Energy 191 (2020) 116526

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

The evolution of energy efficiency in Switzerland in the period 2000–2016

Navdeep Bhadbhade [a, *], Selin Yilmaz [a], Jibran S. Zuberi [a], Wolfgang Eichhammer [b, c], Martin K. Patel [a]

[a] Chair for Energy Efficiency, Department F.-A. Forel for Environmental and Aquatic Sciences, Institute for Environmental Sciences (ISE), University of Geneva, Switzerland
[b] Competence Center Energy Policy and Energy Markets, Fraunhofer Institute for Systems and Innovation Research ISI, Germany
[c] Copernicus Institute of Sustainable Development, Utrecht University, Netherlands

ARTICLE INFO

Article history:
Received 23 May 2019
Received in revised form
5 September 2019
Accepted 9 November 2019
Available online 14 November 2019

Keywords:
Energy efficiency
Decomposition analysis
Energy efficiency trends
Policy

ABSTRACT

Substantial improvement in traditional energy intensity indicator (4.5% p.a.) for Switzerland in the period 2000 to 2016 points towards strong decoupling of economic growth and energy demand. Since the improved energy intensity could be primarily driven by soaring value added, it is necessary to analyse 1) physical energy efficiency (EE) representing the contribution of technical progress to EE improvement and 2) the influence of other drivers of total final energy (TFE) demand. This work evaluates physical energy efficiency (EE) trends in Switzerland at various aggregation levels by applying the ODYSSEE energy efficiency index (ODEX). The ODEX methodology facilitates the estimation of physical (technical) EE trends based on subsector-specific physical activity indicators. Switzerland improved its physical EE by 1.4% p.a. in the period 2000–2016 with household being the fastest and industry being the slowest improving sector. Physical EE improvement was enhanced by structural change but it was partly offset by larger dwellings, more appliances per dwelling and physical activity growth. Although the combined indicator identifies Switzerland as the third best amongst the countries in ODYSEE database, individual sectors in Switzerland still need to increase their rate of EE improvement in order to meet the 2050 targets of Swiss Energy Strategy 2050.

1. Introduction

1.1. Background

Growing concerns about climate change, other environmental impacts and security of supply as well as economic considerations have been the main drivers for industrialised countries to curb their CO_2 emissions and the dependence on oil and gas [1–7]. Improving energy efficiency (EE) can help the countries achieve multiple objectives such as lowering the energy bill, reducing energy dependence, decreasing greenhouse gas (GHG) and non-GHG emission while maintaining or increasing the level of economic activity as well as improving overall sustainability, e.g. by raising the share of renewable energy [8]. EE targets provide a basis and motivation for national governments to establish policies, programs and mechanisms directed toward improved EE [9]. EE targets can be classified into several categories. Energy intensity targets are set to reduce the consumption of total final energy (TFE) per unit of economic activity. Countries such as China and Austria have set energy intensity targets as a percentage reduction compared to a certain base year [9]. The United States and Australia have energy productivity targets which aim to increase the economic activity per unit of energy consumed [9]. As a part of Energy Efficiency Directive (EED), European Union countries adopted a binding EE

Abbreviations: BAU, Business As Usual; CC, Climatic Corrections; Dw, Dwellings; EE, Energy Efficiency; EED, Energy Efficiency Directive; ES2050, Energy Strategy 2050; ETS, Emission Trading System; FSO, Federal Statistical Office; FSOM, First Set of Measures; GDP, Gross Domestic Product; GHG, Green-House Gas; Gtkm, Gross Tonne Kilometer; L, Level of energy intensity (or UC); LMDI, Log Mean Divisia Index; NACE, European Classification of Economic Activities; NOGA, General Classification of Economic Activities in Switzerland; NEP, New Energy Policy; ODEX, Odyssee Energy Efficiency Index; PPP, Purchase power parity; Pkm, Passenger Kilometer; SEC, Specific Energy Consumption; SFOE, Swiss Federal Office of Energy; T, Trend of EE improvement; TFE, Total Final Energy; Tkm, Tonne Kilometer; UC, Unit Consumption; Vkm, Vehicle Kilometer.

* Corresponding author.
E-mail address: navdeep.bhadbhade@unige.ch (N. Bhadbhade).

https://doi.org/10.1016/j.energy.2019.116526
0360-5442/

improvement target of 20% until 2020 and of 32.5% reduction until 2030 as compared to the projections of TFE for the business as usual scenario [10]. These targets were then translated to an absolute (primary and final) energy demand target. According to the Swiss Energy Strategy 2050 (ES2050), Switzerland relies on indicative targets according to which per person TFE demand should be reduced by 16% until 2020 and by 43% until 2035 as compared to the base year 2000 [11,12].

1.2. Methods applied to measure energy efficiency trends

EE indicators are widely considered as means for monitoring the impact of EE policies (usually packages of policies) and as basis for improved design of EE policies in order to achieve national targets [13]. To this end, EE indicators should be reliable (based on credible, available and comparable data), feasible (data cost, widely acceptable and respecting data confidentiality) and verifiable (data monitoring and feedback) [14]. There is a substantial body of international literature on the development, assessment and comparison of EE indicators [13–22], serving as framework for cross-country comparison of EE trends [2,3], decomposition analysis to support policy design [23,24] as well as for benchmarking across countries, sectors and subsectors [25–32].

Traditionally, monetary EE indicators that relate energy use to economic output (e.g. GDP, value added) are used to track the EE performance at the higher level of aggregation (e.g. entire economy) [12,33]. Physical indicators relating the total energy consumed to the physical activity (e.g. tonnes of steel, passenger-kilometres) are generally considered as more closely linked to energy efficiency improvement than monetary EE indicators which are impacted by additional effects such as changes in the value of products, exchange rates etc. [1]. While hence being the preferred choice, they are typically used to track the EE performance at disaggregated levels such as a sector (e.g., residential sector, industry, transport, services) or – more frequently - subsectors (e.g., steel production, space heating, passenger transport etc.) [18]. Creating physical EE indicators for complex sectors with a large number of very diverse products (e.g. food or chemical sector) is not straightforward. The ODYSSEE EE index (ODEX) developed in the context of the ODYSSEE-MURE project (which covers EU28, Norway, Switzerland and Serbia) offers a number of advantages compared to the previous methodologies by allowing to establish EE trends at the higher levels of aggregation (i.e. complete economy or sector) based on subsector specific physical EE indicators and by comparing the trend and level of EE improvement across countries while respecting the sectoral heterogeneity [34] (see section 2.2 for detailed explanation).

1.3. Structure of economy and energy demand in Switzerland

As a result of a large service sector and high value added products in manufacturing, the GDP per person (at Purchasing Power Parity, PPP) is particularly high, making the Swiss economy the third most productive economy amongst the countries included in the ODYSSEE database (after Norway and Luxemburg) [35]. For per person consumption of final energy Switzerland is on the 11th rank, just above the EU average [35]. The Swiss service sector generates 74% of country's total GDP while consuming 17% of TFE [35,36]. The share of the Swiss service sector in GDP gradually increased in the period of 2000–2016 while the share of TFE consumed by the sector remained fairly constant. The industry sector is responsible for 25% GDP generated by the Swiss economy [35] while consuming 18% of TFE (Fig. 1 (a)). The share of industry in GDP as well as its TFE demand remained unchanged during the years 2000–2016. Agriculture contributed less than 1% of Switzerland's GDP. The shares of the transport and household sectors in TFE demand remained approximately at 37% and 28% respectively in the same period [37]. The majority of total primary energy demand of Switzerland is covered by oil products. However, during the period 2000 to 2016, the share of electricity, natural gas and coal grew at the expense of the shares of oil products and nuclear energy (see Fig. 1 (b)). Per person demand of TFE in Switzerland dropped by 14% (0.9% p.a.) from year 2000 until 2016 while the per person demand of electricity decreased by only 3% during the same period [12].

1.4. Energy efficiency policy in Switzerland

The energy article in Swiss energy legislation puts an obligation on the federal government and cantons to ensure an adequate, secure, economic and ecological energy supply and economical and efficient use of energy [40]. The Swiss Energy Strategy 2050 (ES2050) is structured into a so-called "First set of measures" (FSOM, partly implemented to date) which is foreseen to be complemented by a second package (New Energy Policy, NEP). Both packages aim to improve EE and to promote the development of renewable energy, thereby allowing to substantially reduce CO_2 emissions while phasing out nuclear energy [41]. Furthermore, specific directives and policy actions exist for subsectors. For example, an Energy Efficiency Directive (EnV 730.01, 1998R) was implemented which specifies both energy performance for buildings and energy labelling for appliances (in line with EU legislation) [42]. For a number of household appliances, Swiss minimum energy performance standards are stricter than in the EU, making Switzerland a forerunner in this domain [43]. Within the industry sector, large energy consuming and greenhouse gas (GHG) intensive companies in Swiss industry sector are obliged to participate in the Swiss emission trading scheme (ETS) which was introduced in 2008 along with the CO_2 levy in order to curb GHG emissions [44]. Larger companies which are not regulated by ETS can enter into an agreement with the Federal office, the canton or third-party government mandated agencies (e.g. EnAW, act) to commit themselves to reduce GHG emissions, allowing them to get exempted from the CO_2 levy [45] and to obtain full or partial refund of the renewable energy network surcharge (KEV) [46]. A distance-related heavy vehicle fee is levied upon vehicles exceeding a maximum weight limit of 3.5 tonnes. As in the EU, CO_2 emission standards have been implemented in Switzerland for passenger cars to regulate the maximum level of CO_2 emissions per kilometer travelled [45].

