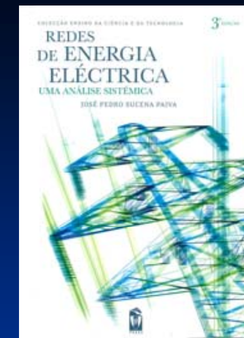

PUBLIC POLICIES FOR ENERGY

ELECTRICITY GENERATION PORTFOLIO

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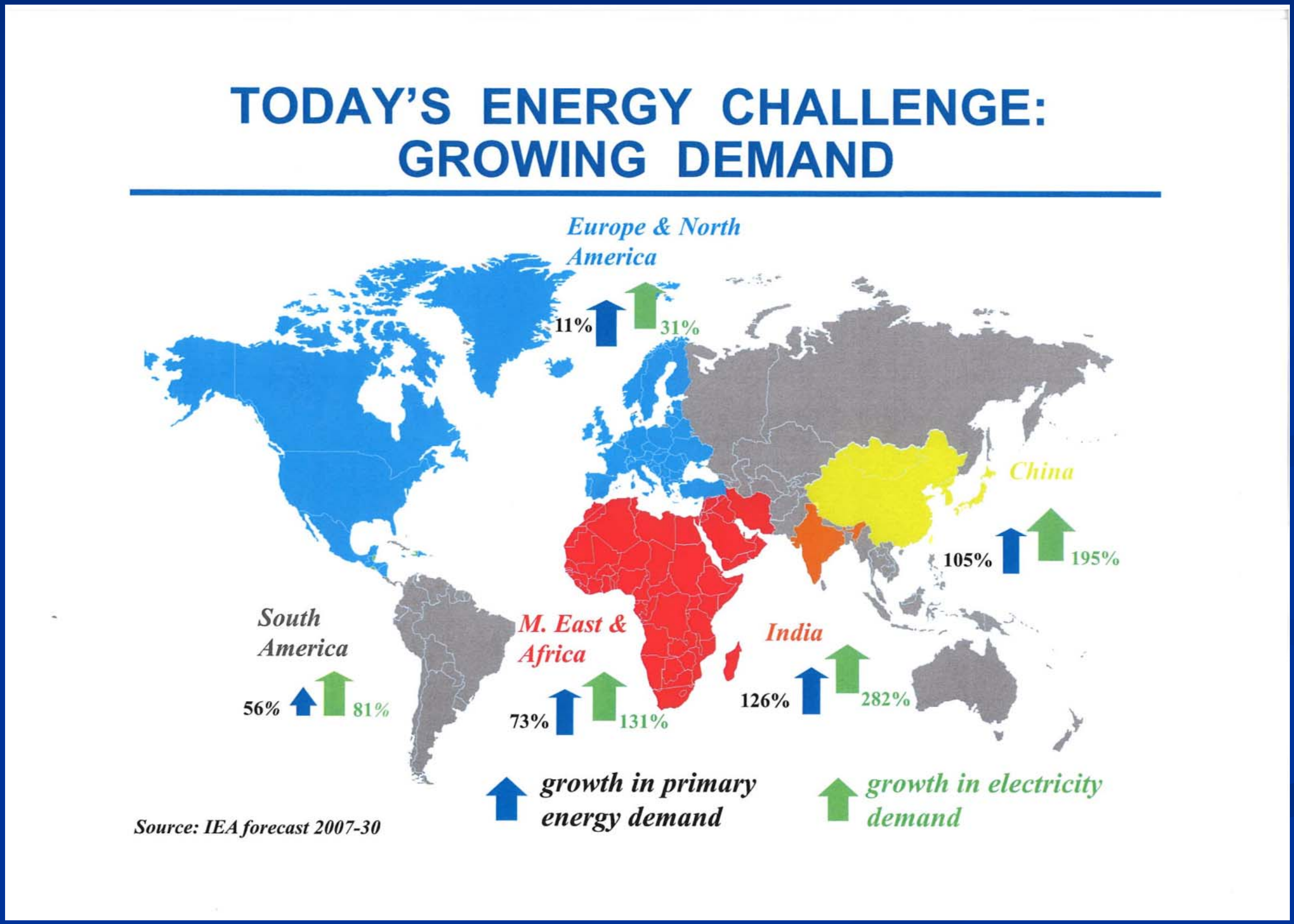
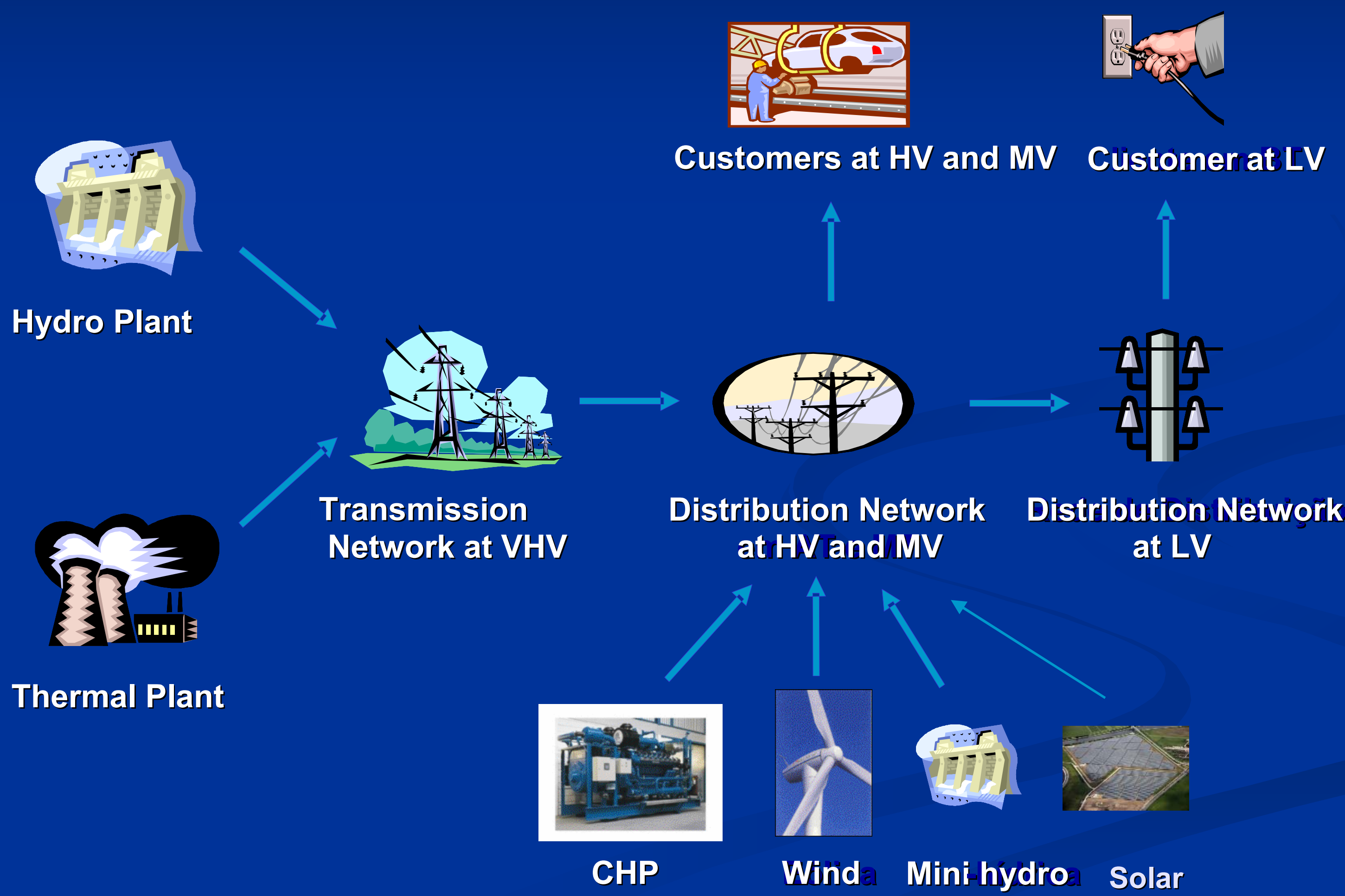
Prof. Emeritus IST

