Renewable Energy in Latin America

APERC 2018

FL Consulting

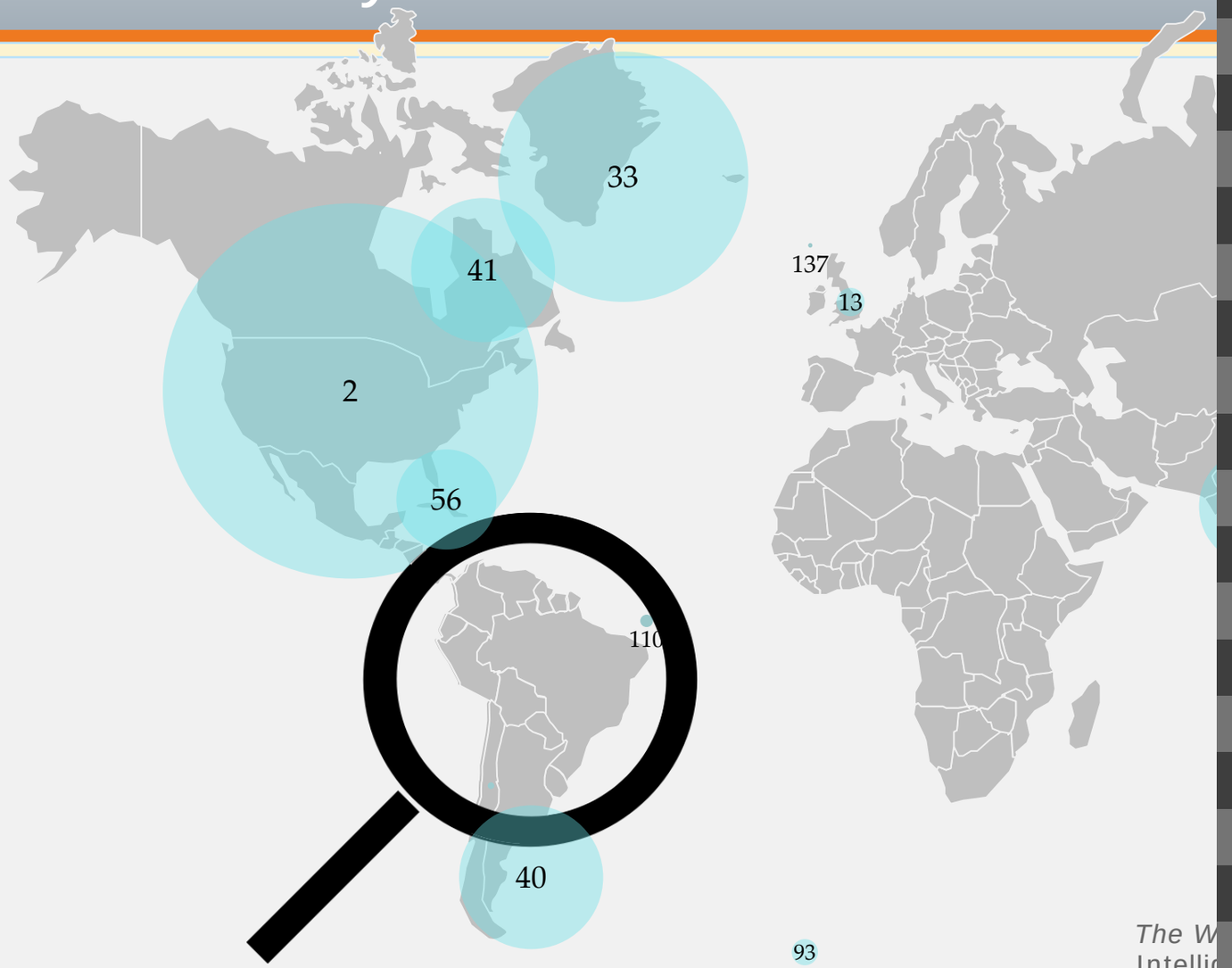
Content

- Region characteristics (compared to the world)
  - Demand, electrification
  - Resources
  - Production (targets)
  - Interconnection
- Cost/Benefits of Complementarity
  - Methodology Framework
  - Scenarios
  - Results

