Towards a renewable energy system: how to integrate power to heat

Wolfram Sparber

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Eurac Research - Institute for Renewable Energy

Applied research on renewable energy and energy efficiency

About 100 collaborators, laboratories in the field of PV, heat pumps, district heating, building envelopes, ...
wir sind südtiroler energie
siamo l'energia dell'alto adige
Climate change

Source: Theconversation.com, Bernhard Staehli, shutterstock
Air quality in urban areas

Source: Times.com, Beijing, China, May 4, 2017
Heat pumps for the heating sector

Using *widely renewable energy, no emissions* on site!

So *THE Solution* for all our heating needs?
Modelling of regional energy systems

South Tyrol’s Climate plan

Target

1,5 tons of CO₂ emissions per person/per year
Questions

- Is it feasible to reach the target of the climate plan? If so, which features should the new energy system have?
- How much will the new energy system cost in comparison to the current one?
- How will the financial structure of the energy system change and which main effects will this have on the energy assets in the upcoming years?
What are we talking about?

- We are talking about a **dynamic model** that simulates the **hourly** energy production and consumption.
- Starting point is a series of data from different sources, internal calculation and assumptions.
- Data accuracy is sometimes limited. Using more accurate data will improve the model accuracy.
- The model takes into account current technologies and natural resources, and their current costs.
Starting point

Energy consumption in South Tyrol
Energy consumption in South Tyrol: 12,4 TWh

- Electricity consumption = 2846.5 GWh
- Heat consumption = 6166.5 GWh
- Transport energy consumption = 3400 GWh

Overall energy consumption in South Tyrol, in the reference year 2014
Energy Production: reference year

*if only River hydro electricity production is considered within the model
Year profile of the heat consumption from district heating, Bolzano 2014. Source: Alperia Ecoplus
Year profile: electricity

Year profile of the electricity consumption, Northern Italy.
Source: Terna
Assumption / simplification: the energy consumption in South Tyrol follows this profile
Profile of solar radiation – average hourly data from 13 different locations in South Tyrol. Source: Province of Bolzano/Bozen
The model
Starting data and assumptions
Modelling of the reference scenario: District heating use

Week in summer

Week in winter
Modelling of the reference scenario: Electricity consumption
Optimization model of the energy system
Optimization of the costs compared to CO₂ emissions, varying different parameters.

Model n objectives – Eurac Research

Simulation model
EnergyPLAN (Aalborg University)

Optimization model
Multi objective evolutionary algorithm MOEA

Each point on the chart shows total costs and CO2 emissions per each energy system.
For each energy system, hourly energy production and consumption have been simulated.
Assumption: constant hydroelectric use
Assumption: possible installation of the building rooftops, except in historical centers. No ground use (max. potential 1250 MW, as calculated in the SolarTirol project)
Assumption: no use of large wind farms in South Tyrol
Assumption: possible use of energy storage systems such as thermal energy storages, batteries and hydrogen production
**Assumption:** constant use of biomass, no increase in biomass import. Slight possible increase in biogas use.
Assumption: Possible use of solar thermal on rooftops for domestic hot water. Possible use of heat pumps as part of the building’s heating system.
**Assumption:** Detailed analysis of the building stock in South Tyrol and evaluation of building refurbishment and costs – see appendix 2.
Evaluation of the total energy consumption and CO2 emissions of the transport sector. Analysis of the needed reduction to reach the target.
25,000 different combinations have been simulated to understand which energy systems could have the better features within the given conditions.
Results
Simulation results—electric and thermal energy

Each point of the cloud represents a specific combination of technologies in the year 2050 with related costs and CO₂ emissions. The $P_{EH}$ scenario represents a combination of technologies with annual costs similar to the reference scenario (current combination of technologies), but with heavily reduced emissions.
P_{EH} scenario – example district heating

Week in summer

Week in winter
The electricity consumption increases and the profiles changes due to the use of heat pumps.
Comparison of the overall energy consumption

