnAW (person. comm. with EnAW representatives). In addition, EnAW stresses implementation of cost-effective measures while companies often also participate in other energy efficiency programs (such as ‘ProKilowatt’ by SFOE) which support measures that are economically not viable. In contrast, our PPI approach takes into account *all* energy savings, even if they are not reported to EnAW or realized in context of different programs. Furthermore, Bhadbhade et al. (2019) [56] shows that the sectoral structural change has been substantial in Switzerland. These changes at the level of 3-digit NOGA classification are included in the overall sectoral results according to the PPI approach but not in the results for the target agreements. In other words, (intra-sectoral) structural effects might have caused the rate of energy efficiency improvement in the overall sector to appear higher than in the EnAW companies. Furthermore, the rate of EnAW companies is purely based on calculated energy savings (ex-ante; conservative estimates). It should be considered here that, prior to implementation of energy efficiency measures, companies usually tend to underestimate energy savings and overestimate the costs [64]. In other words, companies try to minimize risks and negotiate lower targets in the target-setting process; this reflects risk aversion in their decision making. As a consequence of this conservative approach, the real energy savings after implementation tend to be larger than originally estimated [65]. Therefore, the rate of energy efficiency increase reported by EnAW companies can be considered as underestimated (data based on measured savings (ex-post analysis) might have led to slightly different results). Finally, both in PPI approach and ODEX, price indices are used to estimate physical activity based on monetary trends, but it is not known at which level of detail the price indices are being calculated by the statistical office. Therefore, the calculated physical trends in this study are also subject to some uncertainty. For detailed comparison, more detailed information and data on physical activity levels would be required than currently available.

Table 4 Evolution of energy efficiency (% p.a.) in Swiss companies with target agreements in different time periods

Industrial sector	NOGA Code	Phase I	Ongoing Phase II	Overall period
		2006-12	2013-16	2006-16
Food, beverage & tobacco	10-12	-2.76	-1.84	-2.01
Pulp, paper & printing	17-18	-2.10	-1.51	-2.05
Chemical & pharmaceutical	20-21	-1.36	-1.04	-1.17
Non-metallic minerals	23	-1.00[1]	-1.02	-0.38[2]
Primary metals & metal products	24,25	-1.71	-1.36	-1.27

[1] Cement industries are not included which improved its energy efficiency at a rate similar to the other non-metallic mineral sector during this period [51].
[2] Inconclusive because the sectoral coverage increased from 35% to almost 100% in 2013 resulting into a major shift in the energy efficiency trend (see Figure 6).

4. Conclusions

This work is aimed at establishing the evolution of energy efficiency in the five most important industrial sectors in Switzerland. The analysis is partly based on official statistics and partly on data provided in the context of the Universal Target Agreements, which explains the different timeframes. A new bottom-up method, utilizing the sectoral economic indicators for estimating the corresponding physical production, has been developed. The results show that during the period 2009-2016, the level of energy efficiency improved most in the paper sector (3.3% p.a.), followed by the non-metallic mineral (2.3% p.a.) and the food (1.6%) sector. Compared to the year 2009, energy efficiency in the chemical and metal sector have remained at the same level. In order to put the results for energy efficiency indices into perspective and evaluate the overall performance of the individual sectors, annual change in sector-specific final energy demand, production values or sales and price levels during the period 2009-2016 have also been analyzed. The analysis leads to the conclusion that only the food sector performed well according to all performance indicators.

Apart from sector-wide analyses, this paper also aimed to better understand the effectiveness of the target agreements. The detailed analysis of companies having target agreements with EnAW revealed major final energy savings in the chemical and the food sectors during the period 2000-2016. Annual energy efficiency improvement (in % p.a.) of the companies with target agreements was significant in the first phase 2006-2012 while it was substantially lower in the second phase 2013-2016. The food sector realized the highest increase in energy efficiency improvement in both the phases (2.24% p.a. and 1.64% p.a.), followed by the paper sector in the first phase (2.15%) and the non-metallic mineral sector in the second phase (0.98% p.a.). Moreover, with respect to the different categories of energy efficiency measures, process related measures have proven to yield the highest energy savings (in total and per measure) across all sectors in both the time periods. However, changes to production processes are often considered as operational risk; this may explain why most energy efficiency measures have been implemented in the utilities and infrastructure categories in spite of the fact that these are inherently less effective in terms of energy savings. It would therefore be recommendable to explore the viability of policy initiatives promoting energy efficiency measures in core production processes (e.g. implementation of findings from Pinch analyses).