Region characteristics

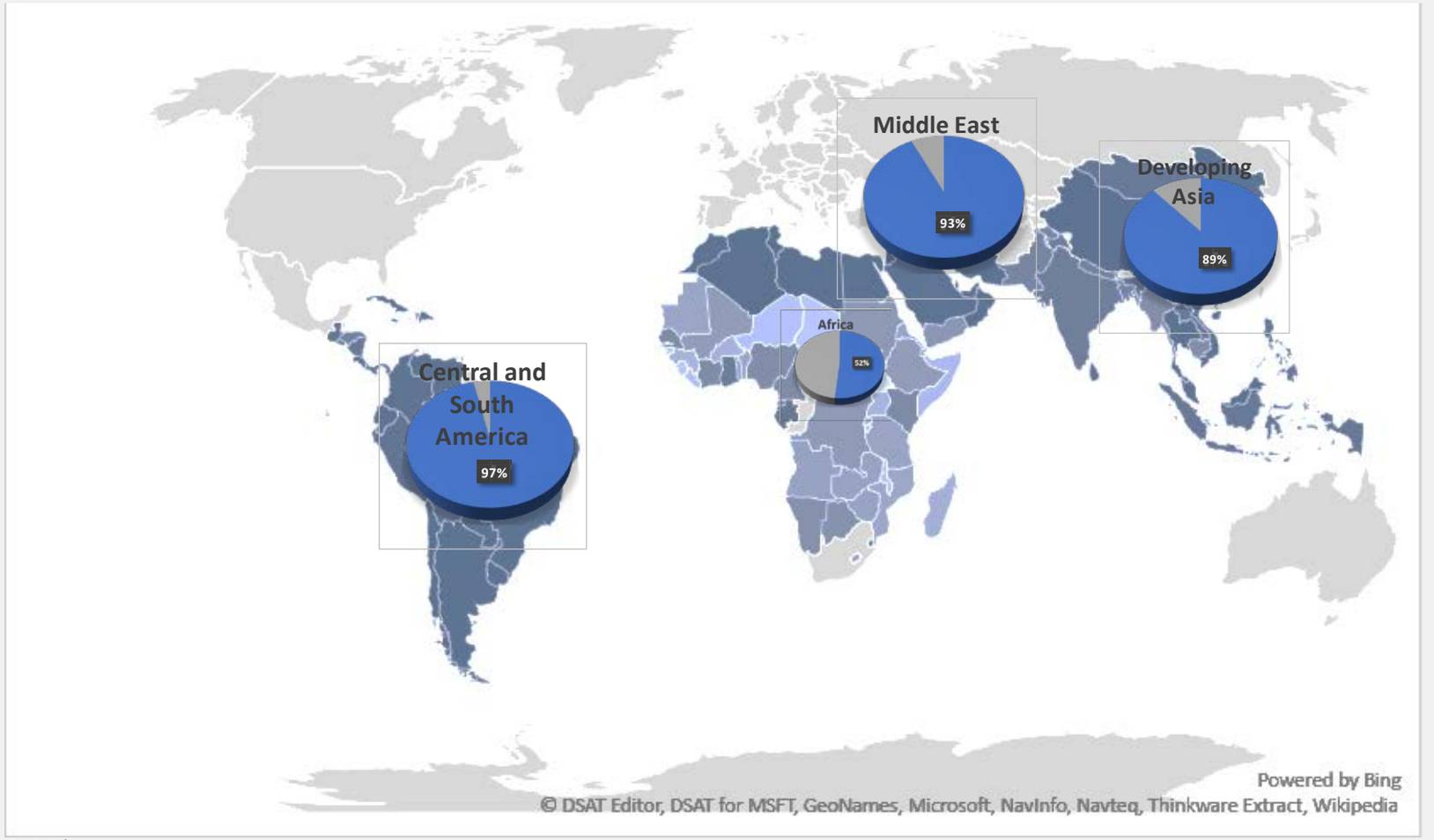
- Demand, electrification
- Resources
- Production (targets)
- Interconnection

Electricity Demand



Rank	Country	Demand [GWh]
2	United States	4,088,000
9	Brazil	559,200
14	Mexico	292,700
31	Argentina	133,800
33	Venezuela	114,400
40	Chile	71,660
41	Colombia	67,260
52	Paraguay	55,190
56	Peru	46,310
71	Ecuador	24,950
93	Uruguay	12,230
97	Guatemala	10,880
99	Costa Rica	10,380
102	Panama	9,724
108	Honduras	8,367
110	Bolivia	8,147
132	Nicaragua	3,218
137	Suriname	2,190
150	Guyana	1,000
183	Belize	248

