Federal University of Rio de Janeiro

Plug-in Hybrid Electric Vehicles as a Way to Maximize the Integration of Variable Renewable Energy in Power Systems: The Case of Wind Generation in Northestearn Brazil

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Energy Planning Program
COPPE / UFRJ

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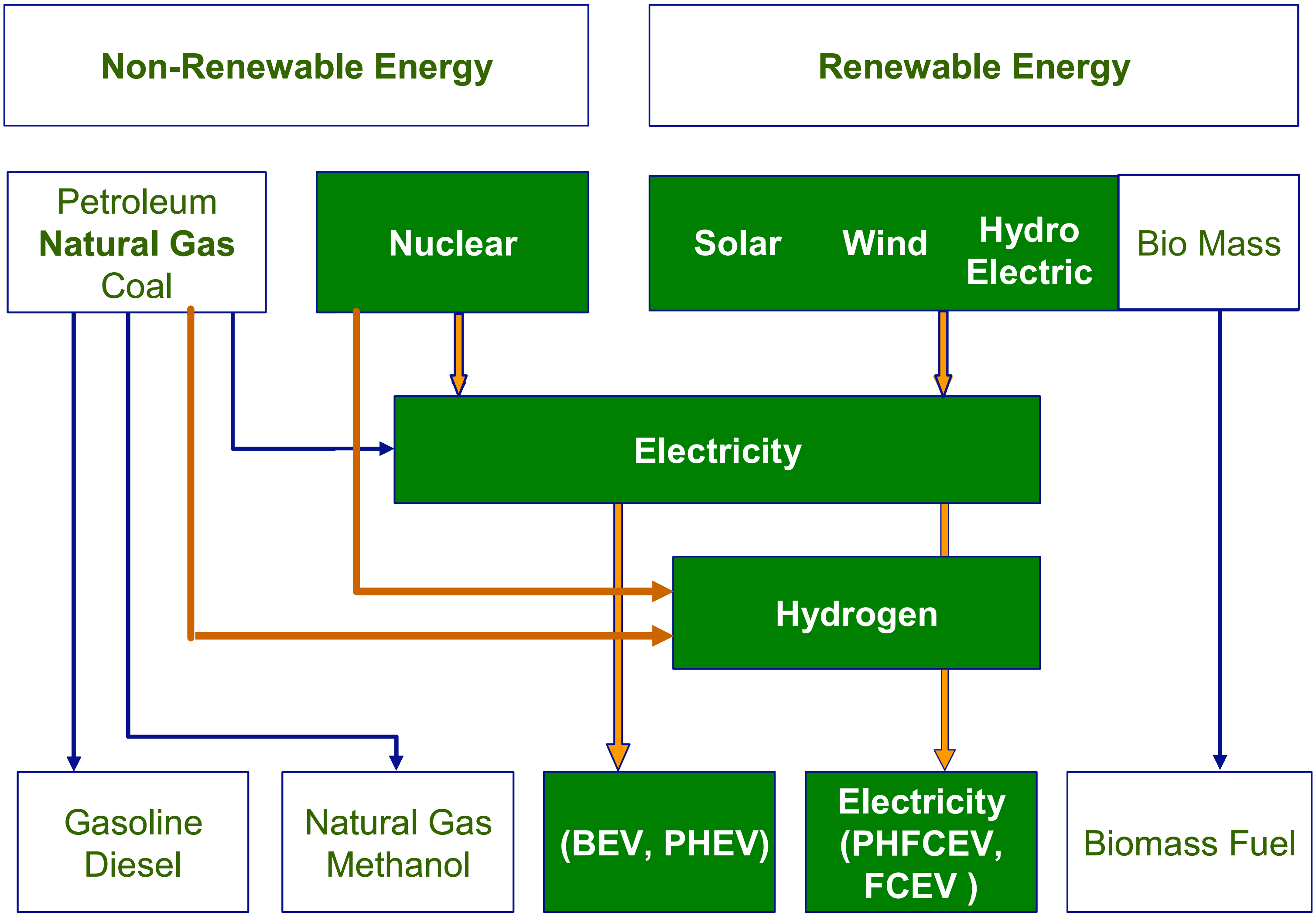
Energy alternatives for the sector



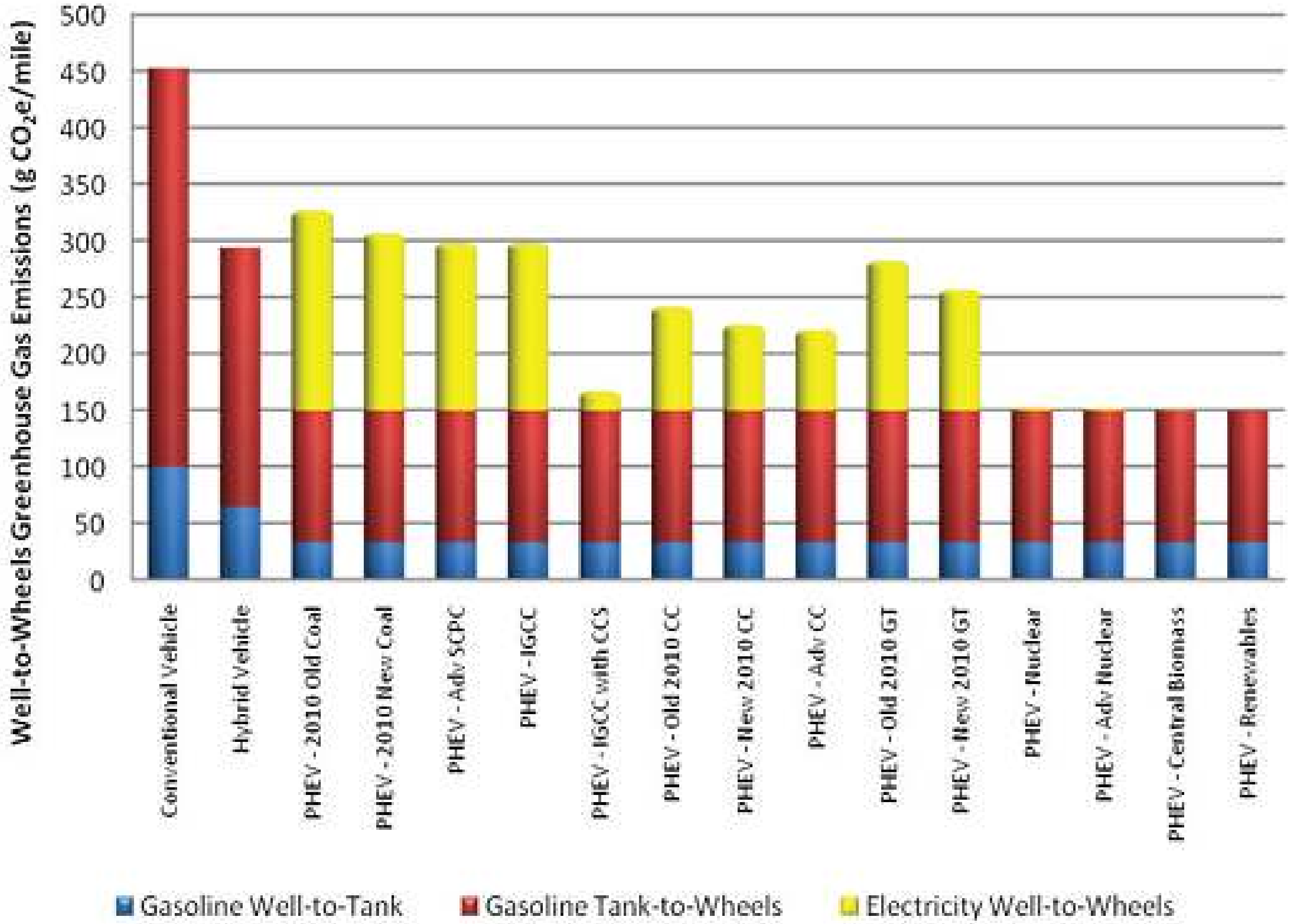
Source: EPRI, 2008

Why Electric Vehicles?