GROWTH IN PRIMARY ENERGY AND ELECTRITY DEMAND, 2007-30

[Source: IEA, World Energy Outlook 2011]



ELECTRIC POWER SYSTEM



SECURITY OF SUPPLY

Essential factors:

- Diversification of the generation mix
- Quality of the electric network
- Interconnection transmission capacity
- Adequate installed capacity
- System operation
- Regulation

GENERATION PORTFOLIO

- Natural gas
- Coal
- Nuclear
- Hydro
- Wind
- Solar
- Biomass
- Efficiency (Negawatts)

COMPARISON OF DIFFERENT GENERATION TECHNOLOGIES

Technology	Power (MW)	Construction time (years)	Useful life (years)	Investment cost	Fuel cost	Operation cost	CO_2 Emissions (kg/kWh)	Annual utilisation (h)
Natural Gas	Medium (400)	Short (2-3)	25	Low	High	Medium	Medium (0,35)	7.000
Coal	High (750)	Long (6 - 8)	40	Medium - High	Medium	Medium	High (0,9-1,2)	7.000
Nuclear	Very high (1.500)	Long (10 – 15)	40	Very High	Low	Low	~ 0	8.000
Hydro	Variable	Medium – Long (5-15)	> 60	High	----	Vert low	~ 0	2.500-4.000
Wind	Low (< 5)	Short (< 3)	20	High	----	Very low	~ 0	2.200

NATURAL GAS

- Normalized design, short construction time.
- Low investment cost.
- Fuel cost is 75-80% of final kWh cost.
- CO_2 emissions are less than 50% of coal.
- No SO_2 and very little NOx emissions.
- Reference for the wholesale market.

