Integrated Energy System Analysis – Optimization (IESA-Opt)

The LP optimization model of the energy system of the Netherlands

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PRESENTATION OVERVIEW

› **First Part:** Model specification, capabilities, and limitations

› **Second Part:** Strategic and institutional implications
FIRST PART: MODEL SPECIFICATION

- Introduction
- Model structure
- Rich technological detail
- Cross-border electricity trade
- Demand Response Flexibility
  - Residential Electricity
  - Residential P2Heat
  - P2Liquids
- Flexibility of CHPs
- Technological Learning
- Transitional Optimization
  - Perfect foresight
  - Retrofitting and decommissioning
- Data Sources
- Pros and Cons
- Needs and foreseen collaborations
INTRODUCTION

- Started in September
- Initial aim: Learning the AIMMS software
- The model showed promising potential, so the AIM changed to be used for ESTRAC
- Several capabilities have been added to the model since then
- The first version of the model will be released by the end of October
### MODEL STRUCTURE (1/2)
(SIMPLIFIED) EXAMPLE

#### Activity
Type of Activity | Volume | eDemand EU | eDemand NL | Transport need | Fuel | Electricity NL | Electricity EU | Oil | Gas | CCUS | CO2 ETS | CO2 n-ETS | Activity Balances
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
General | | | | | | | | | | | | | | |
Transport | ICE car | 4.00 | 1.00 | 1.00 | -1.80 | -1.00 | | | | | | | | |
| ICE car more efficient | 4.20 | 1.00 | 1.00 | -1.50 | | -1.20 | | | | | | | |
| PHV Hybrid car | 5.00 | 1.00 | 1.00 | -0.70 | -1.10 | | | | | | | | |
| BEV Electric car | 5.50 | 1.00 | 1.00 | | -1.90 | | | | | | | | |
Reffineries | Fuel T1 | 3.00 | 1.00 | | | -1.00 | -0.40 | -0.25 | | | | | |
| Fuel T1 wCCS | 3.30 | 1.00 | | | | -1.00 | -0.45 | -0.20 | -0.05 | | | |
| SynFuels | 4.50 | 1.00 | | | | -2.00 | | | | 0.40 | | |
Power NL | Electricity NL Gas | 1.00 | | | 1.00 | | | -2.20 | -1.00 | | | |
| Electricity NL Wind | 1.50 | | | | 1.00 | | | 0.00 | 0.00 | | | |
| Electricity from EU | 0.05 | | | | 1.00 | | | -1.02 | | | | |
Power EU | Electricity EU Gas | 1.10 | | | 1.00 | | | -2.22 | -1.01 | | | |
| Electricity EU Wind | 1.40 | | | | 1.00 | | | | | | | |
| Electricity from NL | 0.05 | | | | | 1.00 | | | | | | |
Primary Energies | Oil Supply | 9.00 | | | | | 1.00 | | | | | | |
| Gas Supply | 7.00 | | | | | | | | | | | |
CO2 related | Carbon Storage | 25.00 | | | | | | | | | | | |
| ETS Allowance | 30.00 | | | | | | | | | | | |
| n-ETS Emission | | | | | | | | | | | | |

**Model:** \( \min C \times X, \text{ while } M \times X \geq Y \)

- **Y:** Exogenous demand of economic activities
- **X:** The use of the available technologies
- **M:** The activity balance of the available technologies
- **C:** The costs of using the activities
MODEL STRUCTURE (2/2)

Activities
- Drivers
- Energy
- Emissions
- External

Technologies
- Residential
- Services
- Agriculture
- Industry
- Etc.

\[ \text{OF} : \text{Min} \left( \sum_{t,t_i,p} \alpha_{t,i,c,t} I_{t,p} + \alpha_{t,r,c,t,i,p} R_{t,t_i,p} + f_{oc,t,p} S_{t,p} + v_{oc,t,p} T_{t,p} \right) \]

- \( t : \sim 700 \) Technologies
- \( p : \) yearly periods, i.e. 2020, 2025, 2030, ..., 2045, 2050

Linear Optimization of NL energy system over the time-horizon (similar to TIMES)
## TYPES OF TECHNOLOGIES

