2050 scenario analysis using the EU CTI 2050 Roadmap Tool

BUILDINGS sector

October 2018
Project context

The approach for the buildings sector

Description of the levers
Structure of the ECF EU CTI 2050 Roadmap model

Demography, economy and lifestyle assumptions
- Economy, fuel prices
- Lifestyle
- Demography

Demand activity input

Technologies, Energy & Resources
- Food production
- Energy requirements by sector: Transport, Buildings, Manufacturing
- Energy supply

Impact on resources
- Land
- Fossil fuels

Trans-boundary effects, Trade, & Flows
- Outside the EU
Structure of the ECF EU CTI 2050 Roadmap model

- **Climate & Technological Transitions**
  - Economy
    - Economy evolution
  - Lifestyle
    - Diet
    - Travel demand, mode & occupancy
    - Building sizes, inside temperature
    - Appliance use, product demand
  - EU & rest of word
    - Demography
    - Dynamics with rest of world

- **Energy & Resources**
  - Food production
    - Livestock
    - Crops
  - Energy requirements by sector
    - Transport
      - Passenger
      - Commercial
      - Transport Technologies
    - Buildings
      - Residential
      - Commercial
      - Heating technologies
      - Appliance efficiencies
    - Manufacturing
      - Product Design
      - Materials production
  - Energy supply
    - Technologies
      - Electricity production
      - Heat production
      - Transport & Distribution
      - Storage
  - Materials
    - Minerals (location based)
    - Fossil fuel reserves
  - Impact on resources
    - Land
      - Land allocation
      - Forests & grasslands
      - Bioenergy crops

- **Trans-boundary effects, Trade, & Flows**
  - Outside EU
    - Food
    - Energy
    - GHG
    - Materials & resources

**Legend**
- Model core
- Additional modules

**Demand activity input**
4 ambition levels are used as boundaries to create scenarios. Any value can be chosen in between.

- **Level 0**
  - **Current development** scenario (existing legal obligations)
  - No additional effort
  - « BAU scenario »

- **Level 1**
  - **Increased ambition** compared to BAU
  - No breakthrough, but more extensive use of existing technologies

- **Level 2**
  - **Ambitious**: Significant effort requiring extensive changes in the system, leveraging best practices available today
  - Typically reaching –85%

- **Level 3**
  - **Transformational**: Max potential based on transformational changes but reflecting technical or physical constraints
Content

Project context

**The approach for the buildings sector**

Description of the levers
### Key issues covered in buildings

#### End-uses of Residential & Services sector

<table>
<thead>
<tr>
<th>Heating</th>
<th>Current data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Energy consumption for the different end – uses</td>
</tr>
<tr>
<td>Cooling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Number of households and total value added of services sector</td>
</tr>
<tr>
<td>Hot Water</td>
<td></td>
</tr>
<tr>
<td>Lighting, appliances &amp; cooking</td>
<td>• Based upon recent literature and available data sources</td>
</tr>
</tbody>
</table>

#### Activity levels

- What is the evolution assumed for **population** and **number of dwellings**?
- Which potential evolution for heating, cooling & hot water **demand**?
- What’s the impact of **behavioral changes** on the different end-uses?
- What are possible demand evolutions for **electric appliances & lighting**?

#### Efficiency

- What’s the physical limit or **maximal efficiency** improvement of the different technologies?
- Which levels of **compactness of houses** can be expected in the residential sector?
- How fast can buildings be **renovated**?
- What level of **demolition/new buildings** will be realistic?

#### Technology and energy vector

- What can be the maximum and minimum **share of the different heating & cooling technologies** (eg. Individual boilers, district heating)?
- What are the implications of the **fuel & technology shifts** in terms of energy consumption?

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**What is possible for 2050?**

What will the situation look like in 2020/30/40/50?

Which are the practical implications?
In practice, 4 main groups of factors will be covered to test the potential for decarbonizing the heating/cooling of the building sector.

Exogenous factors: Evolution of the population & Number of dwellings; Evolution of the services sector.