Reference scenario
- Heat: 6.2 TWh (49.7%)
- Transportation: 3.4 TWh (27.4%)
- Electricity: 2.8 TWh (22.9%)
Overall energy consumption: 12.4 TWh

\(P_{EH}\) scenario
- Heat: 1.85 TWh (22.4%)
- Transportation: 3.4 TWh (41.2%)
- Electricity: 3.05 TWh (36.4%)
Overall energy consumption: 8.3 TWh
Considering zero emission mobility
% of zero emission mobility

* Penetration percentage of zero emission transport on the overall kilometres covered in the transportation sector
% of zero emission mobility
Comparison of the overall energy consumption

Reference scenario:
- Overall energy consumption: 12.4 TWh
- Heat: 6.2 TWh (49.7%)
- Electricity: 2.8 TWh (22.9%)
- Transport: 3.4 TWh (27.4%)

$P_{EH}$ scenario:
- Overall energy consumption: 8.3 TWh
- Heat: 1.85 TWh (22.4%)
- Electricity: 3.05 TWh (36.4%)
- Transport: 3.4 TWh (41.2%)

$P_{EHT}$ scenario:
- Overall energy consumption: 6.8 TWh
- Heat: 1.85 TWh (27.4%)
- Electricity: 3.55 TWh (52.6%)
- Transport: 1.40 TWh (19.9%)
Comparison - electricity

Electricity demand

Production

RS $P_{EH}$ $P_{EHT}$

1050 MW

800 MW

240 MW

PV capacity

RS $P_{EH}$ $P_{EHT}$

7%

26%

Comparison - electricity
Conclusion - modelling
Regional energy modelling - shows:

- Yes, there are different energy systems that allow to reach the set regional climate targets

- For the South Tyrol case – the model leads to a strong reduction of the heating needs, and a strong reduction of fossil fuels for transport, but to an increase of electricity consumption for electrification of transport and of heat

- The financial data show similar overall cost but a big difference in local value ...
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fuel Costs</th>
<th>Local Investment and O&amp;M Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>Oil: 1103 M€</td>
<td>220 M€</td>
</tr>
<tr>
<td></td>
<td>Gasoil: 696 M€</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petrol: 294 M€</td>
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<tr>
<td></td>
<td>Natural gas: 42 M€</td>
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</tr>
<tr>
<td>PEHT</td>
<td>Oil: 696 M€</td>
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<tr>
<td></td>
<td>Gasoil: 294 M€</td>
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</tbody>
</table>

Financial data
Heat and electricity demand: example South Tyrol

Data Sources - South Tyrol:
- Electricity demand: Terna, Italian TSO. Distribution of the North zone. 2014
- Heat for industrial applications is not included

Credits and further information Matteo Prina et. all, publications listed below
Heat and electricity demand: example Italy

Data Sources - Italy:
- Electricity demand: Terna, Italian TSO. Distribution of the whole Italy. 2015
- Heat demand: Elaboration of Hotmaps (http://www.hotmaps-project.eu/) time-series for residential and tertiary sectors. 2015, considering hourly average temperatures and degree days
- Heat for industrial applications is not included
Credits and further information Matteo Prina et. all, publications listed below
From heat to electricity: temperature

Example of COP variation of a heat pump in dependence of the inlet evaporator temperature. Shrinking temperatures lead to a shrinking COP. Eurac Research laboratory tests of a water / water heat pump with a nominal power 9.4 kW. Credits and further information Diego Menegon et. all, publications listed below
From heat to electricity: frequency

Frequency of presence of single COP values at the utilization of a heat pump over a full year.
Dynamic characterization compared with stationary characterization (i.e. Bin method and CTSS) of heat pumps.
Credits and further information Diego Menegon et. all, publications listed below
Heat and electricity demand: example Austria

Credits: Werner Weiss, AEE Intec
Reduction of heat demand through large scale refurbishment