1.5. Aims and objectives

In order to obtain a first understanding of the efficacy of current policy measures and the progress made towards target achievement, the nature and structure of energy use by sector need to be analysed as well as the underlying drivers and barriers. Against this background, the objectives of the current study are:

1. *To estimate the evolution of EE* in Switzerland at different levels of aggregation (i.e. Switzerland as whole, individual sectors and subsectors) and to make comparisons to the targets set by Swiss energy policy.
2. To *understand the factors driving the changes* in TFE demand of Swiss economic sectors by performing a decomposition analysis.
3. To *compare the EE trends and levels* of Switzerland by individual sectors with EU countries (at sector level).

This study further aims to provide better insight into the status and evolution of EE by comparing the EE trend of subsectors based

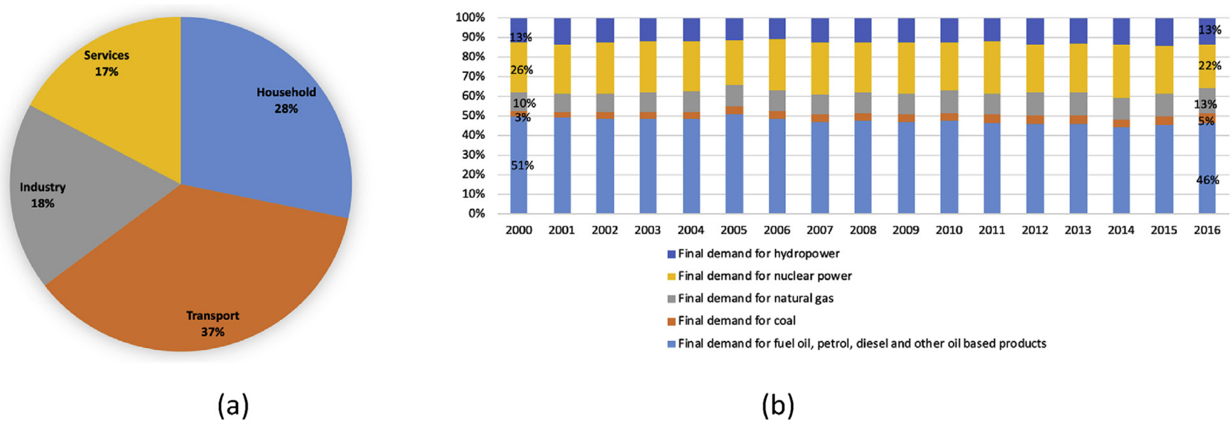

Fig. 1. (a)[11] Share of sectors in TFE demand of Switzerland in 2016 (b) Share of energy carriers in TFE demand of Switzerland (Source: Swiss Federal Office of Energy (SFOE), 2017 [38,39]).

on different activity indicators. The remainder of this paper is organised as follows. Section 2 describes the methodology adopted for the analysis of EE, decomposition analysis, cross-country comparison and benchmarking. Section 3 presents the results of EE trends analysis and decomposition analysis accompanied by a discussion about the comparison of Switzerland with other countries in ODYSSEE database (i.e. the position of Switzerland amongst countries included in ODYSSEE database) based on the level and the trend of EE improvement followed by the comparison of EE trends based on different activity indicators and comparison of current EE trend against the targets established by ES2050. Section 4 concludes.

2. Methodology

2.1. Data sources

To analyse the EE trends, a large dataset has been compiled consisting of macro-economic data (for tracking the development of the complete economy) to energy demand and activity levels of individual sectors (households, service, transport and industry; see Appendix A). The data required for estimating the subsectoral EE indices originates from publicly available national statistics and confidential data sources in some cases. The data required for cross-country comparison originates from the ODYSSEE-MURE database [35].

2.2. Odyssee energy efficiency index (ODEX)

In this study, we use the so-called ODEX, an index developed by the ODYSSEE-MURE project [34], to measure the physical EE progress by sector and for the whole country. The ODEX at the level of the national economy (Global ODEX) is an aggregation of physical EE trends (ODEXs) of the economic sectors (industry and services) as well as households and transport sectors based on their share in TFE demand (eq. (3)). The EE trends for an individual sector is estimated by aggregating the EE trends of the subsectors/end-uses weighted by their respective shares in TFE demand (eqs. (1) and (2)) (except for services; see section 2.2.4). For the subsectors, end uses or transport modes, the EE is tracked with the unit energy consumption index (UC; for details see sections 2.2.1–2.2.4).

$$I_{i,t-1}/I_{i,t} = \sum_j \left(\frac{UC_{j,t}}{UC_{j,t-1}} \times ES_{j,t} \right) \quad (1)$$

where

$I_{i,\ t-1}/I_{i,t}$ = An aggregate index of sector i for the UC variation between the years t-1 and t
$UC_{j,t}$ = Unit Consumption index of subsector or end-use j for the year t (e.g. GJ/tonne product, GJ/pkm, GJ/m^2).
$UC_{j,t-1}$ = Unit Consumption index of subsector or end use j for the previous year t-1 (e.g. GJ/tonne product, GJ/pkm, GJ/m^2).
$ES_{j,t}$ = Final Energy demand Share of subsector, end use or transport mode j for year t

In order to harmonize the scale across all sectors, the ODEX of the first year is set to 100. For each subsequent year, the ODEX for the previous year is multiplied by the reciprocal of eq. (1) (see eq. (2)) (the ODEX value hence decreases with improving EE).

$$ODEX_{i,t} = s \times \left(I_{i,t}/I_{i,t-1} \right). \text{With} s = \begin{cases} 100, t=t_0 \\ ODEX_{t-1}, t>t_0 \end{cases} \text{and} t = t_0, t_1, t_2 \ldots \quad (2)$$

where

S = Scaling factor
$ODEX_{i,t}$ = ODYSSEE energy efficiency index of sector i for the year t
$ODEX_{i,t-1}$ = ODYSSEE energy efficiency index of sector i for the year t-1

$$ODEX_{global,t} = \sum_y ODEX_{i,t} \times ES_{i,t} \quad (3)$$

where

$ODEX_{i,t}$ = ODEX of sector i for year t (i = household, transport, industry and services)
$ES_{i,t}$ = Final Energy demand Share of sector i for year t

2.2.1. Household ODEX

The ODEX for the household sector is estimated by aggregating the UC trends of three end uses (space heating, water heating and cooking) and five large appliances (refrigerators, freezers, washing machines dishwashers and TVs) based on their share in TFE demand of the household sector (equation Eqn 1). The UC trend for residential space heating can either be expressed i) per unit of floor space (m^2), or ii) per dwelling (for comparison see section 3.8). The first option (i) was chosen for the ODEX methodology because it is closest to the technical efficiency and it does not depend on changes in the size of the dwelling. The indicators for hot water and cooking are determined by dividing the respective final energy use by the number of occupied dwellings (this is reasonable because households typically have one stove or washing machine and division by floor area or the average number of inhabitants would be less meaningful). The UC for appliances is calculated as the ratio of annual final energy consumed by a particular appliance type and its stock (kWh/appliance/year). The UC indices of the individual appliance types are weighted by their share in TFE in order to establish an EE trend for all five large appliances.

2.2.2. Transport ODEX

The UC indices of eight transport modes (cars, trucks, light vehicles, motorcycles, buses, air transport, rail, and water transport) are aggregated using their final energy shares as weighting factors to establish the overall EE trend (equation (1)). The EE of cars can be calculated based on several physical activity indicators viz. i) passenger-km (pkm), ii) vehicle-km (vkm) or iii) vehicle stock (see section 3.8 for comparison) [34]. For the estimation of transport ODEX, the EE indicator based on pkm is chosen which is a widely applied activity indicator. It provides a measure of EE, thereby accounting for distance travelled and occupancy level along with an overview of modal shift at higher aggregation [47]. The activity indicator pkm (published as statistical data, see Appendix A) is the result of multiplying the number of passengers by the average distance per passenger. The UC for air transport is tracked using the energy consumed per passenger due to lack of data on pkm. For the same reason, the UC for buses and motorcycles is calculated as energy consumed per vehicle.

For transport of goods by trucks, light vehicles and water transport, the UC is calculated by dividing final energy use by physical activity in tonne-km (tkm, published as statistical data) which is the result of multiplying the weight of goods (in tonnes) by the average distance of transport (in km). Due to transport of both passengers and freight by rail (pkm for passenger and tkm for freight), an aggregate indicator, Gross tonne-km (Gtkm)[2] is used to track physical activity.

2.2.3. Industry ODEX

The ODEX for the industry sector is again a TFE-weighted aggregate of subsectoral UC indices (e.g. indexed form of calculated at the level of two-digit NOGA/NACE classification). UC indices for homogeneous and heterogeneous subsectors are established using different methodologies. The UC trends for the homogeneous subsectors such as steel, cement and paper production are determined using the change in TFE consumed per unit of physical output (kt) of the subsector (e.g., per tonne of cement). UC trends for heterogeneous subsectors such as food and beverage, chemicals and pharma, textile and leather or subsectors with data limitations due to confidentiality of physical production data such as machinery and fabrication, other primary metals (primary metals minus steel), other non-metallic minerals (non-metallic minerals minus cement) and printing are calculated as the change in energy demand relative to the change in production index proxy (PIP). The PIP is determined by deflating the turnover for each subsector (2-digit NOGA) by the producer price index. The process of deflation using the producer price index removes the effect of price changes from the turnover and results in the trend of physical production over time [48] (for details see Appendix B). While more traditional monetary indicators are not used for the EE trend analysis in the ODEX methodology, the comparison of physical EE and monetary EE (Energy demand/Value added) offers valuable insight into the effects of structural shifts occurring at the sectoral and subsectoral level (see Section 3.8).