COMBINED CYCLE GAS POWER STATION
Termoeléctrica do Ribatejo 3×400 MW

COAL

- Coal power stations produce 44% of the 33 bn tons of CO_2 annually emitted worldwide.
- CO_2 can be captured and stored in saline aquifers, spent oil and gas wells and abandoned coal mines.
- This reduces substantially efficiency of energy conversion (at least 10%).
- Investment cost increases about 30%.
- Technology not in commercial operation.
- Four demonstration projects in operation in the USA and Europe (IGCC technology) – which emit CO_2 to the atmosphere.

COAL POWER STATION
Pego 2×320 MW

COAL POWER STATION

Central Tejo 64 MW, Lisboa, 1909-1972

Fotografia de 1930

Créditos Fotográficos: Museu da Electricidade

CENTRAL TEJO
Electricity Museum

NUCLEAR

- Very high rated capacity (1000-1600 MW).
- No CO_2 during operation.
- Operational security is not a problem in normal conditions.
- Residues storage has not a definitive solution – temporary storage is currently used.
- 442 reactors in commercial operation worldwide
- 25 reactors under construction in 25 countries (especially in Asia).
- Energy cost competitive with natural gas
- High ddecommissioning cost.

NUCLEAR POWER STATION
Cattenom (France) 4×1300 MW

HYDRO

- Great value for system operation.
- No CO_2 emissions.
- High investment cost.
- Water reserve is a value in itself.
- Hydro potential far from being over.
- Environmental objections to be assessed on a point-by-point basis.

HYDRO POWER STATION
Alto Lindoso 2×315 MW

HYDRO POWER STATION
Alqueva 2×130 MW

WIND

- Currently exhibits the highest growth rate.
- kWh price close to market price.
- Strong point: environmentally friendly.
- Weak point: volatility.
- Requires compensation of volatility (storage) and expansion of the network: 10-25% cost increase.

WIND GENERATOR 2 MW

CANDEEIROS WIND PARK

37×3 MW = 111 MW

SOLAR PHOTOVOLTAIC

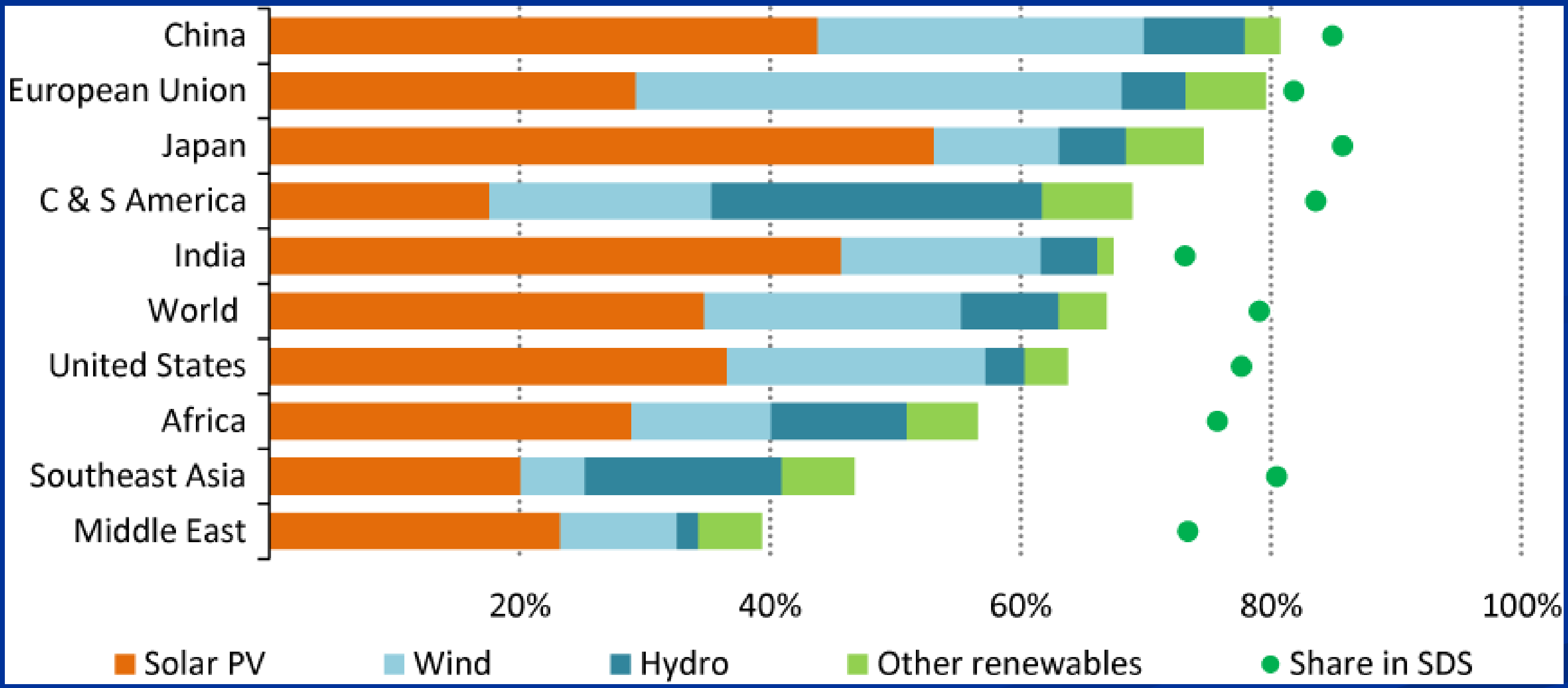
- Virtually inexhaustible.
- Investment cost has been decreasing swiftly.
- High growth rate, accompanying the reduction of cost of photovoltaic cells.
- Yearly utilization of rated capacity lower than wind (1500 vs. 2200 hours).
- Competitive in dispersed low power production.
- Centralized power still coming of age.