- Cooling demand(*)
- Hot water demand(*)

- Evolution of type of heating/cooling/hot water technologies
- Efficiency of these technologies(*)
- Life span of heating technologies(*)

- New buildings & existing buildings
  - Renovation rate
  - Speed of demolition/new buildings

- Evolution of surface per building
- New buildings & existing buildings
- Speed of demolition/new buildings

Behavior

Performance of the building envelope

GHG emissions of Buildings – Heating & Cooling

Urban Planning

Heating & Cooling technologies

(*) Not implemented.
In practice, 3 main group of factors will be covered to test the potential for decarbonizing the electric appliances in the building sector.

Exogenous factors: Evolution of population & number of households; Evolution of the services sector (value added)

- Demand [kWh] for:
  - Black goods - White goods
  - Lighting
  - Cooking
  - This demand is dependent on utilisation level, purchase level etc.

- Technological potential of efficiency improvement:
  - Black goods - White goods
  - Lighting
  - Cooking

- The supply side is covered in the model of the Power sector.
# Levers defined in the EU CTI – Residential buildings

<table>
<thead>
<tr>
<th>Lever category</th>
<th>Lever name</th>
<th>Units</th>
<th>Level 0</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand for conditioned areas</td>
<td>Floor area requirements</td>
<td>[CAGR of m²/cap]</td>
<td>0,58%/year</td>
<td>-0,30%/year</td>
</tr>
<tr>
<td></td>
<td>Household size</td>
<td>[CAGR of inhabitant/household]</td>
<td>-0,31%/year</td>
<td>+0,15%/year</td>
</tr>
<tr>
<td>Buildings efficiency</td>
<td>Renovation depth</td>
<td>[average % savings realized]</td>
<td>20%</td>
<td>90%</td>
</tr>
<tr>
<td>Renovation rate</td>
<td>Renovation rate</td>
<td>[%/year]</td>
<td>1%</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Demolition rate</td>
<td>[%/year]</td>
<td>0,10%</td>
<td>0,25%</td>
</tr>
<tr>
<td>Decarbonized Heat</td>
<td>New/Renovated/Remaining</td>
<td>[Share of fossil fuels in heat]</td>
<td>58%</td>
<td>0% by 2030</td>
</tr>
<tr>
<td>Mix of technologies³</td>
<td>Heat districts⁴</td>
<td>[% of heat districts in non fossil]</td>
<td>Options between 15% and 35%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RES-based single heating systems (SHS)⁴</td>
<td>[% of RES-based systems in non fossil]</td>
<td>Options between 50% and 65% Limited by the heat district contribution.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat pumps</td>
<td>[% of heat-pumps in RES-based SHS]</td>
<td>19%²</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Bioenergy⁵</td>
<td>[% of biomass-firing RES-based SHS]</td>
<td>81%²</td>
<td>10%</td>
</tr>
<tr>
<td>Appliances</td>
<td>Appliance utilization growth rate</td>
<td>[CAGR on 2015-2050]</td>
<td>2,5%/year</td>
<td>-1%/year</td>
</tr>
<tr>
<td></td>
<td>Appliance standards</td>
<td>[% improvement in 2050 vs 2015]</td>
<td>-33%</td>
<td>-50%</td>
</tr>
<tr>
<td></td>
<td>Cooking electrification</td>
<td>[% of fossil fuel w.r.t. baseline]</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

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NOTE: (1) values are considered to be reached by 2050 if not specified otherwise (2) for space heating, similar logic for water heating (3) The remaining is covered by direct electricity heating (4) These are options rather than ambitions (5) Linked to the ‘heat pump’ lever, solar thermal then used as buffer.
Levers defined in the EU CTI – nonresidential buildings

