Multi-objective optimization algorithm coupled to EnergyPLAN software: the EPLANopt model

Motivation

One of the **greatest challenges** of the international community is to **lower** anthropogenic greenhouse gas (GHG) emissions in order to tackle climate change.

**Heat and electricity sectors** produce the **25%** of the overall amount of GHG.

In order to address the **climate change problem** and to increase **security of the energy system**, an always larger number of countries have set **strict energy targets** and increased their share of renewables. European union adopted the **2020 climate and energy package** in 2007 and **2030 climate and energy framework** in 2014.

The **energy planning** is therefore acquiring a central role for **simulating the future energy system** and thus helping policy makers in setting targets and subsidizing mechanism.

The **optimization** problem of an **energy system** is a complex **multi-objective problem**. The ability of an electricity system to balance demand and supply may for instance be in opposition to its efficiency, as higher flexibility typically requires higher fuel consumption.
Originality and objectives

Similar approach of coupling EnergyPLAN to an optimization algorithm:

- Bjelic et al. [1] have realized a methodology of soft-linking of EnergyPLAN software with a generic optimization program (GenOpt – single objective).
- Mahbub et al. [2] have coupled EnergyPLAN to a multi-objective evolutionary algorithm written in Java to evaluate the Pareto front of best configurations of the energy system.

We have further developed this methodology:
- **Open-source** tool written in **python** based on DEAP library
- Multi-objective evolutionary algorithm with the possibility to set **n-objectives**
- Possibility to run **simulation in parallel** to reduce computational time
- Analysis of the input variables of the optimization algorithm, introducing the **energy efficiency** variable connected to building refurbishment

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Methodology: the energy model, EnergyPLAN

- **Deterministic**, analytically programmed energy system simulation model
- Particularly designed for the analysis of energy systems with **high degrees of renewable** energy sources (RES)
- It simulate one-year periods with a **temporal resolution** of one hour to adequately reflect the fluctuations in the various RES
- EnergyPLAN considers the **integration** of three primary sectors of any national energy systems.
- The **results** developed using EnergyPLAN are constantly being **published** within academic journals.
- Possibility to launch it from command prompt line. And so the **possibility** to create an **external code** in order to run serial simulations.
Methodology: the energy model, EPLANopt

Model n objectives

Simulation model

- EnergyPLAN (Aalborg University)

Optimization model

- Multi-objective evolutionary algorithm MOEA (DEAP)

Total annual costs [M€]

CO2 emission per person [t/person]

RS
Methodology: the energy model, EPLANopt

START

Generate initial population

Evaluate each individual (on total costs and CO₂ emissions)

Rank each individual: Fitness function

Stopping criteria met

yes → STOP

no → Generate new population

- Parent selections
- Crossover
- Mutation

Decision variables
- PV capacity
- Capacity of HP
- Capacity of thermal storage

Distribution data (hourly)
- Solar
- Wind

EnergyPLAN.exe

Output (annual)
- Annual costs
- CO₂ emissions
- % RES

MOEA
(Multi objective evolutionary algorithm)

EnergyPLAN
Methodology: the energy model, EPLANopt

https://gitlab.inf.unibz.it/URS/EPLANopt

Main characteristics:
- **Open source**
- Multi-objective optimization with **n-objectives**
- Possibility to **easily change operators and parameters** of the genetic algorithm (type of crossover, mutation, mutation rate,..)
- Possibility to **initialize** part of the population **with known solution** (seeding the population)
- Easy parameters and **data setting** through **.json file**
- Possibility of **parallelization**
- **Documentation** and simple **example** provided
Case study: South Tyrol, Reference year - 2014

Hydro: 5663.8 GWh (2656.8 GWh)*
PV: 264.5 GWh
Biogas: 8 GWh

Heat demand: 4676 GWh

District heating:
- CHP: 220.7 GWh, 765.6 GWh, 72.5 GWh, 21.3 GWh
- CHP waste: 1050 GWh
- Back-up boiler: 263 GWh
- Oil boiler: 420 GWh
- NGas boiler: 2260 GWh
- Biomass boiler: 680 GWh
- NGas boiler: 370 GWh
- Solar thermal: 126 GWh

Individual heating:
- Domestic Hot Water: 528 GWh, 2515 GWh, 978 GWh, 411 GWh

Electricity demand: 3399 GWh
Back-up boiler: 263 GWh

Imp: 16 GWh
Exp: 2846.5 GWh

*Biomass = 1076 GWh, NGas = 418 GWh, Oil = 8.6 GWh

*if only River hydro electricity production is considered within the model
Reference scenario – district heating production

Week in summer

Week in winter

Heat generation

- CHP
- th STO
- CHP waste
- Boiler
- HP
- DH demand

Heat production and demand [MW]

Heat production and demand [MW]
Reference scenario – Electricity production

Electricity generation

Week in summer

Electricity generation

Week in winter
Reference scenario – financial data

Total annual costs include investment costs, operation and maintenance costs and fuel costs for each technology.
Key assumptions and constrains

Which technology might be applied on which scale?

