Creating optimal transition pathways from 2015 to 2050 towards low carbon energy systems using the EnergyPLAN software: methodology and application to South Tyrol

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Introduction

Energy system models

- Top-Down models
- Bottom-up models

State of the art Application

The model

Conclusions

- **Perfect foresight optimization**
  - Assumes decision maker is provided **full information about future** costs and constraints
  - The optimization problem is solved once, considering the whole timeframe

- **Myopic optimization**
  - The decision maker has a **limited view** of the future
  - A **set of optimization problems** has to be solved, where solution of previous problems is used as input for the latter ones

Keppo, Strubegger - "Short term decisions for long term problems – The effect of foresight on model based energy systems analysis"
## State of the art

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**NOVELTY:**

- High time resolution
- Multi-objective optimization including cumulated CO₂ emissions

### EPLANopt

![Diagram of energy system](image)

**Already implemented**

- Deterministic simulation model
- Future scenarios with **high degrees of renewable** energy sources (RES)
- It simulate one-year periods with a **temporal resolution** of one hour
- **Integration** of three primary sectors of any national energy systems.
- Possibility to launch it from command prompt line. And so the possibility to create an external code in order to run serial simulations.

<table>
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**Simulation model**

- EnergyPLAN (Aalborg University)

**Optimization model**

- Multi objective evolutionary algorithm MOEA (DEAP)

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**Introduction**

**State of the art**

**The model**

**Application**

**Conclusions**
EPLANoptTP - EPLANopt for transition pathways

1. Generate initial population
2. Evaluate each individual (on annual costs and CO₂ emissions)
3. Rank each individual according to fitness
4. Convergence reached?
   - Yes: STOP
   - No: Generate a new population
     Through operators:
     - Parent selection
     - Crossover
     - Mutation

Input variables:
- Capacities of RES
- Capacity of electric storage
- Energy efficiency
- ...

Distribution data:
- PV
- Wind
- ...

Costs trends:
- Technologies
- Fuels
- ...

Historical data of plants decommissioning

Multi-Objective Evolutionary algorithm (MOEA)
I. Collects all the input data

II. Performs a capacity conservation balance
Runs EnergyPLAN with the reference scenario modified according to the input data related to the current period, to compute the yearly operation & Maintenance (O&M) costs and the CO2 emissions.

III. Integrates all the time-period costs and emissions to calculate their cumulated values

Decision variables: Total installed capacity [MW / GWh]

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<th>2020</th>
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I. Input parameters:
- Reference scenario
- Cost trends
- Technology parameters
- Historical data of plant commissioning
- Discount rate

III. Output:
- Cumulated CO2
- Cumulated costs
EPLANoptTP - variables

- Capacity (t,k) [optimization variable]:
  - A $(K \times T)$ matrix representing the total installed capacity of all considered technologies $k$ in each timestep $t$

- CO$_2$ emissions (t):
  - Emissions related to the whole energy system (considering thermal and transport) in each timestep $t$, computed by EnergyPLAN and then multiplied for the number of years in that timestep

- O&M costs (t):
  - Fixed and variable operation costs related to the whole energy system in each timestep $t$, computed by EnergyPLAN, discounted to the first year in the timestep

\[
O&M(t) = O&M'(t) \cdot \sum_{y=1}^{Y} (1 + r)^{(1-y)}
\]

- $O&M'(t)$: O&M costs as computed by EPLAN (just for one year)
- $Y$: number of years $y$ in each timestep
- $r$: discount rate
• Investment costs (t,k):
  - Costs related to the installation of new capacity
  - Lump-sum payment in the first year of the same timestep the capacity is installed
  - Unit costs [EUR/kWh] are an input parameter, varying with time

• Salvage value (k):
  - Residual value of capacity of technology k still available after the optimization timespan
  - Calculated assuming constant linear depreciation

\[
\text{Salvage}(k) = \sum_{t = T - \text{Life}(k)}^{T} \text{salvage}(t, k)
\]

\[
\text{salvage}(t, k) = \text{Inv}(t, k) \cdot \left[1 - \frac{T - t}{\text{Life}(k)}\right]
\]
EPLANoptTP - variables

