Contribution of energy efficiency improvement towards deep decarbonization of Swiss Food and Beverage sector

By

Navdeep Bhadbhade, Martin K Patel

Contents

• Introduction
  → Shares of TFE and CO2 emissions
  → Indicative targets

• Methodology
  Data characterization
  → Top down TFE consumption
  → Bottom-up EE potential

• Results
  → Energy efficiency
  → CO₂ abatement potential – Establishment level
  → CO₂ abatement – Sector level

• Sensitivity analysis

• Conclusions
Introduction

Swiss industry (SFOE)

Strategic goal for CO₂ emissions → reach 1.5 tonne CO₂ emissions per inhabitant

Food and beverage subsector

Decarbonization

Swiss industry

- Renewable integration
- Energy efficiency improvement
- Carbon capture and storage
  - Process modifications
  - Heat recovery
  - Steam system improvement

Source: SFOE, Enaw
Source: PROGNOS (2012)
Characterization of process energy consumption (Top down)

**Estimating shares of energy consumed by product groups within EnAW database**

**Food and beverage products (EnAW)**
Dairy industry, meat industry, fruits and vegetables processing, sugar, chocolate, bakery and beverages

- 76% coverage

**Shares of sub-sectoral energy consumption in EnAW in database scaled to National statistics**

**Estimating total final energy consumed by product groups in at national scale**

**Food and beverage sector (Switzerland)**

Based on typical energy consumption profiles of each type of establishment

**Estimating energy consumed for each production step/end use**

**Food and beverage sector**
Pasteurization, evaporation, homogenization, centrifugal separation, drying, cutting and mixing, refrigeration, EMDS

- e.g. % TFE consumed by diary
- e.g. Total final energy in TJ consumed by diary
- e.g. TFE in TJ consumed by pasteurization
Technical EE improvement potentials in Swiss industry (Bottom-up)

Technical energy saving potential at the **level of entire subsector**

**Food and beverage sector**

Aggregate saving potential at **establishment and the level of product groups**

**Food and beverage sector**

Dairy industry, meat industry, fruits and vegetables processing, sugar, chocolate, bakery and beverages

Estimation of technical EE potential at **process level**

**SECs of Individual production processes**

Top-down TFE consumption estimates for individual production processes

**Production estimates**

Description of EEMs in EnAW database or national statistics

**Background**

Methodology

Results
Estimation of cost-effective EE improvement potential (Bottom-up)

Levelized cost

**EECC → Levelized cost on Y-axis, cumulative annual saving potential in X-axis**

\[
\text{Levelized cost} = \frac{I \times ANF + OM - B}{ES} \text{ (CHF/GJ)}
\]

OR

\[
\text{Levelized cost} = \frac{I \times ANF + OM - B}{CS} \text{ (CHF/t-CO}_2\text{)}
\]

**CO₂ abatement cost**

\[
\text{CO₂ abatement cost} = \frac{I \times ANF + OM - B}{CS} \text{ (CHF/t-CO}_2\text{)}
\]

*Source (Blok, 2007)*

\[
ANF = \frac{(1 + r)^L - r}{(1 + r)^L - 1}
\]

r = discount rate
L = lifetime of the measure

\[
B = ELS_y \times P_e + FS_y \times P_f + CS_y \times P_{CO₂}
\]

ELSy and FSy = electricity and fuel savings by measure y per year
Pe, Pf and P_CO₂ = energy and CO₂ prices

\[
CS_y = (ES_y \times EF_r)
\]

EF_r = emission factor for fuel r

**Total 43 EEMs identified**
Bottom-up estimates for SEC and technical potential

- **Largest share of technical EE improvement** → Cheese manufacturing (26% share).
- **Most efficient** → Cocoa and chocolate production

---

**Percentage and absolute technical EE improvement potentials** - Based on the comparison with best practice SECs

- **Technological potential**
  - Ref. Bhadbhade et al., 2020

---

**Technical potential based on comparison with best practices (5.5 PJ); 25%**

**Implicit energy saving targets based on ODEX (6 PJ); 26%**
**Energy efficiency cost curves**

- **Core processes related EEMs** → 30% EE improvement potential.
- **Largest share of EE potential** → Dairy production related EEMs (*Reverse osmosis instead of evaporation*).
- **Cross-cutting processes EEMs** → 70% EE improvement potential.
- **Largest share of cross-cutting EE potential** → WHR related measures (*Process heat integration*).

