Development of the Ethiopian electricity sector – in a regional perspective

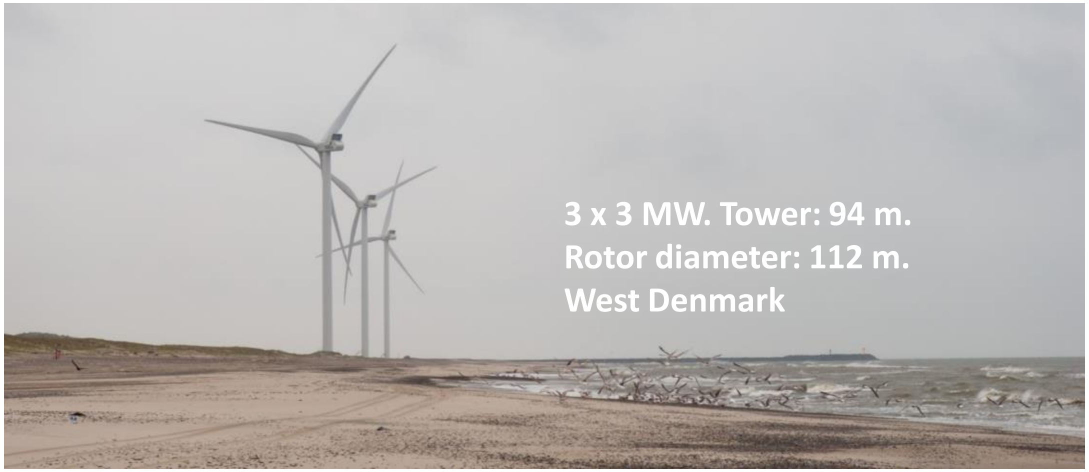
Mikael Togeby

Ea Energy Analyses, Copenhagen

Ea Energy Analyses

Agenda

- Ea Energy Analyses
- Balmorel model
- EAPP Master Plan
- Simulating wind power expansion in Ethiopia
- Summary



EA ENERGY ANALYSES

Ea Energy Analyses

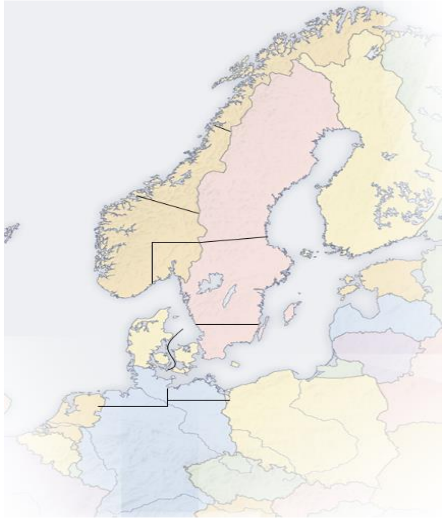
- Private company
  - Started in 2005
  - Background in the Danish Transmission System Operator, TSO
- Consultant for the EAPP Master Plan
  - Together with Energinet.dk
- Models
  - Balmorel: Economic expansion of large electricity systems
  - SisyfosR: Security of supply (stochastic)

BALMOREL MODEL

Electricity system

- Generation and demand must balance at all times
- Models with hourly resolution are needed, e.g. to describe
  - The generation balance after introducing of wind power
  - Optimal use of hydro

Balmorel model



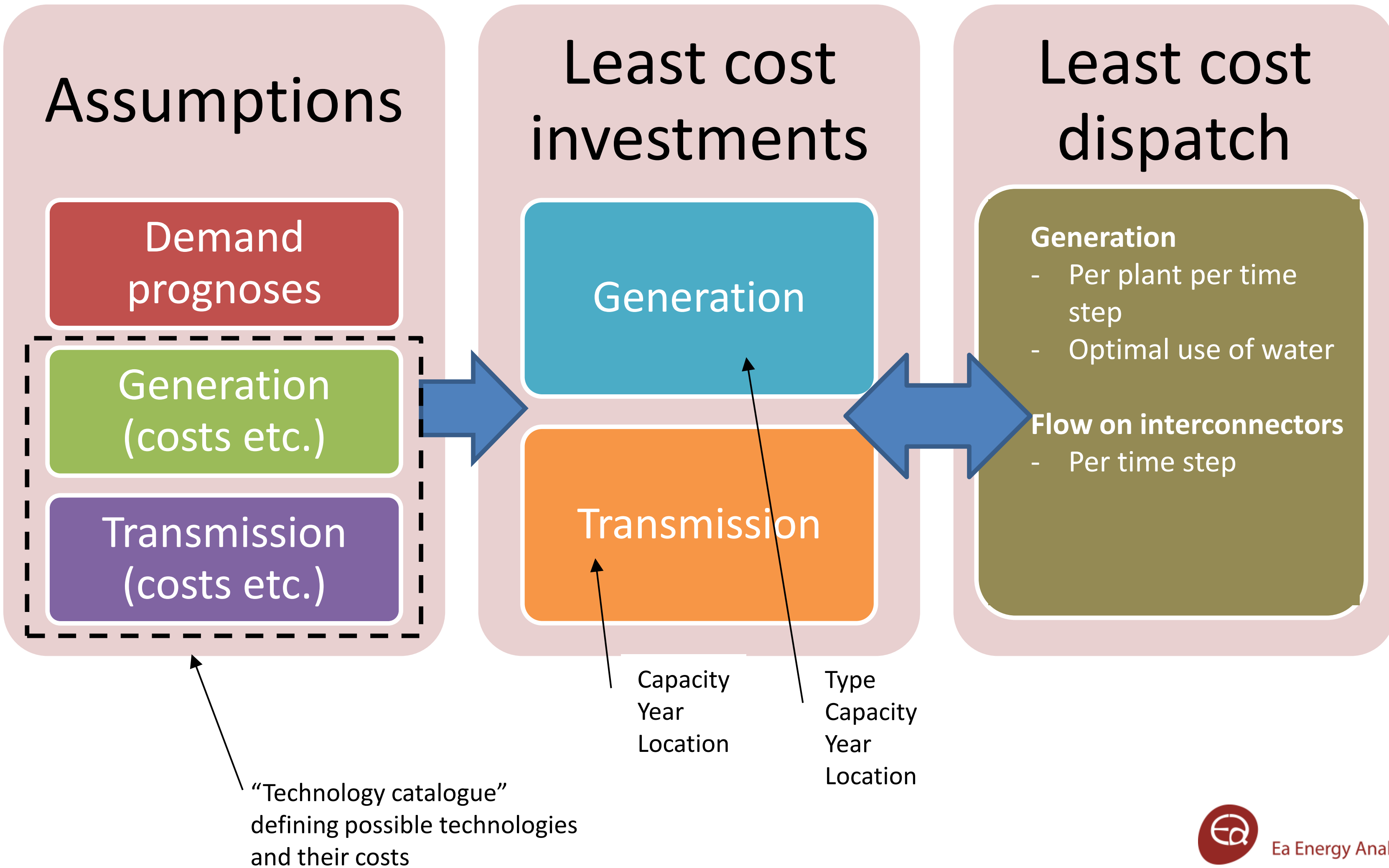
- Transparency
  - Open source. www.balmorel.com
  - Requires a commercial solver: GAMS
    - GAMS = General Algebraic Modelling System, a high-level modelling system for mathematical programming problems (www.gams.com)
- Flexibility
  - Possible to implement new policies, policy objectives, technologies and other considerations
- Transferability
  - Adaptation with local data

The Balmorel model is installed at EAPP HQ in Addis Ababa

Large electricity system

- Balmorel has been used to simulate:
  - China: 4,600 TWh
  - The North European system, 17 countries: 2,700 TWh
  - Eastern Canada and North/East USA: 350 TWh
  - Southern Africa: 300 TWh
  - Eastern African Power Pool, EAPP, 12 countries: 300 TWh
  - Mexico: 300 TWh
  - Egypt: 200 TWh
  - Vietnam: 150 TWh

Model-based investments and dispatch



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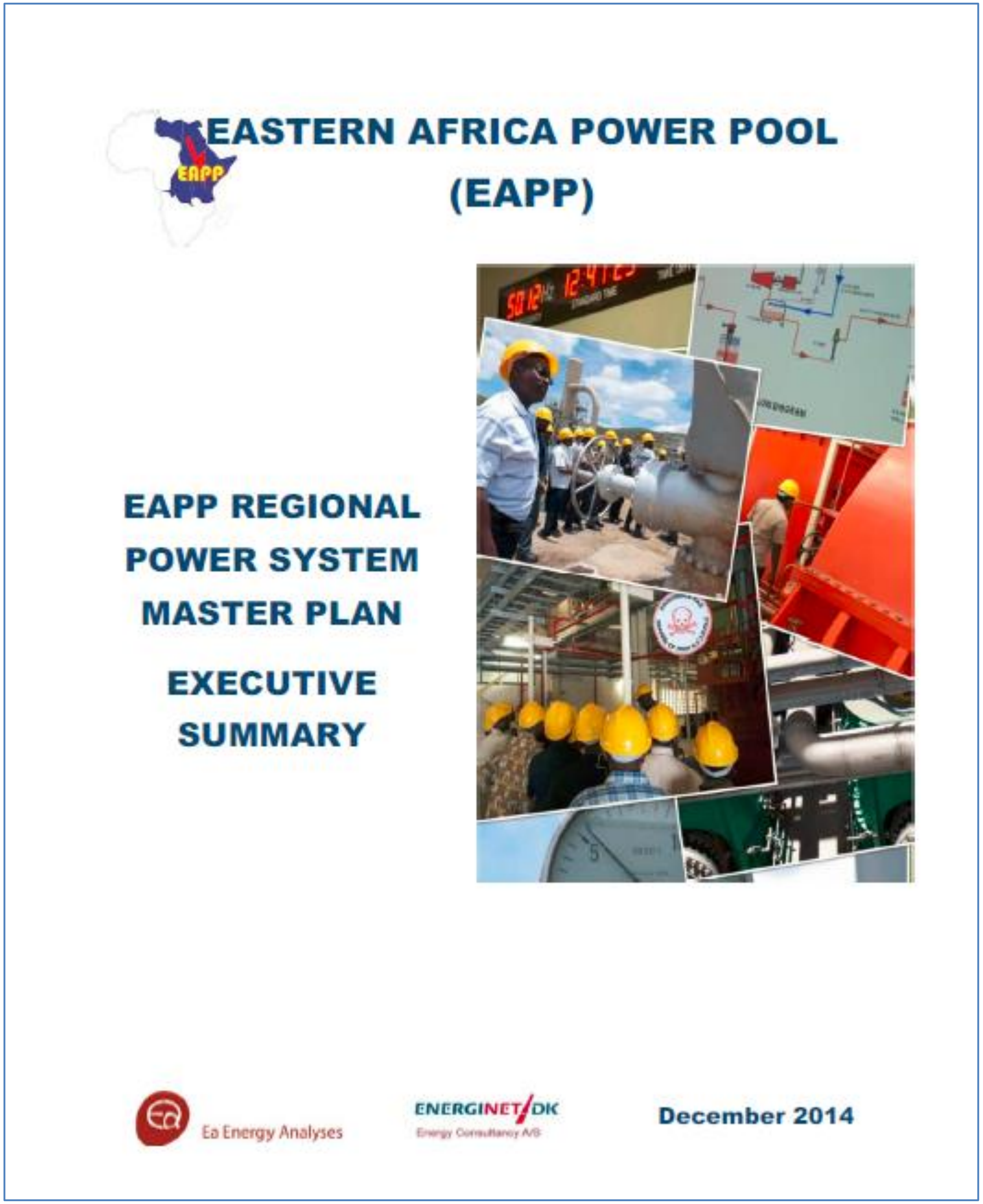
Eastern African Power Pool, EAPP = 10 member states: Libya, Egypt, Sudan, Ethiopia, Kenya, Tanzania, Uganda, Rwanda, Burundi and the DRC.