AMARELEJA SOLAR POWER STATION 46 MW

DESERT SUNLIGHT
SOLAR FARM (USA) 550 MW

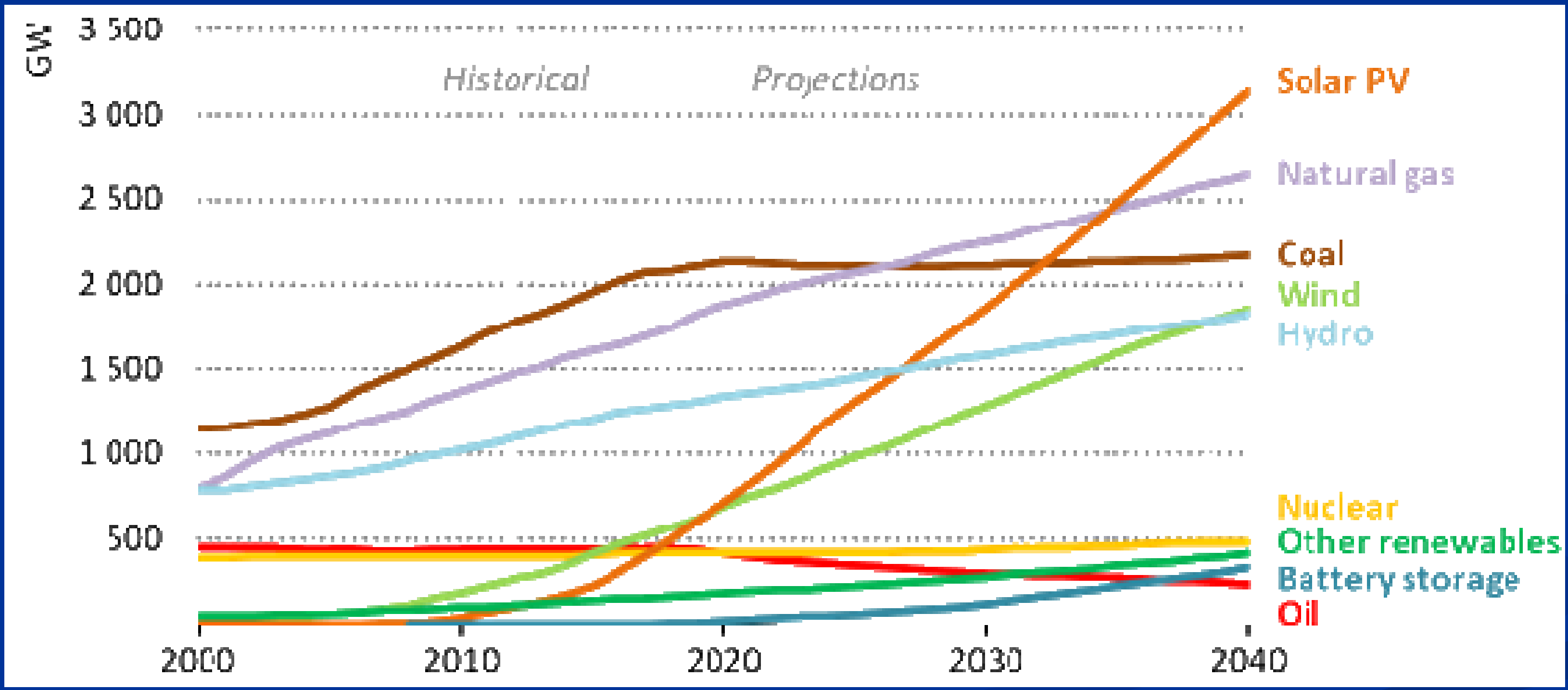
SHARE OF RENEWABLES IN TOTAL CAPACITY ADDITIONS BY REGION AND SCENARIO, 2019-2040