2.2.4. Tertiary ODEX

The tertiary ODEX is calculated by aggregating EE trends for electricity and fuel demand based on their share in TFE of the service sector (see eq. (4)). The EE trends of the service sector's for electricity and fuel demand are established by aggregating UC indices for electricity and fuel respectively for individual subsectors (public administration and government services building, offices, hotels & restaurants, hospitals, wholesale and retail trade services building and education buildings) based on their respective share in final energy (see eqs. (5) and (6)). The UC trend for electricity (and fuel) is estimated as the ratio of the subsector's electricity (and fuel) demand and its number of employees (as closest proxy for floor space in m^2; data on the latter are typically not available at the subsectoral level.).

$$I_{i,t-1}/I_{i,t} = \left(\frac{UCE_t}{UCE_{t-1}}\right) \times ES_t + \left(\frac{UCF_t}{UCF_{t-1}}\right) \times FS_t \tag{4}$$

where

UCE_t *and* UCE_{t-1} = Unit consumption index for electricity demand of service sector year t and t-1 respectively (see eq. (5))
UCF_t *and* UCF_{t-1} = Unit consumption index for fuel demand of service sector for year t and t-1 respectively (see eq. (6))
ES_t = Share of electricity demand in TFE of services for year t
FS_t = Share of fuel demand in TFE of service sector for year t

$$UCE_t = \sum_j \left(\frac{UCE_{j,t}}{UCE_{j,t0}} \times ES_{j,t}\right) \tag{5}$$

$$UCF_t = \sum_j \left(\frac{UCF_{j,t}}{UCF_{j,t0}} \times FS_{j,t}\right) \tag{6}$$

where.

$UCE_{j,t}$ *and* $UCE_{j,t0}$ = Unit consumption index for electricity demand of subsector j for year t and year t_0 respectively
$UCF_{j,t}$ *and* $UCF_{j,t0}$ = Unit consumption index for fuel demand of subsector j for year t and year t_0 respectively
$ES_{j,t}$ = Share of electricity of subsector j in electricity demand of service sector
$FS_{j,t}$ = Share of fuel demand of subsector j in fuel demand of service sector

The tertiary ODEX is then estimated based on equations (4) and (2).

2.3. Decomposition analysis

The variation in TFE demand of the complete country between

[1] Refer to Appendix D for energy demand profile and shares of subsectors in energy demand of each sector.

[2] The Gtkm indicator is calculated by weighting each passenger-km by a factor of 1.7 and each tonne-km by a factor of 2.5 (i.e. Gtkm = 1.7*pkm+2.5*tkm) (34. ODYSSEE-MURE, *Definition of data and energy efficiency indicators in ODYSSEE database*.).

Table 1
Variables that explain the variation on final energy demand and used in the decomposition analysis for each sector.

Sectors	Variables that explain the variation
Households	•Demographic effect: the effect of change in number of dwellings •Larger homes: the effect of change in floor area •Lifestyle effect: the effect of change in household equipment ownership •Climatic effect: the effect of annual change in climatic conditions[5] •Energy savings: the effect of technical development •Other effects: the effect of change in heating behaviour
Services	•Activity effect: the effect of a change in the value added of tertiary Note: the activity indicator chosen for decomposition (value added) differs from the one used for ODEX (number of employees, see section 3.4) •Productivity effect: the change in the ratio of the value added per employment •Climatic effect: the effect of annual change in climatic conditions •Energy savings: the decrease in the energy consumed per employee by subsector •Other effects
Transport	•Activity effect: the effect of change in activity, i.e. person-kilometres (pkm) for person transport and tonne-kilometres (tkm) for goods •Modal shift: the effect of change in the distribution of various transport modes within the sector •Energy savings: the effect of technical improvements •Other effects: the effect of inefficient utilization of capacity for goods transport
Industry	•Activity effect: the effect of change in the physical activity (measured by either physical production statistics or production index estimated from the turnover) •Structural effect: the effect of different rates of growth of energy intensive and non-energy-intensive subsectors of the industry •Energy savings: the effect of technical improvement •Other effects: the effect of inefficient utilization of capacity

[5] The climatic effect is calculated by difference between the variation between t and t_0 (in our case 2016 and 2000, respectively) of the actual energy consumption and the variation between t and t_0 of the energy consumption with climatic corrections.

two given years is decomposed into the activity effect (cumulative activity effect of all sectors), demography effect (number of dwellings), the effect of lifestyle (size of the dwellings and number of appliances per dwelling), the effect of structural change in industry, the effect of annual variations in climate[3] and other effects capturing the inefficiencies in the capacity utilization. The key influencing factors for the TFE demand of individual sectors are summarised in Table 1. Throughout the literature, the Log Mean Divisia Index methods (LMDI 1 and 2) are the preferred choice for the decomposition of TFE demand [23,24,49–52]. These LMDI methods generally consist of three-factor identity for the influencing factors and without any residual term [52], while the method used in the present paper consists of multiple effect identity for the decomposition of final energy demand[4] by sector and by influencing factor with a residual term capturing the effect of inefficient capacity utilization. The formulae developed for the present method mainly differ from LMDI methods in terms of the weighting function used to calculate the influencing factors. The chosen method has the advantage that the contribution of EE can be readily be derived from the trend of ODEX [49].

2.4. Cross country comparison: indicator scoreboard

Comparison of EE trends across countries helps understanding the adequacy of policy measures taken to improve EE [3] and to save energy. This is facilitated by scoring and ranking the countries included in the ODYSSEE database according the level of energy consumption (level indicator) and the rate of EE improvement (trend indicator). The scores for level and trend are calculated for a list of selected indicators representative of end uses, transport modes or subsectors[6] and are normalised (between 1 and 0; 1 being the best) in order to assign the ranks (see Fig. 2). The normalised scores (level and trend) are then aggregated at the sectoral level for each country based on the TFE demand shares of end use, subsector or transport mode respectively. The level and trend scores for each sector are aggregated with equal weight to form a combined level and trend score for each sector of each country. In contrast, no separate scores are estimated for industry at the level of subsectors. The level score for industry is based on *energy intensity* and is calculated assuming for all countries an adjusted EU average industry structure based on the shares of value added (creating a harmonised basis by assuming a common industry structure). The trend score for industry is based on *ODEX* which represents the *total* sector (ODEX is unit less and can therefore not be used as indicator for the level score). The two scores (level, trend) estimated for the sectors are then aggregated to the country level based on their shares of TFE demand. Combined score for country is obtained in the same manner as at the sector level, i.e. by assigning 50% weight to trend and level scores. The global scores are again normalised in order to assign overall rankings [53,54].

3. Results and discussion

3.1. Household sector

Table 2 summarises the trends of activity (number of dwellings) and structural changes (floor area and number appliances per dwelling), TFE demand with climatic corrections[7] (CC) as average annual rates[8] (% p.a.) and EE improvement (ODEX) based on ODEX methodology for each end use of the household sector between 2000 and 2016. For energy indicators and EE trends, TFE is always shown with CC, allowing to better understand the trends

[3] Contrary to all other totals of TFE demand presented in this paper, the total presented in the decomposition analysis (first bar on the left in Figs. 4, 10 and 12) is *not* climate corrected. This choice was made in order to display the effect of the difference in climate conditions in the base year and the target year.

[4] The detailed formulae for estimation of explanatory factors are available in methodological report published by ODYSSEE-MURE (49. ODYSSEE-MURE, *Understanding variation in energy consumption - Methodological report.*).

[6] Household – Space heating, other thermal uses, appliances, penetration of solar water heaters; Transport – Cars, trucks/light vehicles, air transport, modal split; Services – Fuel and Electricity consumption.

[7] An energy demand with climate corrections is the demand which would have occurred, with a normal climate over the heating periods (i.e. the absolute value was corrected by heating degree days). The normal climate is defined as the average climate observed over a certain period over the past (16 years in our case).

[8] Average annual rate is calculated by averaging the change (increase/decrease) over the years by fitting to a simple linear model.