Ref. Bhadbhade et al., 2020

---

**Background**

**Methodology**

**Results**

Ref. Bhadbhade et al., 2020
CO₂ abatement through waste heat recovery

CO₂ abatement potentials for heat pumps

<table>
<thead>
<tr>
<th>Product group</th>
<th>CO₂ emission reduction potential¹</th>
<th>Typical scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat</td>
<td>14% to 28%</td>
<td>Refrigeration to thermal storage</td>
</tr>
<tr>
<td>Bakery</td>
<td>10% to 14%</td>
<td>Refrigeration to thermal storage</td>
</tr>
<tr>
<td>Chocolate</td>
<td>11% to 52%</td>
<td>Refrigeration to hot water network</td>
</tr>
<tr>
<td>Confectionery</td>
<td>23%</td>
<td>Refrigeration to thermal storage</td>
</tr>
</tbody>
</table>

CO₂ abatement potentials for process heat integration

<table>
<thead>
<tr>
<th>Product group</th>
<th>CO₂ emission reduction potential¹</th>
<th>Typical scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>5%-10%</td>
<td>Evaporation to extraction/ Drying to extraction</td>
</tr>
<tr>
<td>Bakery</td>
<td>16% to 30%</td>
<td>Flue gas to thermal storage</td>
</tr>
<tr>
<td>Chocolate</td>
<td>11%</td>
<td>Roaster heat integration</td>
</tr>
<tr>
<td>Beer</td>
<td>11%-21%</td>
<td>Brewhouse integration</td>
</tr>
<tr>
<td>Dairy</td>
<td>4%-13%</td>
<td>Dryer preheating, pasteurized preheating, CIP thermal demand</td>
</tr>
</tbody>
</table>

¹ Percentages estimated relative to total CO₂ emissions generated from particular establishment (Source: EnAW)

Sources: Shares based on EnAW, Temperature levels: BREF, Lorenz et al, J. Klemens
CO₂ abatement cost curves

- Largest share of CO₂ abatement potential in current EE technologies → waste heat recovery EEMs.
- Most cost-effective way to reduce CO₂ emissions → Steam system improvements.

40% reduction from current level

- Pulse electric pasteurization
- High temperature heat pump
- Steam generation from LP evaporation and vapor recompression
- Radio frequency drying

Shares of technology groups in CO₂ abatement potential

Levelized cost of CO₂ abatement (CHF/tonne CO₂)

Cumulative annual CO₂ saving potential (kt)

CO₂ mitigation cost curve

- Process modification
- Renewable integration
- Improvement in steam production and distribution
- Process electrification
- Waste heat recovery

Current CO₂ emissions

CO₂ abatement projections and available levels

- Process modifications; 24%
- Process heat integration; 14%
- Renewable integration; 5%
- Steam production and distribution improvements; 25%
- Heat pump integration; 22%
- Process electrification; 10%
## Sensitivity analysis

<table>
<thead>
<tr>
<th>Exogenous variables</th>
<th>Base case values</th>
<th>Significance</th>
<th>Effect</th>
<th>Significance</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount rate</td>
<td>21%</td>
<td>Companies with stringent economic criterion</td>
<td>Capital intensive EEMs become economically unattractive (e.g. plant wide heat integration, purchasing efficient process equipment)</td>
<td>Companies with less stringent economic criterion</td>
<td>Less sensitivity of cost-effectiveness to any changes</td>
</tr>
<tr>
<td>Energy prices</td>
<td>Fuel: 13.6 CHF/GJ Electric 43.3 CHF/GJ (IEA, 2018)</td>
<td>Future projected energy prices</td>
<td>On average EEMs become more economically attractive</td>
<td>Energy prices for large consumers (sometimes negotiated)</td>
<td>Measures related to EMDS and WHR become economically unattractive</td>
</tr>
<tr>
<td>CO₂ levy</td>
<td>96 CHF/tonne CO2</td>
<td>Future projected values (upto 250 CHF/tonne CO2)</td>
<td>WHR and electrification (MVR or membrane technology instead of evaporation) become economically viable</td>
<td>Current value</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

EE potential (process related):

• Large scope for the expansion of implementation of currently available technologies → 25% of subsector’s TFE reduction.
• High potential for emerging technologies → 18% of subsector’s TFE reduction.
• Most of the available EE improvement technologies are found to be cost-effective → 16% subsector’s TFE reduction.