- Way to both reduce atmospheric emissions (primarily CO_2) and increase supply security of the transportation sector.
- Other benefits:
  - ✓ Quiet operation
  - ✓ Absence or low tailpipe emissions
  - ✓ Higher tank to wheel efficiency
- Smart charging:
  - ✓ Decrease the cycling of the power plants (or avoid additional generator start-ups, which would otherwise decrease the overall efficiency)
  - ✓ Increase the capacity factor of the base load plants

Associated Emissions

Life-cycle emissions



Year 2010 comparison of PHEV 20 GHG emissions when charged entirely with electricity from specific power plant technologies (12,000 miles driven per year).

Source: EPRI, 2009

Recharging modes

Method	Voltage (V)	Current (A)	Power (kW)
Level 1	127 CA	12 - 16	1,5 - 2,0
Level 2 (low)	220 CA	12 - 16	2,5 - 3,5
Level 2 (high)	220 CA	< 80	< 18
Level 3 (AC)	< 600 3ϕ		15 - 96
Level 3 (CC)	600 CC		< 240

- **Level 1 – Standard residential power system**
- **Level 2 – Some changes may be necessary**
- **Level 3 – Under study. High power involved beyond the capacity of current distribution transformers for residential areas and even for some comercial areas**

Recharging Time

Vehicle	Autonomy (km)	Energy (kWh)	Hours		
			Level 1	Level 2	Level 3
			1,9 kW	7,7 kW	150 kW
PHEV	10	1,11	0,58	0,14	0,01
PHEV	20	2,22	1,17	0,29	0,01
PHEV	50	5,56	2,92	0,72	0,04
EV	100	16,67	8,77	2,16	0,11
EV	200	33,33	17,54	4,33	0,22
EV	300	50,00	26,32	6,49	0,33
EV	400	66,67	35,09	8,66	0,44
EV	500	83,33	43,86	10,82	0,56

Impact on the Brazilian Power System

In terms of Energy

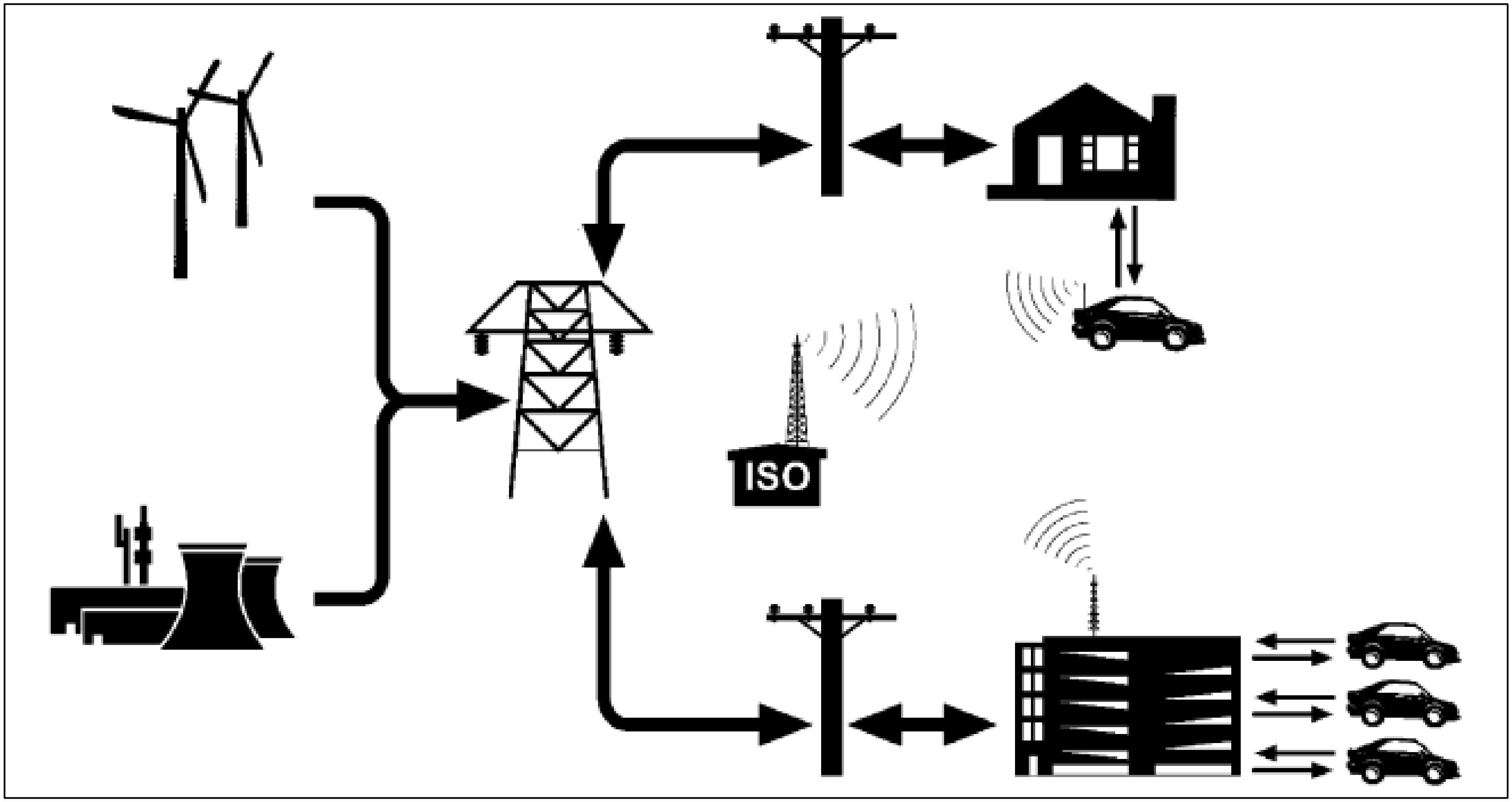
% BEV of the actual fleet*	BEV Fleet	Distance per year (km)	Performance (km/kWh)	Energy (GWh)	% Consumption Brasil 2009**
10	2.548.000	15.000	6,0	6.370	**1,6%**
20	5.096.000	15.000	6,0	12.740	**3,2%**
50	12.740.000	15.000	6,0	31.850	**8,0%**
70	17.836.000	15.000	6,0	44.590	**11,1%**
100	25.480.000	15.000	6,0	63.700	**15,9%**