[Source: IEA World Energy Outlook 2019]



GLOBAL POWER CAPACITY BY SOURCE IN THE STATED POLICIES SCENARIO

[Source: IEA World Energy Outlook 2019]



ENERGY EFFICIENCY (NEGAWATTS)

- It is a consensual strategy – nobody assumes being against improvement of energy efficiency.
- "*Deep greens*" argue that this is the only solution to the energy problem; no even renewables escape their criticism,
- Unless the comfort of the families and competitiveness of the economy fall, the best we can manage is the reduction of the rate of increase.
- Improvement of energy efficiency requires investment, potentially less than those required by new means of production.
- Measures for promotion of energy efficiency:
  - Use of more efficient equipment
  - Energy certification of buildings
  - Alteration of transport patterns, e.g. electric vehicle
  - Carbon taxes

ELECTRIC POWER GRID

- The electric power network is the most complex machine ever designed by scientists and engineers
- It has allowed, for many years, to acquire energy on-line.

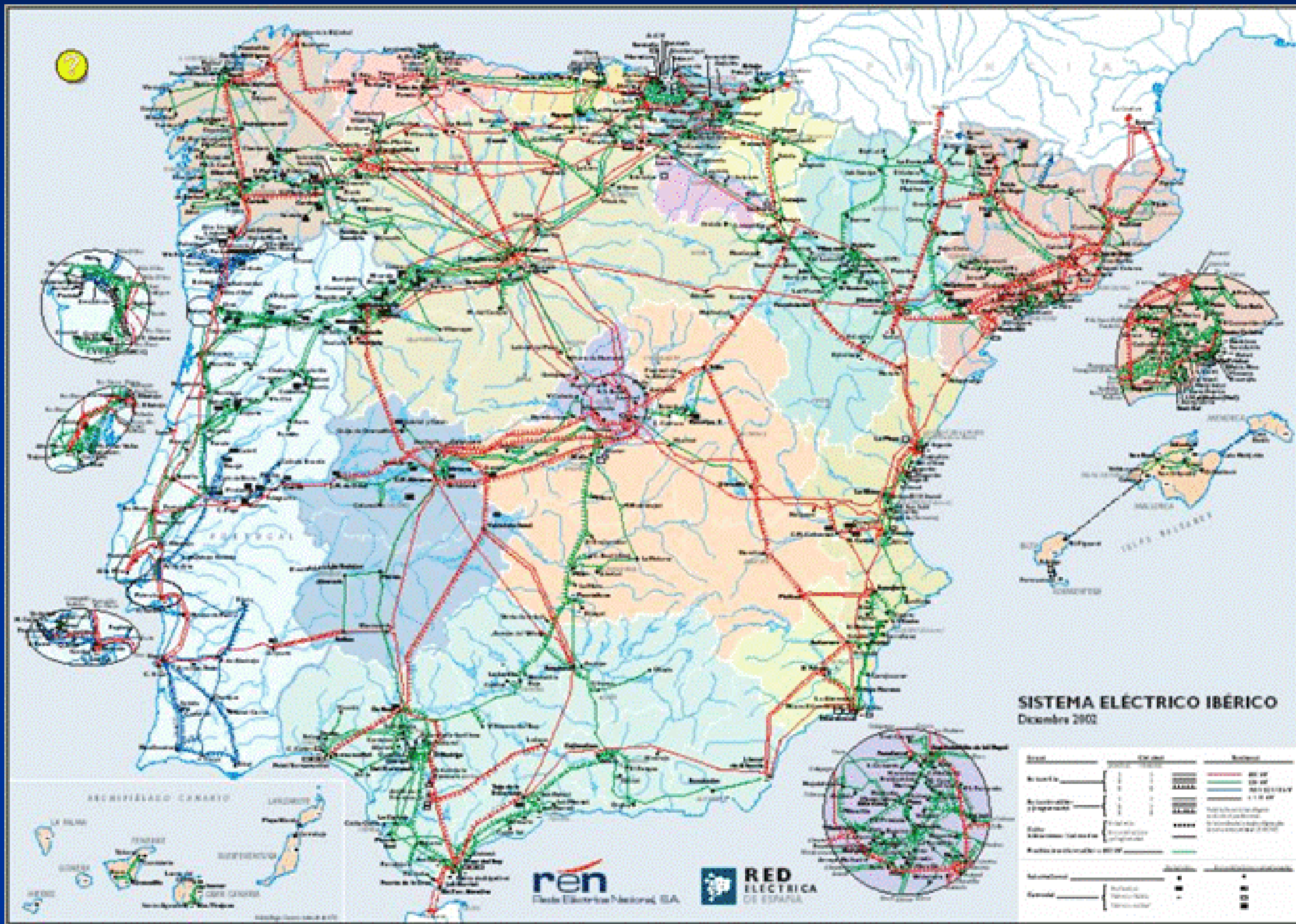
VERMOIM SUBSTATION 220/150/60 kV
360 + 700 MVA = 1090 MVA