The Master plan also includes: South Sudan and Djibouti

EAPP MASTER PLAN

EAPP Master plan

- Published January 2016
- Cooperation between 10 EAPP countries
  - Governments
  - Electricity utilities



EASTERN AFRICA POWER POOL
(EAPP)

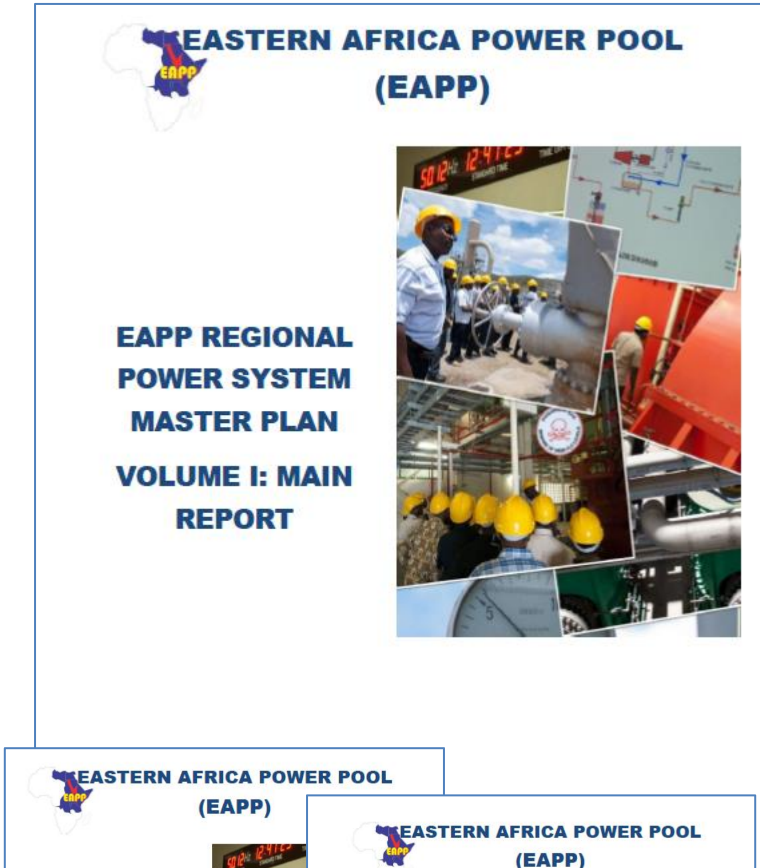
EAPP REGIONAL POWER SYSTEM MASTER PLAN

EXECUTIVE SUMMARY

Ea Energy Analyses

ENERGINET/DK
Energy Consultancy A/S

December 2014



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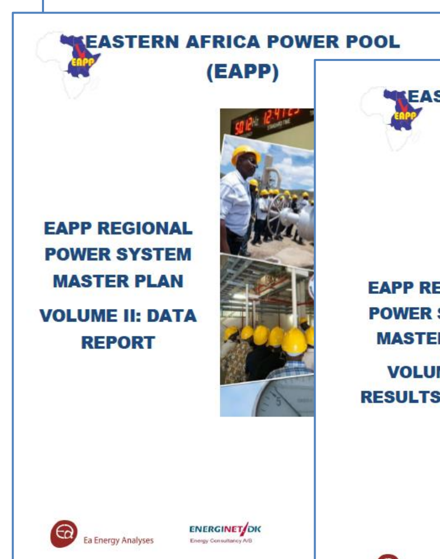
EAPP REGIONAL POWER SYSTEM MASTER PLAN

VOLUME I: MAIN REPORT



EASTERN AFRICA POWER POOL
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EAPP REGIONAL POWER SYSTEM MASTER PLAN

VOLUME II: DATA REPORT

Ea Energy Analyses

ENERGINET/DK
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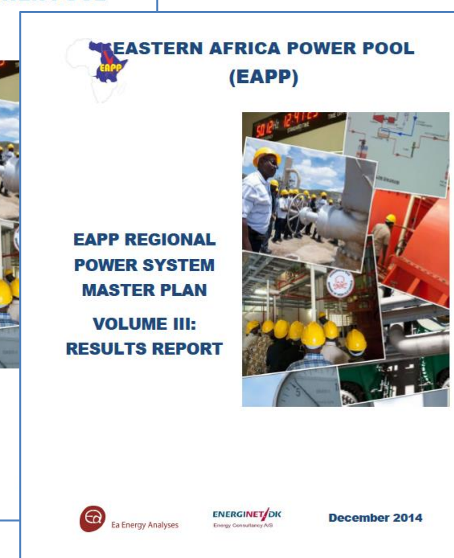


EASTERN AFRICA POWER POOL
(EAPP)

EAPP REGIONAL POWER SYSTEM MASTER PLAN

VOLUME III: RESULTS REPORT

Ea Energy Analyses

ENERGINET/DK
Energy Consultancy A/S

December 2014

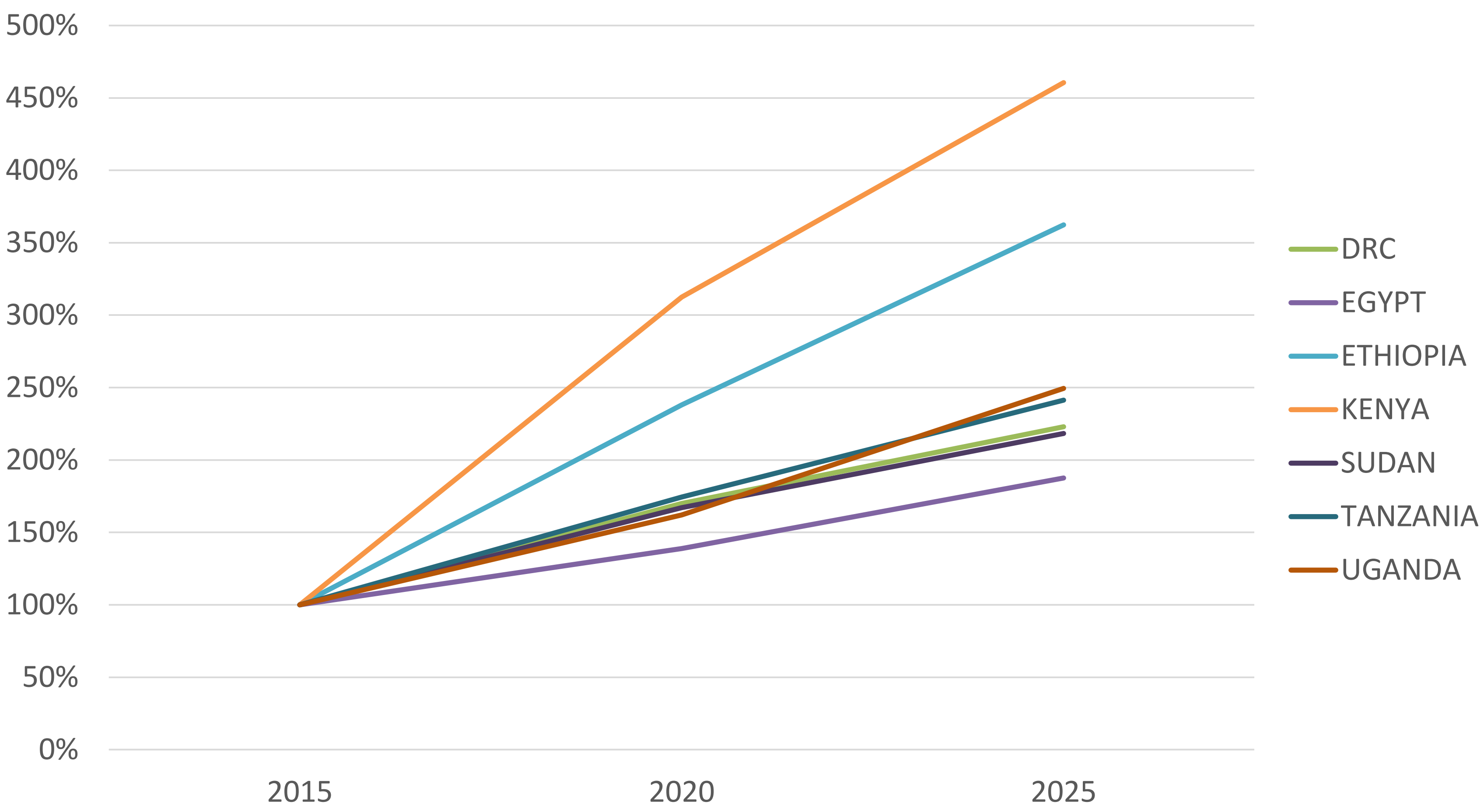
Least cost

- Least cost dispatch
  - Minimize regional cost for supplying electricity
    - Merit order dispatch
    - Optimal use of hydro
- Least cost investments
  - In generation
  - In transmission

