Integration of variable energy resources in a global energy system model

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Outline

1. Introduction
2. Global EFDA TIMES model
3. Methodology for modelling variable energy resources (VER) in a Global Energy Model
4. Determination of VER input parameters to EFDA TIMES
5. Conclusion and Outlook
Introduction

• Ideal mitigation path for low carbon energy supply is determined with Global Energy Models

• Global Energy Models (GEM) predict high shares of renewables without taking into account
  – necessary changes in energy system due to temporal and spatial variability of renewable energy resources
  – technologies lock-ins
Mühlisch and Hamacher (2009) fusion des; van Vuuren, Hooogwijk et al. (2009) EP; Edenhofer, Carraro et al. (2009) RECIPE; ...

• Presentation of the European example
• Implementation in EFDA TIMES currently tested

The EFDA-TIMES Model

• Partial equilibrium TIMES model
• Bottom-up, technology explicit
• Temporal resolution
  – 2000 – 2100, 12 periods
  – 12 timeslices
• Spatial resolution
  – 15 regions
• Focus on electricity supply
Modelling of VER with peak equation

- Global assumption on low security of supply of variable ressources: in the timeslice with maximal load (winterday) only a certain share of wind and solar power is guaranteed
- Lower limit for backup power plants

Modelling of VER without peak equation

- No infrastructure extensions taken into account
- Energy **system** configuration is different for different shares of intermittent resources

→ **Parameterize** system configurations

**Modelling of intermittent resources in a GEM**

**Modelling of variable resources in a GEM**

\[ \alpha - \beta \text{ parameter space} \]
Modelling of variable resources in a GEM

1. Choice of $\alpha_i$ with dummy MIP process

2. Restriction of parameter space: range of ideal solar-wind mix: $\beta_{\text{min}}, \beta_{\text{max}}$
Modelling of variable resources in a GEM

1. Choice of $\alpha_i$ with dummy MIP process

CWIN$^\text{min}$ CWIN$^\text{max}$ CSOL$^\text{max}$ CBACK$^\text{min}$ CGRID$^\text{min}$

$\alpha^1 = 0.1$
$\alpha^2 = 0.2$

2. Restriction of parameter space: range of ideal solar-wind mix: $\beta^\text{min,max}$

3. Confinement of system configuration

EFDA TIMES

Additional Models

Different levels of grid extension can be captured by including several MIPs for each $\alpha_i$.
Model methodologies for VER parameters

1. Timeseries analysis
   - $\beta_{i, \text{min, max}}$
   - $C_{\text{WIN}, i}, C_{\text{SOL}, i}, C_{\text{BACK}, i}$

   • Wind and solar supply timeseries and load curves in hourly resolution 2000-2007, high regional resolution
   
   Moehrlen (2004), Bofinger et al. (2008)

   • Spatial distribution of capacities of wind and solar power plants in 103 regions scales with energy production potential of the regions (Full Load Hours)

2. European Model
   - $C_{\text{GRID}, i}$

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**Timeseries analysis**

\[ \beta = \frac{E_{\text{WIND}}}{E_{\text{WIND}} + E_{\text{SOLAR}}} \]

\[ \alpha = \frac{S}{D} \]

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\[ D_{nt} = \sum_{t} D(t) \]

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Model methodologies for RES parameters

1. Timeseries analysis
   - $\beta_i^{\text{min}, \text{max}}$
   - $\text{CWIN}_i$, $\text{CSOL}_i$, $\text{CBACK}_i$

2. Energy system model for Europe
   - $\text{CGRID}_i$

European model

- Model setup
  - Linear Optimization of total costs for a typical year
  - 103 regions following TSO regions
  - UCTE Grid
  - Hourly resolution
    - Wind and Solar supply
  - Technoeconomic parameters
    - Costs, Losses, Dynamic restrictions

- Scenario setup
  - Existing power plants
  - Solar and Wind energy power plants determined by timeseries analysis
  - Grid extension of UCTE grid possible (@600$/MWkm)
• Grid extension for each $\alpha_i$ and $\beta_i$

• Total system costs only slightly influenced by grid costs
Conclusion and Outlook

1. Conclusion
   - New modelling methodology:
     - Parametrization of system configuration for each share of intermittent resources and different grid extensions
     - Parameters determined with additional models
       + Addresses temporal and spatial variation
       + Extendable to global level
       + Storage can be included
     - Mixed integer programming
   - Results from additional models show that
     - Direct grid integration costs are comparatively cheap

2. Outlook
   - Results with EFDA TIMES to come
   - Include further technologies (e.g. CSP)
   - Storage

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Thank You!

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The EFDA-TIMES Model

- Partial equilibrium TIMES model
- Bottom-up, technology explicit
- Temporal resolution
  - 2000 – 2100
  - 12 periods
- Spatial resolution
  - 15 regions
- Final energy service demands, split into 5 sectors
Supply side: fossil resources

Hard Coal
Total: 1155542 EJ
- reserves
- resources

Lignite
Total: 10944 EJ
- reserves
- resources

Oil
Total: 29057 EJ
- reserves
- resources

Gas
Total: 81228 EJ
- reserves
- resources

Uranium
Total: 17528 EJ
- reserves

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Supply side: fossil resources

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Electricity mix reference case

Timeseries analysis

\[ E_{RE} = E_{WIND} + E_{SOLAR} \]

\[ \beta = \frac{\sum E_{WIND}(t)}{\sum [E_{WIND}(t) + E_{SOLAR}(t)]} \]
Timeseries analysis

\[ S = E_{WIND} + E_{SOLAR} - OP \]

Minimization of the distance between load and supply

\[
\min \left[ \sum_t (OP(t) + UP(t)) \right] = \min \left[ \sum_t (D(t) - E_{RES}(t)) \right]
\]

Energy system model

Plausibility Check:
Cumulative energy production (TWh) in total and for selected regions

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Energy system model

Plausibility Check:
Cumulative transport (TWh) in the UCTE Grid

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• Grid extension for each $\alpha_i$ and $\beta_i$