Transmission Expansion Planning in Practice

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Transmission Expansion Planning (TEP)

- The **intermittent** nature of the output of most renewable energy sources (RES), its **non homogeneous distribution** and the deployment of a large share of this generation is expected to result in a significant **increase in the power flows among areas in large-scale systems**.

- As a result of this, the development of the network of the system should be planned in an integrated way and the number of **operation snapshots** to consider in the planning process should probably be high.

- **In this context**, it is important to identify the **main optimal transmission network corridors to reinforce**, the extent of reinforcements needed in them, and other operation variables affected by the existence of the grid:
  - Investment cost of grid additions
  - Fuel production costs
  - Production by technology
  - Network losses
  - RES curtailment
  - CO2 emissions
Why coordination between generation and transmission expansion planning?

• Decisions are taken by independent entities
  – **Private generation** companies
  – **Publicly owned transmission** system operators

• With different time scopes
  – **Several years** for generation investment
  – **A decade** for transmission investment
Questions to address. Regarding coordination with generation expansion

- **What network reinforcements and how much investment** is required to integrate RES and emerging technologies (e.g., battery storage)?
- Is the network **neutral to the different RES** and emerging technologies used (CCS, CSP, Nuclear)? Which transmission network is needed for future generation storylines?
- How does the **decentralized or centralized location** of generation impact transmission network expansion (e.g., rooftop PV in Germany vs. large PV in Spain)?
- Does the network impact on the **location of the generation** (best spots), coordination between generation and transmission expansion?
Questions to address. Grid infrastructure/architecture options

- **How** the network should be developed (*AC vs. DC vs. supergrid*)?
  - Upgrade aerial lines, underground lines, submarine lines
  - Extensive use of **FACTS**
  - **Reinforcements** of high voltage 400 kV AC transmission network
  - Overlay at high voltage DC (HVDC) network
  - Overlay at ultra high voltage 750 kV AC (HVAC) network

- **What** is the impact of **new emerging network technologies** (*PST, VSC, LCC*) in the operation of the system?

- Overlay at ultra high voltage 750 kV AC transmission network
- Reinforcements of high voltage 400 kV AC transmission network
- Overlay at high voltage DC transmission network
- Extensive use of FACTS
Pan-European SuperGrid

- Pan-European, inter-regional, cross-border projects
  - Project candidates: > 220 kV, > 500 MW of Network Transfer Capacity (NTC)
  - Project assessment based on clear indicators

- Transmission network that allows
  - Large-scale RES integration, decrease RES curtailment
    - North Sea wind generation + Norway/Alps hydro generation
    - South Europe/North Africa solar generation
  - Market integration
USA SuperGrid

The U.S. electric grid is a complex network of independently owned and operated power plants and transmission lines. Aging infrastructure, combined with a rise in domestic electricity consumption, has forced experts to critically examine the status and health of the nation's electrical systems.
First Steps to a Global SuperGrid

http://spectrum.ieee.org/energy/the-smarter-grid/lets-build-a-global-power-grid
Target electric systems

- **Spain/Continental South West (CSW) Region (ES-FR-PT)**
  - Nodes: 500
  - Existing Lines: 750
  - Candidate lines: 100
  - Scope: 10 years
  - Time periods: 100

- **Europe**
  - Nodes: 5000
  - Existing Lines: 7500
  - Candidate lines: 500
  - Scope: 1 year (static), 5 years (dynamic)
  - Time periods: 100

- **Large-scale (Spanish) case can be currently solved but a very large-scale (European) case is not yet affordable**
Some Real TEP Models

TEPES
Spain Case Study
European Case Studies
Comillas’ experience on TEP models

- **Short-term model**
  - StarNet/RD developed by IIT for different companies in Dominican Republic ([https://www.iit.comillas.edu/aramos/starnet.htm](https://www.iit.comillas.edu/aramos/starnet.htm))

- **Medium-term (operational) model**
  - SIMUSIS/SIMUMER/SIMUPLUS developed by IIT for REE

- **Long-term (tactical) models**
  - PERLA (based on Benders decomposition) developed by IIT for REE
  - CHOPIN (based on heuristics) developed by IIT for REE
  - TEPES (based on Benders decomposition) ([https://www.iit.comillas.edu/aramos/TEPES.htm](https://www.iit.comillas.edu/aramos/TEPES.htm))