Strong growth in electricity demand

TWh	2015	2020	2025	2030	2035	2040
BURUNDI	0	1	1	1	2	2
DJIBOUTI	1	1	1	1	1	1
DRC	18	31	41	51	61	72
EGYPT	201	280	378	504	647	772
ETHIOPIA	15	35	53	74	100	124
KENYA	13	42	61	86	110	131
LIBYA	34	47	64	85	109	130
RWANDA	1	2	2	3	4	5
SOUTH SUDAN	1	2	3	4	5	7
SUDAN	15	24	32	39	47	55
TANZANIA	11	20	27	37	48	58
UGANDA	5	8	12	18	23	27
Total	**315**	**492**	**675**	**903**	**1157**	**1384**
Growth, p.a.		9%	7%	6%	5%	4%

Demand growth



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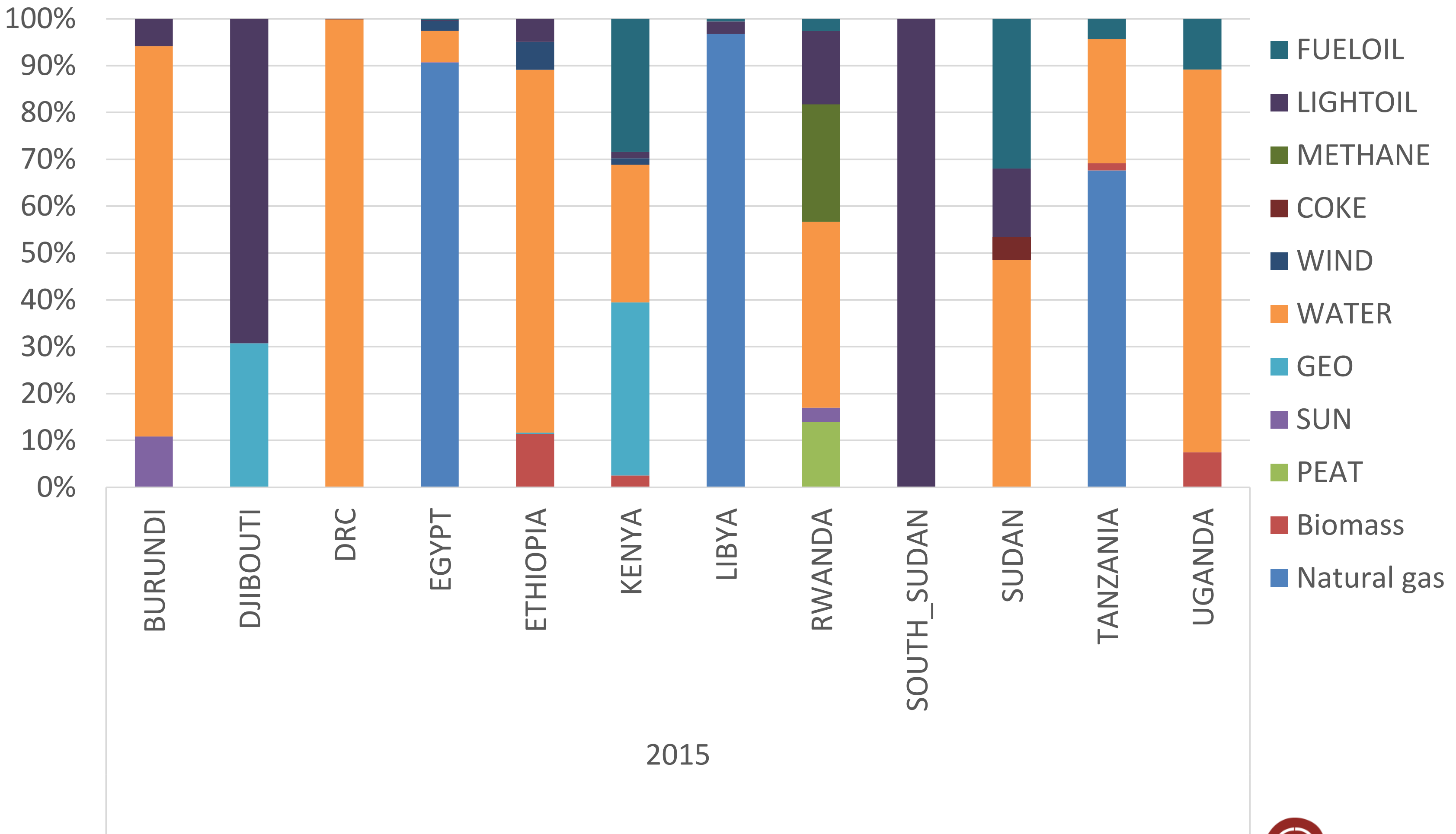
REFERENCE SCENARIO

Variation in generation across countries



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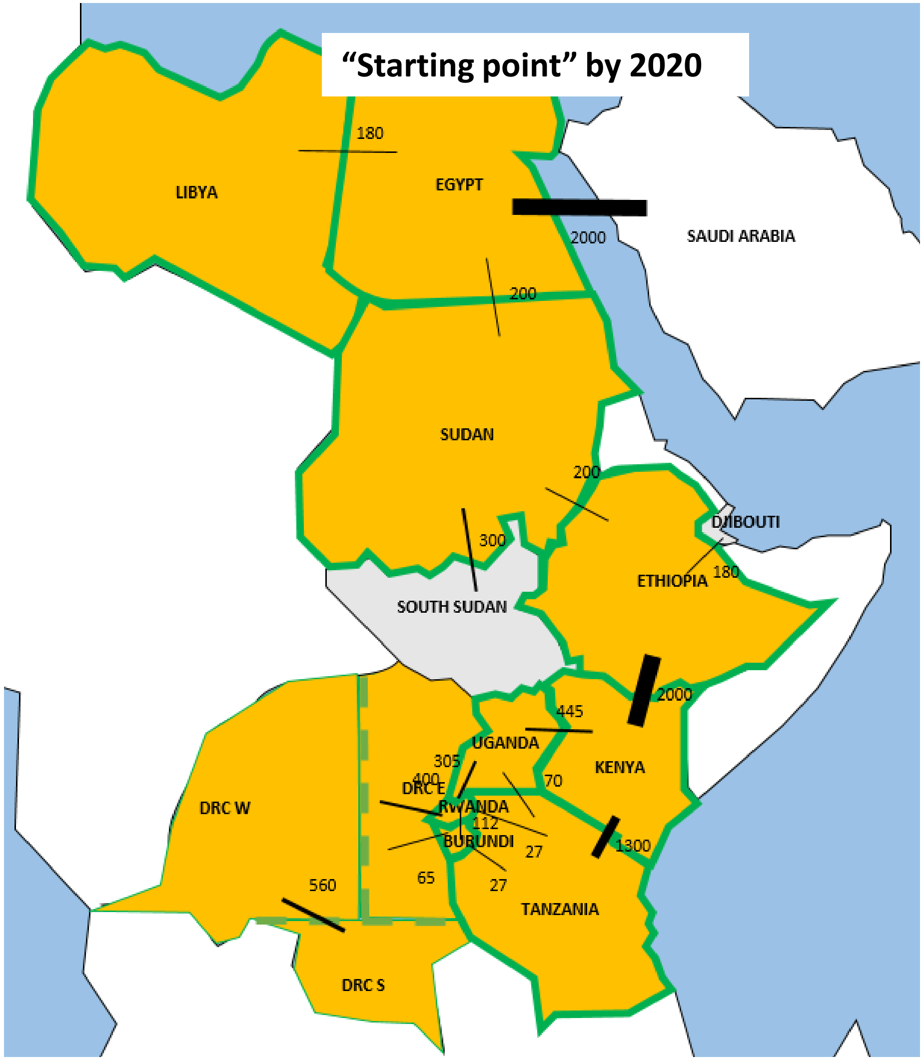
12 countries interconnected by 2020



Existing (2015) and committed lines by 2020

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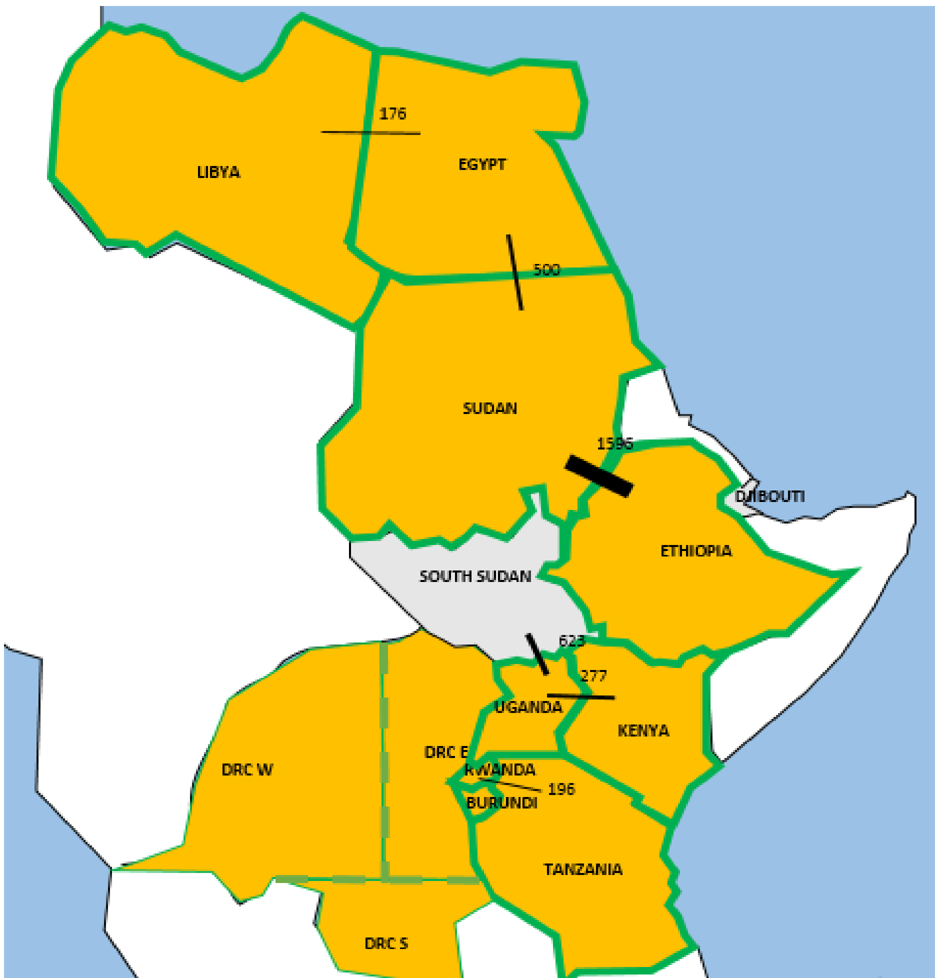
Additional transmission capacity by 2020 and 2025