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispatchable*</td>
<td>Their use is defined on hourly basis.</td>
<td>Electricity generators</td>
</tr>
<tr>
<td>Operation, Flexible</td>
<td>Their usage is defined per year, but they impact the system on hourly basis.</td>
<td>Demand response tech, EVs, Storage tech, flexible heat-pumps, and other similars</td>
</tr>
<tr>
<td>Operation, non-Flexible</td>
<td>Same as above, but they cannot deviate from their operation profile.</td>
<td>Standard non-flexible consumption tech, such as gas boilers and IC vehicles</td>
</tr>
<tr>
<td>CHP flexible</td>
<td>They deviate from their operation profile and from their heat/power output ratio on hourly basis</td>
<td>CHPs</td>
</tr>
<tr>
<td>Shedding (flexible)</td>
<td>Technologies that can curtail their reference operation on hourly basis</td>
<td>Electrolyzers, P-to-Gas, P-to-Liquids, P-to-Ammonia, Hybrid technologies</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>They constraint the use of technologies at different temporal scales, e.g. hours and days</td>
<td>Electricity, Gas, Hydrogen, and district heating networks.</td>
</tr>
</tbody>
</table>

*To consider infrastructure constraints, natural gas and hydrogen will have to be dispatched on a daily (or weekly) basis. Then, we can also give hourly flexibility to the compressors that are changing the pressure of the gas. Question for the audience: In reality, how is natural gas dispatched?
# TYPES OF NETWORKS (CONNECTORS)

## Energy Carriers

### Electricity
- 1. High Voltage
- 2. Medium Voltage
- 3. Low Voltage
- 4. Off-shore
- 5. Import/Export to neighboring countries (5 connectors)

### Heat
- 1. Low Temperature Network
- 2. Low Temp. Services
- 3. Low Temp. Agriculture and Horticulture
- 4. Low Temp. Industrial
- 5. High Temp. Industrial

### Gas
- 1. High Pressure
- 2. Medium Pressure
- 3. Low Pressure
- 4. Import/Export

### Hydrogen
- 1. High Pressure
- 2. Low Pressure
- 3. Import/Export
# INFRASTRUCTURE*

<table>
<thead>
<tr>
<th>Energy Carriers</th>
<th>Types of Connectors</th>
<th>Technology</th>
<th>Activity Constrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>High Voltage</td>
<td>e.g. kilometers of transmission lines</td>
<td>e.g. GW</td>
</tr>
<tr>
<td></td>
<td>Medium Voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low Voltage</td>
<td>e.g. kilometers of transmission lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Off-shore</td>
<td>e.g. kilometers of distribution lines</td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>Low Temperature Network</td>
<td>e.g. kilometers of heat pipelines</td>
<td>e.g. PJ/Day</td>
</tr>
<tr>
<td>Gas</td>
<td>High Pressure</td>
<td>e.g. kilometers of gas pipelines</td>
<td>e.g. PJ/Day</td>
</tr>
<tr>
<td></td>
<td>Medium Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low Pressure</td>
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<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>High Pressure</td>
<td>e.g. kilometers of hydrogen pipelines</td>
<td>e.g. PJ/Week</td>
</tr>
<tr>
<td></td>
<td>Low Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>Charging station</td>
<td>e.g. number of charging stations</td>
<td>e.g. GW</td>
</tr>
<tr>
<td>CCUS</td>
<td>CCUS</td>
<td>e.g. kilometers of CCUS pipeline</td>
<td>e.g. Mton/Week</td>
</tr>
</tbody>
</table>

*Work in progress*
RICH TECHNOLOGICAL DETAIL (1/3)
INDUSTRY (~90 TECH.)
RICH TECHNOLOGICAL DETAIL (2/3)
BUILT ENVIRONMENT (~125 TECH.)

- Boiler Gas / Ins GFE - BE Residential Flat
- Boiler Gas / Ins DC - BE Residential Flats
- Boiler Gas / Ins B - BE Residential Flats
- Boiler Gas / Ins A - BE Residential Flats
- Boiler Gas / Ins A+ - BE Residential Flats
- Boiler Gas w Solar / Ins A+ - BE Residential Flats
- District Heating / Ins GFE - BE Residential Flats
- District Heating / Ins DC - BE Residential Flats
- District Heating / Ins B - BE Residential Flats
- District Heating / Ins A - BE Residential Flats
- District Heating / Ins A+ - BE Residential Flats
- Hybrid Heat Pump / Ins B - BE Residential Flats
- Hybrid Heat Pump / Ins A - BE Residential Flats
- Hybrid Heat Pump / Ins A+ - BE Residential Flats
- Electric Heater / Ins A+ - BE Residential Flats
- Electric Heater wSolar / Ins A+ - BE Residential Flats
- Electric Heat Pump Air / Ins A+ - BE Residential Flats
- Electric Heat Pump Air FLEX / Ins A+ - BE Residential Flats
- Electric Heat Pump GW / Ins A+ - BE Residential Flats
- Electric Heat Pump GW FLEX / Ins A+ - BE Residential Flats
- Micro CHP Gas / Ins A+ - BE Residential Flats
- Micro CHP H2 / Ins A+ - BE Residential Flats