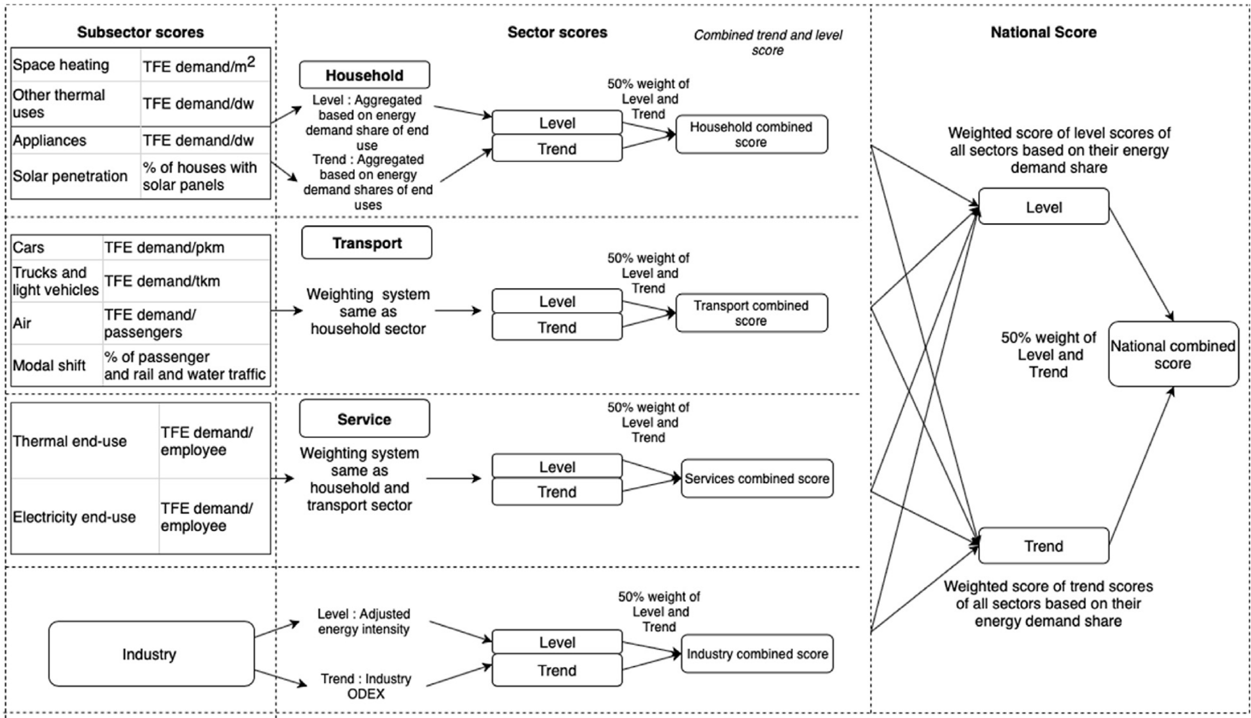

Fig. 2. Indicator scoring methodology (Source: ODYSSEE scoreboard methodology [53]).

Table 2
Swiss household sector — Share of TFE and annual change of TFE, activity and EE improvement between 2000 and 2016.

End use	Share of TFE[a]	TFE demand (with CC)	Activity/Structural changes	EE improvement
Space heating	76%	−0.6%	1.3% (Floor area)	1.9%
Hot water[b]	14%	−0.01%	1.0% (Dwellings)	1.0%
Cooking	3%	0.5%	1.0% (Dwellings)	0.5%
Large electrical appliances	7%	1.5%	2.6% (Stock of appliances)	1.2%
Total		**−0.1%**		**1.7% (ODEX)**

[a] Average share of last three years.
[b] The TFE demand for the hot water and cooking demand did not exhibit a linear trend therefore the average annual rate is calculated by using the values of only the values of the first (2000) and last year (2016).

underlying energy demand (exceptions: total TFE demand in decomposition analysis in Figs. 4, 10 and 12).

The trends of TFE demand and EE improvement (ODEX) are plotted in Fig. 3. According to Table 2 the Swiss household sector TFE (with CC) in absolute terms decreased at an average annual rate of 0.1% while all the indicators of activity (dwellings and floor area) displayed growth. Based on the ODEX methodology, total final EE for the household sector improved at the rate of 1.7% per year (i.e. 23% improvement in 16 years). The growing floor area at an average annual rate of 1.3% was outpaced by the rapid efficiency improvement of the space heating (1.9% p.a.), resulting in an overall reduction of space heating demand of 0.6% p.a. The stock of electrical appliances grew at an average annual rate of 2.6%. However, thanks to the EE improvement rate of 1.2% p.a., the TFE of the appliances grew at a rate of only 1.5% p.a.

The decomposition analysis (Fig. 4) shows that the increase of

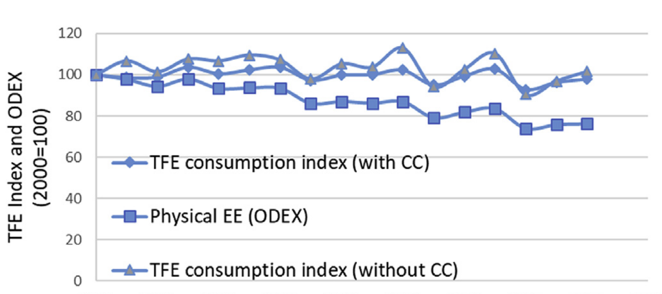

Fig. 3. Swiss household sector - Trend of physical EE and TFE demand (with climatic corrections, 2000–2016).

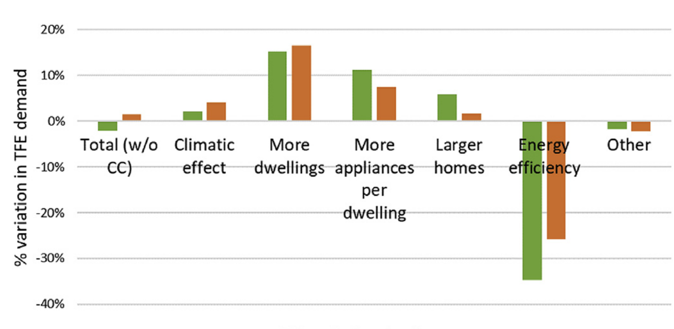

Fig. 4. Swiss and EU household sector - Decomposition analysis for TFE (2000–2016).

TFE demand (*nominal value*, without CC – first curve from the top in Fig. 3 and first bar in Fig. 4) of the Swiss household sector from 2000 to 2016 can be explained by the number of dwellings (resulting in +17% TFE), climatic effects (+4% TFE) (see in Section 2.3 for the definition), number of appliances per dwelling (+7% TFE), and the size of the dwellings (+2% TFE). The increase in TFE is counteracted to some extent by EE (−26% TFE) in combination with "Other factors" (−2% TFE) which include behaviour changes (due to combined effect of price increases and economic recession). It should be noted that the orange bar section for "Climatic effect" is clearly positive, implying that, in Switzerland, 2016 was a colder year than 2000. Had the "Climatic effect" been at the same level in 2016 as in 2000, TFE demand of the household sector would have clearly decreased. At the EU level, the same aforementioned factors were found to contribute to an increase in TFE demand of the household sector. However, Adding up the various components, total TFE demand (without CC) of the household sector in the EU slightly dropped [55].

3.2. Transport sector

The average annual rates of EE improvement, TFE demand and the activity for all transport modes are summarised in Table 3 along with their respective shares in TFE. The activity of transport sector measured in pkm (for passenger transport) and tkm (for goods transport) grew at 1.4% and 1.8% p.a. respectively. Both transport activity and EE improvement were dominated by private transport. As a consequence of the EE improvement of the total transport sector (Transport ODEX) at a rate of 1.5% p.a. from 2000 to 2016 (20% overall improvement in 16 years), the transport sector's TFE in absolute terms hardly changed (0.01% p.a. increase; Fig. 5). Cars and air transport, together responsible for nearly 75% of the TFE consumed by the Swiss transport sector, improved their EE at a rate of 2% p.a. The EE of motorcycles (estimated as energy consumed/vehicle) improved fastest (2.8% p.a.). This finding is likely to be related to the chosen metric (energy consumed/vehicle instead of e.g. energy per pkm or vkm, as a consequence of data availability). The EE improvement rate was slowest for trucks and light vehicles (responsible for 17% of TFE demand) and the EE of buses even deteriorated according to our analysis.

Fig. 6 presents the contribution of selected factors in the change of the Swiss transport sector's TFE demand from 2000 to 2016. The activity (+27% TFE) and EE (−27% TFE) were the two main explanatory variables for the variation of TFE of the transport sector, with the two effects nearly offsetting each other. Although the impact of modal shift (−1% TFE) and other effects (+2% TFE) was negligible, it still indicates a slight increase in the share of public transport in Switzerland. For the variation of TFE of the transport sector at the level of EU, the activity growth (+20% TFE) (in pkm and tkm) outweighed EE improvement savings (−16% TFE), resulting in an increase of the sector's TFE (7%).

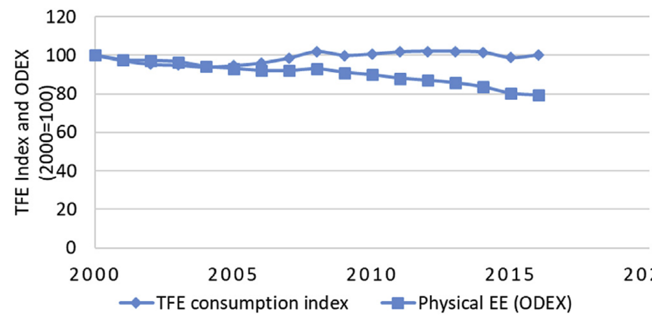

Fig. 5. Swiss transport sector - Trend of physical EE and TFE demand (2000–2016).

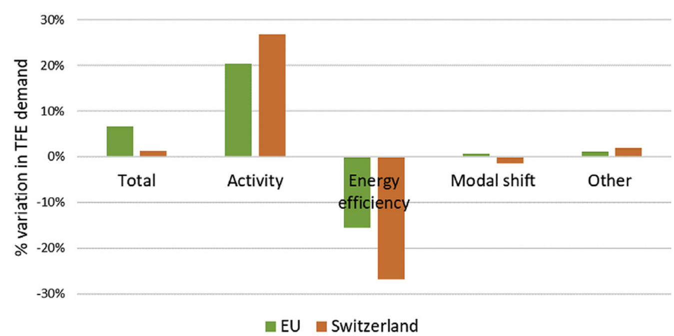

Fig. 6. Swiss and EU transport sector - Decomposition analysis for TFE (2000–2016).