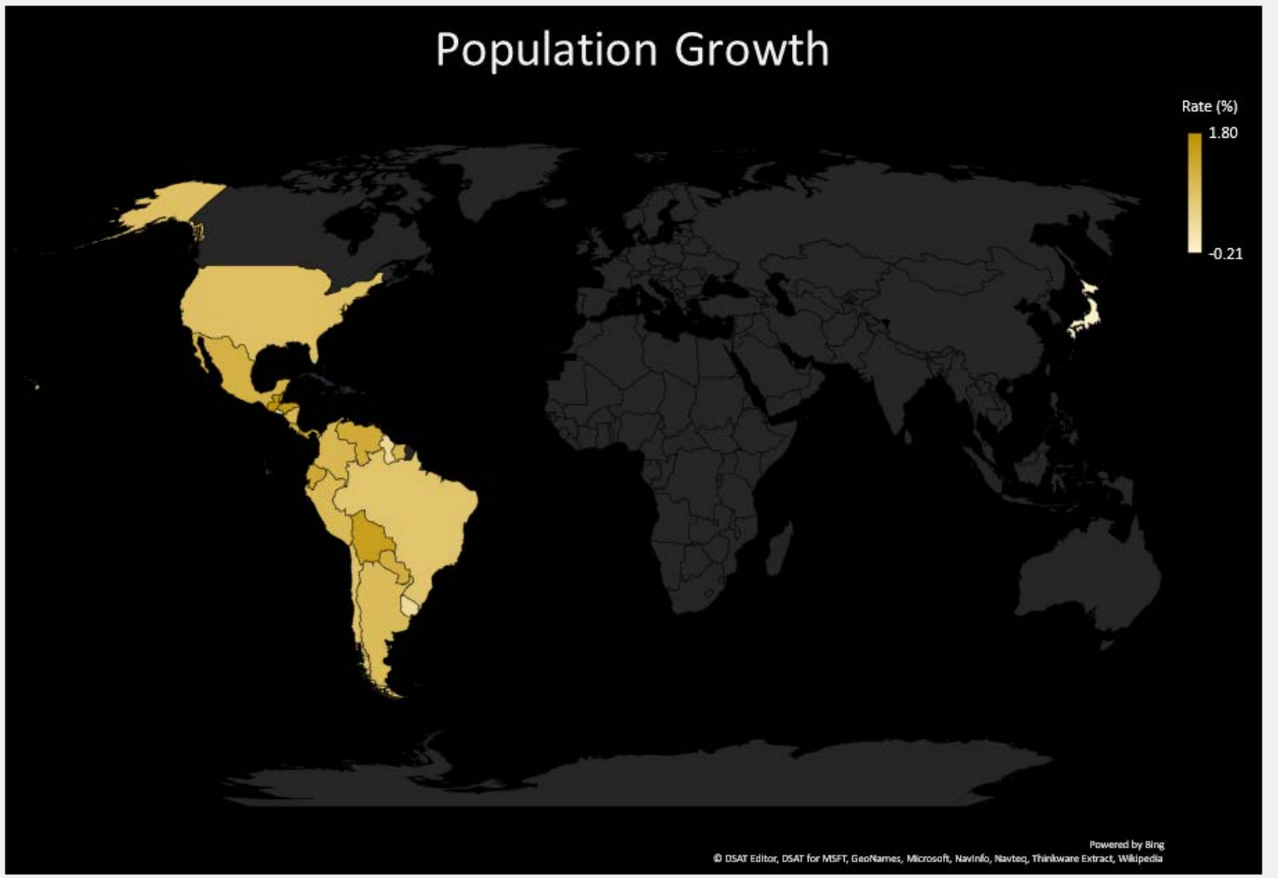
Electricity Demand: Electrification Rate