- **Very long-term (strategic) model**
  - PLAER (trade-off analysis) developed by REE
**SIMUPLUS (i)**

- **Operational transmission planning** (medium term) (5-10 years)
- **Determine incremental investment needs** in transmission network in electricity markets
- **Main assumption**
  - Transmission expansion decisions shouldn’t modify market clearing result
  - They must foster an effective competition within the power system

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1. Monte Carlo sampling
   – Demand bids and generation offers (market prices vs. variable costs)
   – Generation units and circuits availability (reliability assessment)
   – Hydro scheduling and wind/solar generation

2. Single node market clearing
   – Losses included as additional demand

3. Network constraint evaluation minimizing deviations w.r.t. market clearing
   – DC load flow, flow limits, ohmic losses
   – N-1 contingencies. Preventive or corrective dispatch

4. Determine sensitivities (derivative of the objective function w.r.t. investment)
   – Improvement in existing circuits
   – New circuit expansion

5. Multi-attribute investment analysis
   – Weigh sensitivities average, confidence interval, validity range, investment needs, environmental impact, etc.
   – Rank and select investment decisions

6. Repeat the process
SIMUPLUS (iii)

**Spanish Iterative Investment Ranking**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Candidates</th>
<th>Sensitivity mean [M$/M$]</th>
<th>Confidence interval [%]</th>
<th>Validity range [MW]</th>
<th>Multi-attribute value</th>
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<tr>
<td></td>
<td><strong>No more circuits are added</strong></td>
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</table>

- 623 nodes and 1021 circuits, 165 thermal units and 76 hydro units. 12 network expansion alternatives. Sampling of 100 scenarios in each stage and obtain the three best alternatives.
PERLA (Planificación Estática de la Red a LArgo plazo)

- Static tactical transmission planning (long term) (10-20 years)

Automatic generation of transmission expansion plans

Expansion plan

Sensitivity

Economic evaluation of transmission plans:
- Operation module
- Reliability module

CHOPIN (Código Heurístico Orientado a la Planificación INteractiva)

- Static tactical transmission planning (long term) (10-20 years)

Heuristic generation of transmission expansion plans

Expansion plan → Sensitivity

Economic evaluation of transmission plans:
- Operation module
- Reliability module

CHOPIN (Código Heurístico Orientado a la Planificación INteractiva)

- Starts from a user-given transmission plan
- Local search guided by sensitivities extending the depth-first search
- Heuristic truncated enumeration of the complete solution space

\[
\text{Sensitivity} = \frac{\text{operation cost decrement}}{\text{per unit investment cost}}
\]
PLAER (PLAñificación Estratégica de la Red de transporte)

- **Strategic transmission planning** (very long term) (20+ years)
- **Trade-off analysis** between conflicting objective functions
  - Investment and operation costs
  - Environmental impact (e.g., length)
  - Risk (e.g., administrative permits and delays)
- **PERLA** is used internally as the automatic transmission plan generator

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PLAER (PLAnificación Estratégica de la Red de transporte)

- Horizon N
- Future scenario generation
- Transmission plan optimization
- Transmission plan evaluation
- Dominance analysis
- Three-attribute selection
- Robust transmission plans
- Flexible corridors
- Horizon N+1
Long-Term Transmission Expansion Planning Model for an Electric System
TEPES finds the **optimal transmission expansion plan** for a system, given a set of stochastic scenarios and a definition of the problem objectives. It can be used to guide expansion decisions or analyze the impact of RES on network needs.

- **Detailed system modeling** (system sizes of the order of 1000’s of nodes)
  - Hybrid modeling is also possible (different areas have different levels of detail).
  - TEPES can take the output of another model as flows or a rough expansion and carry out a detailed expansion (e.g., Enertile, Empire).
  - This allows to model power plants individually (vs. technology aggregates).
- **Kirchhoff’s Laws** are considered:
  - Loop flows
  - Piecewise linear approximation of losses
- Represents the impact of **different transmission technologies**
  - Voltage levels
  - HVDC
  - PSTs
**Key features (i)**

- **Dynamic**: The model can deal with a range of horizons, from the short-term (i.e., 2020 horizon) to the long-term (i.e., 2050 horizon) planning problem. In the latter case, several planning horizons can be established.
  - The model represents hierarchically the different time scopes to make decisions in an electric system: Year, Period, Sub-period and Load level.
  - This time division allows a flexible representation of the periods where to evaluate the system operation, e.g., using representative snapshots.