*** Considering a fleet of 25 million LDVs (ANFAVEA, 2009)**

**** Assuming a annual electricity consumption of 400 TWh (EPE, 2010)**

- **From na energy point of view, the impact would be acceptable**

Scheme

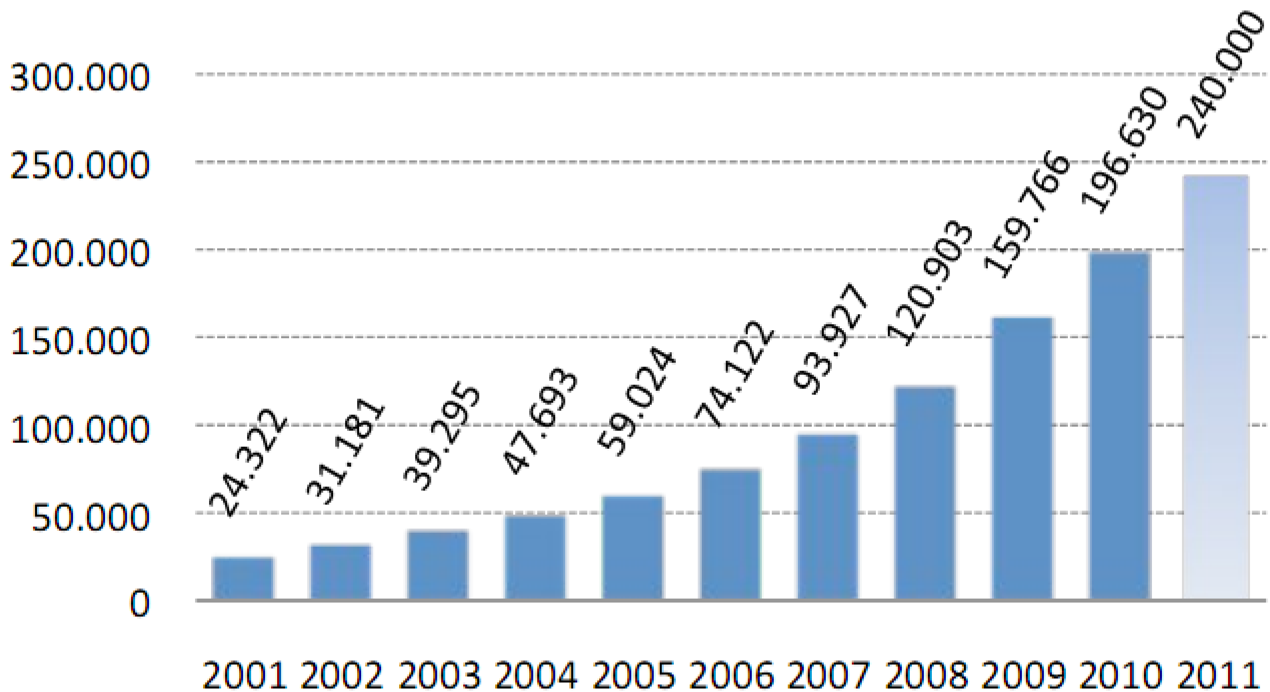


Source: TOMIC e KEMPTON, 2007

Why Wind Power?

➢ **Over the past decade wind power generation has expanded greatly in a number of countries, due to its renewability, declining costs and absence of local and global pollution**

➢ **Total installed wind power capacity in the world jumped eight-fold between 2001 and 2010, from 24 GW to 196 GW**



Source: WWEA, 2011

Wind Power Impacts

- **Wind turbines apply systems often based on power electronics**
- **The primary energy (wind) is not controllable and fluctuates stochastically**
- **The typical size of wind turbines is much lower than that of a conventional power plant**

Impacts of wind power penetration on power systems:

1.Local impacts of wind power occur near the turbines and/or wind farms: voltage control, fault current, harmonic distortion and flicker. These effects are influenced by the applied wind turbine type

2.System wide impacts on power system include the imbalance between load and generation, reactive power generation, and the reduced frequency control. These problems are strongly related to the penetration level in the system as a whole

How to Integrate Wind Power?

P. Denholm, M. Hand / Energy Policy 39 (2011) 1817–1830

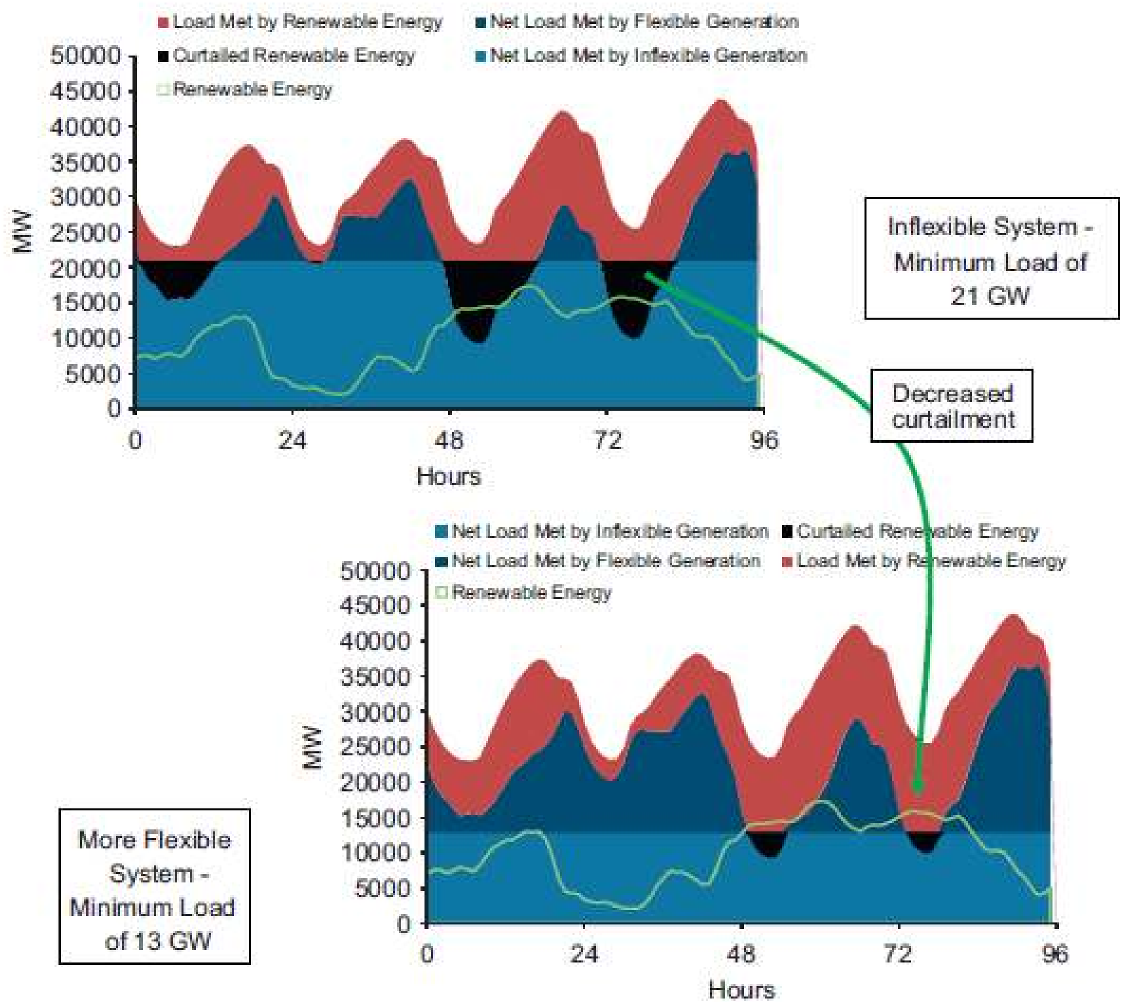


Fig. 3. Impact of system flexibility on curtailed energy.