Services:
- CDR
- Education
- Hospitality
- NCH
- Offices
- Stores
- Wholesale
- Other

- Ins GFE - BE Services CDR
- Ins DC - BE Services CDR
- Ins B - BE Services CDR
- Ins A - BE Services CDR
- Ins A+ - BE Services CDR
**RICH TECHNOLOGICAL DETAIL (3/3)**

**TRANSPORT (~37 TECH.)**

| Road Vehicle ICE 2010 norm - Road Cars | Other Vehicle Zero Emissions - Road Other |
| Road Vehicle ICE 130g - Road Cars | Machinery ICE 2010 norm - Mobile Machinery |
| Road Vehicle ICE 95g - Road Cars | Machinery Battery EV - Mobile Machinery |
| Road Vehicle ICE 70g - Road Cars | Standard defense technologies - Defence |
| Road Vehicle ICE hybrid - Road Cars | Standard rail technologies - Rail |
| Road Vehicle Plug-In Hybrid EV - Road Cars | Ship ICE 2010 norm - Ship Recreation |
| Road Vehicle Battery EV - Road Cars | Ship Battery EV - Ship Recreation |
| **Road Vehicle Fuel Cell EV - Road Cars** | Ship ICE 2010 norm - Ship Inland |
| Light Duty Vehicle ICE 2010 norm - Road LDV | Ship LNG - Ship Inland |
| Light Duty Vehicle ICE 175g - Road LDV | Ship ICE 2010 norm - Ship NCP |
| Light Duty Vehicle ICE 147g - Road LDV | Ship LNG - Ship NCP |
| Light Duty Vehicle ICE 114g - Road LDV | Standard Airplane - Air LTO |
| Light Duty Vehicle ICE hybrid - Road LDV | Ship ICE 2010 norm - Ship Fishing |
| Light Duty Vehicle Plug-In Hybrid EV - Road LDV | Ship LNG - Ship Fishing |
| Light Duty Vehicle Battery EV - Road LDV | Ship ICE 2010 norm - Ship International |
| **Light Duty Vehicle Fuel Cell EV - Road LDV** | Ship LNG - Ship International |
| Heavy Duty Vehicle ICE 2010 norm - Road HDV | Standard Airplane - Air International |
| Heavy Duty Vehicle ICE efficient - Road HDV | |
| Heavy Duty Vehicle Fuel Cell EV - Road HDV | |
| **Other Vehicle ICE 2010 norm - Road Other** | |
HOURLY TEMPORAL RESOLUTION (1/2)

- ~70 Different hourly profiles
  - Wind on-shore (NL and 20 EU nodes)
  - Wind off-shore (NL and 16 EU nodes)
  - Sun (NL and 20 EU nodes)
  - Electric Vehicles
  - Built environment
  - NL and 20 EU nodes Loads
  - Flat profile
The Nederlands Electricity Dispatch in 2030 (PJ/Year)
LP OR MILP?

“The results show that LP underestimates storage demand, as it neglects technical restrictions which affect operating costs, leading to an unrealistically flexible thermal power plant dispatch. Contrarily, storage expansion is higher in MILP. The deviation between both approaches however becomes less pronounced if the share of renewable generation increases.”*
### Considered technologies

<table>
<thead>
<tr>
<th>Old Technology</th>
<th>New Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Coal CCS*</td>
</tr>
<tr>
<td>CCGT</td>
<td>CCGT CCS*</td>
</tr>
<tr>
<td>CHP**</td>
<td>GT</td>
</tr>
<tr>
<td>Oil***</td>
<td>Waste**</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Other RES***</td>
</tr>
<tr>
<td>Biomass</td>
<td>Hydro Power</td>
</tr>
<tr>
<td>Wind Onshore</td>
<td>Wind Offshore</td>
</tr>
<tr>
<td>Sun</td>
<td>Hydro PS***</td>
</tr>
</tbody>
</table>