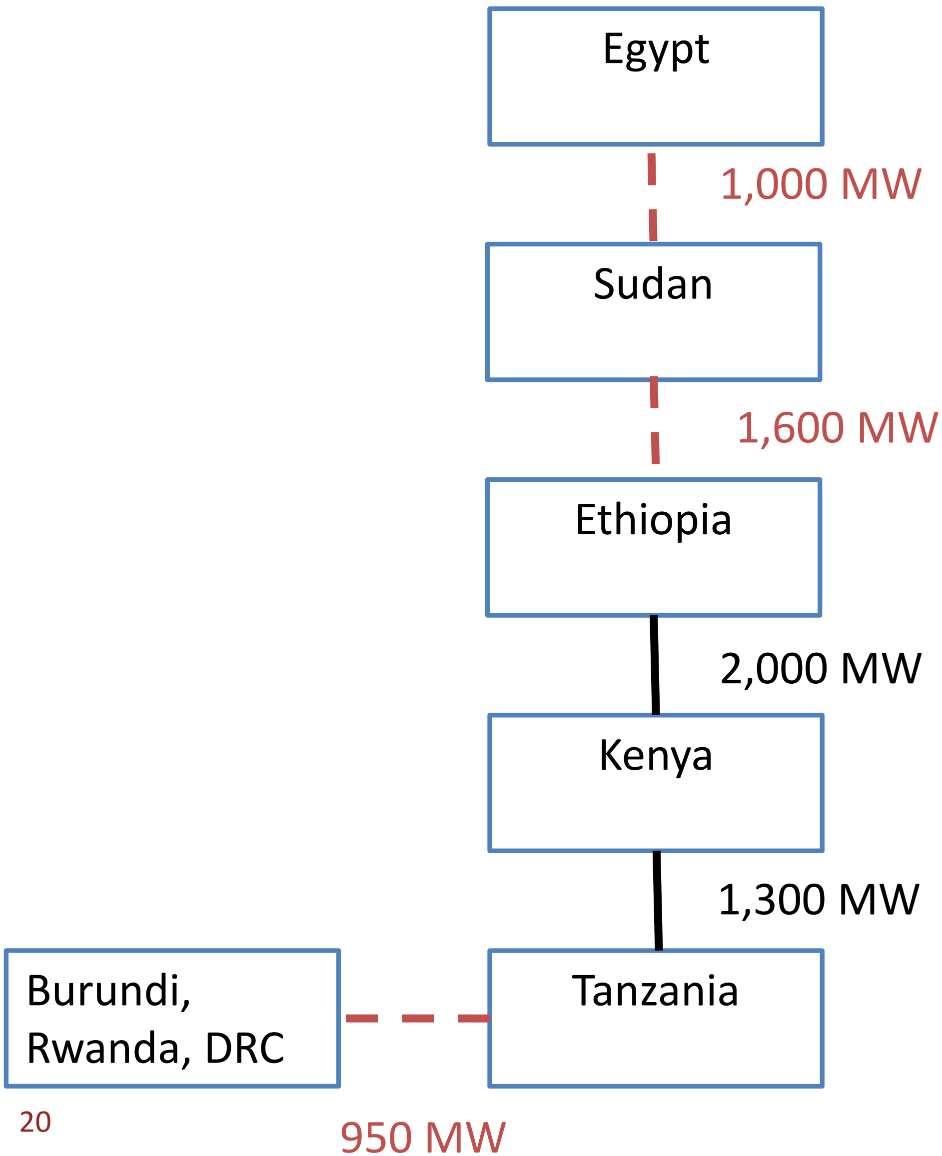


Six recommended new lines by 2020. Reference scenario

Nine recommended new lines by 2020 and 2025 accumulated. Reference scenario

/ses

Backbone expansion, simplified, 2025



Black solid = Existing (2015) and committed (2020)
Red dashed = Recommended

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MODEL BASED SCENARIOS

Model-based scenarios

- Describes a specific understanding of *scenarios*
  - Not predictive
  - Analytical
  - Purpose: To support policy process
- Focus on electricity systems

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06-09-2015
Mikael Togeby

The use of model based energy scenarios to support policy development

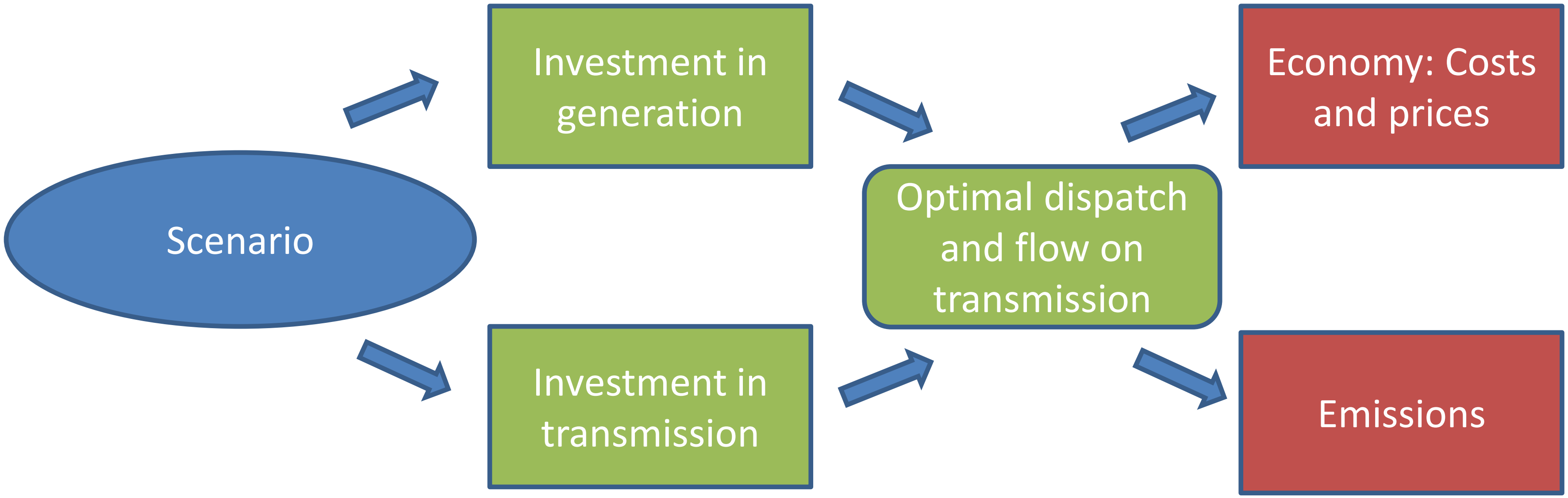
In this text, "model based energy scenarios" is used about computer-generated results describing potential developments of the electricity system in a country or a region. The methods and the assumptions must be transparent and the results must be understandable and verifiable. Scenarios can be input driven or goal driven.

Computer models as tools

It has an analytical purpose, when we use computer models to describe potential futures. The idea is not that the computer shall make policy. The result from a group of scenarios will help to qualify the political discussion.

Electricity systems are large systems where interaction take place though synchronous AC systems, e.g. covering distances of more than 2,000 km (e.g. from West Denmark to Portugal). The balance between demand and generation must be maintained at the level of microseconds and extra input of electricity at one point must be balanced by reducing generation elsewhere. These features makes it relevant to study the impact of new technologies like wind and solar power in models covering large areas, e.g. large synchronous areas.

For each scenario



Per country
Per five year

Per hour

21 scenarios =>
21 generation plans and
21 transmission plans for the 12 countries

The many scenarios are used to study robustness

Assumptions

- 10% interest rate (real)
  - Two scenarios with higher and lower interest rate
- 20 years life time for generators
  - 50 years for hydro and nuclear
- Cost of unserved electricity demand of 1.2 $/kWh
  - Practically no unserved electricity in the scenarios
- All countries are required to have 110% capacity compared to the peak demand
  - One scenario without this requirement
- 10% of thermal power plant capacity is reserved for planned and unplanned maintenance
- Strict definition of *committed* plants
  - Construction started or finance must be secured

EAPP Technology catalogue

- Existing plants: 184 plants
- Committed plants: 140 plants
- The toolbox: Technology catalogue:
  - – Candidate power plants
    - 10 generic plant types
      - – coal, natural gas, diesel, geothermal, nuclear, solar and wind
    - 87 individual projects (typically hydro)
  - – Candidate transmission projects
    - 26 potential transmission projects