Wind Power Penetration

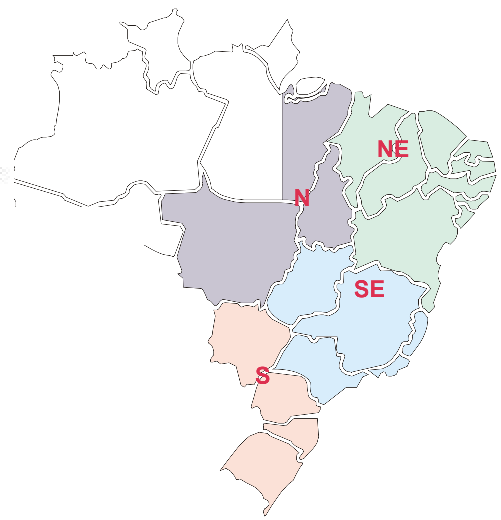
- The variability of wind power can affect the balance between ele … city su … ble sy

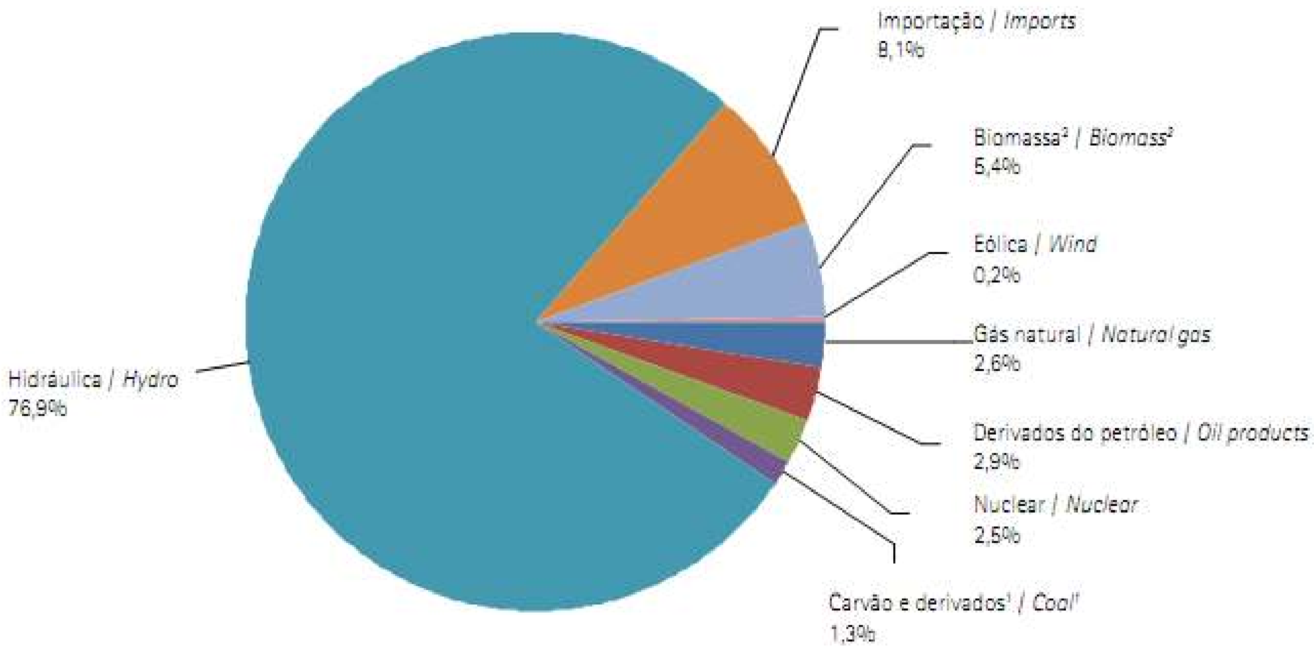
Let us test the use of a PHEV fleet of taxis in northeastern Brazil as a way to stimulate the electrification of vehicles and postpone the costs of smart grids. The battery charging time of these vehicles could be easily controlled using, for instance, a fleet management

- V … 030 MV … 13, ma

- I … is ex … the planned construction of nuclear and run-of-the-river hydroelectric power plants

Brazil's Electric Power System





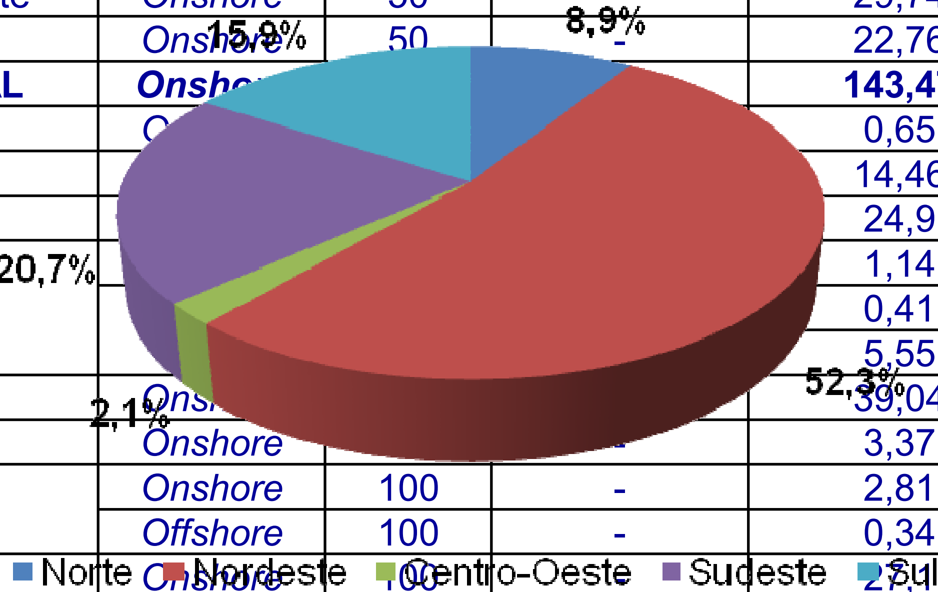
Notas/ Notes:

1 Inclui gás de coqueria / Includes coke gas.

² Biomassa inclui lenha, bagaço de cana, lixívia e outras recuperações / Biomass includes firewood, sugar cane bagasse, black liquor e other wastes.