Non-EU Balkan emissions?
CROSS-BORDER ELECTRICITY TRADE (2/6) COMPETES’ CASE STUDY

- Comparison with results of competes
  - Based on Sustainable Transition 2030 TYNDP Scenario

### Power Dispatch

**IESA - OPT**

**COMPETES**
CROSS-BORDER ELECTRICITY TRADE (3/6) COMPETES’ CASE STUDY

IESA-Opt

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Source</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil Fuels</td>
<td>159</td>
<td>Others</td>
<td>056</td>
</tr>
<tr>
<td>RES</td>
<td>203</td>
<td>Imports</td>
<td>076</td>
</tr>
<tr>
<td>Exports</td>
<td>-080</td>
<td>Demand</td>
<td>-415</td>
</tr>
</tbody>
</table>

COMPETES

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Source</th>
<th>Value</th>
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<td>RES</td>
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<td>Imports</td>
<td>108</td>
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<tr>
<td>Exports</td>
<td>-119</td>
<td>Demand</td>
<td>-415</td>
</tr>
</tbody>
</table>
CROSS-BORDER ELECTRICITY TRADE (4/6) COMPETES’ CASE STUDY

Imports

IESA-Opt

COMPETES

Exports

IESA-Opt

BE  DE  DK  NO  GB
CROSS-BORDER ELECTRICITY TRADE (5/6) COMPETES’ CASE STUDY

COMPETES

IESA-Opt
CROSS-BORDER ELECTRICITY TRADE (6/6) COMPETES’ CASE STUDY

Hydro Power Storage

Supplied electricity [PJ]

COMPETES
IESA-Opt
OTHER TEMPORAL RESOLUTIONS

- The model is able to assign different temporal resolutions to balance specific technologies
  - e.g. seasonal storage technologies can use month (or season, or semester) resolution for balancing
  - e.g. P2Heat technologies use 4-hours resolution for balancing

<table>
<thead>
<tr>
<th>Temporal resolution</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-hours</td>
<td>[q]</td>
</tr>
<tr>
<td>1-day</td>
<td>[d]</td>
</tr>
<tr>
<td>3-days</td>
<td>[r]</td>
</tr>
<tr>
<td>1-week</td>
<td>[w]</td>
</tr>
<tr>
<td>1-month</td>
<td>[m]</td>
</tr>
<tr>
<td>1-season</td>
<td>[s]</td>
</tr>
<tr>
<td>Semester</td>
<td>[b]</td>
</tr>
<tr>
<td>Year</td>
<td>[y]</td>
</tr>
</tbody>
</table>
FLEXIBILITY OPTIONS (1/4)

Three main constraints to define flexibility options

- Balance: The sum of upward and downward flexibility in specific ranges should add to zero.
- Capacity: The sum of flex energy should not be more than available flex capacity in the system
- Saturation: Total available upward flexibility for a specific hour is not more than electricity demand in remaining hours in a specific range (i.e. the demand cannot go negative)
DEMAND RESPONSE FLEXIBILITY (3/4)
RESIDENTIAL P2HEAT (PASSIVE STORAGE)
DEMAND RESPONSE FLEXIBILITY (4/4)
RESIDENTIAL P2HEAT (SEASONAL STORAGE 2030)
P2LIQUIDS

1) CO₂ from DAC + H₂ from the market = SynFuel from CO₂ and H₂ (methanol pathway) = Benzene®

2) CO₂ from the market + H₂ from the market = SynFuel from CO₂ and H₂ (methanol pathway) = Benzene®

3) CO₂ from DAC + H₂ from the market = SynFuel from CO₂ and H₂ (FT pathway D) = SynFuel

4) CO₂ from the market + H₂ from the market = SynFuel from CO₂ and H₂ (FT pathway D) = SynFuel

5) CO₂ from DAC + H₂ from LT electrolysis = SynFuel from CO₂ and H₂ (methanol pathway) = Benzene®

6) CO₂ from the market + H₂ from LT electrolysis = SynFuel from CO₂ and H₂ (methanol pathway) = Benzene®

7) CO₂ from DAC + H₂ from LT electrolysis = SynFuel from CO₂ and H₂ (FT pathway D) = SynFuel

8) CO₂ from the market + H₂ from LT electrolysis = SynFuel from CO₂ and H₂ (FT pathway D) = SynFuel
PEAK-SHAVING (FLEXIBILITY)