World wide: 86%

SOURCE: IEA, Energy Access Outlook 2017

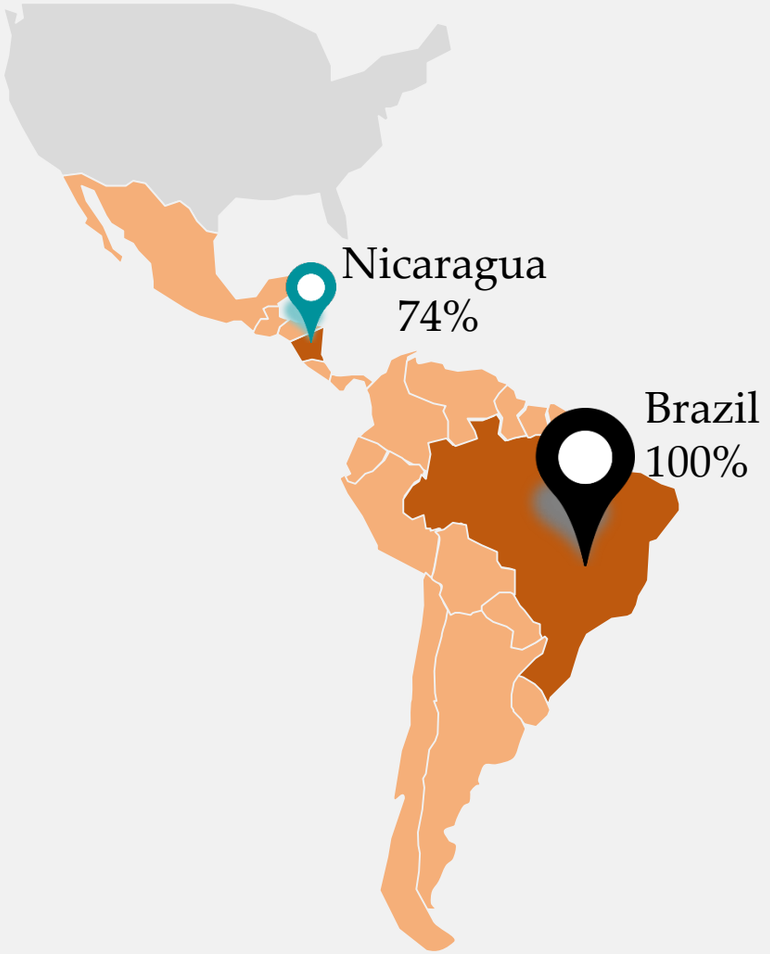
How much electricity we need?