Wind Power Potential

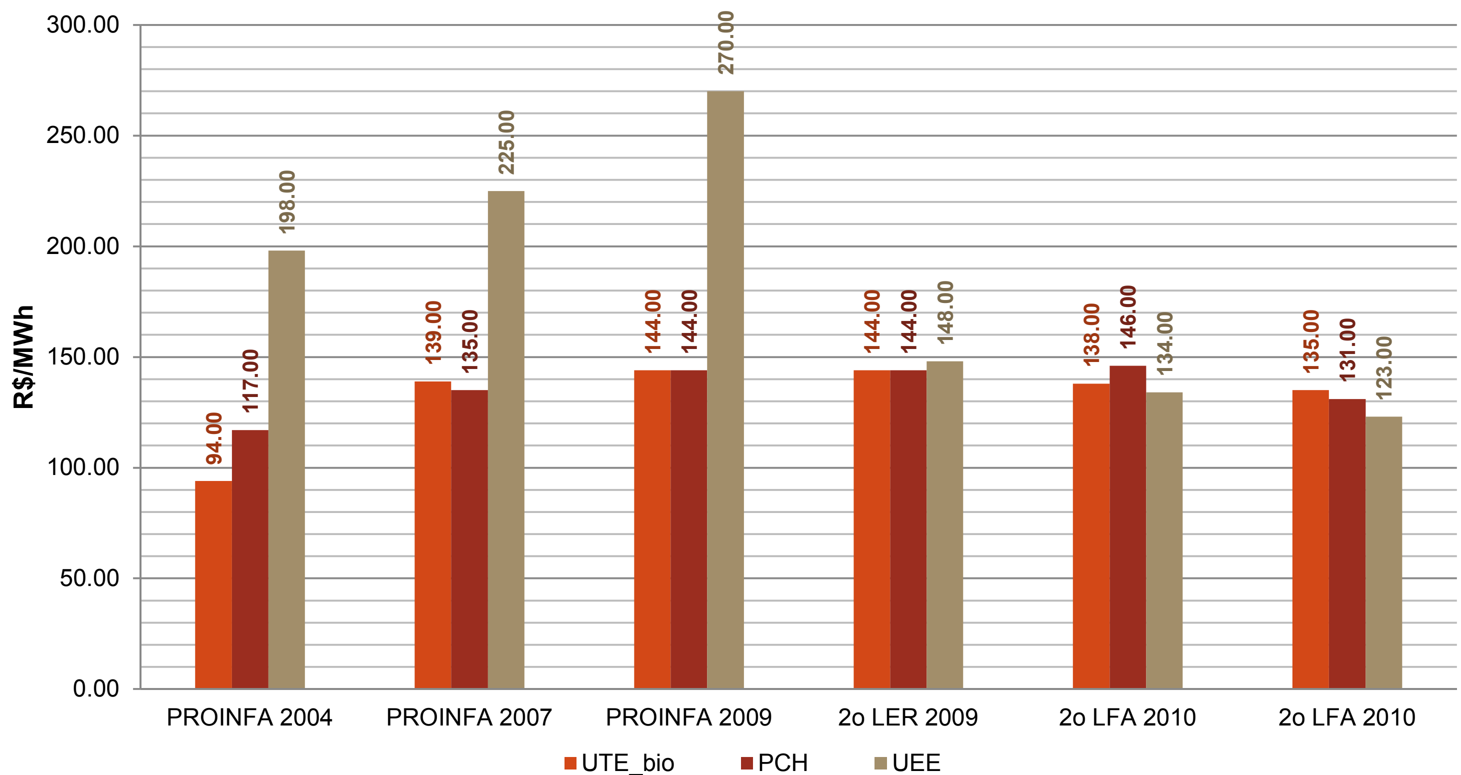
Região		Onshore/ offshore	Altura (m)	Profundidade (m)	Potência instalável (GW)	Fator de capacidade (%)
Brasil (Atlas do Potencial Eólico Brasileiro)	Norte	*Onshore*	50	-	12,84	20,0 – 30,0%
	Nordeste	*Onshore*	50	-	75,05	20,0 – 30,0%
	Centro-Oeste	*Onshore*	50	-	3,08	20,0 – 30,0%
	Sudeste	*Onshore*	50	-	29,74	20,0 – 30,0%
	Sul	*Onshore*	50	-	22,76	20,0 – 30,0%
	TOTAL	[illegible]	[illegible]	[illegible]	**143,47**	**20,0 – 30,0%**
Alagoas		[illegible]	[illegible]	[illegible]	0,65	21,7 – 30,3%
Bahia		[illegible]	[illegible]	[illegible]	14,46	25,0 – 32,0%
Ceará		[illegible]	[illegible]	[illegible]	24,9	22,0 – 32,0%
Espírito Santo		[illegible]	[illegible]	[illegible]	1,14	23,0 – 30,0%
		[illegible]	[illegible]	[illegible]	0,41	24,8 – 31,5%
		[illegible]	[illegible]	[illegible]	5,55	24,6 – 31,9%
Minas Gerais		[illegible]	[illegible]	[illegible]	39,04	24,6 – 31,8%
Paraná		*Onshore*	[illegible]	-	3,37	31,0 – 37,7%.
Rio de Janeiro		*Onshore*	100	-	2,81	34,6 – 40,2%
		Offshore	100	-	0,34	32,1 – 39,9%
Rio Grande do Norte		*Onshore*	100	-	27,1	32,0 – 41,5%
Rio Grande do Sul		*Onshore*	100	-	115,2	24,0 – 33,0%
		Offshore	100	0 - 10	19,74	24,0 – 33,0%
Sul e Sudeste *offshore (cálculo para o aerogerador GE 3.6s)*		*Offshore*	80	0 - 20	27	>40%
		Offshore	80	20 - 50	75	>40%
		Offshore	80	50 - 100	114	>40%
		TOTAL	80	0 - 100	216	>40%