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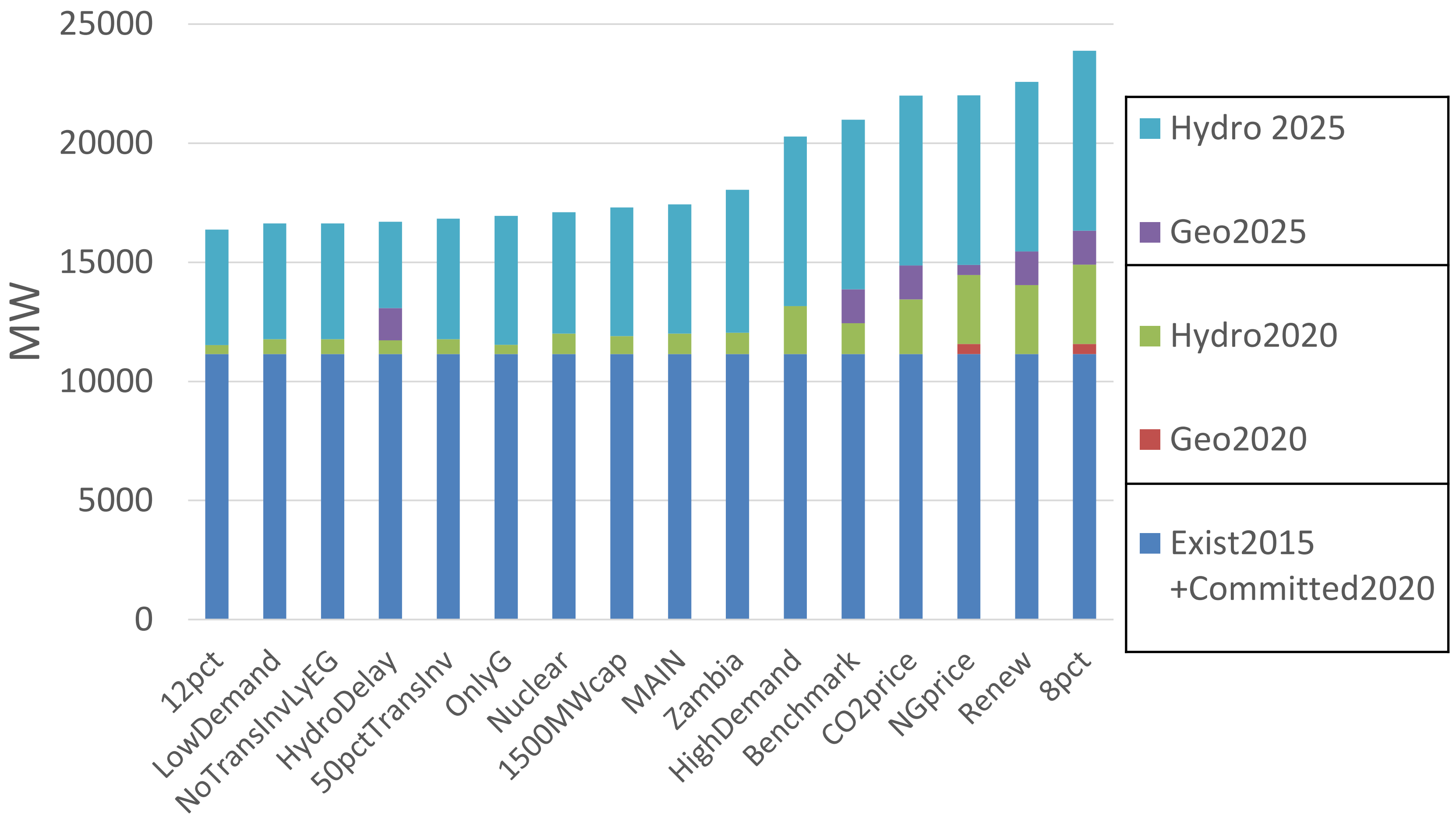
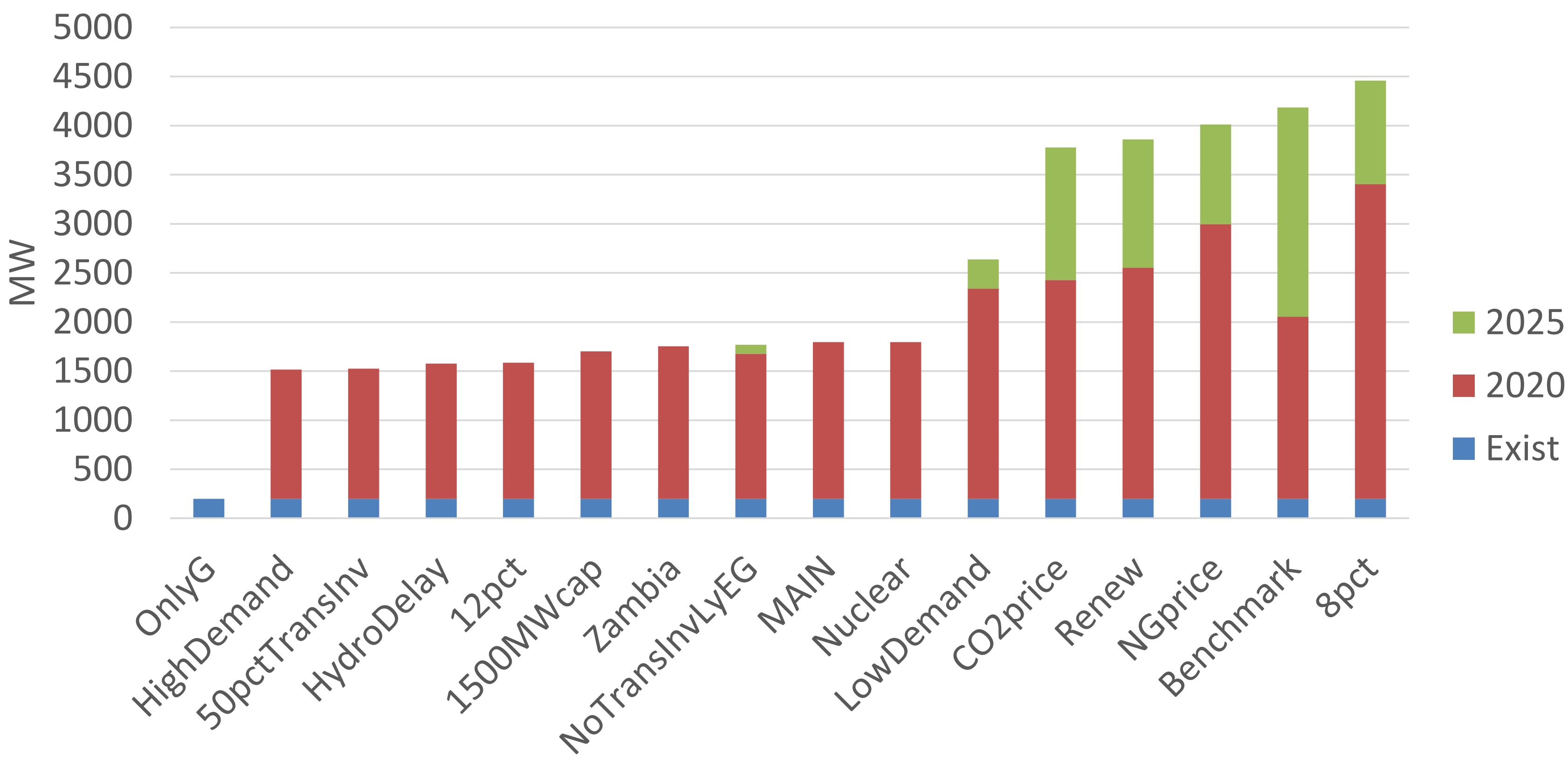
Generation capacity: Ethiopia as a case



Other five scenarios only have impact after year 2025.
Similar results for the other 11 countries

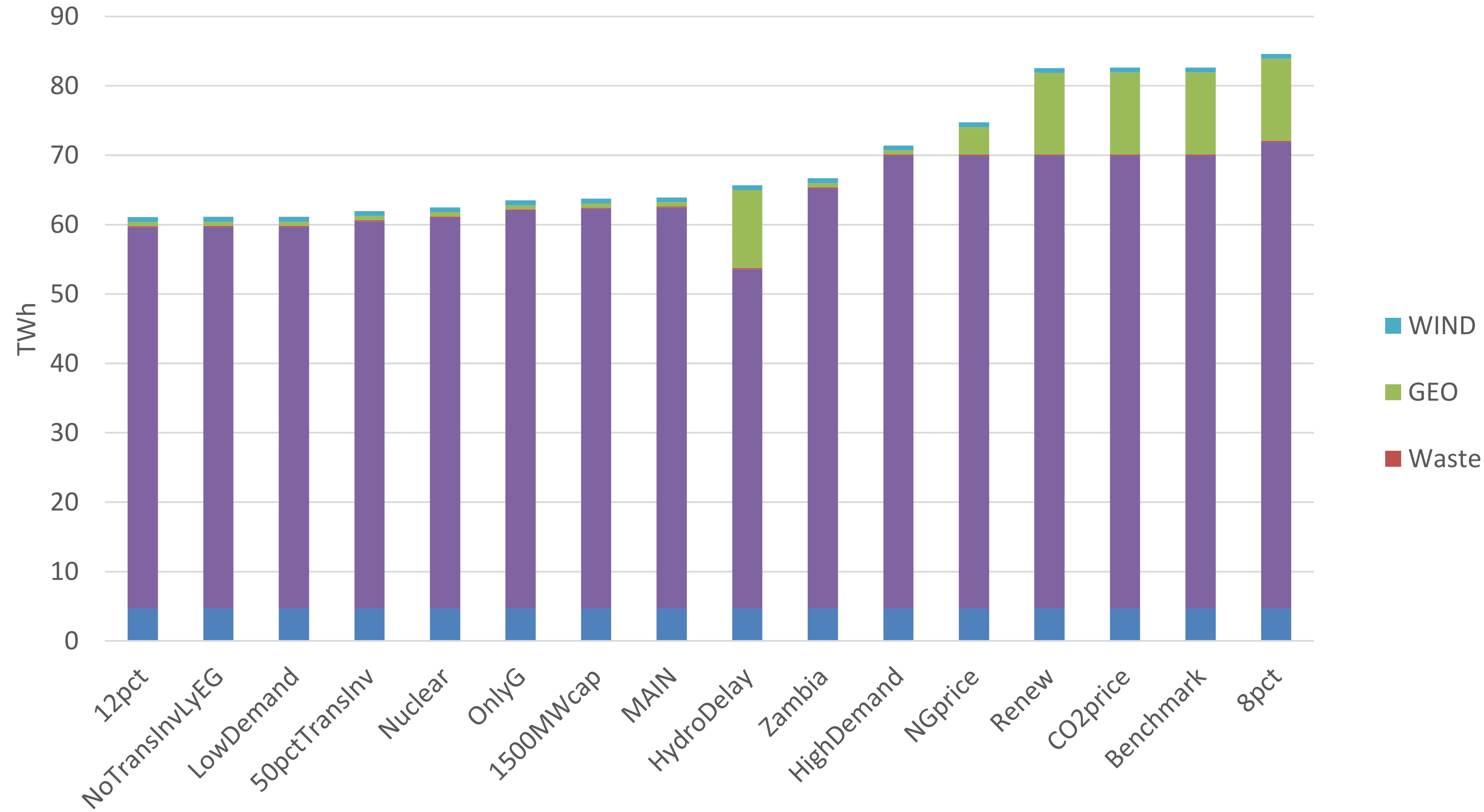
Transmission: Ethiopia – Sudan as a case