Key assumptions and constrains for a possible application of single technologies are listed in the table. PV assumptions are based on the simulations carried out within the SolarTirol project.

It is shown in which steps the range of application of a single technology has been considered in the single simulation iterations.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Simulation range (step)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PV [MW]</strong></td>
<td>250 – 1250 (25)</td>
</tr>
<tr>
<td><strong>Biogas power plants [MW]</strong></td>
<td>0-10 (10)</td>
</tr>
<tr>
<td><strong>Electric storage Batteries [GWh]</strong></td>
<td>0 – 10 (1)</td>
</tr>
<tr>
<td><strong>Electric storage Hydrogen [GWh]</strong></td>
<td>0 – 500 (10)</td>
</tr>
<tr>
<td><strong>Electrolyser [MW]</strong></td>
<td>0 – 1500 (100)</td>
</tr>
<tr>
<td><strong>Fuel cell [MW]</strong></td>
<td>0 – 1500 (100)</td>
</tr>
<tr>
<td><strong>Large heat pumps [MW]</strong></td>
<td>0 – 30 (5)</td>
</tr>
<tr>
<td><strong>Seasonal thermal storage [GWh]</strong></td>
<td>0 – 100 (10)</td>
</tr>
<tr>
<td><strong>Solar thermal [GWh_th]</strong></td>
<td>126 -500 (50)</td>
</tr>
<tr>
<td><strong>Heat pumps individuals [%]</strong></td>
<td>0 – %Energy Eff.</td>
</tr>
<tr>
<td><strong>Energy efficiency [%]</strong></td>
<td>0 – 75 (5)</td>
</tr>
</tbody>
</table>

Application of heat pumps in the building stock has been allowed in the model only after deep energy refurbishment of the building.
Through the Solar tyrol project is possible to estimate the maximum rooftop PV potential for the South Tyrol area that is equal to 1250 MW (while the current installed power is equal to 240.5 MW).
Energy efficiency

1. **Analysis and classification** of the provincial residential **building stock**: construction period, the **types of buildings** (single family house, multi family house, detached, block) and the heating degree days (HDD).

2. **Evaluation** of the **specific heat consumption** for each municipality, construction period, and type of buildings.

3. **Assessment of the cost of retrofit** and the **actual energy savings** associated to retrofit measures (through Passive House Planning Package (PHPP) simulations launched to evaluate the thermal energy consumption in post-retrofit conditions)

4. **Assumption** that the **energy saving percentage** is **the same regardless** of the **municipality** and the **construction period** of the buildings.

5. Possible to calculate the **annual thermal energy savings** for each construction period and type of building and also the value of the **euro per kWh saved**. The results obtained show therefore higher values of energy savings for municipalities with colder climates.

Measures that produce high energy savings compared to the costs (roof insulation for old SFH built before 1946, façade insulation and basement insulation)

Measures that produce low energy savings compared to the costs (window replacement for new houses)
Simulation result clowd – Hydro tot

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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
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<td>1196</td>
<td>27.3</td>
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<td>0</td>
<td>0</td>
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<td>1215</td>
<td>18.0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.3</td>
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<td>1258</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>100</td>
<td>100</td>
<td>0</td>
<td>10</td>
<td>0.5</td>
<td>671</td>
<td>1359</td>
<td>10.2</td>
</tr>
</tbody>
</table>
P4 – district heating production

**Week in summer**

**Heat generation**

- CHP
- CHP waste
- Boiler
- HP
- DH demand

**Week in winter**

**Heat generation**

- CHP
- CHP waste
- Boiler
- Old DH demand
- DH demand
- HP
- th STO
P4 – Electricity production

Week in summer

Week in winter

Electricity generation

- CHP
- CHP_waste
- PV
- River_hydro
- Biogas_PP
- batt Storage
- H2 Storage
- Import
- old_demand
- new_demand