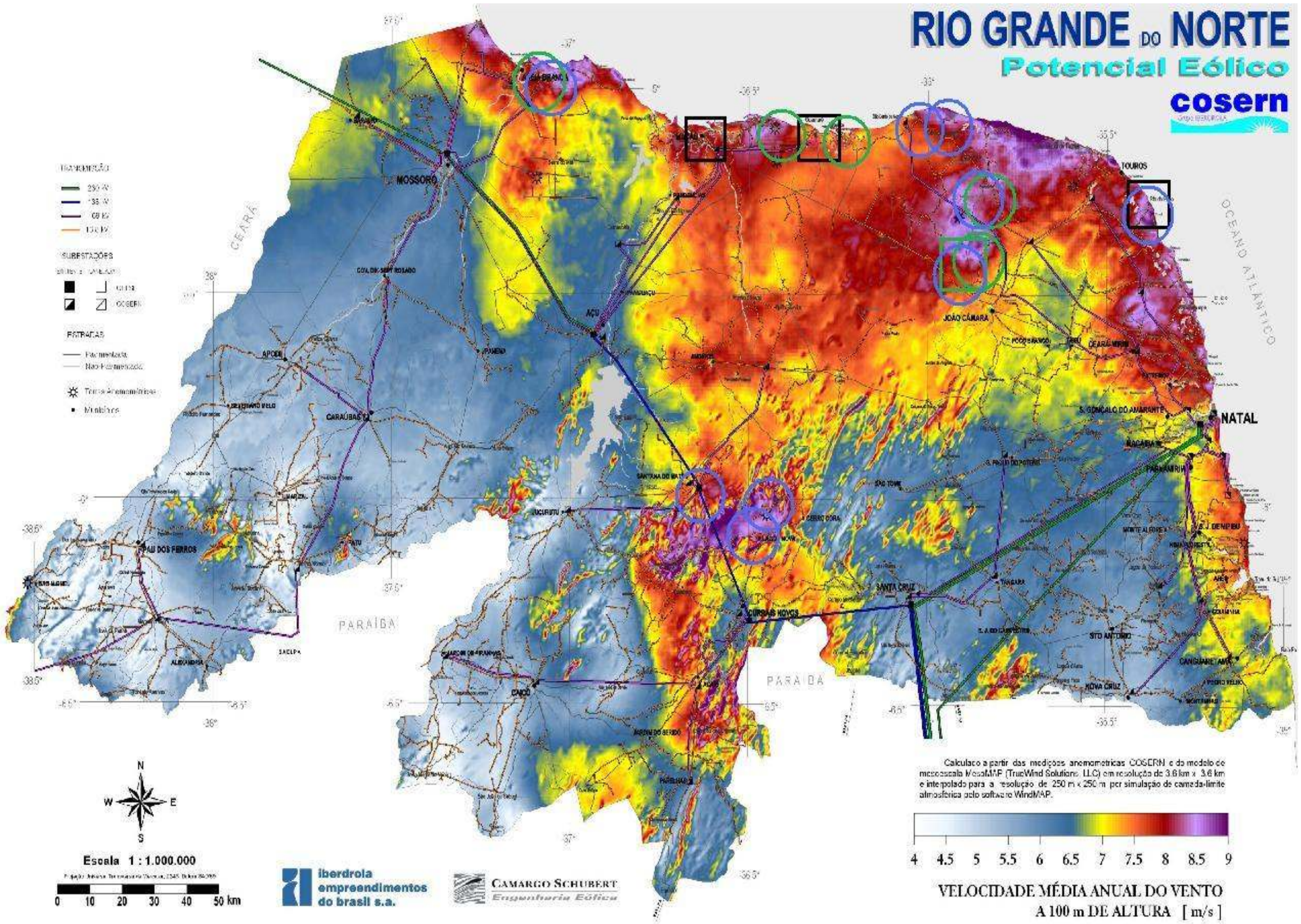
Schaeffer et al., 2011

Wind Power Auction

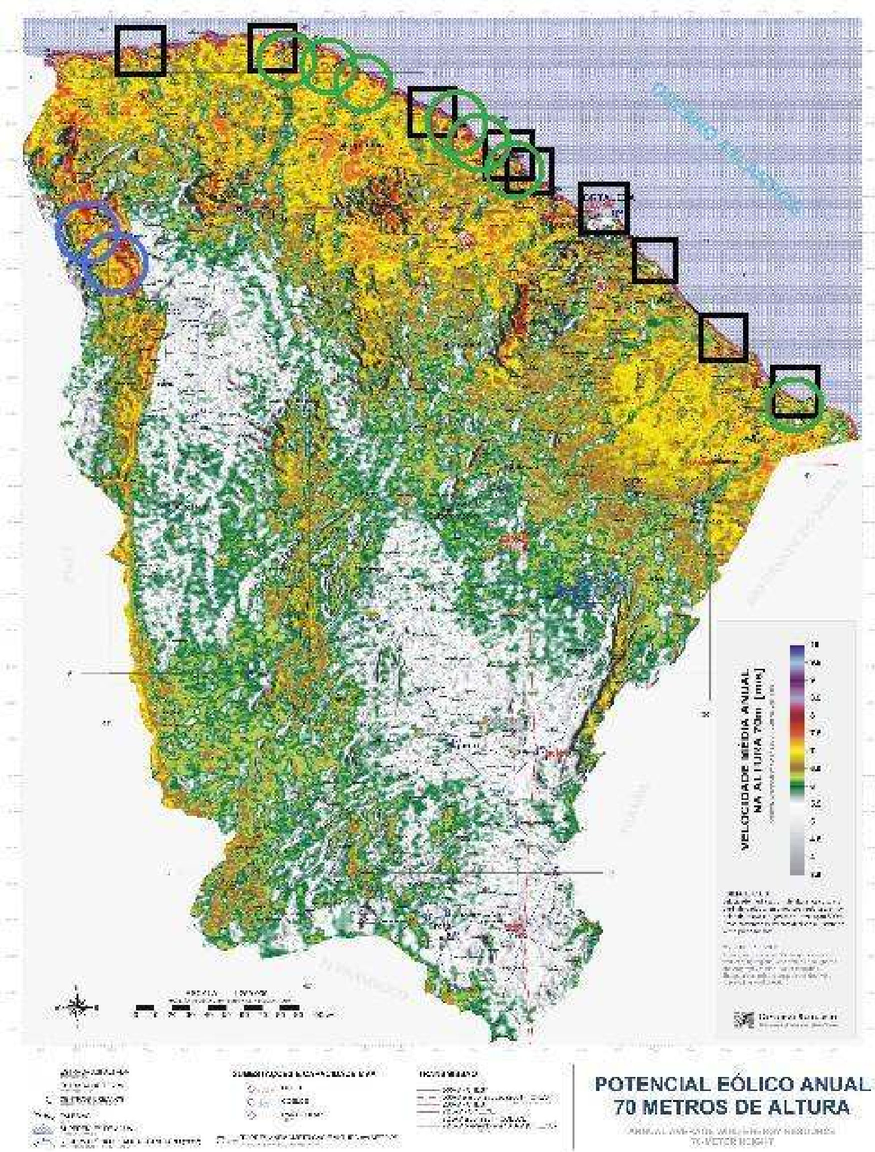
- Installed Capacity in 2011: 926.9 MW
- Installed Capacity in 2013: 3,800 MW
- Decreasing bidding prices
- Over 50% of the new capacity contracted (1,721.6 MW) will be located in Rio Grande do Norte state