<table>
<thead>
<tr>
<th>Lever category</th>
<th>Lever name</th>
<th>Units</th>
<th>Level 0</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand for conditioned areas</td>
<td>Floor area requirements</td>
<td>[CAGR of m²/cap]</td>
<td>1%/year</td>
<td>-1%/year by 2030</td>
</tr>
<tr>
<td>Buildings efficiency</td>
<td>Renovation depth</td>
<td>[average % savings realized]</td>
<td>20%</td>
<td>90%</td>
</tr>
<tr>
<td>Renovation rate</td>
<td>Renovation rate</td>
<td>[%/year]</td>
<td>1%/year</td>
<td>4%/year</td>
</tr>
<tr>
<td>Demolition rate</td>
<td></td>
<td>[%/year]</td>
<td>0,10%</td>
<td>0,25%</td>
</tr>
<tr>
<td>Decarbonized Heat</td>
<td>New/Renovated/Remaining</td>
<td>[Share of fossil fuels in heat]</td>
<td>69%</td>
<td>0% by 2030</td>
</tr>
<tr>
<td>Mix of technologies⁴</td>
<td>Heat districts⁴</td>
<td>[% of heat districts in non fossil]</td>
<td>Options between 15% and 35%</td>
<td></td>
</tr>
<tr>
<td>RES-based single heating systems (SHS)⁴</td>
<td></td>
<td>[% of RES-based systems in non fossil]</td>
<td>Options between 50% and 65%</td>
<td>Limited by the heat district contribution.</td>
</tr>
<tr>
<td></td>
<td>Heat pumps</td>
<td>[% of heat-pumps in RES-based SHS]</td>
<td>33%²</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Bioenergy²</td>
<td>[% of biomass-firing RES-based SHS]</td>
<td>65%²</td>
<td>10%</td>
</tr>
<tr>
<td>Appliances</td>
<td>Appliance utilization growth rate</td>
<td>[CAGR on 2015-2050]</td>
<td>2,5%/year</td>
<td>-1%/year</td>
</tr>
<tr>
<td></td>
<td>Appliance standards</td>
<td>[% improvement in 2050 vs 2015]</td>
<td>-33%</td>
<td>-50%</td>
</tr>
<tr>
<td></td>
<td>Cooking electrification</td>
<td>[% of fossil fuel w.r.t. baseline]</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

NOTE: (1) values are considered to be reached by 2050 if not specified otherwise (2) for space heating, similar logic for water heating (3) The remaining is covered by direct electricity heating (4) These are options rather than ambitions (5) Linked to the ‘heat pump’ lever, solar thermal then used as buffer.
# Links between levers and end-uses

<table>
<thead>
<tr>
<th>Lever category</th>
<th>Lever name</th>
<th>Space heating</th>
<th>Water heating</th>
<th>Cooling</th>
<th>Lighting</th>
<th>Appliances</th>
<th>Cooking</th>
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</thead>
<tbody>
<tr>
<td>Compactness</td>
<td>Floor area requirements</td>
<td>v</td>
<td></td>
<td>v</td>
<td>v</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household size</td>
<td></td>
<td>v</td>
<td></td>
<td>v</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings efficiency</td>
<td>Renovation depth</td>
<td>v</td>
<td></td>
<td>v</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Renovation rate</td>
<td>v</td>
<td></td>
<td>v</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Demolition rate</td>
<td>v</td>
<td></td>
<td>v</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decarbonizing heat</td>
<td>New/Renovated/Remaining</td>
<td>v</td>
<td>v</td>
<td></td>
<td>v</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Elec only</td>
<td></td>
</tr>
<tr>
<td>Mix of technologies</td>
<td>Heat districts</td>
<td>v</td>
<td>v</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RES-based individual heating</td>
<td>v</td>
<td>v</td>
<td></td>
<td></td>
<td></td>
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<td>Heat pumps/Bioenergy</td>
<td>v</td>
<td>v</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Appliances</td>
<td>Appliance utilization growth</td>
<td></td>
<td></td>
<td></td>
<td>v</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Appliance standards</td>
<td>v</td>
<td></td>
<td>for exist. systems</td>
<td>v</td>
<td>v</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooking electrification</td>
<td></td>
<td></td>
<td></td>
<td>v</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Content

Project context

The approach for the buildings sector

Description of the levers

Buildings efficiency

Decarbonizing heat
Mix of technologies
Appliances
Renovation depth: Ambition levels

Average energy savings of renovation in the EU [% reduced w.r.t. initial consumption]

<table>
<thead>
<tr>
<th>Level</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Current average energy savings of building renovation occurring at a 1%/year rate</td>
</tr>
<tr>
<td>1</td>
<td>Factor 2: Existing growing initiatives (e.g. RenoWatt (BE), Picardie Pass Renovation (FR))</td>
</tr>
<tr>
<td>2</td>
<td>Factor 4: High political ambition and best-practices initiatives (Renovation strategies (BE, FR), DoRéMi (FR), EnergySprong (NL, UK, FR))</td>
</tr>
<tr>
<td>3</td>
<td>Factor 10: Scaling up pilot projects</td>
</tr>
</tbody>
</table>
There is a growing political will laid down in renovation strategies (2050 targets):
- FR: Renovation of all the buildings stock at BBC level (80kWh/m²/year)\(^{(i)}\)
- BE (Wallonia): Reaching in average 85kWh/m²/year for residential buildings\(^{(ii)}\), net zero energy for non-residential ones\(^{(iii)}\)