Other lines from Ethiopia (Existing 2015 and Committed 2020):

- To Djibouti: 180 MW
- To Kenya 2000 MW (DC)
- No connection to South Sudan
- Somalia and Eritrea not included in the study

Generation (2025): Ethiopia as a case



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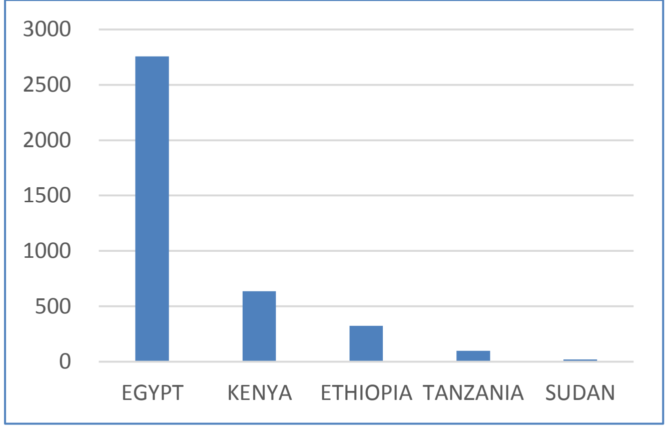
7000 MW WIND EXPANSION IN ETHIOPIA

Lake Turkana, Kenya
image-store.slidesharecdn.com/5d514c35-fe60-4ab6-a9b8-96fcc2f70425-original.jpeg

Wind power



- Included in Master plan:
  - 3,836 MW wind power (Existing 2015 + Committed 2020)
  - Very limited model-based investments in wind power in 2020 and 2025
  - In three scenarios there are significant expansion of wind power from 2030:
    - Renewable energy goals
    - CO_2 price
    - 8% interest rate
  - Data improvement needed: More detailed information about wind resources
    - Special focus on best sites needed

More wind planned for Ethiopia

- Growth and Transformation II (GTPII) period 2016-2020: 5,200 MW wind

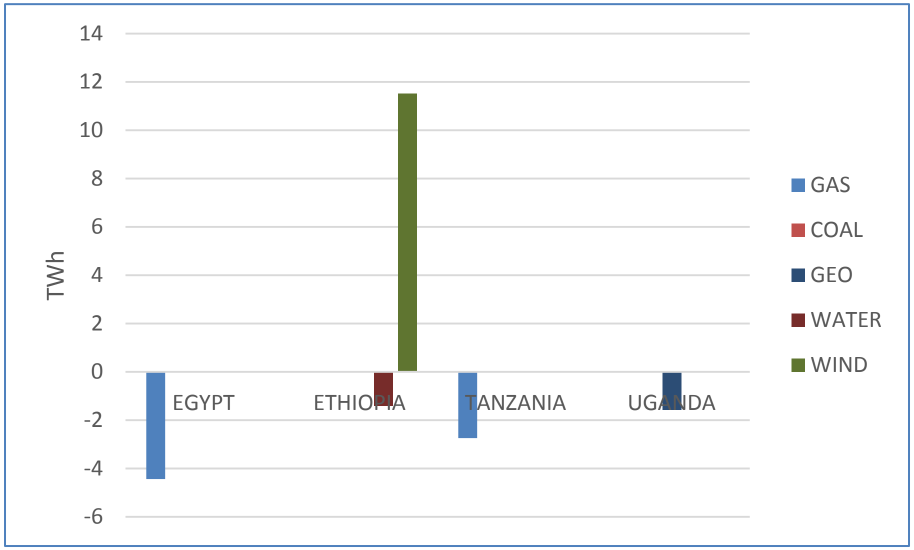
Illustrative case: Extra wind in Ethiopia

- New scenario developed for this presentation
  - Scenario #22!
- 7,000 MW wind in Ethiopia
  - 3,500 MW in 2020 and additional 3,500 MW in 2025
  - Wind data from NCEP, Climate Forecast System Reanalysis (3,200 FLH)
- Study of system-wide impact
  - Change in regional …
    - Investment in generation and transmission
    - Generation
      - More wind, less…?

Wind data: rda.ucar.edu/datasets/ds093.1/

Change in generation

2020

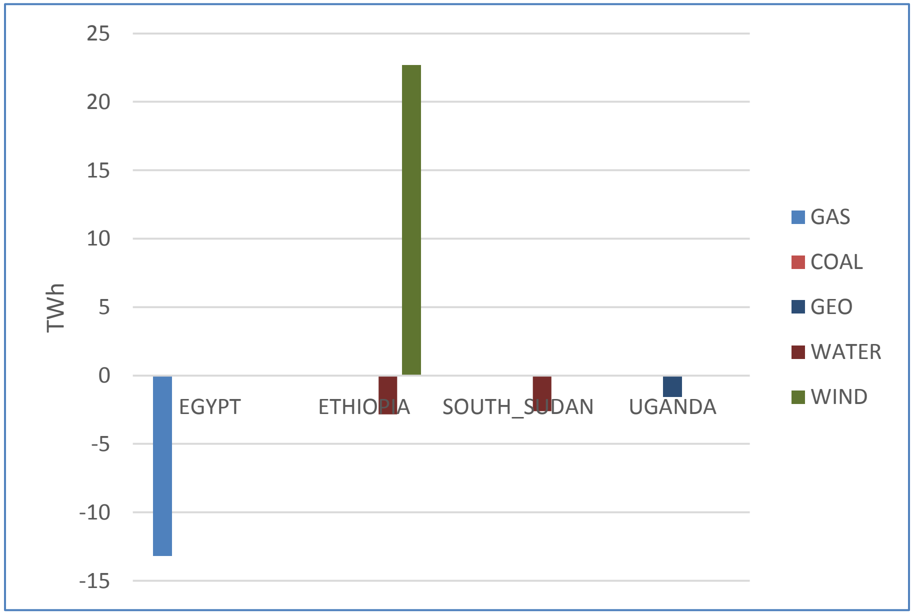


Comparing two regional optimal scenarios:

- Reference EAPP scenarios
- +7,000 MW wind in Ethiopia

Only changes > 1 TWh shown

2025



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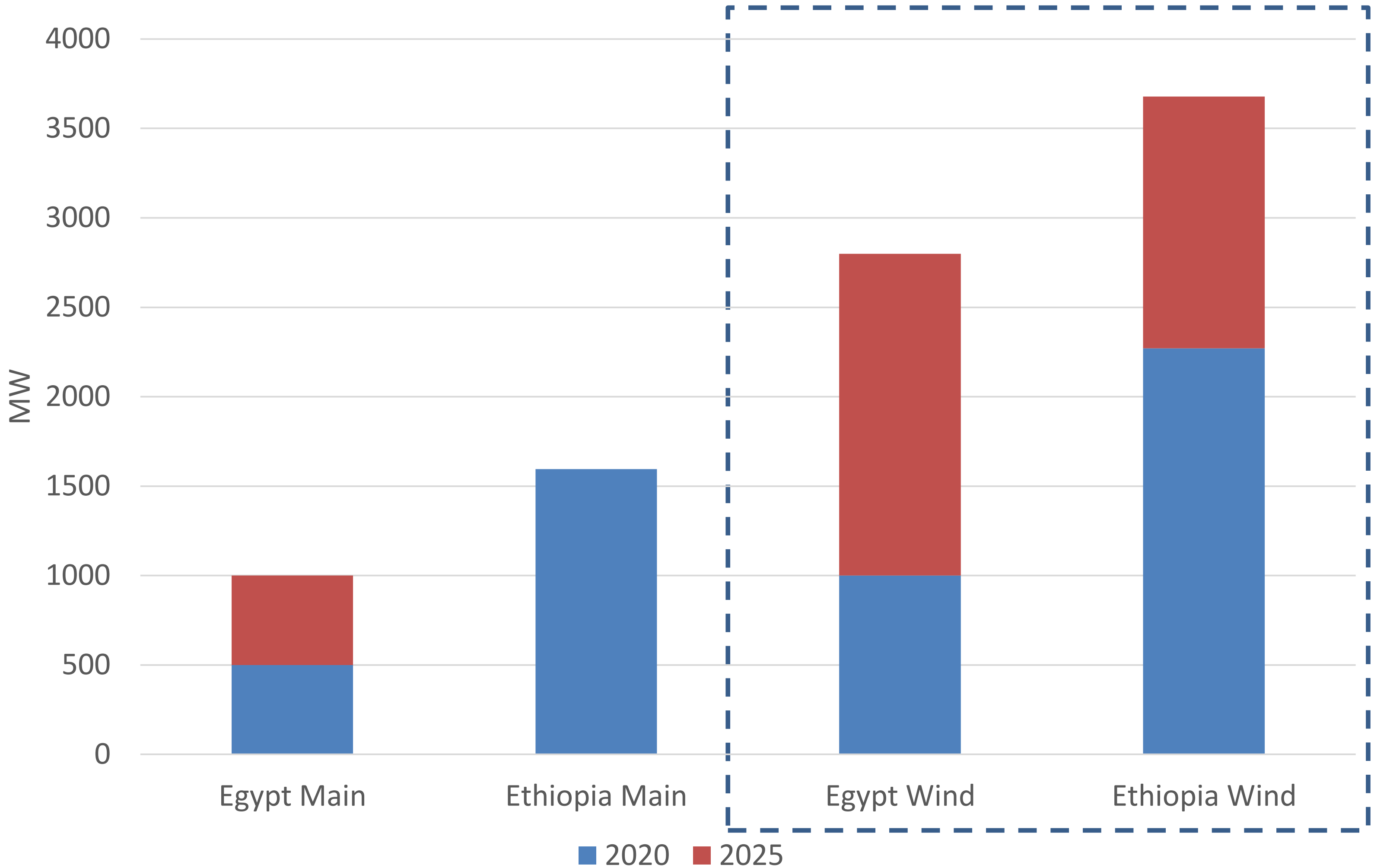
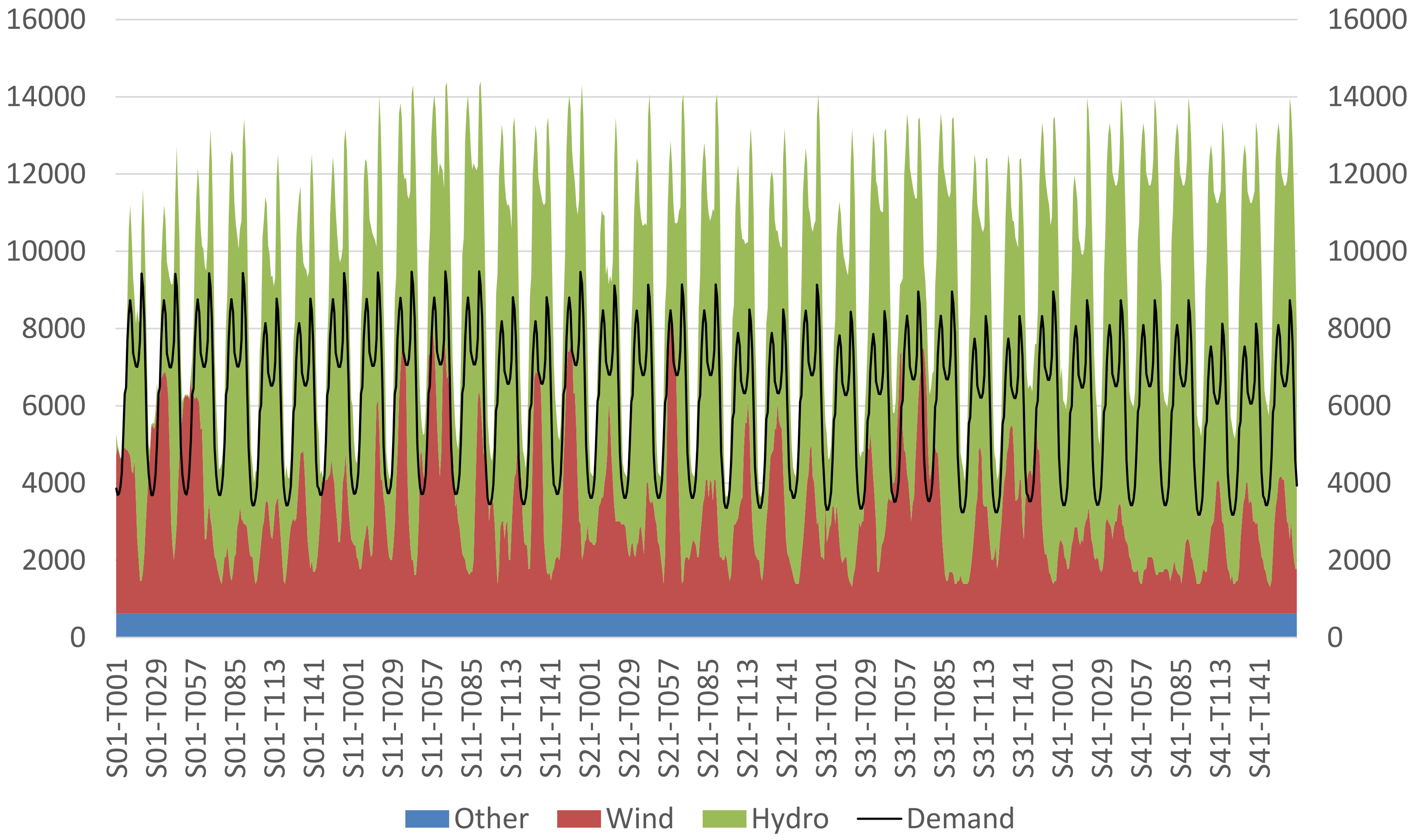
Transmission: To/from Sudan as a case