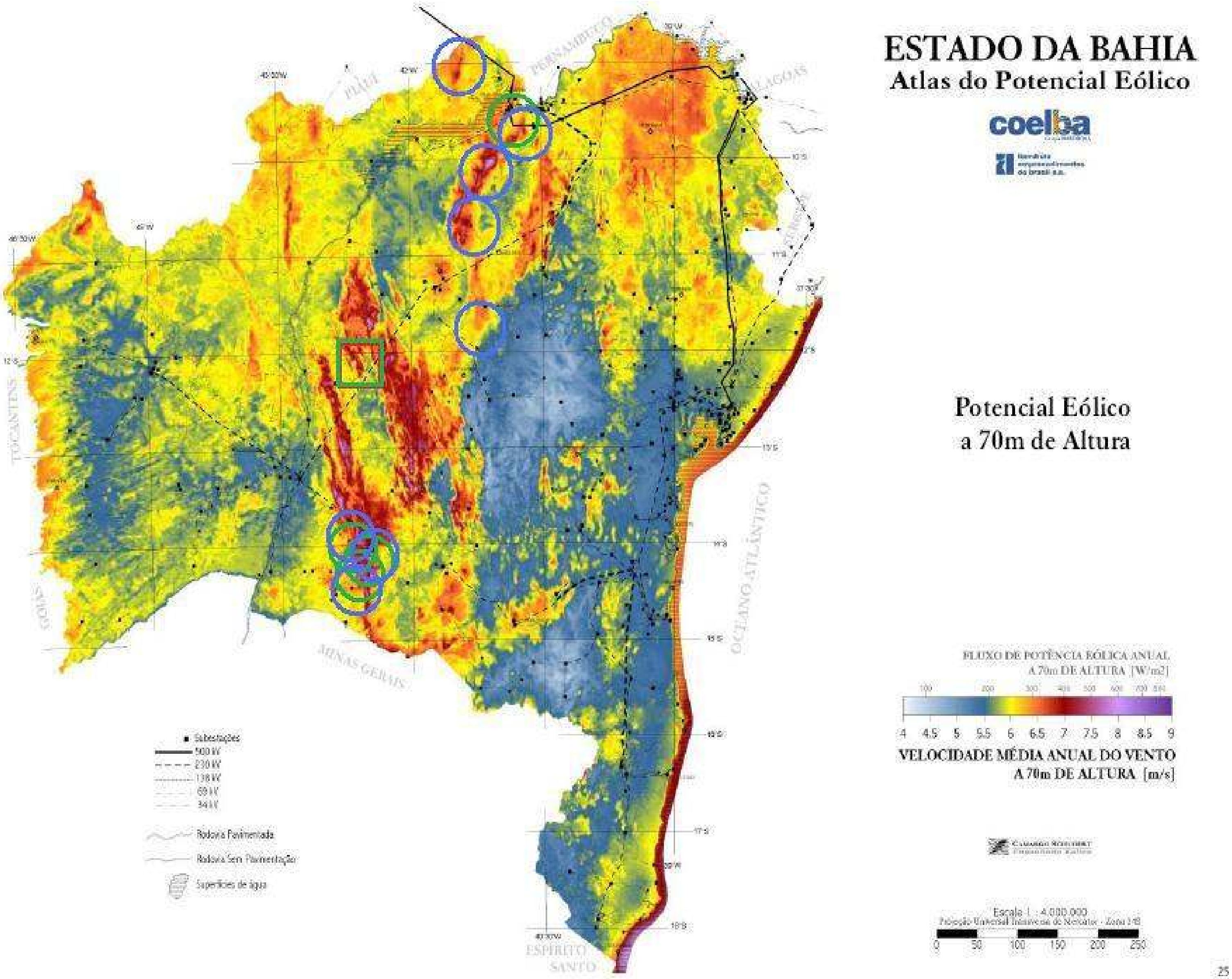
Wind Power Potential



Wind Power Potential



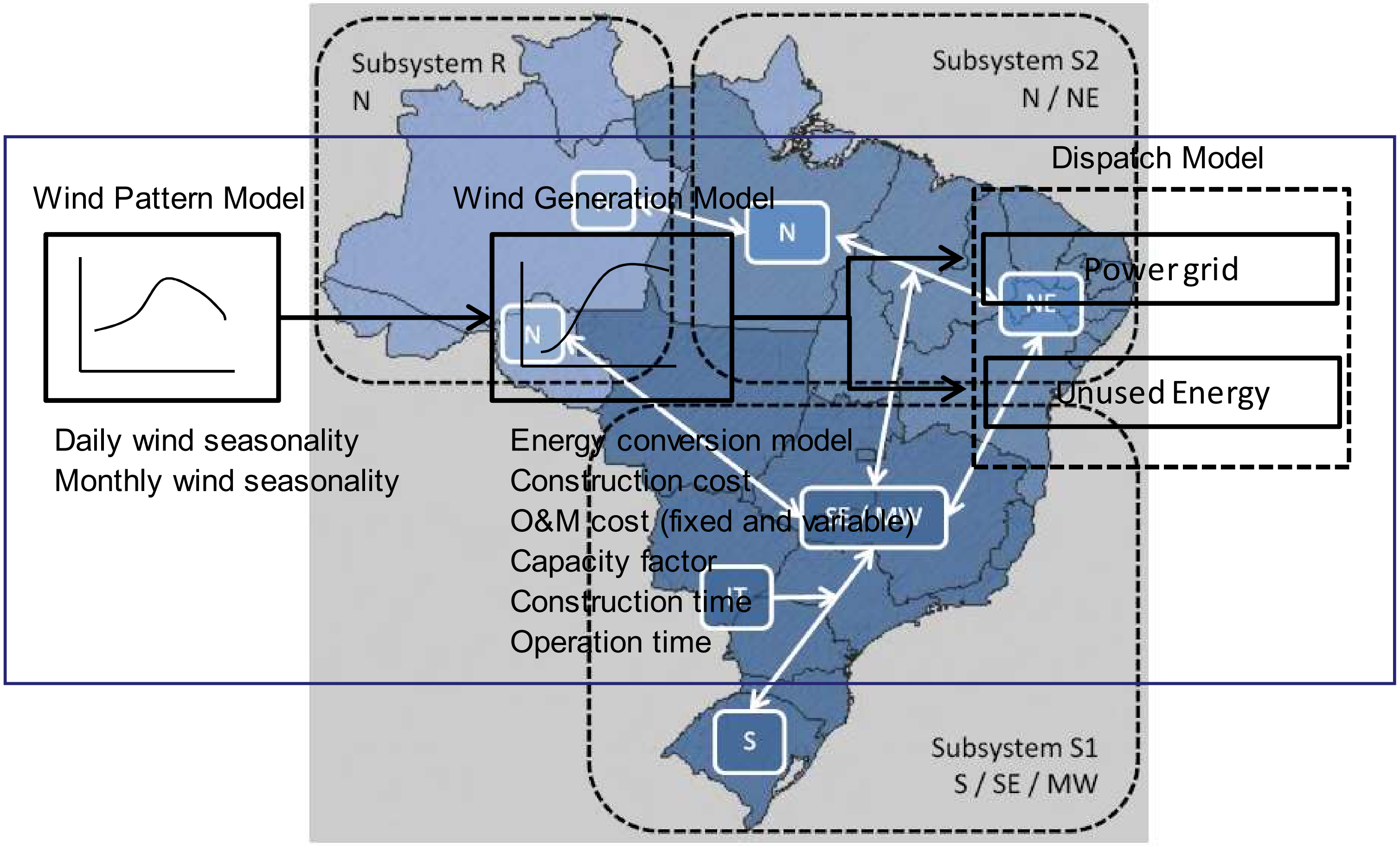
Wind Power Potential



Brazil's Electric Power System

1. Wind power penetration in Brazil up to 2019:
   - ✓ 544 MW/yr (PDE / EPE)
2. Run-of-the-river hydroelectric power plant expansion in the Northeast and North regions:
   - ✓ Belo Monte, Santo Antônio and Jirau projects
3. Plans to build nuclear plants in NE (initial study phase):
   - ✓ Government plans envision the construction of two nuclear plants in NE with approximately 1,000 MW each, and there is also the possibility of four more nuclear plants of the same capacity before 2030
4. Tendency for less operational flexibility in the Northeast power system
   - ✓ According to EPE, the expansion of storage capacity at hydroelectric plants over the horizon to 2019 will be 11%, against an increase in installed capacity of 61%

Integrating PHEVs with Large-Scale Wind Farms in Northeast Brazil



Notes: N – North, S – South, SE – Southeast, NE – Northeast, MW – Midwest, IT – Itaipu Hydroelectric Station.

Characteristics of power generation in MESSAGE

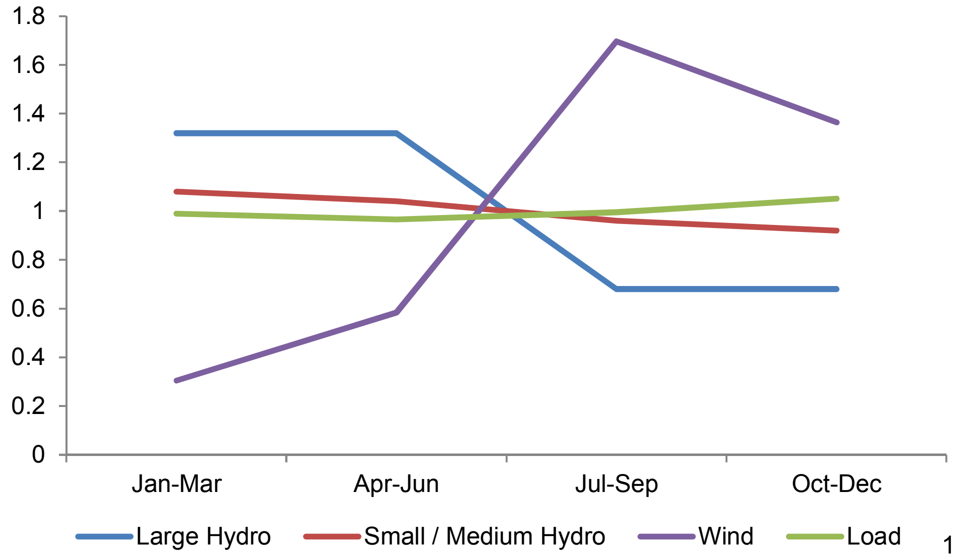
	Investment cost US$/kW	Variable O&M cost US$/MWh	Fixed O&M cost US$/kW	Capacity factor
Large hydroelectric (>300MW)	2,091	-	64.58	*
Medium hydroelectric (>30MW<300MW)	2,513	-	58.43	*
Small hydroelectric (<30MW)	2,936	-	52.28	*
Open-cycle natural gas	450	0.41	-	0.90
Combined-cycle natural Gas	850	0.41	12.65	0.85
Coal	2,530	3.57	24.30	0.70
Nuclear	4,000	0.42	56.44	0.85
Backpressure 22 Bar bagasse	2,885	10.62	-	0.90
CEST bagasse	2,712	10.22	-	0.90
BIG-GT bagasse	3,995	21.53	-	0.80
Wind	1,810	-	41.62	0.35
RSU	7,050	-	211.50	0.74
Diesel	1,000	7.99	-	0.95
Fuel oil	1,070	10.84	-	0.85

*** The capacity factors for hydroelectric generation are shown in next slide**

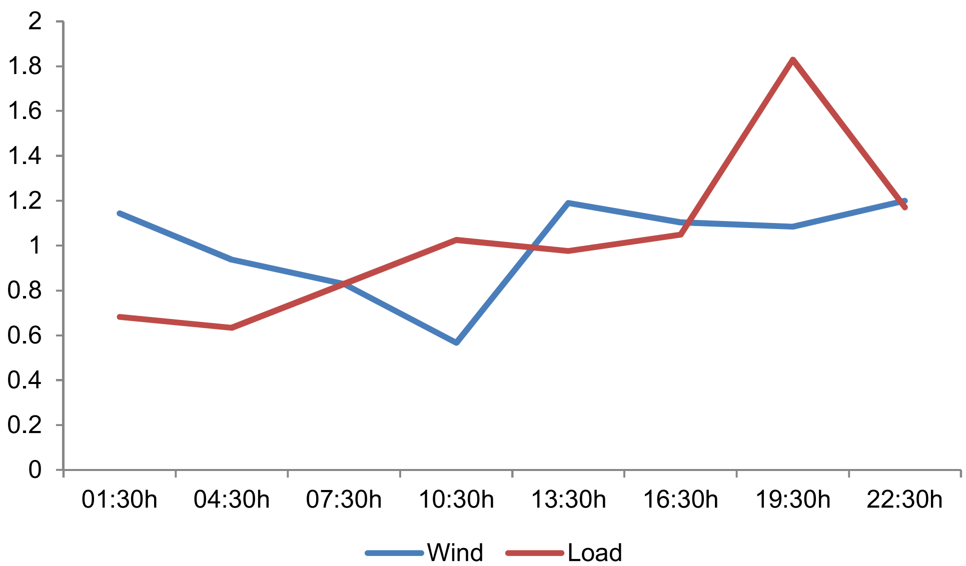
Exchange	MW	Operation Date
S1 → S2	5,000	Present
S1 → R	500	Present
S2 → S1	5,300	Present
S2 → R	1,500	2015
R → S1	5,600	2015
R → S2	6,000	2015