Best-practice initiatives rely on different strategies, involving stakeholders differently:
- EnergieSprong: standardized procedures, \textit{industrialization and pre-fabricated} modules
- DoRéMi: \textit{capacity buildings for local labor force}

Notes: (i) with variations according to climate zones (ii) heating, cooling and ancillaries (iii) idem residential + lighting
Level 3: Factor 10 energy renovation is feasible but requires transformational changes for deployment

Average energy savings of renovation in the EU [% reduced w.r.t. initial consumption]

- There exist pilot projects targeting the diversity of typologies (see next slide)
- Factor 10 needs disruptive technologies and processes, so support to R&D and pilot projects (see e.g. P2ENDURE and links on next slides for examples of technical solutions)
- It can probably be rolled-out only with industrialized solutions (so lower benefits for local actors/SMEs)
- It needs strong building codes for renovation compared to Factor 4 renovation (Level 2)
Factor 10 energy renovation is feasible but needs strong support and (reinforced) building codes for renovation

Selection of factor 10 renovation examples [% reduced w.r.t. initial consumption]

- **Residential**
  - 87% of 3 story multifamily terraced houses (link)
  - **Frankfurt**

- **Office building**
  - 413 > 37kWh/m²/year
  - 1,900€/m², 5€/saved kWh (link)
  - **Paris**

- **School**
  - 220 > 28kWh/m²/year
  - (6 class rooms, 733m²) (link)
  - **Portugal**

Potential time evolution for the penetration of factor 10 renovation

Source: GBPN (Sophie Shnapp)
The renovation rate needs to be significantly increased to renovate the whole park by 2050. Level 3 allows to go even faster.

Renovation rate in the EU in the 4 ambition levels
[%/year]

Rationale for the levels:

Level 0. Low ambition REALIZATION of current policies: Even if MS are required to develop renovation strategies, results have not been proven on the field yet. 60% is renovated by 2050.

Level 1. Best-practice policies are deployed and deliver: 2,5%/year by 2030, 75% is renovated by 2050.

Level 2. Optimistic interpretation of best-practice policies: renovation of most buildings by 2050 (e.g. FR, Wallonia) 3%/year by 2030, 87% is renovated by 2050 (i)

Level 3. Building codes for renovation and binding targets for MS: 3,4%/year by 2030, 96% is renovated by 2050(i)

Note: (i) if not demolished
Content

Project context
The approach for the buildings sector

**Description of the levers**
- Buildings efficiency
- Decarbonizing heat
- Mix of technologies
- Appliances
Full heat decarbonization by between 2050 and 2035 is realistic, many cities/localities have already pledge to reach 100% RES heat

Share of fossil-fuel heating in EU residential buildings for the four ambition levels
[% of energy used for heating]

Rationale for the levels:

**Level 0. Trend toward decarbonized heat by 2100**
There remain supports to fossil-fueled heating systems, low fossil-fuel prices

**Level 1. Trend toward decarbonized heat by 2070**

**Level 2. Ambitious policies** are adopted and deliver
DK targets 100% RES heat by 2050
Many cities/localities have already pledge to reach 100% RES heat (see next slide)

**Level 3. Best-practice policies** are adopted and deliver e.g. 100% RES heat by 2030 targeted by Upper Austria. 2035 is considered to account for a minim 15-year lifetime of heating systems

The means to provide the decarbonized heat is defined by other levers (see following slides)

Note: (i) 71% in service buildings

Source: Ecofys, 2016. EU pathways to decarbonized heating sector
Dozens of territories and institutions in the EU have shifted or are committed to shifting within the next few decades to 100% renewable energy in at least one sector\(^{(i)}\).