Electricity production and demand [MW]

4100 4150 4200 4250 4300

hours

8500 8550 8600 8650 8700

hours
P4– energy consumption

- **Reference scenario**:
  - Heat: 49.7%
  - Electricity: 22.9%
  - Transport: 27.4%

- **P4**:
  - Heat: 18.9%
  - Electricity: 38.5%
  - Transport: 42.6%

**Overall energy consumption**:
- Reference scenario: 12.4 TWh
- P4: 7.9 TWh
P4– financial data

![Financial Data Chart]

The chart illustrates the costs of the energy system, broken down into various components such as total costs, costs per source, income from export, imp-exp, energy efficiency, CHP units, Boilers, Batteries, H2 Storage, HP individual, Thermal Storage, HP DH, Natural gas, Biomass, Petrol, Gasoil, Oil, Solar Thermal, RH, PV.
Conclusions

- **EPLANopt** model couples energyPLAN software with a multi-objective evolutionary algorithm
  - Open source
  - n-objectives
  - Parallelization of the code, low computational time
  - **EPLANopt** is open-source software that allows for multiple objectives and parallel processing.

- Through an external code has been possible to consider **energy efficiency variable** within energyPLAN simulation tool and adding a constraint on individual heat pumps
  - By integrating external code, the model can consider energy efficiency as a variable, providing more accurate results.

- The methodology has been applied to a case study, the provincial area of South Tyrol, and the final results presented
  - Applied to South Tyrol to demonstrate the model's effectiveness in real-world scenarios.

- The following methodology allows for identifying the **future optimal mix** configuration of an energy system starting from the **current situation** and **potentials of renewables** or different sources.
  - Identifies the best energy mix considering current and future energy potentials.

- Multi-objective optimization approach provides more informations to the decision makers or policy makers if compared to single-objective approach.
  - Offers a comprehensive view, aiding in making informed decisions.
Thanks for your attention

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P4 – Electricity annual balance

Reference scenario

P4

- HPind
- HP
- demand
- Biogas
- River Hydro
- PV
- CHP_waste
- CHP
- export
- import
Zero emission transports
PT – district heating production

Week in summer

Week in winter
PT – Electricity production

Week in summer

Week in winter

Electricity generation

- CHP
- CHP_waste
- PV
- River_hydro
- Biogas_PP
- batt Storage
- H2 Storage
- import
- old_demand
- new_demand
PT – energy data

Overall energy consumption:
- Reference scenario: 12.4 TWh
- PT: 6.8 TWh
PT – Electricity annual balance
PT – financial data
financial data

Reference scenario

Local investment and O&M costs

220 M€

Fuel costs:
Oil
Gasoil
Petrol
Natural gas

1103 M€

Point PT

Local investment and O&M costs

559 M€

Fuel costs:
Oil
Gasoil
Petrol
Natural gas

453 M€

Energy efficiency costs

1323 M€

1012 M€
Energy efficiency

1. **Analysis** of the provincial residential building stock and classification according to the **construction period**, the **types of buildings** (single family house, multi family house, detached, block) and the **heating degree days (HDD)**.

2. **Evaluation** of the **specific heat consumption** for each municipality, construction period, and type of buildings.

3. **Assessment of the cost of retrofit** and the **actual energy savings** associated to retrofit measures. **Passive House Planning Package (PHPP) simulations** have been carried out for the following four types of housing: single family house (SFH) 250 m², multi family house (MFH) 904 m², detached 1363 m² and block 2308 m². PHPP simulations were launched to evaluate the thermal energy consumption in post-retrofit conditions with the aim of quantifying actual energy savings.

4. Assumption that the **energy saving percentage** is the same regardless of the **municipality** and the **construction period** of the buildings.

5. Possible to calculate the **annual thermal energy savings** for each construction period and type of building and also the value of the euro per kWh saved. The results obtained show therefore higher values of energy savings for municipalities with colder climates.
Retrofit actions – all residential buildings

- Facade insulation
- Roof insulation
- Basement insulation
- Window replacement

Share of total surface

Annual savings in TWh

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8
Retrofit actions by building type

Annual savings in TWh

Share of total surface

- 1-2 FH
- Small MFH
- Big MFH
- Block
Retrofit actions by construction period

- Before 1946
- 1946-1990
- 1991-2005
- After 2005