• Cumulated CO2 emissions & discounted cumulated costs:
  • Objective functions, to be minimized by the genetic algorithm

\[
\begin{align*}
C_{\text{CO2 cumulated}} [OBJ_1] &= \sum_{t=1}^{T} C_{\text{CO2}(t)} \\
C_{\text{Costs cumulated}} [OBJ_2] &= \sum_{t=1}^{T} \left[ (1 + r)^{Y(t-t)} \cdot \left( \sum_{k=1}^{K} I_{\text{Inv}(t,k)} + O&M(t) \right) \right] - (1 + r)^{Y(1-T)} \cdot \sum_{k=1}^{K} S_{\text{Salvage}(k)}
\end{align*}
\]

- **T:** number of timesteps
- **K:** number of technologies
- **Y:** number of years y in each timestep
- **r:** discount rate

CO2(t): CO2 emissions of the whole energy system in timestep t
Inv(t,k): investment costs for technology k in timestep t
O&M(t): O&M costs for the whole energy system in timestep t
Salvage(k): Salvage value of residual capacity of technology k
EPLANoptTP – South Tyrol

- **4 decision variables:**
  - PV
  - PV+Li-ion battery storage
  - Hydrogen storage
  - Energy efficiency in buildings

- Installed capacity of other technologies is assumed to remain constant (replaced at null cost)

- 7 timesteps of 5 years each, ranging from 2015 until 2050

- Linear decrease of electricity production from Hydro due to climate change

- Constant electric demand

- PV+Li-ion battery storage: costs on 3 kW PV and 4kWh battery

- Growth constraints on
  - PV = 65 MW/year
  - Energy efficiency in buildings = 6%/year
EPLANoptTP – cost trends

**Residential PV**

- Vartiainen
- EPLAN
- SETIS
- ETIP
- Average

**Lithium-ion batteries**

- IRENA
- Vartiainen
- IEA min
- IEA max
- Average

**Capital costs [€/kW]**

Year: 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050

**Capital costs [€/kWh]**

Year: 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050
EPLANoptTP – results

The graph shows the relationship between cumulative costs (in millions of Euros) and cumulative CO2 emissions (in Mt) for different scenarios labeled P1 to P5. The graph indicates that as cumulative CO2 emissions increase, the cumulative costs also tend to increase. The scenario RS is marked with a triangle and shows a higher cumulative cost compared to the other scenarios for a given cumulative CO2 emission level.

The figure is part of a presentation or report that contains sections such as Introduction, State of the art, The model, Application, and Conclusions.
EPLANoptTP – results

![Graphs showing PV capacity, PV+battery capacity, H2 storage capacity, and Energy efficiency capacity for P1 to P5 over time from 2015 to 2050.](image)

- **PV capacity [MW]**
- **PV+battery capacity [MW]**
- **H2 storage capacity [GWh]**
- **Energy efficiency capacity [%]**

Legend:
- **Total capacity**
- **Residual**
- **2020**
- **2025**
- **2030**
- **2035**
- **2040**
- **2045**
- **2050**
EPLANoptTP – results

Final energy [TWh/y]

P5

P3

P1

REF

DH Biomass cogeneration
DH NG Boiler
DH Oil Boiler
DH Waste cogeneration
HH Heat Pumps generation
HH NG for hot water
HH Biomass Boiler
HH NG Boiler
HH Oil Boiler

Introduction  State of the art  The model  Application  Conclusions
EPLANoptTP – results

Annual electricity production [TWh/y]

P5      P3      P1      REF

- EI demand + HP
- EI demand + HP
- EI demand
- Waste CHP
- CHP
- PV
- PV + battery
- River Hydro
- Import

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EPLANoptTP – results
EPLANoptTP – results

Introduction

State of the art

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P1_60

P1_40

P1_20

P1

Annual energy [TWh/y]

Electricity demand
El. demand from HP
El. demand from BEV
Thermal demand
Transport demand

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Introduction | State of the art | The model | Application | Conclusions
Conclusions

- An **optimization methodology** of energy transition pathways has been developed starting from the simulation software *EnergyPLAN* (very large community).


- It highlights the importance to consider **cumulated CO₂ emissions** as objective function and not only the CO₂ emissions of the year 2050.

- The advantage of using a genetic algorithm is the possibility to parallelize the code to save computational time.
Thanks for your attention

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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)