3.3. Industry sector

Table 4 provides the TFE shares and average annual rates of change for TFE and EE improvement of the major energy consuming industry subsectors. The TFE demand of the total Swiss industry decreased at the rate of 0.8% p.a. in spite of an increase in the activity by 1.8% p.a. Based on the industry ODEX calculation (see section 2.2.3), the EE of the Swiss industry improved at a moderate rate of 1.0% p.a. from 2000 to 2016 (15% improvement overall in 16 years; see Fig. 7).

As evidenced by the physical activity indicators, the paper sector (−1.3% p.a.) and non-metallic mineral sector (−2.3% p.a.) are shrinking. However, the average annual rate of physical EE improvement was highest for the paper and pulp sector (by 2.6% p.a., possibly due to consolidation of the sector) whereas the physical EE of non-metallic minerals deteriorated from 2000 to 2016 (by −1.9% p.a.; a possible reason may be structural change within this sector as indicated by difference in monetary and physical EE trend). The physical EE for the chemical and food and beverage sector improved at a low average annual rate of 0.3% and 0.2% respectively. Basic metals sector was the second fastest improving subsector from 2000 to 2016 in terms of physical EE

Table 3
Swiss transport sector – Share of TFE and annual change of TFE, activity and EE improvement between 2000 and 2016.

Mode of transport	Share of TFE[a]	TFE	Activity	EE improvement
Cars	52%	−0.6%	1.4% (pkm)	2.0%
Buses	3%	2.6%	−0.1% (stock)	−2.8%
Trucks and light vehicles	17%	1.2%	1.4% (tkm)	0.1%
Motorcycles	1%	−0.5%	2.1% (stock)	2.8%
Air transport	23%	0.3%	2.5% (passengers)	2.1%
Rail transport	4%	0.9%	1.8% (Gtkm)	0.9%
Total		**0.01%**	**1.4% (pkm)** **1.8% (tkm)**	**1.5% (ODEX)**

[a] Average share of last three years.

Table 4
Swiss industry (selected subsectors) – Share of TFE and annual change of TFE, activity and EE improvement between 2000 and 2016 (2000–2016).

Subsector	TFE share[a]	TFE demand	Physical activity[9]	Monetary activity	Physical EE improvement	Monetary EE improvement
Chemical and Pharmaceutical	25%	−0.2%	0.05% (PIP)	6.7%	0.3%	6%
Basic metals	8%	−0.8%	0.7% (PI)	0.1%	1.5%	0.9%
Non-metallic minerals (including cement)	12%	−0.3%	−2.3%[10] (PI)	3.4%	−1.9%	4.7%
Food and beverage	12%	0.9%	1.1% (PIP)	3.9%	0.2%	3.1%
Paper and pulp	8%	−3.9%	−1.3% (PI)	−1.0%	2.6%	4.0%
Other industries	35%	−1.6%	0.6%	4.8%	2.2%	6.4%
Total	**100%**	**−0.8%**	**1.8% (PIP)**[b]	**5.6%**	**1.0%(ODEX)**[c]	**5.3%**

[a] Average share of last three years.
[b] This activity index is obtained from national statistics which is calculated by deflating the turnover for complete industry.
[c] This is an aggregate EE indicator calculated based on individual EE indicators of subsectors (see methodology section 2.2).
[9] Physical activity for homogeneous sectors is estimated based on physical production (PI) whereas the physical activity trend for the heterogeneous sector is estimated using turnover statistics (PIP; details in Appendix B).
[10] Although the activity of non-metallic sector is decreasing, the activity of cement production (which is a subsector of the non-metallic sector) is growing at 1% p.a.

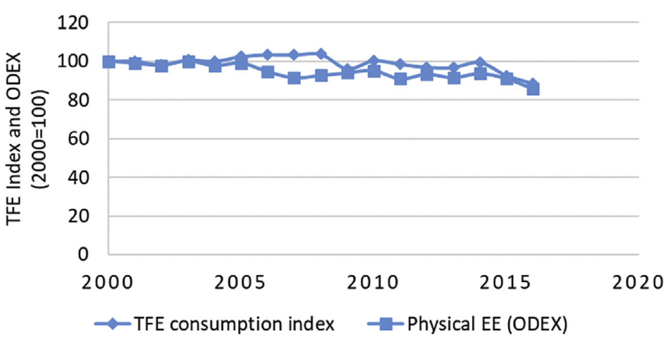

Fig. 7. Swiss industry sector[1] - Trend of Physical EE and TFE demand (2000–2016)[11].

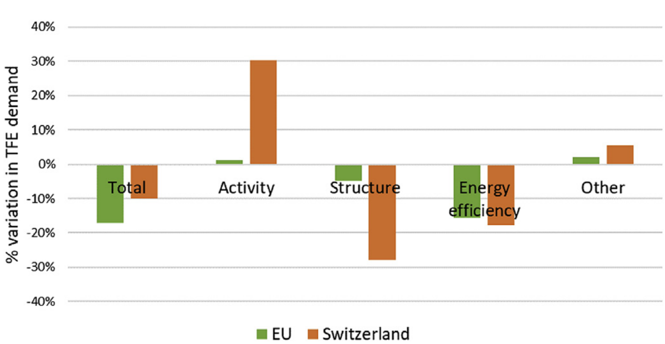

Fig. 8. Swiss and EU industry sector - Decomposition analysis for TFE (2004–2016)[1] [12].

(1.5% p.a.).

Fig. 8 shows the decomposition analysis performed for the industry sector. Although the physical activity of the Swiss industry sector increased (30% TFE), the combined effect of structural change (−28% TFE) and EE (−18% TFE) resulted in a clear decrease of the Swiss sector's TFE demand from 2004 to 2016. The strong contribution of structural change to the reduction in Swiss industry's TFE demand indicates that subsectors whose products have a relatively low Specific energy consumption (SEC) grew faster than subsectors characterized by products with high SEC. In fact, the production level of the subsector with the highest SEC, paper and pulp production, decreased while the subsectors with low SECs such as cement and steel grew relatively fast, thus contributing to lowering of the TFE demand (see appendix C; Fig. C2). At the level of EU (1.2% p.a. decrease of TFE), the contribution of activity was negligible (+1% TFE) and structural change played only a minor role (−5% TFE) while EE contributed more significantly to the reduction in TFE demand (−16% TFE; similar contribution as in Switzerland).

3.4. Service sector

The average annual rates of EE improvement, activity change and UC change for the subsectors of the service sector are summarised in Table 5. The activity of service sector, measured in the number of employees, grew at an average annual rate of 1.4%, while the floor space increased at the rate of 0.9% per year. The average annual improvement of physical EE (tertiary ODEX, based on employees) at the rate of 1.0%, together with a negligible contribution of structural change (not displayed), resulted in almost no reduction of TFE demand (with CC) of the Swiss service sector (changed

Table 5
Swiss service sector – Share of TFE and annual change of TFE, employees (activity indicator) and EE improvement between 2000 and 2016.

Subsector	Activity (number of employees)	TFE demand	Share in fuel demand[a]	Share in electricity demand[a]	Fuel EE improvement	Electricity EE improvement	EE improvement
Offices	1.5%	0.4%	49%	57%	1.9%	0.2%	0.9%
Health and social work	2.8%	0.31%	13%	10%	2.9%	1.4%	2.3%
Wholesale	0.3%	−0.5%	19%	20%	1.4%	−0.01%	0.7%
Hotels and restaurants	−0.8%	−0.1%	11%	11%	0.4%	−0.9%	−0.7%
Education	1.7%	1.6%	1%	1%	0.7%	−1.1%	0.01%
Other[b]	1.8%	−2.1%	7%	5%	4.8%	1.9%	3.5%
Total	**1.4%**	**−0.04%**	**51% (Share of TFE of services)**	**49% (Share of TFE of services)**	**1.8%**	**0.2%**	**1.0% (ODEX)**

[a] Average share of last three years.
[b] The TFE of the complete service sector is adopted from (SFOE) [56] while the TFE demand for individual subsectors is adopted from (FSO) [57]. The sum of the TFE values across all individual subsectors (FSO) does not coincide with the total according to SFOE due to inconsistency of the two statistics. In order to make the totals match we adjusted the TFE demand of the subsector "other".

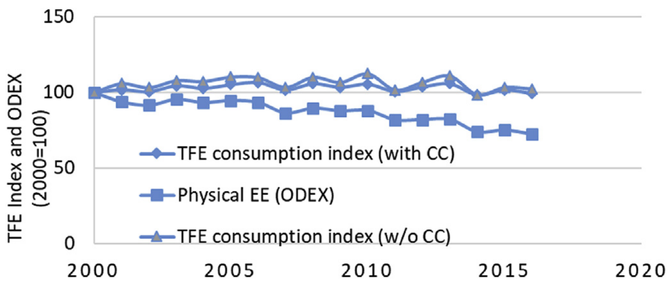

Fig. 9. Swiss service sector - Trend of physical EE and TFE demand (with climatic corrections, 2000–2016).