PHASE SHIFT AUTOTRANSFORMER
400 kV/150 kV – 450 MVA

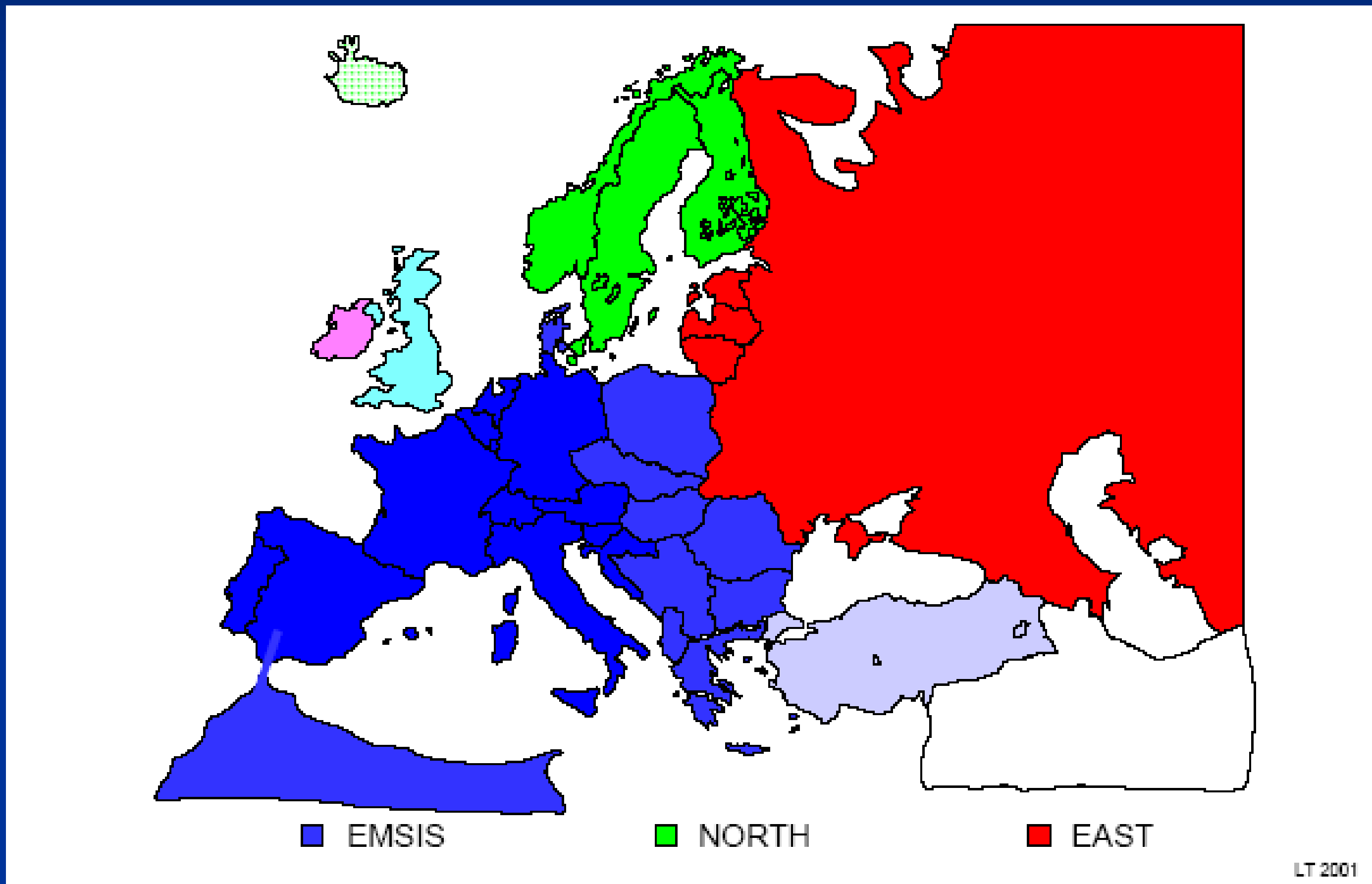
ELECTRIC POWER LINE 400 kV

ELECTRIC POWER LINE 220 kV

IBERIAN ELECTRIC NETWORK

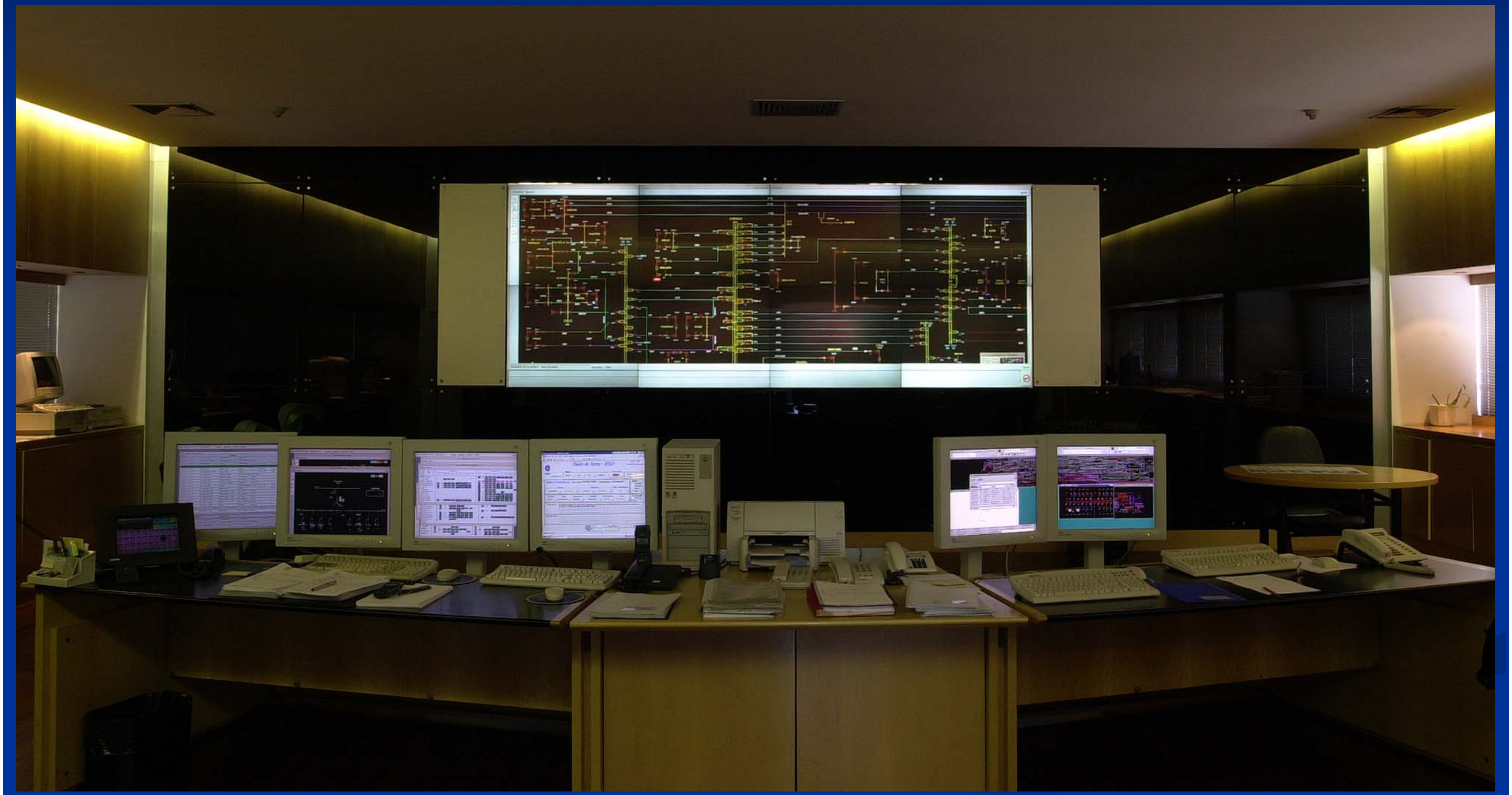


INTERCONNECTED EUROPEAN NETWORKS



PORTUGUESE TRANSMISSION NETWORK CONTROL AND OPERATION CENTER

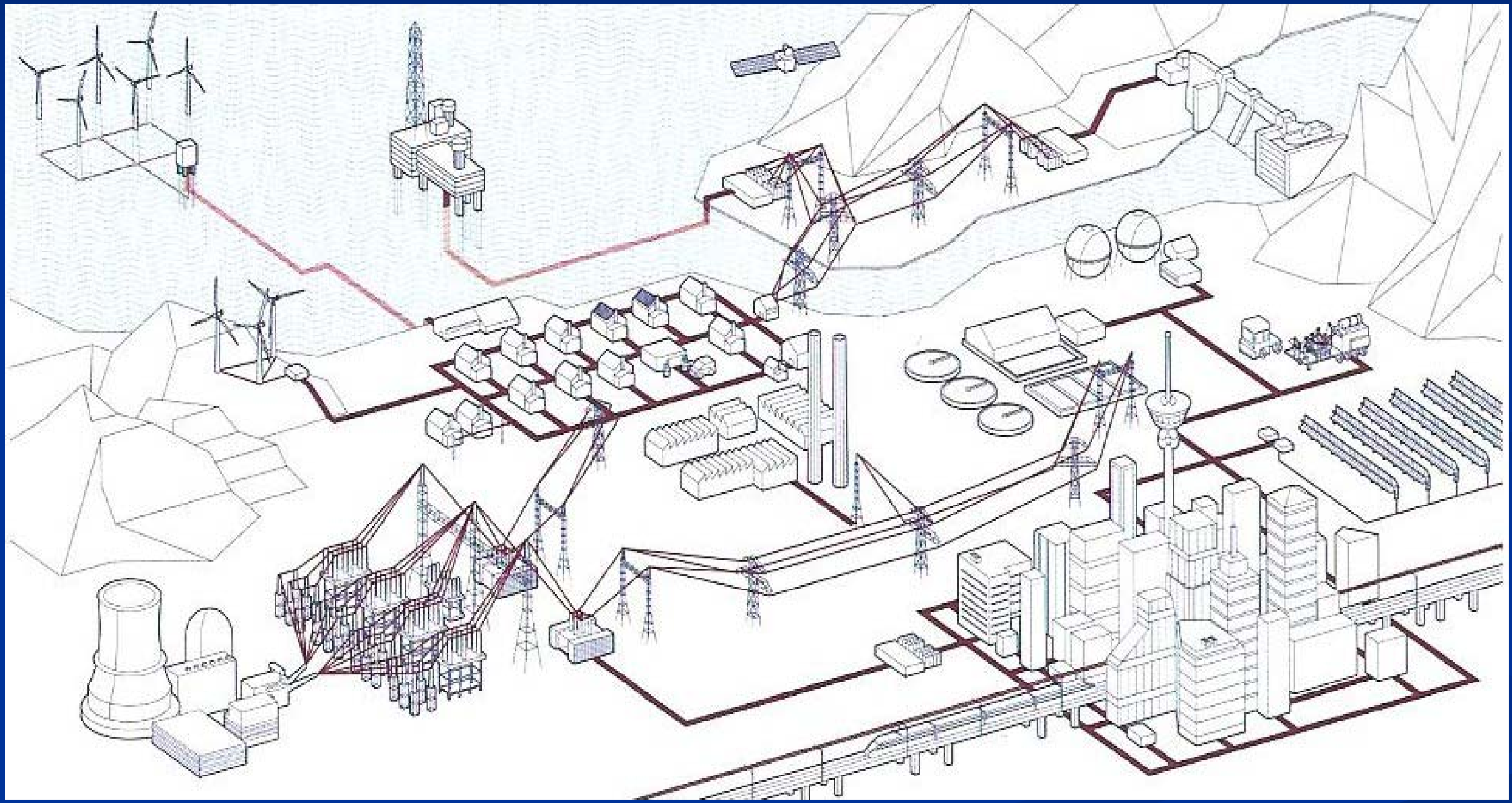
DISTRIBUTION NETWORK CONTROL AND OPERATION CENTER



SMART GRID

- Use of digital intelligence and communications to improve the operation of the transmission and distribution networks.
- Installation of advanced metering to replace the old electromechanical meter.
- Deployment of appropriate technologies, devices and services, to access and use energy usage information, connect to electric vehicles and integrate decentralized renewable generation.
- Provision of the ability to collect and store information to effectively address climate change issues.

SMART ELECTRIC GRID



CONCLUSIONS

[Source: IEA World Energy Outlook 2019]

- Solar, wind, storage & digital technologies are transforming the electricity sector, but an inclusive and deep transition also means tackling legacy issues from existing infrastructure

- All have a part to play, but governments must take the lead in writing the next chapter in energy history and steering us onto a more secure and sustainable course