- **Stochastic** (random) demand, hydro inputs, fuel costs, renewable energy production, contingencies in generation and transmission assets.

- **Multicriteria**
  - Transmission investment cost,
  - Variable operation costs (including generation emission cost),
  - Reliability cost associated to N-1 generation and transmission contingencies.

- **Solved with** Stochastic Mixed-Integer Programming using
  - Direct solution
  - An efficient version of Benders decomposition
Stochastic optimization problem

- Operation scenarios: demand, RES generation, hydro inflows, fuel and emission costs
- Generation and network contingency scenarios

All the scenarios are evaluated
Key features (ii)

- Decides the **optimal investments** from an initial list of **pre-defined candidates** (including new lines, reinforcements and transformers) or **candidates automatically generated by the model**
  - Fractional investments can be allowed in some cases
  - Centralized, cost-based operation
- Implemented in GAMS, solved with CPLEX or GUROBI, exchanges data with Microsoft Excel and shows outputs in Google Earth.
- Outputs include:
  - **Operation:**
    - Output of different units and technologies (thermal, storage hydro, pumped storage hydro, RES)
    - Fuel consumption
    - Emissions
    - RES curtailment, hydro spillage
    - Hydro reservoir scheduling
    - Line flows, line ohmic losses, node voltage angles
    - Consider existing and candidate HVDC lines and converting stations into the model
  - **Marginal:**
    - Long-Run Marginal Costs
    - Transmission Load Factors (TLF)
Publications

- Q. Ploussard, L. Olmos and A. Ramos *An operational state aggregation technique for transmission expansion planning based on line benefits* IEEE Transactions on Power Systems 10.1109/TPWRS.2016.2614368
Some Real TEP Models
TEPES
Spain Case Study
European Case Studies

Spain Case Study
Transmission network development

http://www.minetad.gob.es/ENERGIA/PLANIFICACION/PLANIFICACIONELECTRICIDAD/DYGAS/Paginas/desarrollo-redes.aspx

• Reports on network expansion planning
  – Desarrollo de la red de transporte de la electricidad 2008-2016.
  – Desarrollo de la red de transporte de la electricidad 2002-2011.
Spain-France underground interconnection


• Line of 400 kV in DC that will increase the exchange capacity up to 2,800 MW.
• 65 km length, totally buried by means of a trench system and will use other already existing linear infrastructures when possible.
• Two converter substations: Santa Llogaia (Spain) y Baixas (France).
• Tunnel of 8.5 km and 3.5 m of diameter will house the cables in the section crossing the Pyrenees.
Mainland Spain 2025

Energy [GWh] 169291
Max Load [MW] 27253
Min Load [MW] 13545
Peak/OffPeak Ratio [p.u.] 2.0
Nuclear [MW] 5770 21%
Domestic Coal [MW] 2769 10%
Imported Coal [MW] 1456 5%
CCGT [MW] 4044 15%
Oil [MW] 115 0%
RES + run of the river hydro [MW] 5417 20%
Storage hydro [MW] 7927 29%
Installed Capacity [MW] 27496 100%
Thermal generation [MW] 14153 51%
Natural Hydro Inflows (W) [GWh] 37909
Natural Hydro Inflows (D) [GWh] 19883
Energy cost
Nuclear [€/MWh] 15
Domestic Coal [€/MWh] 27
Imported Coal [€/MWh] 22
CCGT [€/MWh] 31
Oil [€/MWh] 46
CO2 emission cost [€/t CO2] 0

Years 1
Periods 1
Sub-periods 1
Load levels 10
Operation scenarios 2
Gen contingency scenarios 0
Net contingency scenarios 0
Nodes 428
Existing lines 625
Candidate lines 93
Thermal units 50
Hydro plants 122
Intermittent generators 41
Mainland Spain. 400 kV Nodes. Demand and Generation
Mainland Spain. 400 kV existing and candidate lines
Summary of cases

- Introducing network contingencies with the continuous variables approaches them to binary ones.
- Introducing network contingencies with the binary variables increases the total investment.