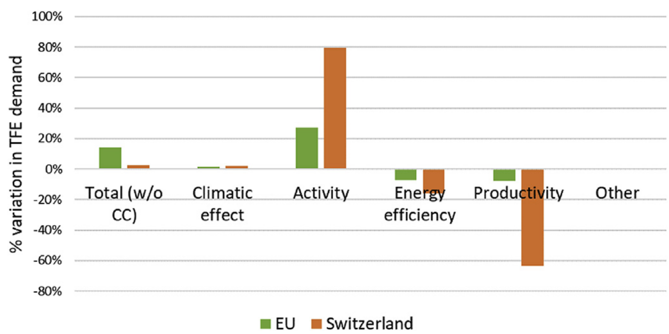

Fig. 10. Swiss and EU service sector - Decomposition analysis for TFE (2000–2016[1])[13].

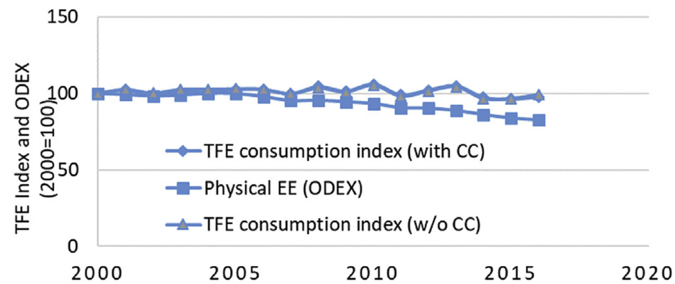

Fig. 11. Trend of physical EE and TFE demand for Switzerland as a whole (2000–2016).

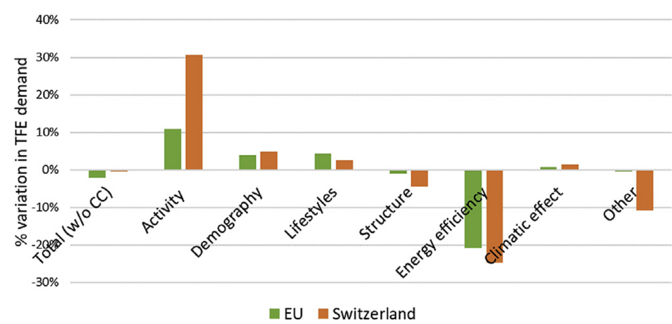

Fig. 12. Decomposition analysis of TFE variation for Switzerland and EU (all sectors), 2004–201[1]6[15].

at a rate of -0.04% p.a.) from 2000 to 2016 (see Fig. 9). The EE of “Other sectors”, improved at the fastest rate amongst the subsectors of Swiss service sector followed by health & social work and wholesale subsectors. In contrast, the rate of total final EE improvement was lowest for education (0.01% p.a.), only surpassed by hotels and restaurants where EE even deteriorated (−0.7% p.a.) in the period from 2000 to 2016.

The decomposition analysis presented in Fig. 10 shows that TFE demand of the service sector marginally increased in nominal terms (2%, without CC; first curve from the top in Fig. 9 and first bar in Fig. 10) from 2000 to 2016 (note that the TFE demand in Table 5 is climatically corrected value). Although the EE (−16% TFE) and employee productivity (Value added/employee; −64% TFE) contribute towards the TFE demand reduction, the impact of activity growth in terms of value added (+80% TFE), together with other factors (+1% TFE) and climatic effect (+2% TFE) was more dominant, resulting in the above-mentioned slight overall increase of the service sector’s TFE demand. A similar trend could also be observed at the level of EU, however less pronounced changes in activity (+27% TFE), EE (−7% TFE) and productivity (−8% TFE), overall resulting in a more significant rise of TFE (+14%) compared to Switzerland. Although the UC in ODEX calculation is based on the activity indicator “number of employees” (as the closest proxy for floor space), the value added is better suited as the activity indicator to measure the different growth rates of subsectors since it represents their economic output.

Table 6
Average annual rates of change (activity, TFE and ODEX) for all Swiss sectors, 2000–2016.

Sector	Share of TFE[a]	Activity	TFE demand (with CC)	EE improvement (ODEX)
Household	28%	1.1% (floor space) 1.0% (dwellings) 2.6% (Appliances)	−0.1%[b]	1.7%[b]
Transport	36%	1.4% (pkm) 1.8% (tkm)	0.01%[c]	1.5%[c]
Industry	18%	1.8% (PIP)	−0.8%	1.0%
Services	16%	1.4% (employees)	−0.04%	1.0%
Total		**4.0% (GDP)**	**−0.1%**	**1.4% (Global ODEX)**

[a] Average share of last three years.
[b] Combined indicator for space heating, other thermal requirements and electric appliances.
[c] Combined indicator for both transport of passengers and of goods.

3.5. Overall Switzerland

The TFE demand of Switzerland (with CC) decreased at an average annual rate of 0.1% during 2000 and 2016. The growth of

[12] Due to lack of the availability of physical activity data for heterogeneous subsectors before 2004, the decomposition analysis is carried out for the years 2004–2016.
[12] Due to lack of the availability of physical activity data for heterogeneous subsectors before 2004, the decomposition analysis is carried out for the years 2004–2016.

Table 7
Level, trend and combined ranks for all sectors of top five countries (based on overall combined rank)[161] (Abbreviations: L – Level, T – Trend, L&T – level and trend combined rank).

Country	Overall			Transport			Households			Industry			Services		
	L & T	L	T	L& T	L	T	L & T	L	T	L & T	L	T	L & T	L	T
UK	1	1	2	1	3	2	**4**	8	7	**7**	4	13	**2**	7	9
Slovakia	2	8	4	**11**	2	22	**3**	11	4	**4**	12	6	**13**	23	4
Switzerland	***3***	***6***	***1***	***6***	***27***	***1***	***9***	***4***	***18***	***10***	***1***	***24***	***8***	***18***	***6***
Portugal	4	9	6	**3**	4	6	**14**	27	2	**20**	20	21	**1**	2	15
Latvia	5	18	3	**5**	17	4	**13**	21	12	**6**	15	5	**22**	18	24

GDP for the same period was recorded at 4% p.a. resulting in an average annual improvement of 4.5% in energy intensity (Energy demand/GDP) of Switzerland. As shown in Table 6 and Fig. 11, the physical EE of Switzerland improved at an average rate of 1.4% per year. All the individual sectors in Switzerland experienced growth in their respective activities during the years 2000–2016 (Table 6). The TFE demand of all sectors except the transport sector (0.01% p.a. increase) decreased during the same period. Household sector improved its EE at the fastest rate (1.7% p.a.) whereas industry was the slowest sector to improve its EE (1.0% p.a.).

Fig. 12 shows the decomposition analysis of TFE demand for the entire country. The overall growth of physical activity of Swiss industry and transport (bar "Activity"; +31% TFE), the rising number of dwellings (bar "Demography"; +5% TFE), the number of appliances per dwelling (bar "Lifestyles"; +3% TFE) and climatic conditions (bar "Climatic effect"; +2% TFE) contribute to increase in the TFE demand. These effects were slightly overcompensated by the industry structure and the modal shift in the transport (bar "Structure"; −4% TFE), other effects (bar "Other"; −11% TFE) and especially energy savings across all the individual sectors in Switzerland (bar "Energy efficiency"; −25% TFE) which contributed to the reduction of TFE demand during 2000 and 2016. As a consequence, TFE demand (not climate corrected[14]) shows very slight decline (−0.2% TFE) from the year 2000–2016 (bar "Total"). For comparison, for the EU as a whole, the effect of energy savings (−21% TFE) was more dominant than the effect of activity (+11% TFE) which, together with all other components, resulted in a reduction of TFE demand by −2% during the same period [55].

3.6. Cross-country comparisons

Based on the scores calculated following the methodology explained in Section 2.4, Switzerland is at the first position in terms of the rate of EE improvement (trend) and ranks at 6th position for the current level energy intensity (see Table 7). Swiss household sector ranks 4th in comparison to other countries included in the ODYSSEE database for the UC (level). The rate of EE improvement (trend) puts Swiss household sector on the 18th rank amongst the other countries. Due to rapid diffusion of more efficient vehicles, the Swiss transport sector ranks at the top of the table for the rate of EE improvement (trend). However, it is one of the least performing countries (27th) in terms of the UC (level) in the transport sector. One of the reasons may be that the Swiss car market is characterized by a large share of vehicles with high engine capacity in Europe (23% cars with engine capacity more than 2000 cm^3 [35]), thus consuming more fuel per pkm as compared to most of other countries included in the ODYSSEE database. For the cross-country analysis, the score for industry was established by assuming an average European industry structure in order to ensure a fair comparison. The large share of high value added (non-energy intensive) sectors results in Swiss industry being one of the best performing sectors in terms of energy intensity (level) (energy demand/value added). The rate of EE improvement (trend indicator) in Swiss industry is one of the lowest of the countries included in ODYSSEE database placing it at the 24th position. Swiss service sector ranks at 18th rank amongst the countries in ODYSSEE database for the level of UC (energy demand/employee) whereas it ranks at 6th position for the rate of EE improvement (trend).