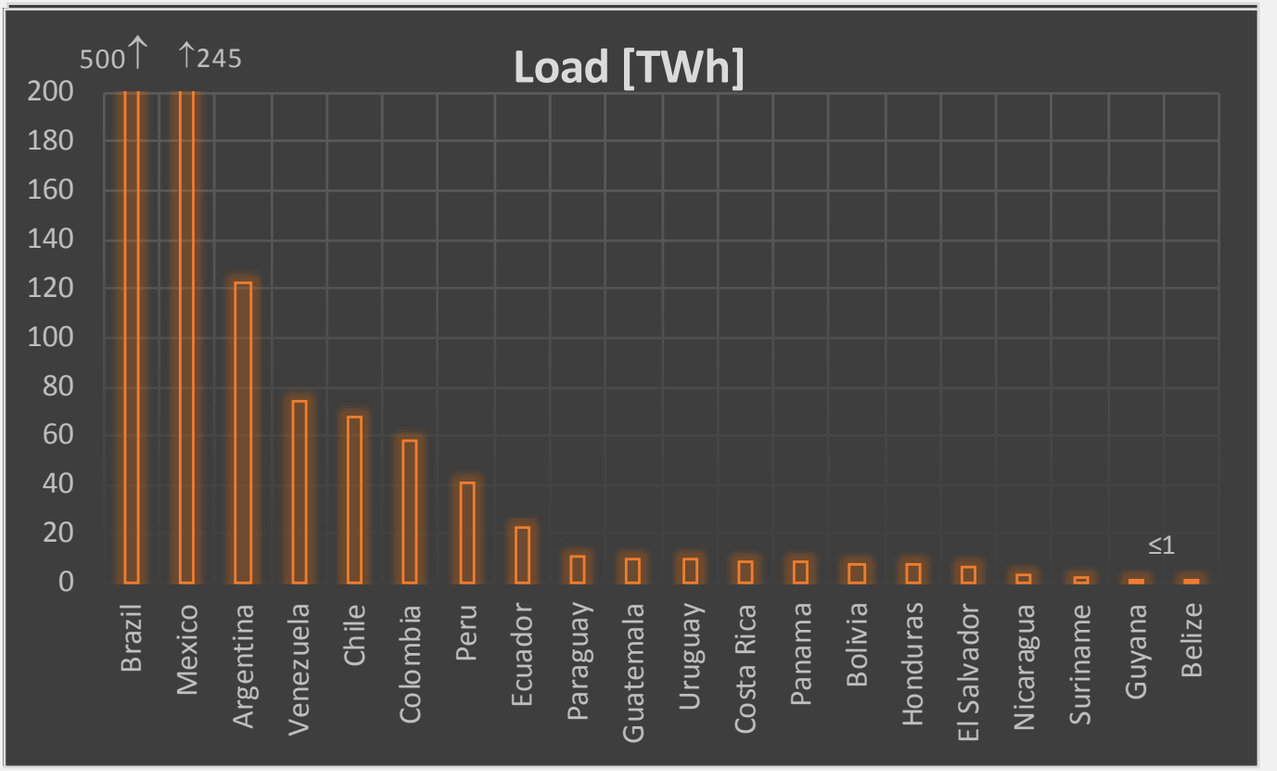


It's not really about electrification.
It's about developing

Sources: The World Factbook 2018. Washington, DC: Central Intelligence Agency, 2018.

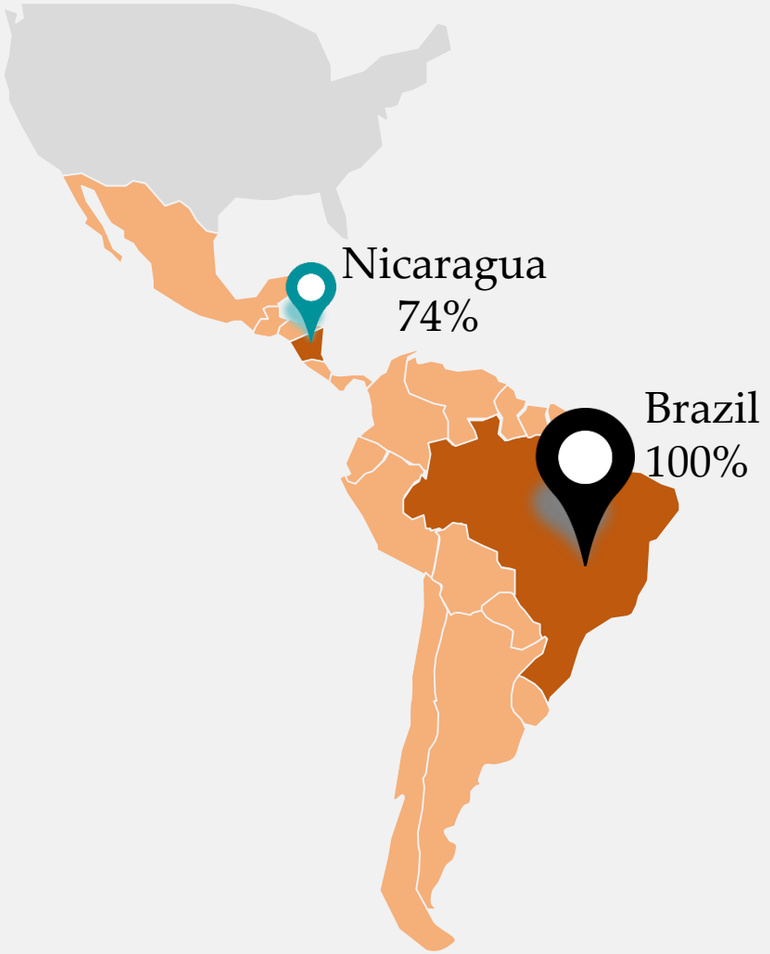
How much electricity we need?