Linear relaxation of binary variables is not the solution to focus the candidate lines.
Mainland Spain. Installed lines. Iteration 1
Mainland Spain. Installed lines. Iteration 2
Mainland Spain. Installed lines. Iteration 3
Mainland Spain. Installed lines. Iteration 4
Mainland Spain. Installed lines. Iteration 7
Mainland Spain. Installed lines. Iteration 9
Mainland Spain. Installed lines. Iteration 10
European Case Studies
ENTSO-E’s System Development Team

https://www.entsoe.eu/about-entso-e/system-development/system-development-team/Pages/default.aspx
ENTSO-E Grid Map 2018
Map of European wind farms

https://setis.ec.europa.eu/sites/default/files/report_graphs/farm_locations_0.png
Mid-term Adequacy Forecast

• Pan-European probabilistic assessment of adequacy (long term) (5-15 years)
• Definition: System adequacy of a power system is a measure of the ability of a power system to supply the load in all the steady states in which the power system may exist considering standard conditions. [ENTSO-e]
  – Every two years. Non-binding
  – Overview of national or regional generation adequacy for the summer and winter period and highlight possibilities for neighboring countries to contribute to the generation/demand balance in critical situations
  – Technical resilience: withstand with extreme system situations (rare contingencies, meteorological events)

Source: http://astro.ukho.gov.uk/eclipse/0112015/
Ten-Year Network Development Plan (TYNDP) ([http://tyndp.entsoe.eu/]())

- **Biannual, non-binding.** TYNDPs published in 2010, 2012, 2014, 2016 and recently released 2018
- **Increase information and transparency** regarding the investments in electricity transmission systems which are required on a pan-European basis and to support decision-making processes at regional and European level.
- **Six regional groups**, designed to address the challenges for grid development and the integration of new generation, especially RES, at a regional level through a structure which reflects the regions’ particularities and needs.

**Bottom-Up Approach**
TYNDP 2018 Map

TYNDP 2018 Project List

- Project Status
  - Any status

- Highlight Region
  - BS  CSE  COS  CSE  CSW  NL

TYNDP 2018 Projects Map

Select a line, station or bubble for more information on that project.

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TYNDP 2016 Maps

Medium term

Long term
TYNDP 2016 Outcomes

- **€150bn investments**, of which 70-80 by 2030
- **1 to 2 €/MWh** impact on bills due to transmission investment
- **45 to 60% RES** across 4 visions for 2030
- **50% to 80% emissions cut** depending on the vision
- **1.5 to 5 €/MWh potential reduction** in wholesale prices
- **40% reduction in congestion hours**
Projects of Common Interest (PCI). Overview

• Provide a high-value to the Internal Electricity Market (IEM) of the EU
• Facilitated permit granting process and improved regulatory treatment to ensure their deployment
• Identified based on the results of a Cost-Benefit Analysis (CBA) using the beneficiaries pay principle
Projects of Common Interest (PCI). Selection process

Selected on the basis of five criteria:

1. have a **significant impact on at least two EU countries**
2. **enhance market integration** and contribute to the integration of EU countries' networks
3. **increase competition on energy markets** by offering alternatives to consumers
4. **enhance security of supply**
5. **contribute to the EU's energy and climate goals.** They should facilitate the integration of an increasing share of energy from variable renewable energy sources.

PCI list for electricity interconnectors in Member States below 10%

Electricity Transmission Expansion Planning

Integrated methodology for large-scale planning

- **SET-Nav (2050)**
  - Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation developed for the European Union

- **eHighWay2050 (2030)**
  - Modular development plan of the pan-European transmission system 2050 developed for the European Commission.