3.7. Target monitoring

The ODEX methodology (see section 2.2) allows estimating the extent to which the energy savings due to technical improvement (i.e. physical EE improvement) is expected to contribute in the overall TFE change. The projected contributions of physical EE improvement for all the sectors in Switzerland are estimated based on the projected TFE values and the projected activity levels (production index) presented in the Energy Perspectives 2050 document ([11]; Table 7-30) for the First set of Measures (FSOM) until 2020 and the New Energy Policy (NEP)[17] until 2050 (Energy Perspectives 2050 document was used as basis for defining the Swiss Energy Strategy 2050 and is hence a legitimate starting point for our analysis). Observed average annual rates for the 2000–2016 time period and projected average annual rates of the physical EE improvement are summarised in Table 8. The overall EE progress of Switzerland from 2000 to 2016 is sufficient (1.4% p.a.) to reach the target for 2020 (0.8% p.a.). However, the rate of EE improvement should be accelerated to reach the target level of 2050. The EE improvement rate (1.0% p.a.) for industry is below par and should be improved to reach the target rate of 2050 (1.4% p.a.). Service sector also needs to improve its rate of EE improvement (from 1.0% p.a. to 2% p.a.) in order to reach the 2050 objective. The past EE rate for household sector is 1.7% p.a., falling short of the 2.7% p.a. rate estimated based on ES2050. When interpreting the "projected rates" according to Table 8 it should be considered that we assume activity, structure and 'Other' to exactly follow the projections of the Energy Perspectives 2050 [11].

3.8. EE indicator comparison

The choice of activity indicator used to measure the EE depends on the definition of EE, i.e. economic EE or physical (technical) EE

[15] Due to insufficient data for Industry sector for the years before 2004, the decomposition for whole country is also analysed from 2004 (see footnote 16).

[15] Due to insufficient data for Industry sector for the years before 2004, the decomposition for whole country is also analysed from 2004 (see footnote 16).

[14] Therefore, separately taken into account by means of column "Climate".

[17] NEP scenario is Federal Council's target scenario set in May 2011 (11. PROGNOS, *Die Energieperspektiven für die Schweiz bis 2050, Energienachfrage und Elektrizitätsangebot in der Schweiz 2000 – 2050*.2012, BFE: Basel.). This scenario projects the energy demand by taking in to account additional EE improvement in addition to the effect of structure, activity and energy savings taken in to account for the BAU scenario.

Table 8
Average annual rates of current and required EE improvement.

Sector	Current rate of EE improvement (based on ODEX) (2000–2016)	Projected rate of EE improvement (based on ES2050) (2000–2020)	Projected rate of EE improvement (based on ES2050) (2020–2050)
Households	1.7% p.a.	1.2% p.a.	2.7% p.a.
Transport	1.5% p.a.	0.5% p.a.	1.6% p.a.
Industry	0.7% p.a.	1.4% p.a.	1.4% p.a.
Services	1.0% p.a.	1.0% p.a.	2.0% p.a.
Total	**1.4% p.a.**	**0.8% p.a.**	**1.9% p.a.**

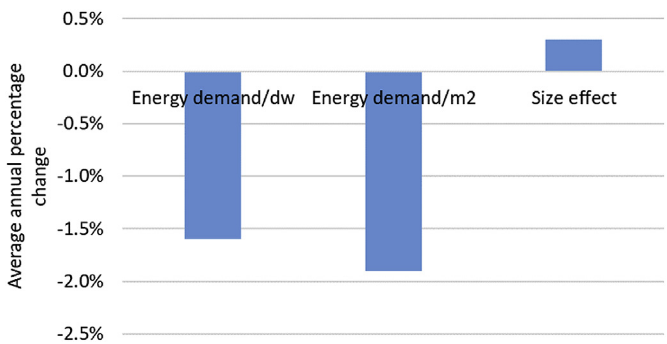

Fig. 13. Space heating in Swiss households - Comparison of the trend of final energy demand per dwelling and per m^2 (2000–2016).

and type of policy measure to be evaluated [34]. The current work aimed to estimate the physical EE of Switzerland (and individual sectors); therefore, wherever possible (i.e. contingent upon data availability), the indicator representing the best physical activity of end-use/subsector was chosen as the activity indicator. However, there is sometimes a choice among alternative activity indicators and the interpretation of EE trends can be enriched through the comparison of these EE indicators.

The unit consumption for space heating in the household sector can be monitored with two activity indicators m^2 and number of dwellings. For Swiss household sector, a small difference between the rates of change of TFE demand/m^2 (1.9% p.a.) and TFE demand/dwelling (1.6% p.a.) implies that the larger size of the dwellings does not have a significant impact on the sector's TFE demand (slightly offsets the EE improvement) (see Fig. 13). Similarly, the comparison of EE indicator based on the activity measured in pkm and vkm for cars provides an insight into the effect of car occupancy on the TFE demand of the road transport [47]. Energy demand/vkm (measured in l/100 km) for Swiss cars changed at the rate faster than the energy demand/pkm indicating lowering of car occupancy in Switzerland from 2000 to 2016, which resulted in slightly offsetting the EE improvement (see Fig. 14).

Value added is not the preferred choice of activity indicator to estimate the physical EE improvement trends since it is influenced by external economic factors. However, the comparison of EE improvement trends based on monetary and physical output helps to quantify the effect of structural change on TFE demand at the level of subsectors. Monetary EE for Swiss industry improved at much faster than the physical EE (5.3% p.a. vs 1.0% p.a.) signifying a substantial effect of the structural change on the sector's TFE demand (complementing the EE improvement). The largest effect of structural change complementing the EE improvement could be seen in the Chemical and Pharmaceutical subsector while the effect

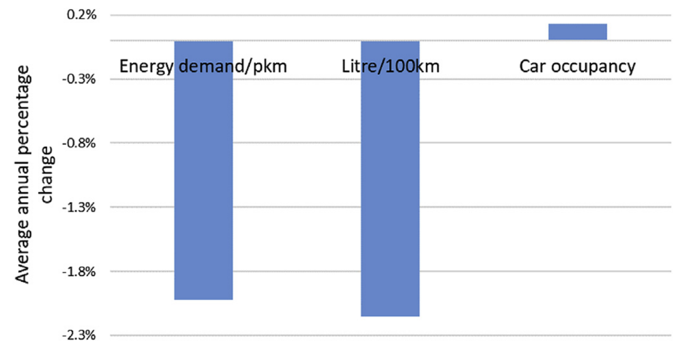

Fig. 14. Passenger car transport in Switzerland - Comparison of EE indicators for (2000–2016).

of structural change in the Basic metals sector, although small, offset the EE improvement (see Fig. 15).

Since largest share of TFE is consumed in the tertiary sector is related to space heating (57%; [58]), it can be argued that the floor area is the most accurate choice to monitor the activity trends (among the options of choosing floor space, value-added and the number of employees). However, due to lack of floor space data availability at subsectoral level, the number of employees is selected as the closest proxy for floor space. The monetary EE improvement for the Swiss tertiary sector improved faster (i.e. 5% p.a.) than the EE improvement based on the number of employees (i.e. 1% p.a.) indicating a substantial effect of productivity on the Swiss tertiary sector's TFE demand (complementing the EE improvement) (see Fig. 16).

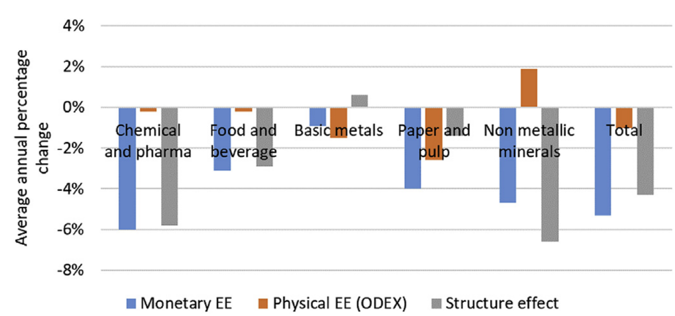

Fig. 15. Comparison of physical and monetary EE trends for selected industry subsectors (2004–2016[1])[18].

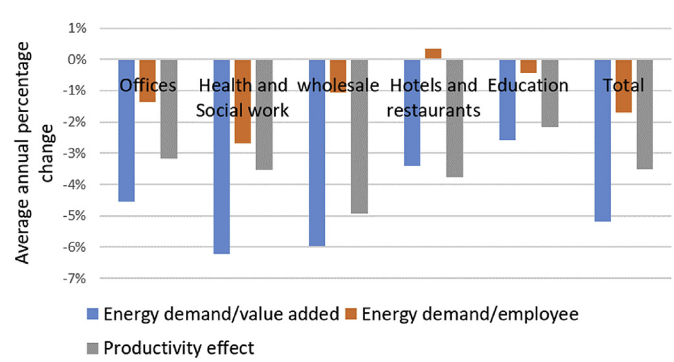

Fig. 16. Comparison of EE of Swiss service sectors based on value added and number of employees (2000–2016).

[16] Fore detailed ranking table refer to appendix E; table E2.

4. Conclusions

In Switzerland, Total Final Energy (TFE) demand (with CC) decreased by 0.1% p.a. during the years 2000–2016, while the economy (GDP) grew at a rate of 4% per year. This points towards strong decoupling of economic growth and energy consumption, however without providing insight into the rate of improvement of *physical* energy efficiency (EE). To study the latter, the Odyssee energy efficiency index (ODEX) is analysed for individual sectors and at the country level. It has been found that physical EE of Switzerland (global ODEX) improved at an average annual rate of 1.4% and it was accompanied by considerable structural change. Physical EE in the household sector, responsible for 28% of TFE demand of Switzerland, improved at the highest rate while industry, responsible for 18% TFE, experienced the lowest rate of physical EE improvement.