**Pledges logged on GO100%.org\(^{(1)}\)**

- EU: 86 pledges logged on the platform
- Worldwide:
  - 59 Countries,
  - 72 Cities,
  - 63 Regions/States,
  - 9 Utilities,
  - 21 NonProfit/Educational/Public Institutions,

Totaling more than 1.8 billion people

**100% RES champions\(^{(2)}\)**

- Electricity consumption covered by RE
- Heat consumption covered by RE

- Knežice (CZ) 100%, 96%
- Dobbiaco (IT) 100%, 100%

Note: (i) e.g. electricity, transportation, heating/cooling

Content

Project context
The approach for the buildings sector

Description of the levers
- Buildings efficiency
- Decarbonizing heat

Mix of technologies
- Appliances
Heat pumps could provide up to 65% of the heat load in retrofitted systems and 100% in new buildings

Share of heat pumps in the heating energy [% w.r.t. RES-based single heating systems]

Note: This leads so similar ambitions (in terms of number of systems) than the ones suggested by Ecofys(1), when combined with the maximum ambition for RES-based SHS (65%).

Source: (1) Ecofys, 2013. Heat Pump Implementation Scenarios until 2030

Rationale for the levels (based on Ecofys 2013(1)(i)):

**Level 0. Current policy implementation**

**Level 1. Moderate heat pump ambition scenario**
Defined as intermediate between 1 and 3

**Level 2. Ambitious heat pump scenario**
In terms of shares in new sales, this corresponds to 50% in new installations and 30% in retrofits

**Level 3. Very ambitious heat pump scenario**
In terms of shares in new sales, this corresponds to 65% in new installations and 50% in retrofits (i.e. 100% of sales in individual heating systems)
The carbon intensity of heat districts is derived from the heat decarbonization lever

Impact of non-RES heat on GHG emissions:
- Emissions from recovered heat are accounted in the power and industry models
- Emissions from fossil fuels are derived based on a mix similar to the one of individual heating systems

The rationale follows the one of heat decarbonization lever:

Level 0. Trend toward decarbonized heat by 2100
Level 1. Trend toward decarbonized heat by 2070
Level 2. Heat districts decarbonized by 2050
Level 3. Heat districts decarbonized by 2030
Content

Project context
The approach for the buildings sector

Description of the levers
  Buildings efficiency
  Decarbonizing heat
  Mix of technologies

Appliances
Most of energy savings are offset by a growing demand as shown in this slide for historical consumption (2000 to 2015)

Drivers in the EU CTI model:

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Number of households</th>
<th>Appliance utilization Growth rate</th>
<th>Floor area requirement</th>
<th>Energy efficiency of heating and appliances (a.o.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption 2000</td>
<td>291</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More dwellings</td>
<td>43.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More appliances per dwelling</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larger homes</td>
<td>20.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy savings</td>
<td>-98.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>-9.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption 2015</td>
<td>273.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Higher conditioned space area is driven by demographic assumptions and the average size of dwelling
- It is useful to distinguish higher demand for appliances from improved efficiency of electrical equipment

Source: www.odyssee-mure.eu
In the BaU demand for appliances is projected to increase by 137%

Rationale for the levels:

**Level 0. EU Reference scenario 2013** (1)
The projection is obtained by removing the effect of energy efficiency and demographic evolutions from the projections for the electricity demand in households.

**Level 1.** Growth limited to +1%/year

**Level 2.** Appliance utilization stabilized at today’s level

**Level 3.** Reduction with -1%/year

The resulting electricity consumption for appliances results from the combination of this lever with the one defining energy efficiency improvement.

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**Evolution of electricity-dependent services of households with constant efficiency [% w.r.t. demand in 2015]**

Source: (1) CE - 2013 - EU Energy, transport and GHG
Energy efficiency of electrical equipment is projected to increase up to 2030

Rationale for the levels:

**Level 0. EU Reference scenario 2013**
- -2,0%/year up to 2020
- -2,9%/year up to 2030
- -0,1%/year up to 2050

**Level 1.**
Higher improvements on 2030-2050:
additional -0,5%/year

**Level 2.**
+ Higher improvements on 2020-2030:
additional -0,5%/year

**Level 3.**
+ Further improvements on 2030-2050:
additional -0,5%/year

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**Evolution of energy intensity of appliances**
[% w.r.t. demand in 2015]

Source: (1) CE - 2013 - EU Energy, transport and GHG