Network investment needs associated to large-scale integration of RES in Europe from MENA countries in 2030 and 2050

- **DESERTEC (2030 and 2050)**
  - Pre-feasibility analysis on power highways for the Europe-MENA region integration in the framework of the Dii Rollout Plan 2050 developed for Desertec Industrial Initiative (Dii).
  - [http://desertenergy.org/getting-connected/](http://desertenergy.org/getting-connected/)

Network developments associated to different European RES policies

- **RESCost (2030 and 2050)**
  - Estimating costs of renewable energies compared to conventional energy sources up to 2030 and beyond developed for Fraunhofer ISI.

Impact on transmission network due to RES integration

- **Beyond2020**
  - Design and impact of a harmonized policy for renewable electricity in Europe (Beyond 2020) developed for the European Commission.
e-HighWay 2050

https://youtu.be/fBcwJmZ6qK0?list=PLXEY7WtH7KEXw3Mre9OJwNABY09fwVlk8

- ENTSO-E Position Paper on a Framework Regarding Electricity Highways
  - Analyzing and justifying bulk power transmission needs taking into account future generation and its spread throughout the whole transcontinental region,
  - Proposing concrete implementation, operation and governance principles for needed grid investments throughout Europe and to neighboring areas,
  - In the interest of security, efficiency, feasibility and sustainability, consider the whole energy supply chain including relevant technical/technological, economical/financial, ecological, political/sociopolitical and geopolitical/security issues,
  - Following a modular approach: 2030, 2035, 2040, 2045 and 2050,
  - Proposing general strategic Electricity Highways architectures including technology options.

Top-Down Approach
e-HighWay 2050. Work packages
e-HighWay 2050. WP2. Grid architectures for 2050

• Scenario development
  – Assessment of existing scenarios for 2030 and beyond (EC Roadmap 2050, PRIMES forecast)

• Pan-European model of the Transmission System
  – Regionalization of the European network

• Market simulation

• Grid architecture development

• Sanity check of the architectures proposed
e-HighWay 2050. WP2. Grid architecture development

• Automatic computation of transmission expansion plans
  – Classical optimization of the expansion of the grid
    • Results in optimal expansion plans according to criteria considered in WP2
    • An optimization problem is solved for this
  – Intelligent search for a suitable plan based on the application of heuristic rules
    • Does not guarantee that the optimality of the plan that is computed
    • Suitable to be applied to large and complex systems

• Iterative search for a suitable expansion plan
  – Planning module proposes (a set of) network investments based on techno-economic information produced in other modules
  – Operation including the set of reinforcements proposed is computed and new information is sent to the planning module
e-HighWay 2050. WP2. Classical optimization of the expansion of the grid (i)

- Adapted to both long and medium term expansion planning of both large and small systems
- Dedicated tool maximizing social welfare with limited modeling detail
- Involves representing the operation of the system in a simplified way
  - Not very large number of nodes (granularity considered in e-highways may be appropriate)
  - Part of existing technical constraints are not represented: voltage constraints, dynamic stability ones, maximum short circuit currents
e-HighWay 2050.
WP2. Classical optimization of the expansion of the grid (ii)

• Requires separately assessing the technical feasibility of the expansion plan proposed → using a separate grid analysis tool
  – If infeasibilities detected by grid analysis tool are local and not many, changes to the expansion plan can be proposed using this same tool
  – Otherwise, grid tool is used to identify new boundary conditions considered in the optimal expansion planning problem
e-HighWay 2050. WP2. Automatic search for a plan based on the application of heuristic rules

- Adapted to both long and medium term expansion planning of both large and small systems
- Use of a dedicated planning tool for this
- Economic impact of network investments considered endogenously
- Able to work with larger systems and with a higher level of technical modeling detail than the optimization approach
  → May consider the most relevant technical constraints within the search process

... However, given the size and complexity of the problem to solve, the solution computed may be far from optimal

- Carrying out a grid (technical) analysis of the solution provided by the planning module may or may not be necessary
  - This will depend on the level of complexity of the grid model used in the planning algorithm
• Best adapted to medium term planning of not very large systems
• Requires iteration between planning module and grid analysis module
  – For any given network architecture, the network analysis module computes the economic dispatch subject to relevant technical constraints, producing:
    • Relevant information on the economic impact of reinforcements
    • Set of non-satisfied technical constraints
  – Planning module proposes changes to the set of network reinforcements based on information produced in the grid analysis module
    • Aimed at maximizing social welfare
    • While addressing technical infeasibilities previously detected
e-HighWay 2050. WP2. Iterative search for a suitable expansion plan (i)