CO₂ emission reduction potential:

• Further electrification and renewable integration to reach expected reduction levels → 27% of CO₂ emissions reduction potential by current technologies + 13% by emerging technologies.
• Waste heat recovery technologies represent the largest share of current CO₂ emissions reduction potential → 36% potential of currently available technologies
  → HPs represent relatively larger CO₂ abatement potentials at establishment level
• Improvements in steam generation can reduce CO₂ emissions in the most cost-effective manner

Sensitivity analysis of cost-effective potential

• Higher CO₂ levy favorable for adoption of WHR and capital-intensive measures → Heat integration projects and electrification of production steps become cost-effective.
Thank you!
Additional slides
Sensitivity analysis

Sensitivity results for cost-effective EE potential in Swiss F&B sector

Sensitivity results for cost-effective CO2 abatement potential in Swiss F&B sector
Categorization of techno-economic data for energy efficiency measures

EEM classification

Core process related
(e.g. evaporation, pasteurization)

Cross cutting
(e.g. EMDS, steam system, WHR)

Top down energy consumption estimations
(production steps and end uses)

Energy saving potential of individual measures reported in EnAW database

Relative energy savings (and specific energy savings)

Average relative energy savings by each category

Average initial investment cost

\[ ES_y = (ELS_y + FS_y) \times dr_y \]

- \( ES_y \): energy savings of measure \( y \)
- \( ELS_y \): energy savings by measure \( y \) in a certain sector
- \( FS_y \): fraction of measure \( y \) cost to total energy savings
- \( Pr_i \): production of sub sector \( i \)
- \( dr_y \): remaining diffusion of measure \( y \)
ODEX methodology – Energy efficiency improvement trend and energy savings

Global ODEX

\[ ODEX_{\text{global},t} = \sum_i ODEX_{i,t} \times ES_{i,t} \]

Aggregation based on shares of each main sector in country’s TFE (ESi)

Main sector ODEX

\[ ODEX_{i,t} = s \times \left( \frac{l_{i,t}}{l_{i,t-1}} \right) \]

With \( s = \begin{cases} 100, & t = t_0 \\ ODEX_{t-1}, & t > t_0 \end{cases} \) and \( t = t_0, t_1, t_2 \)

\[ \sum_j \frac{UC_{j,t}}{UC_{j,t-1}} \times ES_{j,t} \]

Unit consumption (UC)

\[ UC_{j,t} = \frac{EC_{j,t}}{A_{j,t}} \]

Aggregation based on share of each subsector (ESj) in main sector’s TFE

For entire country

At main sector level (i) e.g. Industry, Transport, Households, Services

At subsector level (j) e.g. Metals production and fabrication, and food

Unit consumption index

\[ UC_{j,t} \text{ is Unit consumption index for subsector j and year t} \]

\[ EC_{j,t} = \text{Final Energy demand of subsector j} \]

\[ A_{j,t} = \text{Activity of subsector j for year t} \]

ODEX → EE indicator developed in the framework of ODYSSEE-MURE project to evaluate EE trends at the level of main sectors and entire country based on subsectoral physical EE indicators.

Ref. Bhadbhade et al 2019, Odyssee methodology
Discount rate

• Discount rates: used to discount future cash flows to present value in order to reflect both the time value of money and perceived risk.

• Typically industry prefers the economic criterion of simple payback time (SPB).

• Target agreement: for exemption from CO₂ tax in CH, all measures with SPB up to 4 years must be implemented (for process related measures).

• Techno-economic data presented in the EnAW database allows the estimation of internal hurdle rates (or IRR) as well as SPB for each investment.

• The economic criterion of 4 years SPB implies the discount rate of at least 21% for Swiss F&B establishments.

• In order to reflect the firm level decision criteria, 21% was chosen as discount rate for base case cost-effectiveness analysis.

Correlation between Internal hurdle rates (implicit discount rates) and Simple payback period for Swiss F&B industry (Based on EnAW database)
F&B sector: EE improvement is expected to reduce 26% of TFE reduction until 2050 → Energy saving target 6 PJ
Trends of fuel demand in F&B sector

[Bar chart showing fuel demand trends from 2002 to 2016 with percentages for different types of fuel.]

- 30% Electricity
- 10% Heating oil extra
- Natural gas
- Coal
- Industrial waste
- Heating oil heavy
- District heating total
- Wood
Remaining diffusion estimates

\[ dr = \left( \frac{EC_x - ED_{yEnAW}}{EC_x} \right) \times Pt_x \]

• \( EC_x \) = Energy consumption of process x
• \( ED_{yEnAW} \) = Energy demand to which measure y refers implemented in EnAW database
• \( Pt_x \) = technical potential for the process x = \( \frac{SEC_{CHx} - SEC_{wx}}{SEC_{CHx}} \)

\[ \rightarrow \text{E.g. } ECx \text{ for evaporation} = 1193 \text{ TJ} \]
\[ ED_{yenaw} = 144 \text{ TJ} \]
\[ Pt_x = 60\% \rightarrow 40\% \text{ of energy demand cannot be further reduced} \]
\[ dr = 52\% \text{ for vapor recompression in evaporation} \]