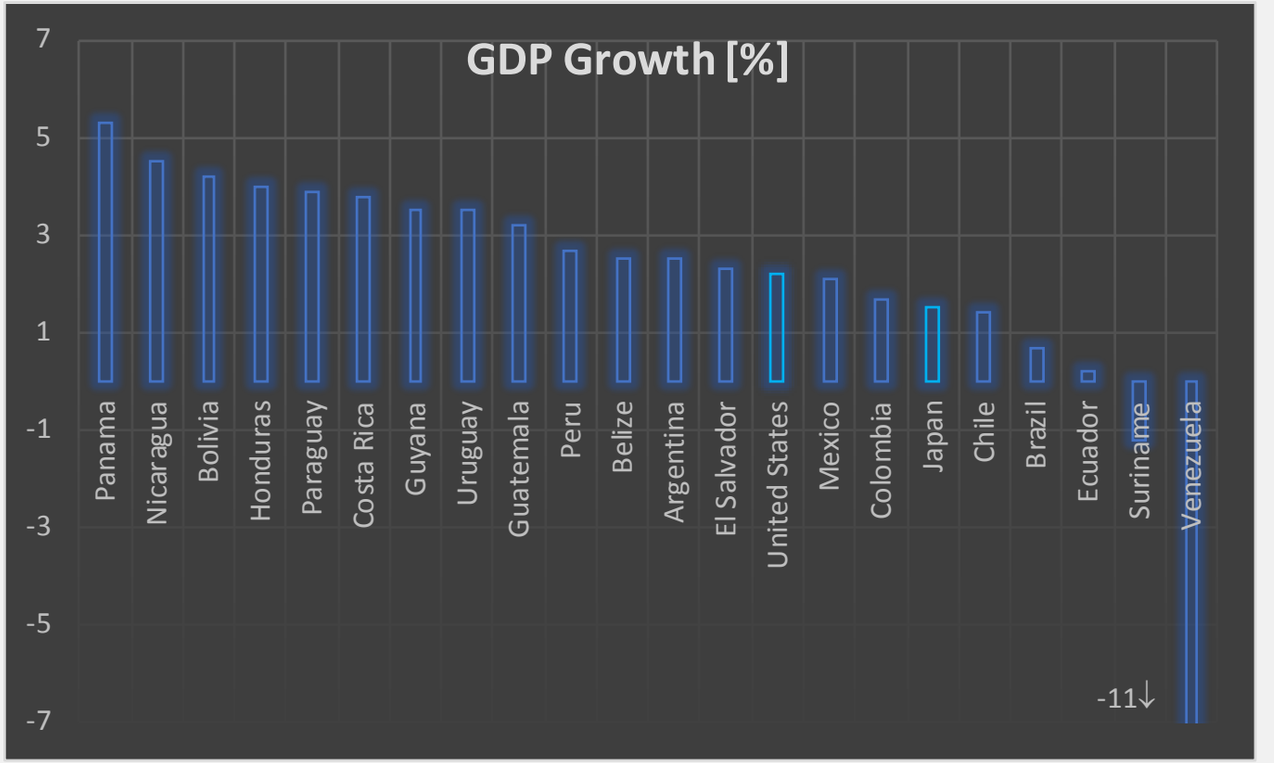




Sources: The World Factbook 2018. Washington, DC: Central Intelligence Agency, 2018.

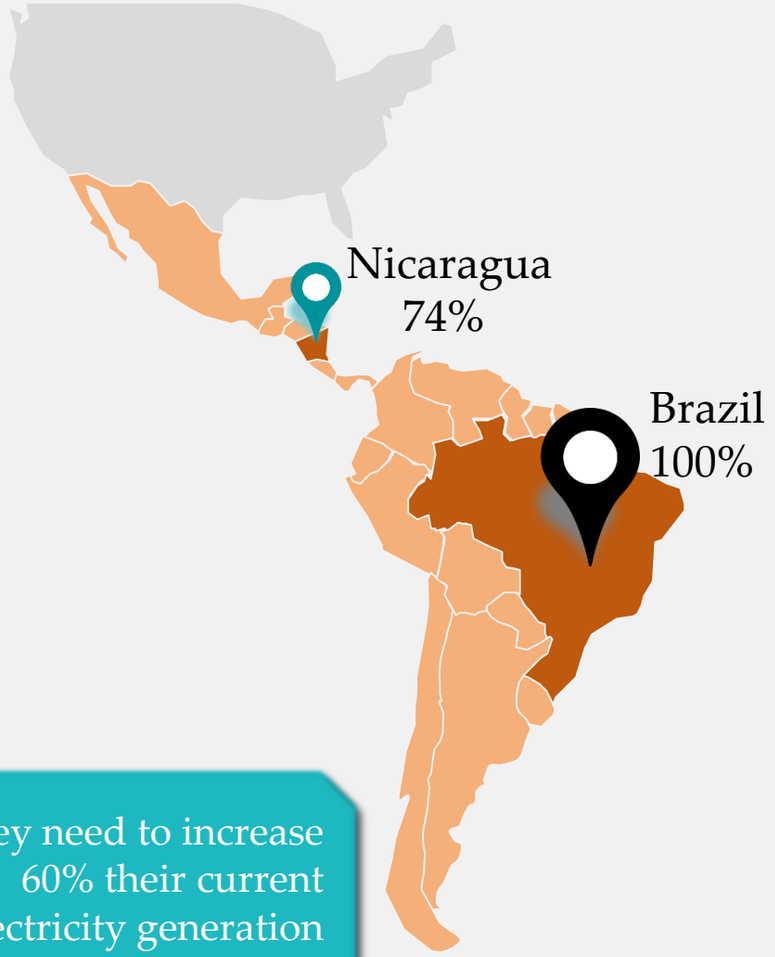
How much electricity we need?