- Appropriate indicators of the economic impact of network reinforcements must be defined previously
  - Maybe based on marginal impact
e-HighWay 2050.
Long-Term TEP Scenarios

Source: João G. Dedecca et al. Governance of the Integrated North Sea Offshore Grid: Simulation of Expansion Planning Constraints
e-HighWay 2050. Large-scale RES 100 % RES
e-HighWay 2050.
Big & Market

Small & Local
e-HighWay 2050.
Fossil & Nuclear
e-HighWay 2050.
WP6. Socio-economic analysis

- Multi-criteria methodology for comparing transmission investments by assessing socio-economic impact on the basis of costs, risks and benefits for society and stakeholders
- And incorporating the impact of the governance models
e-HighWay 2050.
WP8. Enhanced transmission planning methodology

• Define a new methodology able to address challenges in long-term grid planning
• Elaboration of test cases
• Definition of generation and demand scenarios
• Enhanced modular development plan
• Robustness of the grid architecture proposed
• Enhanced methodology for long-term planning and specification of the associated tools
e-HighWay 2050. Challenges for TEP

- Spatial complexity: Europe to smart cities
- Temporal complexity: msec. to decades

Stochastic complexity: *weather conditions* and *human behaviors*
e-HighWay 2050.
Overview of the WP8 methodology (i)

1. Network reduction
   \textbf{Reduce}
   (from nodal to zonal grid)

2. Optimal grid expansion at zonal level
   \textbf{Expand}
   (dynamic transmission expansion planning at zonal level)

3. Optimal grid expansion at nodal level
   \textbf{Develop}
   (static transmission expansion planning at nodal level)

e-HighWay 2050. Overview of the WP8 methodology (ii)

STEP 1 – ADEQUACY WITHOUT GRID

STEP 2 – DETECTION OF OVERLOAD PROBLEMS

STEP 3 – NETWORK REDUCTION ACCORDING TO CRITICAL BRANCHES (≈100 NODES)

STEP 4 – OPTIMAL GRID EXPANSION AT ZONAL LEVEL FROM TODAY TO 2050

STEP 5 – GRID EXPANSION AT NODEAL LEVEL

STEP 6 – ROBUSTNESS OF THE PROPOSED GRID ARCHITECTURES

All time horizons and scenarios

First two time horizons

Initial grid (current conditions)

Grid for final time horizon and a given scenario

Grid for an intermediate time horizon common to all scenarios

TIME HORIZON

SCENARIO
### e-HighWay 2050. European original network

<table>
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<th>Number</th>
<th>Value</th>
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<tbody>
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<td>Number of nodes</td>
<td>5155</td>
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<tr>
<td>Number of 400kV nodes</td>
<td>1385</td>
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<tr>
<td>Number of lines</td>
<td>10209</td>
</tr>
<tr>
<td>Number of 400kV PST</td>
<td>17</td>
</tr>
<tr>
<td>Number of 400kV interconnection lines</td>
<td>69</td>
</tr>
<tr>
<td>Number of HVDC links</td>
<td>3</td>
</tr>
<tr>
<td>Number of generating units with $P_{\min} &gt; 0$</td>
<td>418</td>
</tr>
<tr>
<td>Number of hydro units with reservoir</td>
<td>348</td>
</tr>
</tbody>
</table>
e-HighWay 2050. European network reduction

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Number of zones</td>
<td>100</td>
</tr>
<tr>
<td>Number of 400kV corridors</td>
<td>243</td>
</tr>
<tr>
<td>Number of PST</td>
<td>17</td>
</tr>
<tr>
<td>Number of HVDC links</td>
<td>3</td>
</tr>
</tbody>
</table>
e-HighWay 2050
Zonal expansion
e-HighWay 2050.
Nodal expansion
Overall method for TEP studies

• Definition of main assumptions
  – 2050 towards a low carbon economy
  – Up to 17% of Europe's demand for power in 2050 from the deserts of North Africa and the Middle East
  – Generation storylines

• Determine localized long-term European/regional generation expansion plans
  – Localize future generation and demand in nodes
  – Hourly time periods

• Determine snapshots (~80) to evaluate transmission expansion plans

• Determine cross-border interconnections
  – Save (flexible, no regret) decisions
  – Dynamic decisions are more important that final “optimal” decisions. Alternatively, sequential static decisions for some target years (2030, 2050, etc.)
  – Modular development

• Determine specific national reinforcement studies
SET-Nav. Overview

Stakeholder dialogue and Dissemination are the central elements of the dissemination part, including the organisation of topical stakeholder workshops and a broad set of complementary dissemination activities (regional workshops, final conference, web, policy briefs etc.).