- Total Generation in 2050: 42.5 PJ, 0 PJ from conventional
- The Electrolyzers installed capacity allows for 161.4 PJ/y, but 117.9 PJ were shaved in the year
- The resulting hydrogen price in 2050 was of 29.7 M€/PJ
• Total Generation in 2050: 53.3 PJ, 35.4 PJ from conventional and 17.9 PJ from electrolyzers
• The Electrolyzers installed capacity allows for 34.2 PJ/y, but 16.3 PJ were shaved in the year
• We can play with the curtailing volume allowed (i.e. the graph represents a maximum of 50% per week)
• The resulting hydrogen price in 2050 was of 31.56 M€/PJ
FLEXIBILITY OF CHP

Range of use
Flexible surface of operation
Reference point of operation
Slope determined by the efficiency of the CHP accordingly with:
\[ \varepsilon = \frac{P}{F - H/\eta} \]
Range of power output
Slope determined by output to fuel ratio
TECHNOLOGICAL LEARNING (1/3)

- Exogenous Technological Learning (ETL)
- 2-factor ETL based on Capex A and B
- Global scenario data from various sources
- ~215 technologies follow ETL

Figure 6.2  Generation capacity by technology

Key point: Generation capacity by 2050 is higher in the 2DS compared to the 4DS, despite lower electricity demand due to greater deployment of variable renewables with lower capacity factors.
TECHNOLOGICAL LEARNING (3/3)
COST REDUCTION FROM 2020 TO 2050

- On-shore wind
- Off-shore wind
- Solar PV
- Steel with CCS
- BioGas with CCS
- Boiler Gas / Ins GFE
- Hybrid Heat Pump / Ins A+
- Electric Heat Pump GW wSolar / Ins A+
EFFICIENCY IMPROVEMENT

Activity Balance\((t, a)\) * (1 – Eff Improvement\((t, a, p)\))

<table>
<thead>
<tr>
<th>Technologies (t)</th>
<th>Activity (a)</th>
<th>Efficiency Improvement [%2020]</th>
<th>Periods (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector</td>
<td></td>
<td></td>
<td>2020</td>
</tr>
<tr>
<td>Basic Metals</td>
<td>Hisarna - Steel Production</td>
<td>Industrial SHT Heat</td>
<td>0.03</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Nafta Steam Cracker Improved - HV Chemicals Production</td>
<td>Industrial SHT Heat</td>
<td>0.02</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Nafta Steam Cracker Improved - HV Chemicals Production</td>
<td>Industrial HT Heat</td>
<td>0.02</td>
</tr>
<tr>
<td>Emissions</td>
<td>CO2 from Direct Air Capture</td>
<td>Electricity</td>
<td>0.10</td>
</tr>
<tr>
<td>Emissions</td>
<td>CO2 from Direct Air Capture</td>
<td>Industrial HT Heat</td>
<td>0.17</td>
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<tr>
<td>Hydrogen</td>
<td>Alkalyne Electrolyzer - Hydrogen Production</td>
<td>Electricity</td>
<td>0.02</td>
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<tr>
<td>Refineries</td>
<td>P2L methanol pathway, ext. H2, DAC - Refineries</td>
<td>Industrial LT Heat</td>
<td>0.17</td>
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<tr>
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<td>...</td>
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<tr>
<td>Refineries</td>
<td>P2L FT pathway, alk. electrolysis, ext CO2 - Refineries</td>
<td>Electricity</td>
<td>0.02</td>
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</tbody>
</table>
TRANSITIONAL OPTIMIZATION (1/2)

SYSTEM COST (M€)

- **Variable Operational Cost**
- **Fixed Operational Cost**
- **Retrofitting Cost**
- **Capital Cost**
### TRANSITIONAL OPTIMIZATION (2/2)

**RETROFITTING AND DECOMMISSIONING**

\[
Retrofitting(it, jt, p) \leq Retrofit\_Relations(it, jt) \times Tech\_Stocks(it, p)
\]