DETAILED RESULTS FOR ETHIOPIA (HOURLY)

Generation: 5 weeks, hourly



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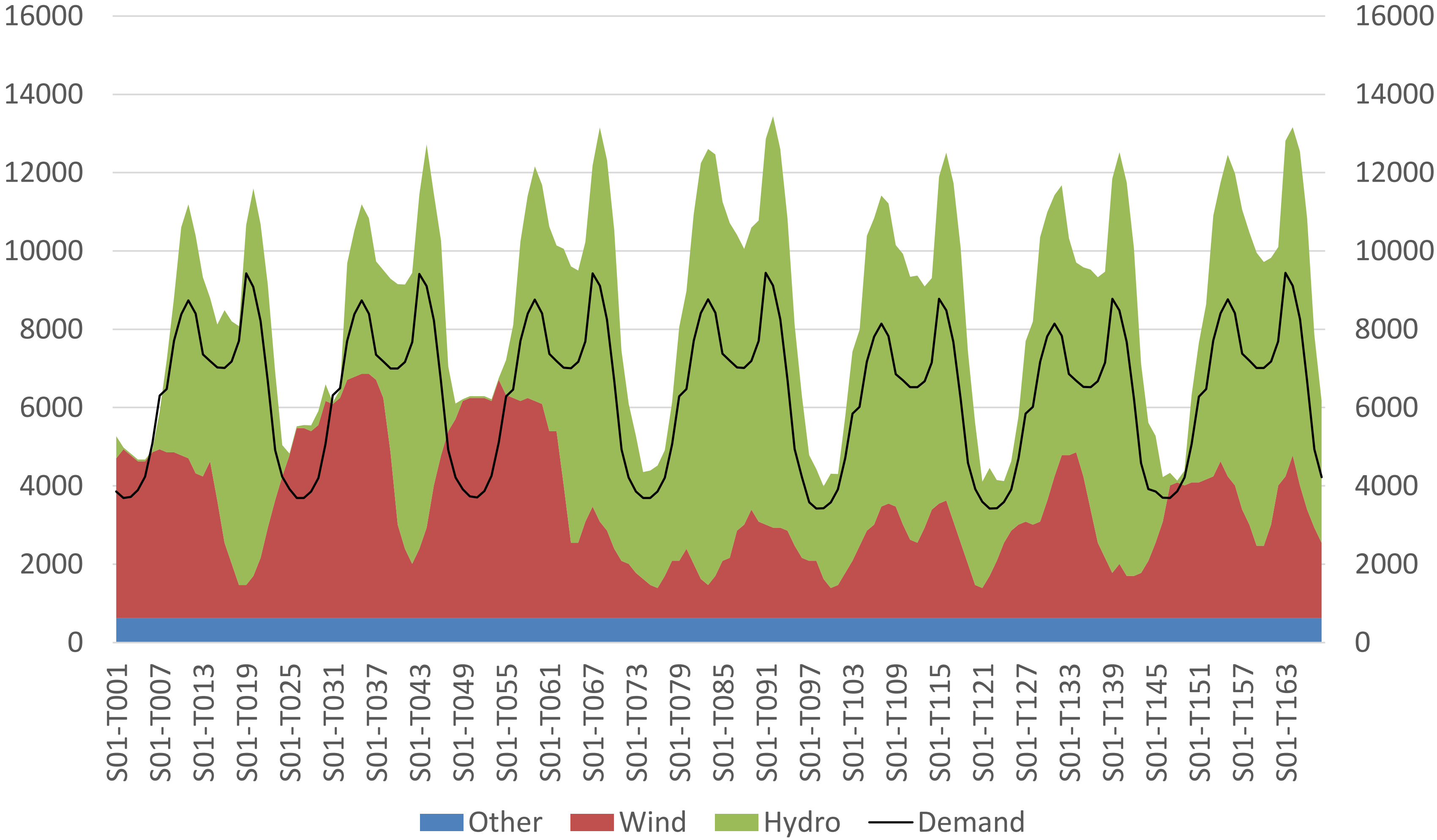
Generation: 1 week, hourly



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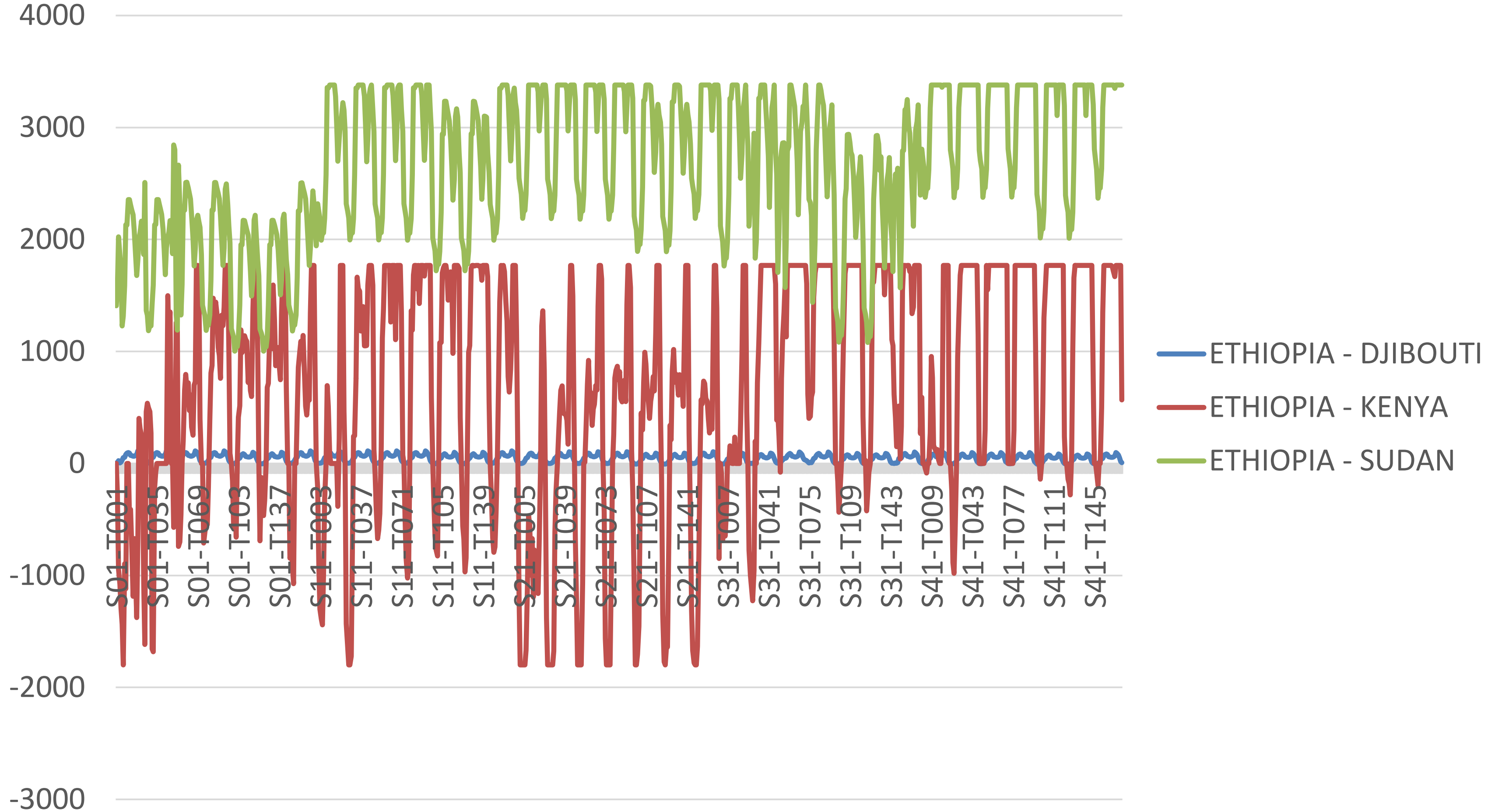
Transmission: 5 weeks, hourly



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SUMMARY

Summary

- The electricity system must be in balance at all times
  - The Balmorel model has been used in EAPP Master Plan and in an special run with extra wind power in Ethiopia
  - Without adequate system expansion, curtailment of wind can occur
  - Wind-hydro interaction is attractive
- 7,000 MW extra wind power in Ethiopia can be absorbed by the system
  - Economic with more transmission
  - Main reduction: Less use of natural gas in Egypt
  - Results illustrate the dynamic use of hydro and of export

Thank you!