Technology innovation and Policy Implications will integrate insights on innovation system policies into SET-Plan scenarios and modelling to develop novel empirical relationships between innovation systems and key innovation processes relevant to the SET-Plan.

Model integration and Global Perspectives will provide key parameters regarding the potential development of global fossil fuel markets and other parameters ("global perspectives") to the EU-centered modelling works in SET-Nav.

Energy Systems: Demand Perspective will provide and apply the modelling framework for the demand side of energy systems including buildings, industrial processes and transport.

Energy Systems: Infrastructure will assess the needs for electricity infrastructure brought by the transformation of the energy system. Complementarily, the needs for gas infrastructure and for Carbon Capture and Storage (CCS) infrastructure that will accompany the anticipated developments will be addressed considering the interrelationships between the three different infrastructure systems.

Energy Systems: Supply Perspective will develop a strong modelling framework regarding energy supply with a particular focus on electricity. In this context enabling and improving interaction between the different models with complementary strengths (system optimisation, policy representation, etc.) is a strong focus.

Macroeconomic Aspects will analyse the interrelationship between energy transformation and the economy, evaluating the macro-economic impacts of the distinct energy transformation pathways.

Comparative assessments: Technology/Policy Options and Pathways carries out a coordinating function in two ways: On the one hand it manages the process that defines transformation pathways that are run by all modelling groups and that ensures consistent implementation of the pathway iterations across models. On the other hand the results from all the case studies, pathway analyses and other complementary assessments are consolidated here.

Modelling forum / Capacity building is in charge of the development of new approaches for building advanced, more holistic energy-economy-environment models. Cross-fertilisation of ideas across distinct modelling methodologies is a central pillar thereby, as is capacity-building and sharing of “best-practice examples” in applied energy system modelling.
SET-Nav. Interlinkages for all supply models
RESCost. Objective

- EC proposal for 2030
  - 40 % reduction target of emissions from 1990
  - 27 % for RES in final energy consumption
  - 30 % energy efficiency target from 2007
- Germany Ministry of Economics wanted to study 3 future generation storylines
RESCost. Generation storylines

- **GHG40**
  - 40% GHG emission reductions by 2030
  - ETS main driver for low-carbon technology support
  - Energy efficiency measures in place
  - Achievement of 2020 RES targets
  - No dedicated support for RES beyond 2020
  - 26.4% RES share by 2030

- **30Quo**
  - 40% GHG emission reductions by 2030
  - ETS one driver for low-carbon technology support
  - Energy efficiency measures in place
  - Achievement of 2020 RES targets
  - After 2020 continuation of RES support by means of an EU green certificate scheme
  - 30% RES-Share by 2030

- **30SNP**
  - 40% GHG emission reductions by 2030
  - ETS one driver for low-carbon technology support
  - Energy efficiency measures in place
  - Achievement of 2020 RES targets
  - Continuation of RES support with balanced RES support across countries in terms of a feed-in premium
  - 30% RES-Share by 2030
RESCost. TEP modeling summary

- Base case is ENTSO-e 2012
- Area division in each country
- Allocation of demand and generation to areas
- Losses proportional to the corridor flow
- Capacity of each corridor
- Transportation model load flow
- Expansion up to 2030 and 2050 directly from 2020