<table>
<thead>
<tr>
<th>Old Technology</th>
<th>Retrofitted Technology</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dummy standard electricity consumption – Residential</td>
<td>Dummy standard electricity consumption FLEX – Residential</td>
<td>0</td>
<td>8.95</td>
<td>15.52</td>
</tr>
<tr>
<td>Boiler Gas / Ins GFE - BE Residential Flat</td>
<td>Boiler Gas / Ins DC - BE Residential Flats</td>
<td>0.08</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Boiler Gas / Ins DC - BE Residential Flats</td>
<td>Boiler Gas / Ins B - BE Residential Flats</td>
<td>0.091</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Boiler Gas / Ins B - BE Residential Flats</td>
<td>Boiler Gas / Ins A+ - BE Residential Flats</td>
<td>0.14</td>
<td>0.006</td>
<td>0</td>
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<tr>
<td>Boiler Gas / Ins A - BE Residential Flats</td>
<td>Boiler Gas / Ins A+ - BE Residential Flats</td>
<td>0.23</td>
<td>0.078</td>
<td>0.004</td>
</tr>
<tr>
<td>Electric Heat Pump Air / Ins A+ - BE Residential Flats</td>
<td>Electric Heat Pump Air FLEX / Ins A+ - BE Residential Flats</td>
<td>0.003</td>
<td>0.001</td>
<td>0</td>
</tr>
<tr>
<td>Electric Heat Pump GW / Ins A+ - BE Residential Flats</td>
<td>Electric Heat Pump GW FLEX / Ins A+ - BE Residential Flats</td>
<td>0.003</td>
<td>0.001</td>
<td>0</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
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<tr>
<td>Hisarna - Steel Production</td>
<td>Hisarna wCCS - Steel Production</td>
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<td>0</td>
<td>2.55</td>
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<td>Haber Bosch - Ammonia Production</td>
<td>Haber Bosch New wCCS - Ammonia Production</td>
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<td>0.42</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CHP Waste - Waste Incineration</td>
<td>CHP Waste wCCS - Waste Incineration</td>
<td>0</td>
<td>0</td>
<td>0.11</td>
</tr>
<tr>
<td>Electricity from CCGT - Power NL</td>
<td>Electricity from CCGT wCCS - Power NL</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Boiler Gas - SHT Heat for Industry</td>
<td>Boiler Gas wCCS - SHT Heat for Industry</td>
<td>0</td>
<td>0</td>
<td>3.22</td>
</tr>
<tr>
<td>Basic cracking refinery - Refineries</td>
<td>Basic cracking refinery wCCS - Refineries</td>
<td>1.74</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
**TRANSITIONAL OPTIMIZATION**

**PERFECT FORESIGHT & SEQUENTIAL (MYOPIC)**

---

**P. Foresight (198.22 B€)**

**SYSTEM COST (B€)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Investment Cost</th>
<th>Retrofitting Cost</th>
<th>Fixed Operational Cost</th>
<th>Variable Operational Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>16.30</td>
<td>9.97</td>
<td>18.49</td>
<td>1.33</td>
</tr>
<tr>
<td>2030</td>
<td>27.52</td>
<td>12.09</td>
<td>12.09</td>
<td>1.34</td>
</tr>
<tr>
<td>2040</td>
<td>29.20</td>
<td>12.05</td>
<td>19.61</td>
<td>0.19</td>
</tr>
<tr>
<td>2050</td>
<td>27.41</td>
<td>13.58</td>
<td>0.00</td>
<td>5.88</td>
</tr>
</tbody>
</table>

---

**M. Foresight (202.22 B€)**

**SYSTEM COST (B€)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Investment Cost</th>
<th>Retrofitting Cost</th>
<th>Fixed Operational Cost</th>
<th>Variable Operational Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>19.01</td>
<td>10.48</td>
<td>11.07</td>
<td>0.01</td>
</tr>
<tr>
<td>2030</td>
<td>30.25</td>
<td>12.29</td>
<td>0.16</td>
<td>9.49</td>
</tr>
<tr>
<td>2040</td>
<td>32.91</td>
<td>13.97</td>
<td>0.39</td>
<td>9.04</td>
</tr>
<tr>
<td>2050</td>
<td>28.05</td>
<td>15.13</td>
<td>0.89</td>
<td>13.07</td>
</tr>
</tbody>
</table>