The results of decomposition analysis for the period between 2004 and 2016 show that at the country level, despite the growth of physical activity in industry, services and transport along with the effect of larger dwellings, more appliances in the household sector and colder climate contributing to the increase in TFE demand, the effect of structural change in industry and the transport sector along with other smaller effects complemented the physical EE improvement across all sectors resulting in negligible decrease in TFE demand. The apparent small rate of decrease in TFE demand is the result of the choice to display annual climate variations as one of the influencing factors in decomposition analysis (in contrast, the TFE demand decreases at a slightly higher rate when corrected for annual climate variations[19]). A similar trend could be observed at lower aggregation levels, for services and household sectors, where the TFE demand appears to increase when decomposed to display the influence of climate change. The comparison of EE indicators based on different activity indicators further revealed that the lower occupancy of cars and growing size of homes slightly offset the EE improvement in transport and household sectors respectively. In contrast, the structural shift towards higher value-added products and services for most of the subsectors of Swiss industry and services substantially complemented the physical EE improvements.

The cross-country comparisons show that Switzerland ranks third after the UK and Slovakia amongst the countries included in ODYSSEE database based on the overall level and trend rankings. All the individual sectors in Switzerland rank in top ten positions as well in comparison with the countries based on the weighted level and trend indicator. The Swiss transport sector ranks at 6th position, service sector ranks at 8th position, Industry at 10th position and the household sector ranked at 9th position amongst the countries in ODYSSEE database based on the aforementioned weighted indicator.

From 2000 to 2016, Switzerland's EE improved faster than most of the countries represented in ODYSSEE database. The average annual rate of EE improvement for all sectors except industry was found to be sufficient to reach the country's 2020 target. However, in order to reach the 2050 target, the EE improvement rate needs to be accelerated for all sectors.

Acknowledgement

This research is financially supported by the ODYSSEE-MURE project and is part of the EU-funded H2020 project.

[18] See footnote 16.
[19] See footnote 7.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.energy.2019.116526.

References

[1] Farla J. Physical indicators of energy efficiency. 2000.
[2] Phylipsen GJM, Blok K, Worrell E. International comparison of energy efficiency - methodologies for the manufacturing industry. Energy Policy 1997;25.
[3] Bosseboeuf D, CB, Lapillonne B. Cross-country comparison of energy efficiency indicators: on-going European effort towards a common methodology. Energy Policy 1997;25.
[4] Energy efficiency directive. 2018. Available from: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive.
[5] Council E. Directive on the energy performance of buildings. In: Official journal of eropean journal; 2010. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN.
[6] Council E. Directive on energy performance of buildings (amendment). In: Official journal of European union; 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN.
[7] IEA. Energy policy highlights: in-depth energy policy reviews (IDRs) of 21st century. In: Energy policies of IEA countries. Paris: OECD Publishing; 2014. https://doi.org/10.1787/9789264200630-en.
[8] IEA. Capturing the multiple benefits of energy efficiency. 2014. https://www.iea.org/publications/freepublications/publication/Multiple_Benefits_of_Energy_Efficiency.pdf.
[9] IEA. Energy efficiency insights brief. 2017.
[10] EU. Energy efficiency. Available from:: https://ec.europa.eu/energy/en/topics/energy-efficiency/eu-targets-energy-efficiency.
[11] PROGNOS, *Die Energieperspektiven für die Schweiz bis 2050, Energienachfrage und Elektrizitätsangebot in der Schweiz 2000 – 2050*. 2012, BFE: Basel.
[12] IEA. Energy policies of IEA countries - Switzerland. International Energy Agency; 2018. Review. 2018.
[13] Phylipsen GJM. Energy Efficiency Indicators: best practice and potential use in developing country policy making. 2010.
[14] Tanaka K. Assessment of energy efficiency performance measures in industry and their application for policy. Energy Policy 2008;36(8):2887–902.
[15] Giacone E, Mancò S. Energy efficiency measurement in industrial processes. Energy 2012;38(1):331–45.
[16] Proskuryakova L, Kovalev A. Measuring energy efficiency: is energy intensity a good evidence base? Appl Energy 2015;138:450–9.
[17] Ang BW. Monitoring changes in economy-wide energy efficiency: from energy–GDP ratio to composite efficiency index. Energy Policy 2006;34(5):574–82.
[18] Ang BW, Mu AR, Zhou P. Accounting frameworks for tracking energy efficiency trends. Energy Econ 2010;32(5):1209–19.
[19] IEA. *Energy efficiency* in *Market report*. 2017.
[20] Horowitz MJ, Bertoldi P. A harmonized calculation model for transforming EU bottom-up energy efficiency indicators into empirical estimates of policy impacts. Energy Econ 2015;51:135–48.
[21] Patterson MG. What is energy efficiency? Concepts, indicators and methodological issues. Energy Policy 1996;24(5).
[22] ODYSSEE-MURE. Energy efficiency indicators in Europe. 2018. Available from: http://www.odyssee-indicators.org/index.php.
[23] Ang BW, FQZ. A survey of index decomposition analysis in energy and environmental studies. Energy 2000;25:1149–76.
[24] Ang BW. Decomposition analysis for policymaking in energy. Energy Policy 2004;32(9):1131–9.
[25] Wu L-M, et al. Structure model of energy efficiency indicators and applications. Energy Policy 2007;35(7):3768–77.
[26] Al-Mansour F. Energy efficiency trends and policy in Slovenia. Energy 2011;36(4):1868–77.
[27] Song C, et al. Research on energy efficiency evaluation based on indicators for industry sectors in China. Appl Energy 2014;134:550–62.
[28] Saygin D, et al. Benchmarking the energy use of energy-intensive industries in industrialized and in developing countries. Energy 2011;36(11):6661–73.
[29] Mondal MAH, et al. Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions. Energy 2018;149:161–72.
[30] Gielen D, Taylor P. Indicators for industrial energy efficiency in India. Energy 2009;34(8):962–9.
[31] Allouhi A, et al. Energy consumption and efficiency in buildings: current status and future trends. J Clean Prod 2015;109:118–30.
[32] Ruzzenenti F, Basosi R. Evaluation of the energy efficiency evolution in the European road freight transport sector. Energy Policy 2009;37(10):4079–85.
[33] IEA. Energy efficiency indicators highlights. 2018.
[34] ODYSSEE-MURE, Definition of data and energy efficiency indicators in ODYSSEE database.
[35] ODYSSEE-MURE. Odyssee database (Subscription based database). 2018.
[36] FSO. Industries production account. 2017.
[37] SFOE. Schweizerische gesamtenergiestatistik. 2017.

[38] SFOE. Analyse des schweizerischen Energieverbrauchs 2000 - 2016 nach Verwendungszwecken. 2017.
[39] BFE. Schweizerische Gesamtenergiestatistik 2016. 2017.
[40] SFOE. Energy Policy. Available from:: https://www.bfe.admin.ch/bfe/en/home/policy/energy-policy.html.
[41] SFOE. The first set of measures. 2018. Available from: https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050/the-first-set-of-measures.html.
[42] Council TF. Energy regulation 2018. Available from: https://www.admin.ch/opc/de/classified-compilation/20162945/index.html.
[43] SFOE 2018. Available from: https://www.bfe.admin.ch/themen/00526/00541/00542/02167/index.html?lang=de&dossier_id=06722.
[44] (SFAO), S.F.A.O., Evaluation of incentive effect of emissions trading scheme Federal Office for the Environment.
[45] Confederation S. Switzerland's seventh national Communication and third biennial Report under the UNFCCC fourth national Communication under the kyoto Protocol to the UNFCCC. 2018. https://unfccc.int/sites/default/files/resource/624078315_Switzerland-NC7-BR3-1-CHE_NC7_BR3_2018.pdf.
[46] EnAW. DER PARTNER FÜR KLIMASCHUTZ UND ENERGIEEFFIZIENZ. 2016.
[47] IEA. Energy Effic Indicat : Fundam Stat 2014. https://www.iea.org/publications/freepublications/publication/IEA_EnergyEfficiencyIndicatorsFundamentalsonStatistics.pdf.
[48] International recommendations for the index of industrial production 2010;vol. 107. in Series F No, https://unstats.un.org/unsd/industry/Docs/F107_edited.pdf.
[49] ODYSSEE-MURE, Understanding variation in energy consumption - methodological report.
[50] Duran E, Aravena C, Aguilar R. Analysis and decomposition of energy consumption in the Chilean industry. Energy Policy 2015;86:552–61.
[51] Trotta G. Energy efficiency trends in the European Union: decomposition analysis and policy implications. 2018. https://doi.org/10.13140/RG.2.2.31271.24484.
[52] Goh T, Ang BW. Tracking economy-wide energy efficiency using LMDI: approach and practices. Energy Efficiency; 2018.
[53] ODYSSEE-MURE. ODYSSEE Scoreboard methodology. 2018.
[54] Wolfgang Eichhammer SV, Kelly Meggan, Scholmann Barbara. Comparing energy efficiency scoreboard methodologies and results. In: ECEEE summer study; 2017.
[55] ODYSSEE-MURE. Decompos tool 2018. Available from: http://www.indicators.odyssee-mure.eu/decomposition.html.
[56] SFOE. Energieverbrauch in der Industrie und im Dienstleistungssektor. 2017.
[57] FSO. Comptes de l'énergie des ménages et de l'économie, par branches et par agents énergétiques. 2018. en TJ.
[58] PROGNOS. Analyse des schweizerischen Energieverbrauchs 2000 - 2017 nach Verwendungszwecken. BFE; 2018.