## RESCost. Results

<table>
<thead>
<tr>
<th></th>
<th>GHG40</th>
<th>30QUO</th>
<th>30SNP</th>
</tr>
</thead>
<tbody>
<tr>
<td>System costs in 2030</td>
<td>65 €/MWh</td>
<td>64 €/MWh</td>
<td>68 €/MWh</td>
</tr>
<tr>
<td>Transmission Network Costs in 2030</td>
<td>0.16 €/MWh</td>
<td>0.19 €/MWh</td>
<td>0.30 €/MWh</td>
</tr>
<tr>
<td>Generation investment</td>
<td>26.5 % share of RES</td>
<td>a lot of WG-onshore and half of 30SNP PV</td>
<td>a lot PV and WG-offshore</td>
</tr>
</tbody>
</table>
RESCost. Existing extended network in 2020 with TEPES
RESCost. New investments in 2030 GHG40 with TEPES
RESCost. New investments in 2030 30Quo with TEPES
RESCost. New investments in 2030 30SNP with TEPES
RESCost 2050

<table>
<thead>
<tr>
<th>Years</th>
<th>1</th>
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<tbody>
<tr>
<td>Periods</td>
<td>1</td>
</tr>
<tr>
<td>Sub-periods</td>
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<tr>
<td>Load levels</td>
<td>80</td>
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<tr>
<td>Nodes</td>
<td>254</td>
</tr>
<tr>
<td>Lines (existing + candidates)</td>
<td>447+1807</td>
</tr>
</tbody>
</table>
RESCost. New investments in 2050 GHG40 with TEPES
RESCost. New investments in 2050 30Quo with TEPES
RESCost. New investments in 2050 30SNP with TEPES
Desertec Industrial Initiative (Dii) (http://desertenergy.org/)

- Private industry consortium working towards enabling this vision in Europe, the Middle East and North Africa (EUMENA).
- The power generated from sun and wind is intended primarily to meet the local demand of the producer countries, but could also be exported to Europe. The overall objective of Dii is to create a market for RES from the deserts.
- Development of numerous individual projects in the field of power generation and transmission and a suitable regulatory framework which will evolve over the coming years and decades

- Desert Power 2050: Perspectives on a Sustainable Power System for EUMENA
- Desertec Power: Getting Connected (2030)
Desertec 2050

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
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</thead>
<tbody>
<tr>
<td>Period</td>
<td>1</td>
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<tr>
<td>Subperiod</td>
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</tr>
<tr>
<td>Load Level</td>
<td>80</td>
</tr>
<tr>
<td>Thermal units</td>
<td>468</td>
</tr>
<tr>
<td>Hydro plants</td>
<td>0</td>
</tr>
<tr>
<td>Nodes</td>
<td>79</td>
</tr>
<tr>
<td>Lines (existing + candidates)</td>
<td>127+183</td>
</tr>
</tbody>
</table>
## Desertec 2030

<table>
<thead>
<tr>
<th>Year</th>
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<tbody>
<tr>
<td>Period</td>
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<tr>
<td>Subperiod</td>
<td>1</td>
</tr>
<tr>
<td>Load Level</td>
<td>70</td>
</tr>
<tr>
<td>Thermal units</td>
<td>169</td>
</tr>
<tr>
<td>Hydro plants</td>
<td>94</td>
</tr>
<tr>
<td>RES</td>
<td>1649</td>
</tr>
<tr>
<td>Nodes</td>
<td>1667</td>
</tr>
<tr>
<td>Lines (existing + candidates)</td>
<td>3560+252</td>
</tr>
</tbody>
</table>

![Map of Desertec 2030 network](image-url)

- Ensure **energy security**, reduce greenhouse gases and **boost economic development** through a range of ambitious co-development projects around the Mediterranean.
- Transmit electricity from solar or wind power plants to load centers on either rim of the Mediterranean.
- Requires new infrastructure in the shape of **submarine High-Voltage Direct Current (HVDC) cables**.
- Better interconnection will **strengthen the reliability** of power systems and **create a large electricity market** in the South, to satisfy energy demands at the best possible price.
**MedGrid Objectives**

- Identify some alternative **reinforcement plans** of the **Western corridor’s transmission network**
  - to increase the NTC values in +1GW, +2GW, +3GW
  - between North Africa and France (crossing Spain and Portugal)
  - taking as reference the network already foreseen for 2020-2022

- **Comparison and selection** of the best alternatives
Saudi Arabia
Prof. Andres Ramos

https://www.iit.comillas.edu/aramos/

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