Seasonality in Subsystem S2

Monthly seasonality – Hydro and wind power



Hourly seasonality – Wind power and Load



Case Study

Results

Projected installed capacity in subsystem S2 (MW)

	2010	2015	2020	2025	2030
Backpressure 22 bar bagasse	398	398	398	398	398
BIG-GT bagasse	0	0	0	0	2,604
Combined-cycle natural gas	1,137	1,137	1,137	1,137	1,137
Open-cycle natural gas	10,762	12,182	12,182	12,182	13,108
Large hydroelectric	18,513	18,513	18,513	18,513	18,513
Medium hydroelectric	1,046	3,535	3,535	5,535	7,535
Small hydroelectric	89	131	180	180	180
Diesel oil	853	853	853	853	853
Nuclear	0	0	2,000	4,000	6,000
Wind	671	4,093	6,000	8,500	11,000
Total	**33,469**	**40,842**	**44,798**	**51,298**	**61,328**

roughly 18% of total installed capacity in the subsystem

Results

Projected wind energy surplus in subsystem S2

Quarter	GWh/period	2015	2020	2025	2030
Jan/Feb/Mar	1 - 6h	269	462	654	846
	6 - 10h	0	0	0	0
	10 - 18h	0	0	0	0
	18 - 21h	0	0	0	0
	21 - 24h	0	0	0	0
April/May/Jun	1 - 6h	425	344	707	1,352
	6 - 10h	0	0	0	0
	10 - 18h	0	0	0	0
	18 - 21h	0	0	0	0
	21 - 24h	0	0	0	0
Jul/Aug/Sept	1 - 6h	0	0	0	0
	6 - 10h	0	0	0	0
	10 - 18h	0	0	0	0
	18 - 21h	0	0	0	0
	21 - 24h	0	0	0	0
Oct/Nov/Dec	1 - 6h	0	0	0	0
	6 - 10h	0	0	0	0
	10 - 18h	0	0	0	0
	18 - 21h	0	0	0	0
	21 - 24h	0	0	0	0

Results

Electricity surplus in Subsystem S2 and fleet of plug-in hybrid vehicles necessary to use this energy

	Energy Surplus (GWh)	S2 Demand (TWh)	%	Number of Vehicles
2015	695	108	0.6%	521,010
2020	805	123	0.7%	604,119
2025	1361	142	1.0%	1,020,426
2030	2198	159	1.4%	1,648,558

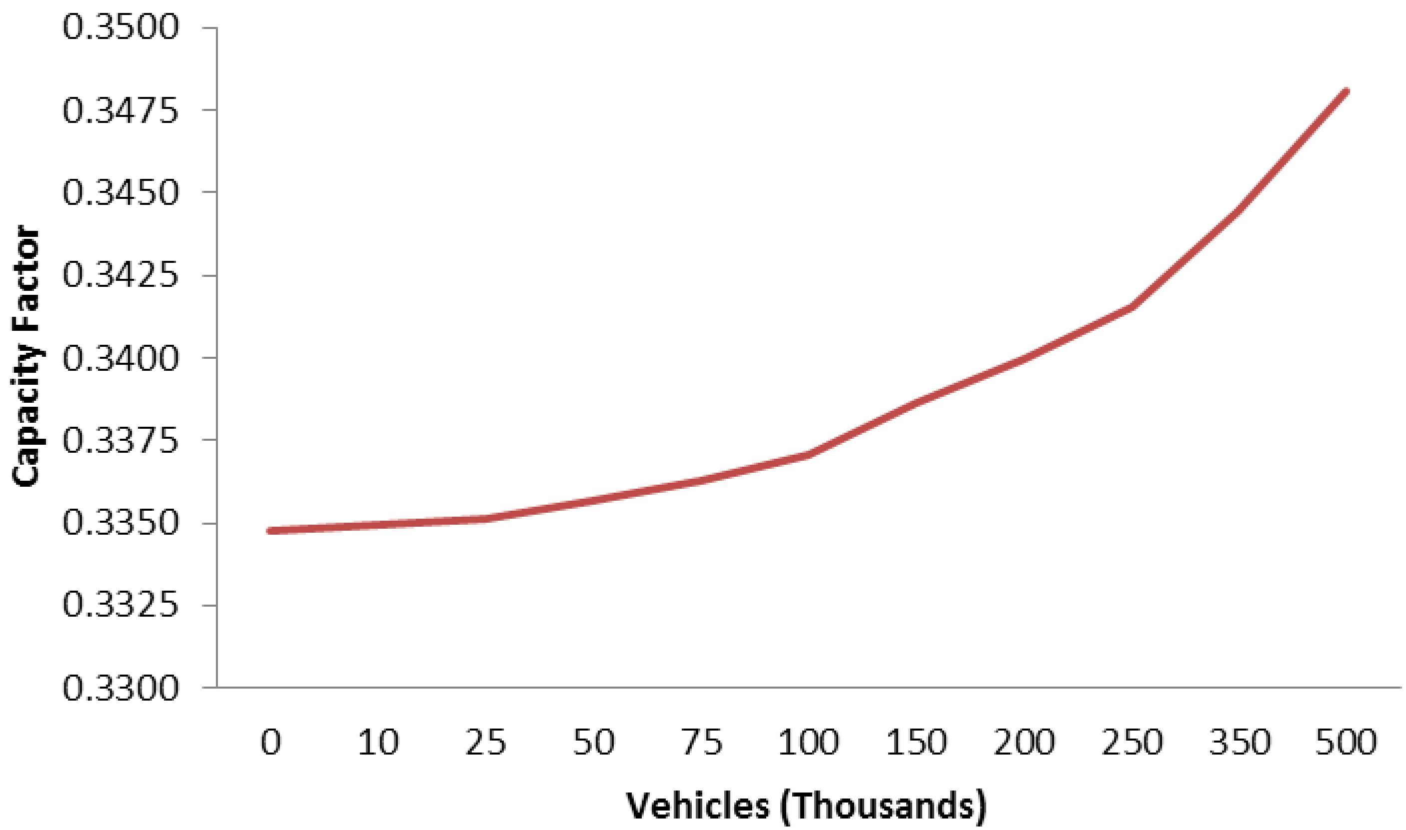
→ PHEV50

In sum...

1. The wind annual generation surplus, with proper coordination, can be used to supply a PHEVs fleet
2. Battery recharging during overnight hours can be achieved through timers and would be easier to manage with a fleet of taxi vehicles
3. This control in the first phase (in the next decade) would permit formulating strategic plans for further electrification of the transportation sector while delaying the costs of smart grid
4. The energy surplus would mainly occur between January and June
   - ✓ This could be an advantage due to the complementation with the sugarcane harvest in the Northeast region, which occurs between September and March. This would permit use of a fleet of plug-in hybrid vehicles with ethanol engines
5. Such a fleet can help increase the capacity factor of wind farms and thus stimulate the technology in the country, reduce demand for liquid fuels and foster the entrance of PHEVs

Results

Capacity Factor of Wind Farms with the Entrance of PHEVs with High Controllability



Thank you

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