The results indicate the successful implementation of energy efficiency measures in Swiss industrial sectors favored by the Swiss regulatory framework and third-party accompanied target agreement mechanism. However, the impact of Swiss energy and climate policy on the energy efficiency improvement of the individual sectors can currently not be established with certainty due to lack of detailed data. Energy efficiency improvement of EnAW companies was higher in the first target agreement phase than it has so far been in the ongoing second phase. Possible reasons for this slowdown have been identified. Although there is a reasonable evidence that many of the cost-effective measures have already been implemented by the companies with target agreements in first phase (higher rates than those in the second phase), there are still large unexploited potentials [19,24,51,54,57]. Future research should continue addressing the question how to successfully extend and boost the implementation of energy efficiency measures.

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References

[1] IEA. Market Report Series: Energy Efficiency 2017. 2017.

[2] Bukarica V, Tomšić Ž. Energy efficiency policy evaluation by moving from techno-economic towards whole society perspective on energy efficiency market. Renewable and Sustainable Energy Reviews 2017; 70:968–75. doi:10.1016/j.rser.2016.12.002.

[3] Prognos AG/BFE. Die Energieperspektiven für die Schweiz bis 2050. Basel: BFE; 2012.

[4] BAFU. Emissionen nach CO_2 Gesetz und Kyoto Protokoll. 2014.

[5] Mörikofer A. Voluntary agreements by Swiss industry, trade and services, Copenhagen, Denmark: 2001.

[6] BAFU. Emissionen von Treibhausgasen nach revidiertem CO_2-Gesetz und Kyoto-Protokoll, 2. Verpflichtungsperiode (2013–2020). 2016.

[7] Energy Agency of the Swiss Private Sector (EnAW). By Business, for Business n.d. https://enaw.ch/en/ (accessed March 5, 2018).

[8] Andersson E, Karlsson M, Thollander P, Paramonova S. Energy end-use and efficiency potentials among Swedish industrial small and medium-sized enterprises – A dataset analysis from the national energy audit program. Renewable and Sustainable Energy Reviews 2018; 93:165–77. doi:10.1016/j.rser.2018.05.037.

[9] Johansson MT, Thollander P. A review of barriers to and driving forces for improved energy efficiency in Swedish industry– Recommendations for successful in-house energy management. Renewable and Sustainable Energy Reviews 2018; 82:618–28. doi:10.1016/j.rser.2017.09.052.

[10] Bertoldi P, Rezessy S. Voluntary Agreements in the Field of Energy Efficiency and Emission Reduction: Review and Analysis of Experiences in the European Union. Energy Policy 2011:7121. doi:10.1016/j.enpol.2011.08.030.

[11] Rietbergen MG, Farla JCM, Blok K. Do agreements enhance energy efficiency improvement? Analysing the actual outcome of long-term agreements on industrial energy efficiency improvement in The Netherlands. Journal of Cleaner Production 2002; 10:153–63. doi:10.1016/S0959-6526(01)00035-X.

[12] Rezessy S, Bertoldi P. Are voluntary agreements an effective energy policy instrument? Insights and experiences from Europe 2005.

[13] Business School of Lausanne and University of St Gallen. The EnAW Case - Final Report. 2012.

[14] Kowalska-Pyzalska A. What makes consumers adopt to innovative energy services in the energy market? A review of incentives and barriers. Renewable and Sustainable Energy Reviews 2018; 82:3570–81. doi:10.1016/j.rser.2017.10.103.

[15] Krarup S. Voluntary agreements in energy policy : implementation and efficiency / 2000.

[16] Bertoldi P. The use of long term agreements to improve energy efficiency in the industrial sector: Overview of the European experiences and proposal for a common framework. American Council for an Energy-Efficient Economy, Washington, DC (US); 1999.