* Objective function was lower 563.33 vs 572.51 B€
## DATA SOURCES

<table>
<thead>
<tr>
<th>Sector/Activity</th>
<th>Technologies</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dummy</td>
<td>Dummy</td>
<td>ENSYSI</td>
<td>Some data from ENSYSI was transferred into the excel database and used to test the model structure.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Load shifting</td>
<td>Dummy</td>
<td>Flexible demand was introduced in the residential sector to test computational capabilities.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Built Env.</td>
<td>Dummy</td>
<td>The flexible built environment was introduced in the residential sector to test computational capabilities.</td>
</tr>
<tr>
<td>All</td>
<td>All</td>
<td>ENSYSI</td>
<td>All the remaining sectors and technologies were imported from ENSYSI. Note: investment data have not yet been imported with learning.</td>
</tr>
<tr>
<td>Refineries</td>
<td>P2Liquide</td>
<td>Factsheets</td>
<td>Includes FT and methane pathways towards Synfuels accordingly with factsheet structure.</td>
</tr>
<tr>
<td>Power EU, Power IC</td>
<td>Generators and interconnection</td>
<td>COMPETES</td>
<td>Data from COMPETES was aggregated into two regions, EU &amp; IC, and added into the model. The data and excel procedure is in the folder.</td>
</tr>
<tr>
<td>Power IC disaggregation</td>
<td>EU 21 nodes (22 COMPETES)</td>
<td>COMPETES</td>
<td>Data used in the COMPETES TYNDP Sustainable Transition scenario was used to provide data of marginal costs and generation and interconnection capacities.</td>
</tr>
<tr>
<td>Question/area of application</td>
<td>Does IESA-Opt answer it?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How could a cost optimal future Dutch energy system look like that is in line with the Paris agreement?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What if you allow for nuclear? Have a yearly CCS potential of x Mton? Low amount of biomass? Etc.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the cost optimal transition path?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What should the CO$_2$ price be in ETS and non-ETS sectors?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When do you have to invest in CCS? When in hydrogen?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which sectors (and technologies) are more suitable to provide flexibility to the energy system?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the optimal seasonal storage capacity that satisfies the high shares of renewables?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How does the current energy system stocks affects the optimal configuration of the energy transition?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the role of retrofitting in the energy transition of NL?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the impact of the efficiency and technological learning on the energy transition of NL?</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the impact of different EU energy sub-systems on NL energy system?</td>
<td>Yes for Elec. (Gas, and Hydro should be added)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The idea is obtained from OPERA presentation by Joost van Stralen
## WHAT QUESTIONS THE MODEL CAN’T ANSWER?

<table>
<thead>
<tr>
<th>Question/area of application</th>
<th>Does IESA-Opt answer it?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which technologies can be clustered to reduce the infrastructure costs?</td>
<td>No, but it could</td>
</tr>
<tr>
<td>What is the role of industrial waste heat?</td>
<td>No, but it could</td>
</tr>
<tr>
<td>How can infrastructure limitations affect the energy system?</td>
<td>No, but it could</td>
</tr>
<tr>
<td>What is the impact of specific policies on the cost-optimal system configuration?</td>
<td>No, but it could</td>
</tr>
<tr>
<td>What is the role of non-rational (behavioral, imperfect foresight, etc.) decisions in the energy transition?</td>
<td>No (IESA-Sim)</td>
</tr>
<tr>
<td>What is the regional impact of the optimal energy system of the NL?</td>
<td>No (IESA-Spatial)</td>
</tr>
<tr>
<td>What is the impact of the energy transition on the NL economy?</td>
<td>No (IESA-Macro)</td>
</tr>
</tbody>
</table>

The idea is obtained from OPERA presentation by Joost van Stralen
PROS AND CONS

+ Hard-linked with a European electricity market model
+ Able to define other objective functions such as minimum emission
+ Transitional optimization
+ Low entry barrier
+ Focus on analysing flexibility options
+ Resolution is added where it’s required
+ Linear Programming (Helps to integrate more sectors and cover a wider energy system description)
+ Self-developed

- Not all emissions, only CO2
- Lack of infrastructure
# WISH LIST: MODEL DEVELOPMENT