Mikael Togeby
mt@eaea.dk

Ea Energy Analyses
Frederiksholms Kanal 4
1220 Copenhagen
Denmark
www.eaea.dk

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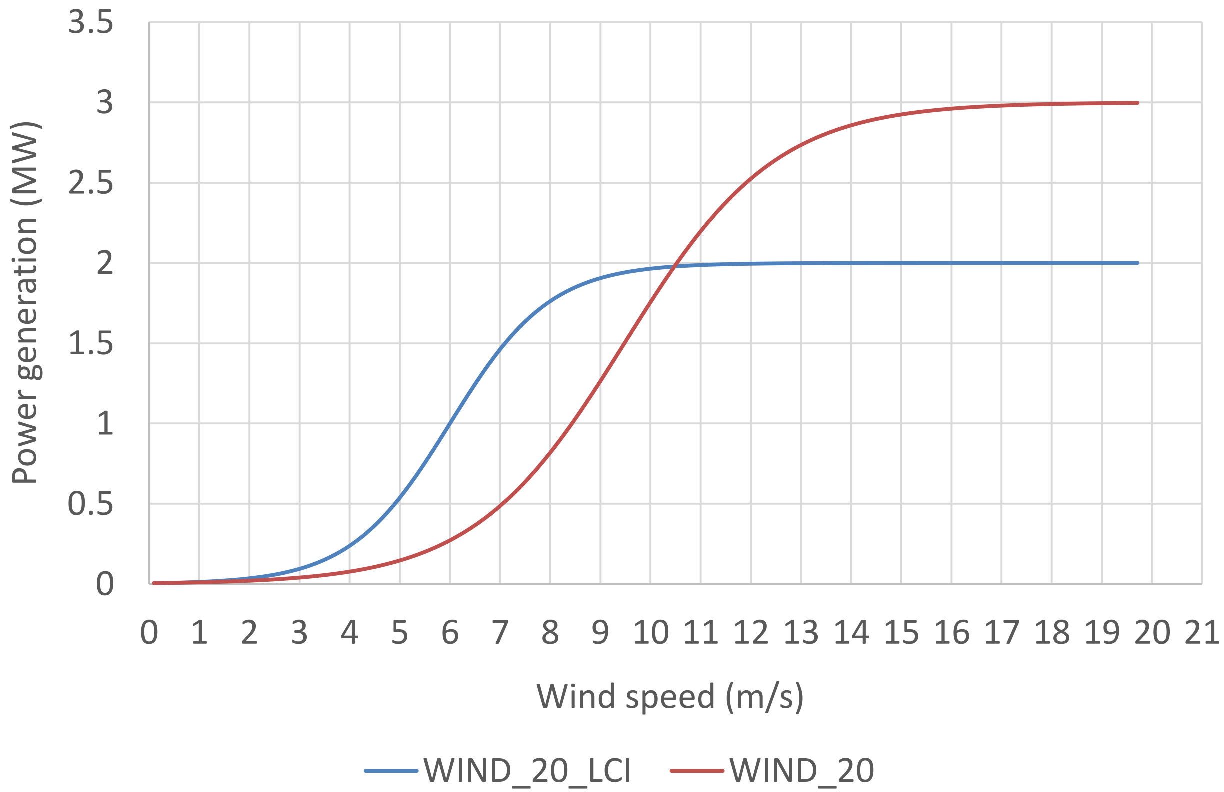
EXTRA

Wind turbine technologies

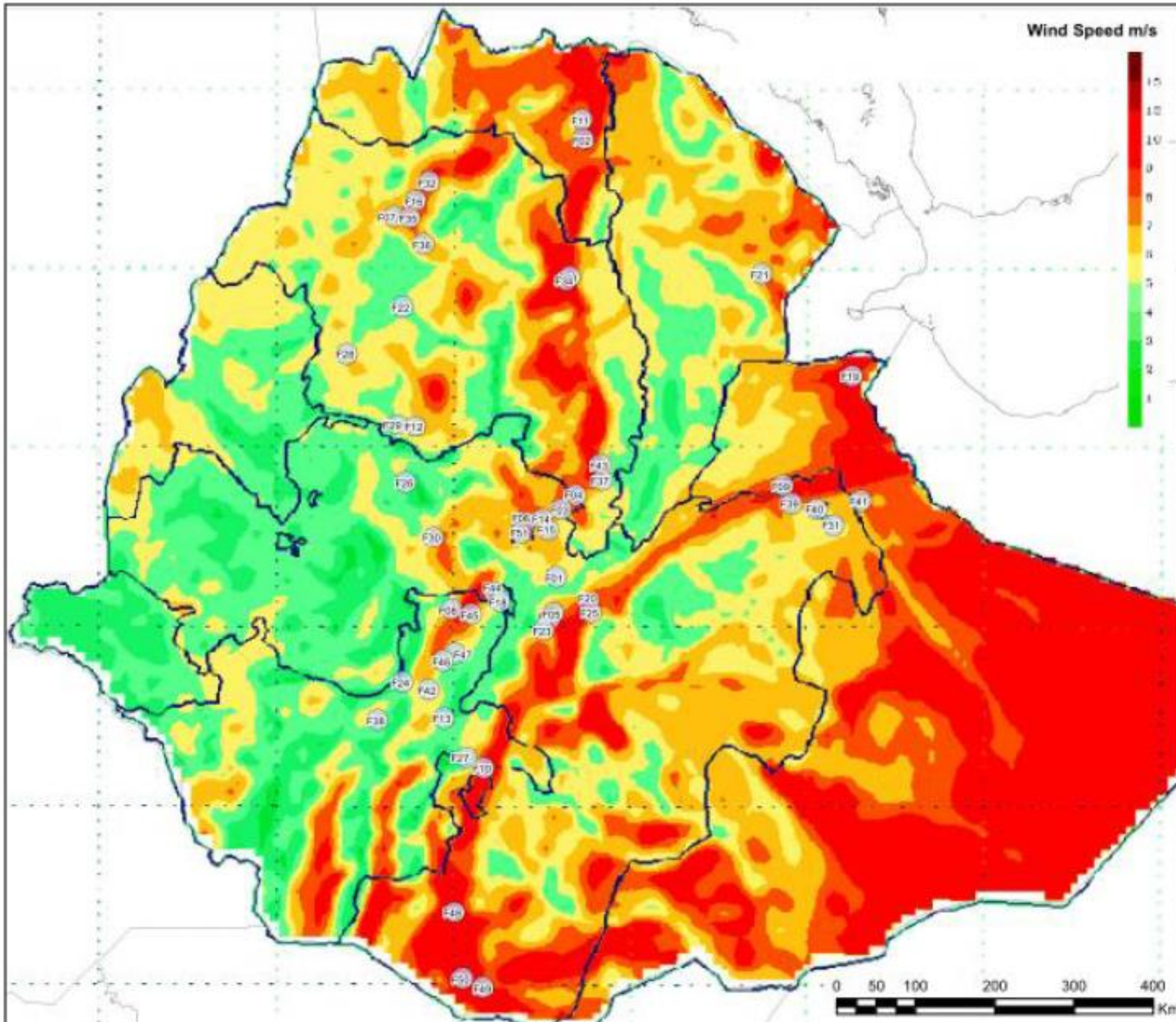
Power curves representative of different technologies



From 2014 Master plan

Wind sites	Capacity	Year
Adama (1)	51 MW	2009
Ashegoda (1)	30 MW	2013
Ashegoda (2)	90 MW	2013
Adama (2)	153 MW	?

Figure 6-2: Location of HydroChina candidate plants



- Hydro China (from Master plan):
  - 51 sites, 6,720 MW
- Cost of Wind: US $ 1.9 /MW

Investments in transmission

MW	Reference		Wind		Difference	
From To	2020	2025	2020	2025	2020	2025
DRC						
RWANDA		318		204	0	-114
UGANDA		488		602	0	114
EGYPT						
LIBYA	176	176	173	173	-3	-3
SUDAN	500	1000	1000	2799	500	1799
ETHIOPIA						
SUDAN	1596	1596	2270	3678	673	2082
KENYA						
UGANDA	277	624	3	499	-273	-125
LIBYA						
EGYPT	176	176	173	173	-3	-3
RWANDA						
DRC		318		204	0	-114
TANZANIA	196	954	257	838	61	-116
SUDAN						
EGYPT	500	1000	1000	2799	500	1799
ETHIOPIA	1596	1596	2270	3678	673	2082
SOUTH SUDAN		330			0	-330
SOUTH SUDAN						
SUDAN		330			0	-330
UGANDA	623	623	610	610	-12	-12
TANZANIA						
RWANDA	196	954	257	838	61	-116
UGANDA						
DRC		488		602	0	114
KENYA	277	624	3	499	-273	-125
SOUTH SUDAN	623	623	610	610	-12	-12
Total	6738	12219	8627	18808	1889	6589