[17] Delmas MA, Montes-Sancho MJ. Voluntary agreements to improve environmental quality: symbolic and substantive cooperation. Strategic Management Journal 2010; 31:575–601. doi:10.1002/smj.826.

[18] Videras J, Alberini A. The appeal of voluntary environmental programs: which firms participate and why? Contemporary Economic Policy 2000; 18:449–60. doi:10.1111/j.1465-7287.2000.tb00041.x.

[19] Zuberi MJS, Bless F, Chambers J, Arpagaus C, Bertsch SS, Patel MK. Excess heat recovery: An invisible energy resource for the Swiss industry sector. Applied Energy 2018; 228:390–408. doi:10.1016/j.apenergy.2018.06.070.

[20] Sager F, Bürki M, Luginbühl J. Can a policy program influence policy change? The case of the Swiss EnergieSchweiz program. Energy Policy 2014; 74:352–65. doi:10.1016/j.enpol.2014.07.005.

[21] Wakabayashi M, Arimura TH. Voluntary agreements to encourage proactive firm action against climate change: an empirical study of industry associations' voluntary action plans in Japan. Journal of Cleaner Production 2016; 112:2885–95. doi:10.1016/j.jclepro.2015.10.071.

[22] FOEN. CO_2 levy n.d. http://www.bafu.admin.ch/klima/13877/14510/14511/index.html?lang=en (accessed February 15, 2016).

[23] Konferenz Kantonaler Energiedirektoren. Mustervorschriften der Kantone im Energiebereich (MuKEn): Ausgabe 2014. 2015.
[24] Zuberi MJS, Tijdink A, Patel MK. Techno-economic analysis of energy efficiency improvement in electric motor driven systems in Swiss industry. Applied Energy 2017;205:85–104. doi:10.1016/j.apenergy.2017.07.121.
[25] Zielvereinbarung mit der act oder der EnAW (UZV) n.d. https://www.umwelt.sg.ch/home/Themen/Energie/grossverbraucher/drei_wege_zur_zielerreichung/zielvereinbarungmitderenaw.html (accessed October 23, 2018).
[26] EnAW. Tätigkeitsbericht - Der Partner für Klimaschutz und Energieeffizienz. 2016.
[27] EnAW. Der partner für klimaschutz und energieeffizienz. Zürich: 2014.
[28] EnAW. Tätigkeitsbericht - Der Partner für Klimaschutz und Energieeffizienz. 2017.
[29] EnAW. Tätigkeitsbericht - Der Partner für Klimaschutz und Energieeffizienz. 2014.
[30] Phylipsen G, Blok K, Worrell E. Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry. Department of Science, Technology and Society, Utrecht University; 1998.
[31] Blok K. Introduction to Energy Analysis. Techne Press; 2007.
[32] FSO. Producer and Import Price Index, Producer Price Index (PPI) 2018. https://www.bfs.admin.ch/bfs/en/home/news/whats-new.assetdetail.6366021.html (accessed November 30, 2018).
[33] Blok K. Introduction to Energy Analysis. Techne Press; 2007.
[34] Neelis ML. Monitoring Industrial Energy and Carbon flows. Utrecht University; 2008.
[35] FOEN. Switzerland`s Greenhouse Gas Inventory 1990-2016. Bern: 2018.
[36] BFE. Zielvereinbarungen mit dem Bund zur Steigerung der Energieeffizienz. 2014.
[37] NACE Rev. 2 - Statistical classification of economic activities - Eurostat n.d. https://ec.europa.eu/eurostat/web/nace-rev2 (accessed October 26, 2018).
[38] FSO. General Classification of Economic Activities | Fact sheet 2016.
[39] Database - Eurostat n.d. https://ec.europa.eu/eurostat/data/database (accessed October 26, 2018).
[40] Price level index (PLI) - Statistics Explained n.d. https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Price_level_index_%28PLI%29 (accessed October 26, 2018).
[41] BFE. Energieverbrauch in der Industrie und im Dienstleistungssektor. BFE; 2017.
[42] Saygin D, Patel MK, Worrell E, Tam C, Gielen DJ. Potential of best practice technology to improve energy efficiency in the global chemical and petrochemical sector. Energy 2011; 36:5779–90. doi:10.1016/j.energy.2011.05.019.
[43] Farla J, Blok K, Schipper L. Energy efficiency developments in the pulp and paper industry: A cross-country comparison using physical production data. Energy Policy 1997; 25:745–58. doi:10.1016/S0301-4215(97)00065-7.
[44] Saygin D, Patel MK, Gielen DJ. Global industrial energy efficiency benchmark : an energy policy tool-working paper. UNIDO; 2010.
[45] Hendrickson J. Energy Use in the U.S. Food System: a summary of existing research and analysis 2008.
[46] Murray A, Lagrange L. Theoretical energy calculations for food processing under South African conditions. Procedia Food Science 2011; 1:1778–84. doi:10.1016/j.profoo.2011.09.261.
[47] Pydipati T. Energy Use of Print vs. Electronic Media 2010.
[48] CMP. Environmental reporting - Material Balance 2014.
[49] Energy Efficiency Centre. Energy saving potential - Soap n.d. http://www.eec-fncci.org/content-learn-soap#content-learn-soap_energy_efficiency (accessed October 26, 2018).
[50] Habitat. Energy for Building: Improving Energy Efficiency in Construction and in the Production of Building Materials in Developing Countries. United Nations Centre for Human Settlements (Habitat); 1991.
[51] Zuberi MJS, Patel MK. Bottom-up analysis of energy efficiency improvement and CO_2 emission reduction potentials in the Swiss cement industry. Journal of Cleaner Production 2017; 142, Part 4:4294–309. doi:10.1016/j.jclepro.2016.11.178.
[52] Ecofys. Methodology for the free allocation of emission allowances in the EU ETS post 2012 - Sector report for the mineral wool industry. 2009.

