EnergyPLAN + MOEA: Development of an innovative tool for multi-objective optimization of energy systems

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Introduction

CHALLENGES:

▪ Increase of energy demand
▪ Reserve of fossil fuels
▪ Environmental and Climate Issues
▪ Integration of Renewable Energy
  - Difficulties:
    ▪ fluctuating behavior
    ▪ limited availability
    ▪ financial obstacles

SOLUTION:

▪ Integrated energy systems with proper control strategies
Problem

Which optimal Energy System?

- Capacity optimization
- Minimization of objectives (e.g. CO$_2$ emissions and annual cost)
- Single-objective or Multi-objective optimization problem?
- Constrained optimization problem

Example:

- Optimal capacities (kW):
  - Wind power
  - Solar power
  - Biomass CHP
  - Gas CHP
- Constraints:
  - Biomass usage $\leq x$ (GWh)

Multi-objective optimization (example below)
- CO$_2$ emission (tons)
- Annual cost (euro)
Heterogeneous competences serving a multidisciplinary problem

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Multi-objective Optimization

- Have more than one objective
- Often the objectives are conflicting to each others
  - A solution does not typically minimize/maximize all the objectives simultaneously.
- Pareto-optimal solutions:
  - Solutions that cannot be improved in any of the objectives without degrading at least one of the other objectives
- Pareto dominance and Pareto-front
Main motivation

- No framework for optimize different sectors together
- Manual iterative process
- Time consuming
- No guarantee for finding optimal solutions
Why integrated optimization is important?

- **Traditional System**
  - Mainly based on fossil fuels
  - No Interconnection among energy sub-systems

- **Smart Energy System**
  - **Sector Coupling**: interconnection of all major energy sectors
  - New kind of flexibility is added into the system
  - In this architecture more renewable energy could be added
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Source: IEA
PHASE 1
System integration currently not a relevant issue

PHASE 2
Draw on existing flexibility in thermal & hydro power plants, grids

PHASE 3
Flexibility investments: all power plants, demand side, storage, grids

PHASE 4
Require advanced technologies to ensure grid reliability

Status of VRES

Share of wind and solar PV in power generation
Source: IEA 2016
EnergyPLAN

Simulation

Some customized parameters
- Energy dependency for a region
- Load following capacity
**Proposed Framework and results**

Integration of Multi-objective evolutionary algorithm with EnergyPLAN

**Initial test problem:**
- Energy system optimization of Aalborg municipality
- Optimization of on-, off-shore wind, PV, CHP, heat pump capacity in order to minimize CO₂ emission and annual cost

* Combining multi-objective evolutionary algorithms and descriptive analytical modelling in energy scenario design, Md Shahriar Mahbub, Marco Cozzini, Poul Alberg Østergaard, Fabrizio Alberti; Applied Energy, 2016
Recognition from Aalborg University as developers of EnergyPLAN + MOEA

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New study on combining EnergyPLAN with multi-objective evolutionary algorithms

In a new study by Mahbub et al, the versatility of EnergyPLAN and in particular the ability of EnergyPLAN to be run from other modelling environments is exploited in an automated methodology for generating scenarios, evaluating these according multiple objectives and subsequently generating new scenarios. EnergyPLAN is thus used in an application more commonly associated with investment optimisation models. See http://dx.doi.org/10.1016/j.apenergy.2015.11.042 for further details.
Designing optimized energy scenarios for an Italian Alpine valley: the case of Udine Esterni

Md Shahriar Mahbub, Diego Viesi, Sara Cattani and Luigi Crema

Abstract

The design of future local energy scenarios, under the framework of covenant of mayors' initiative, is an important and challenging task for the energy and policy planners. Designing energy scenarios is a multi-objective optimization problem, hence, a framework that combines a multi-objective evolutionary algorithm and EnergyPLAN is employed to identify optimized scenarios. In this study, optimized scenarios for the policy makers of Udine Esterni are identified, so that they are able to face the challenges of minimizing energy costs and CO2 emissions, decreasing the dependency on foreign resources, and integrating large amount of renewable energy. The results show that economically attractive, environmental friendly and less dependent energy scenarios can be achieved by 1) increasing the capacity of photovoltaics, 2) maximizing local biomass usage through individual wood boilers, and 3) partially electrifying the thermal sector through ground source heat pumps. The modification of the transport sector by introducing electric cars is not economically viable under the current market conditions. Our kind of study can be performed for the policy makers of other regimes as well, by 1) collecting energy data, 2) identifying local renewable resources, 3) modelling reference scenarios, 4) identifying optimized scenarios, 5) studying the scenarios according to the requirements.
Case Study Giudicarie Esteriori

- Study area: Alpine Valley named Giudicarie Esteriori
- Analyze electricity, thermal and transportation demands
- A reference scenario is modeled (year 2013)
- Four objectives:
  - $\text{CO}_2$ emission
  - Annual cost
  - Load following capacity (LFC)
  - Energy system dependency (ESD)
- Decision variables: oil, gas and biomass individual boiler; individual heat pump; biomass CHP; PV; petrol, diesel and electric car

* Designing of optimized energy scenarios for an “Italian Alpine Valley”: the case of Giudicarie Esteriori, Md Shahriar Mahbub, Diego Viesi, Luigi Crema, submitted to Energy journal, review phase
Results for Giudicarie Esteriori

- **401** optimized Scenarios are identified
- Compare to reference scenario
  - **Emission**: All optimized scenarios
  - **Annual cost**: 26 are less costly
  - **LFC**: 54 are better
  - **ESD**: All optimized scenario

- **13** scenarios are better in all objectives
Case Study Val di Non approach to transition targets

- Study area: Val di Non
- Three time periods: 2008-2020, 2020-2030 and 2030-2050
- Two objectives: CO₂ emission and annual cost
- Considered different emission targets:
  - 2020: 50-55% emission reduction
  - 2030: 65-70% emission reduction
  - 2050: 95-100% emission reduction
- Selecting scenario within the considered range by using the techniques of maximizing decision space diversity.
Future Directions

▪ Research:
  – Which policies helps to reach optimized scenarios for different time period?

▪ New case study:
  – Smart Energy Plan for the Autonomous Province of Trento (2021-2050)
List of published papers

- **Journal papers:**

- **Conference papers:**