Example building in Bolzano part of the FP7 smart city project SINFONIA

Città di Bolzano
Stadt Bozen

Credits: AREA architetti

BEFORE

264* kWh/m² year

AFTER

26 kWh/m² year

Example building in Bolzano part of the FP7 smart city project SINFONIA
Utilization of locally available renewable resources

Alperia – district heating Sesto, utilization of (local) biomass
Sector coupling through co-generation

Alperia – district heating Chiusa, combined heat and power
... and storage

Alperia – district heating Bolzano, energy tower and co-generation
... and heat pumps and other integrated technologies

a2a - district heating Milan, Canavese plant including heat pumps
Evolution of district heating systems

From fossil fuel based heating systems, to renewable based systems producing heat and power. Including thermal storage.

Allowing to take an active role for the electricity grid by producing electricity when needed, transforming oversupply electricity into heat, storing heat.
Further step: low temperature rings with heat pumps

Elaboration of substations for connection to DHC network through reversible heat pumps

A decentralised low-temperature DHC network at 15-25 °C for new city quarters or grid expansion
Example FLEXYNETS concept allowing large scale waste heat integration

The traditional substations of district heating systems are replaced with heat pumps. End-users become prosumers in dependence of their energy needs. The heating network serves as well as low temperature storage.
Closing remarks
Considering actual heat and electricity demand curves in Europe a full shift to electrification of heat is critical.

For a transformation to a low carbon energy system allowing a high degree of independence actions in many fields are needed. Including renewable energy sources for heat and electricity and large scale refurbishment of buildings.

Heat pumps, co-generation, thermal storage, district heating and low temperature rings allow the coupling of the electric and thermal energy systems and an active grid management.

In such a context heat pumps can give an important contribution to reduce on site emissions and enhance the application of renewables.
Development of the model for regional energy systems:

Elaboration of the case study – South Tyrol

Full presentation including technical background, free for download:

Simulations on the Italian Energy Systems

Further publication under review at present.
Additional information about dynamic heat pump performance:

Test method:

Heat pump performance:

Dynamic performance:

Component test method:

Heat pump performance:

System performance:
Additional information connected projects:

Low temperature district heating systems
Smart city projects with large scale building refurbishment

Open source information on heating in EU
Building refurbishment concepts including heat pumps

Full list of projects and including links is available under:
Urban Energy Transition: Renewable Strategies for Cities and Regions, second edition is a definitive science and practice compendium of energy transformations in the global urban system. This volume is a timely and rich resource as citizens, companies and their communities, from remote villages to megacities and metropolitan regions, rapidly move away from fossil fuel and nuclear power, to renewable energy as civic infrastructure investment, source of revenue and prosperity, and existential resilience strategy.

This book and its chapters present an entirely new edition throughout, in content, structure and science. Structured into four sections on design, technology, planning and finance, they feature:

- advanced urban planning and design, infrastructure, landscape, mapping and modelling, and governance issues related to urban renewable energy transformations
- community and user enabling aspects: energy access, prosperity and democracy, and urban renewable energy legislation, programs and incentives
- individual and mass transport innovations in the context of mobility related energy trends
- city-wide solar strategies and urban thermal performance planning, energy sector coupling, and distributed renewable energy and storage systems
- practical innovations in renewable energy finance, blockchain technology-enabled peer-to-peer renewable energy trading, and the case for regional monetary systems and sustainable lifestyles.
- analytic case insights into successful practices from cities and regions around the globe that provide local, regional and country-specific governance and organizational perspectives

Urban Energy Transition, second edition is a cross-disciplinary handbook that enables an immediate, principled and systems-based understanding of essential policy frameworks and action for a sustainable, climate stable world.

Cover image: Degrees of self-sufficiency in locally generated renewable electricity reached by 2050 under a decarbonize scenario, mapped for each of the local government areas in Europe. (Author: C. Fankhauser, O. Tschakert, G. J. Heal, 2010).
Thank you for your attention
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