[53] Helsel ZR. Energy Use and Efficiency in Pest Control, Including Pesticide Production, Use, and Management Options 2016.
[54] Bhadbhade N, Zuberi MJS, Patel MK. Bottom-up analysis of energy efficiency improvement and CO2 emission reduction potentials in Swiss metals sector. Forthcoming 2019.
[55] Energy Efficiency Indicators | Odyssee | Energy efficiency in Europe n.d. http://www.indicators.odyssee-mure.eu/ (accessed October 26, 2018).
[56] Bhadbhade N, Yilmaz S, Patel MK. Energy efficiency development of Swiss economy. Forthcoming 2019.
[57] Zuberi MJS, Patel MK. Cost-effectiveness analysis of energy efficiency measures in the Swiss chemical and pharmaceutical industry. Int J Energy Res 2018. doi:10.1002/er.4267.
[58] Zuberi MJS, Patel MK. The importance of additionality in evaluating the economic viability of motor-related energy efficiency measures, Rome, Italy: 2017.
[59] Scienceindustries. The Swiss Chemical and Pharmaceutical Industry. Zurich: 2012.
[60] FSO. Establishments and employed persons by economic branch and establishment's size class, secondary sector 2016. https://www.pxweb.bfs.admin.ch/Selection.aspx?px_language=de&px_db=px-x-0602010000_101&px_tableid=px-x-0602010000_101\px-x-0602010000_101.px&px_type=PX (accessed July 14, 2016).
[61] Pehnt M, Bödeker J, Arens M, Jochem E, Idrissova F. Die Nutzung industrieller Abwärme technisch-wirtschaftliche Potenziale und energiepolitische Umsetzung. Heidelberg, Karlsruhe: 2010.
[62] Jakob M, Häberli A. Stromeffizienz der Schweizer Wirtschaft-Auswertung und Szenarien aus der Erfahrung der EnAW. Zurich: TEP Eenergy; 2012.
[63] Mathis K, Huber BR. Energy Law and Economics. Springer; 2018.
[64] Palacios A. Techno-economic analysis of energy efficiency measures for industry implemented under the Negawatt Program of SIG. MSc thesis. University of Geneva, 2015.
[65] Fehr Advice. Anreizsysteme für eine wirksame CO_2 - Emissionsreduktion in Unternehmen: Positionspapier aus Sicht der Verhaltensökonomie 2017.

Highlights:

- A bottom-up method is developed for estimating the Swiss physical activity levels.
- Sector-specific energy efficiency indices are determined and analyzed.
- A detailed analysis of the data on Swiss target agreements is done.