<table>
<thead>
<tr>
<th>Categories</th>
<th>Description</th>
<th>Collaborations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>• Implement the complete methodology of Manuel’s paper</td>
<td>• German? Ozge?</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>• EU hydrogen and gas networks</td>
<td>• Bert? Jeffery Sipma?</td>
</tr>
<tr>
<td></td>
<td>• Infrastructure costs and realistic constraints</td>
<td>• Francesco? Bert?</td>
</tr>
<tr>
<td></td>
<td>• Clustered technologies and retrofitting</td>
<td>• Joost? Bert?</td>
</tr>
<tr>
<td></td>
<td>• Waste heat and geothermal</td>
<td>• Bert?</td>
</tr>
<tr>
<td>Resolution</td>
<td>• Spatial analysis integration</td>
<td>• Somadutta or/and Rafael</td>
</tr>
<tr>
<td></td>
<td>• Higher sectoral segregation</td>
<td>• Joost?</td>
</tr>
<tr>
<td></td>
<td>• Other sources of non-CO2 emissions</td>
<td>• Koen Smekens? Joost?</td>
</tr>
<tr>
<td>Other energy system elements</td>
<td>• Adapt model to policy tool-boxes</td>
<td>• Bert? Paul? Francesco?</td>
</tr>
<tr>
<td></td>
<td>• Adapt model to macroeconomic sectors</td>
<td>• Paul? Frederic Reynes?</td>
</tr>
</tbody>
</table>
# WISH LIST: DATA AND SCENARIO

<table>
<thead>
<tr>
<th>Categories</th>
<th>Description</th>
<th>Collaborations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>• Technology descriptions from Factsheets (when available)</td>
<td>• Koen Smekens?</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>• Add the existing infrastructure of NL</td>
<td>• Bert?</td>
</tr>
<tr>
<td></td>
<td>• Add the description of the costs of different types of infrastructure</td>
<td>• Bert?</td>
</tr>
<tr>
<td>Resolution</td>
<td>• Add more sectoral load profiles</td>
<td>• ?</td>
</tr>
<tr>
<td></td>
<td>• Highlights of key spatial constraints from Spatial analysis</td>
<td>• Somadutta or/and Rafael</td>
</tr>
<tr>
<td>Other energy system elements</td>
<td>• Update from the Factsheet project</td>
<td>• Koen Smekens?</td>
</tr>
<tr>
<td></td>
<td>• Learning rates and efficiencies</td>
<td>• ?</td>
</tr>
<tr>
<td></td>
<td>• Biomass and Transport constraints</td>
<td>• KEV team?</td>
</tr>
<tr>
<td></td>
<td>• Update the existing technological stocks of NL</td>
<td>• Bert?</td>
</tr>
<tr>
<td></td>
<td>• Update data of current energy policies</td>
<td>• Francesco?</td>
</tr>
<tr>
<td></td>
<td>• Decommissioning costs</td>
<td></td>
</tr>
<tr>
<td>Scenario description</td>
<td>• Update baseline scenario from the KEV database (and validation)</td>
<td>• Paul?</td>
</tr>
<tr>
<td></td>
<td>• Align to the Scenario project?</td>
<td>• Larissa Riquelme?</td>
</tr>
<tr>
<td></td>
<td>• EU Res capacities and interconnections</td>
<td>• Ozge?</td>
</tr>
<tr>
<td></td>
<td>• Expected CO2 and Fuel prices, etc.</td>
<td>• Francesco?</td>
</tr>
</tbody>
</table>
WISH LIST: DISSEMINATION

- Version management
- User-interface
- Visualization and automatization
- Getting Open-source
  - Web-page including documentations, articles, data, reports, model code, etc.
  - Open Energy Modelling Initiative
SECOND PART: STRATEGIC IMPLICATIONS

ESTRAC IESA key objective:

“To provide detailed and quantitative insights in the transition paths towards future integrated energy systems at both the regional and the (inter)national level, based on detailed representations of the full energy system, which includes the various parts of the energy system (electricity, gas, heat etc.) at different geographical scales, taking into account economic, societal and spatial aspects and using information on, for example, flexible technologies, the potential for energy efficiency, demand response and data on consumer behavior.”

Key Impact No.5:

“The impacts and results will be based on further developed and new tools and databases as described above…This program will build a state-of-the art knowledge base in the Netherlands which includes data, models, methodologies and experts needed for the analysis of the energy transition. Based on this, Dutch research can reconnect with ongoing work within the EU and broader. This will help assimilate insights from abroad and increase the Dutch contribution to the international scientific debate, a debate that will be one of the sources on which policies and strategies for the energy transition will be built.”
BENEFITS FOR TNO AND PBL

› Low entry-barrier model
  › Lower costs for model development (by employing Ph.D. and M.Sc. students)

› Open-source model
  › Connection with other research institutes across EU and facilitating results’ dissemination
  › Further increase the presence of TNO Energy Transition (i.e. ECN) and PBL in academic publications related to ESM

› Connection with other projects
  › e.g. Scenario project, ENSYSTRA
BEDANKT VOOR UW AANDACHT

TNO.NL/ECNPARTOFTNO