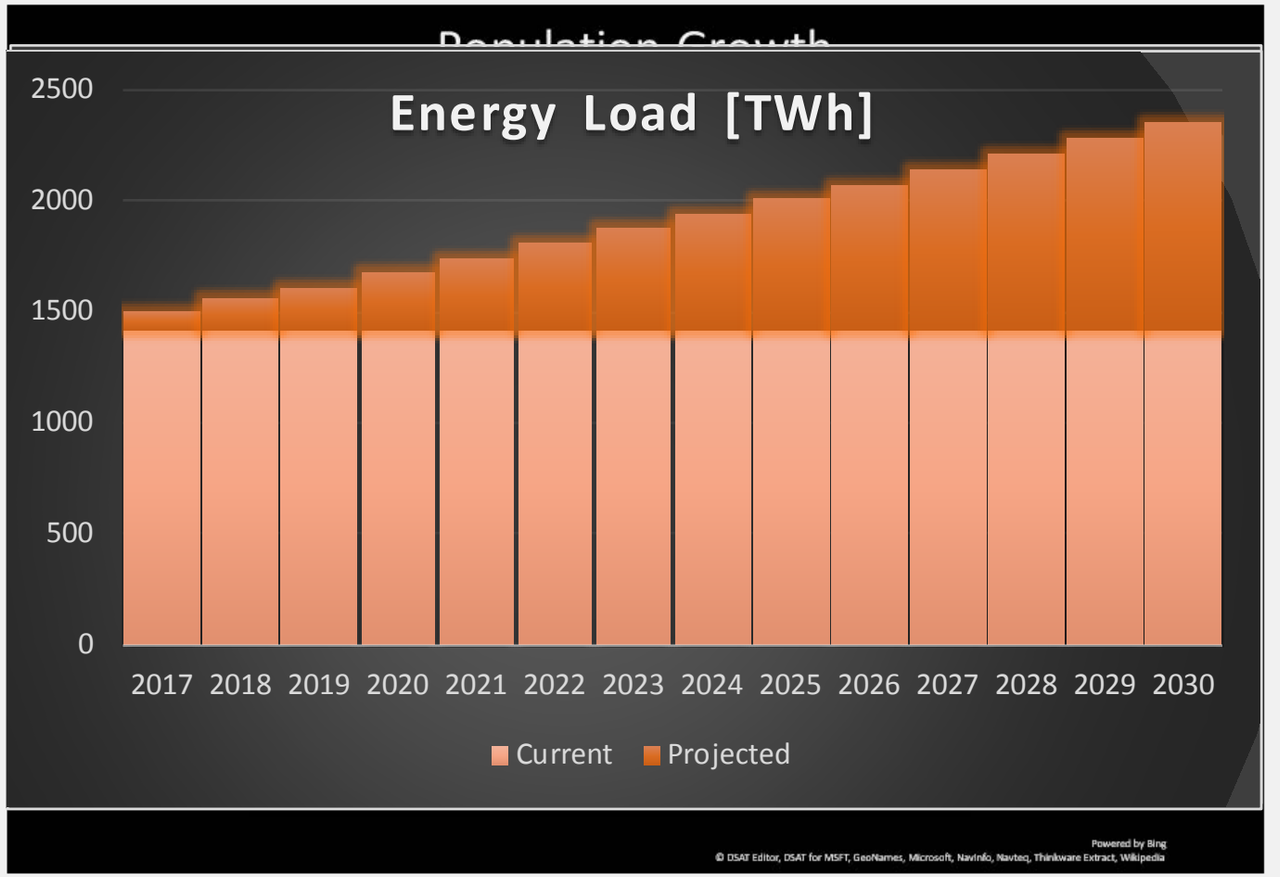




Sources: The World Factbook 2018. Washington, DC: Central Intelligence Agency, 2018.

How much electricity we need?

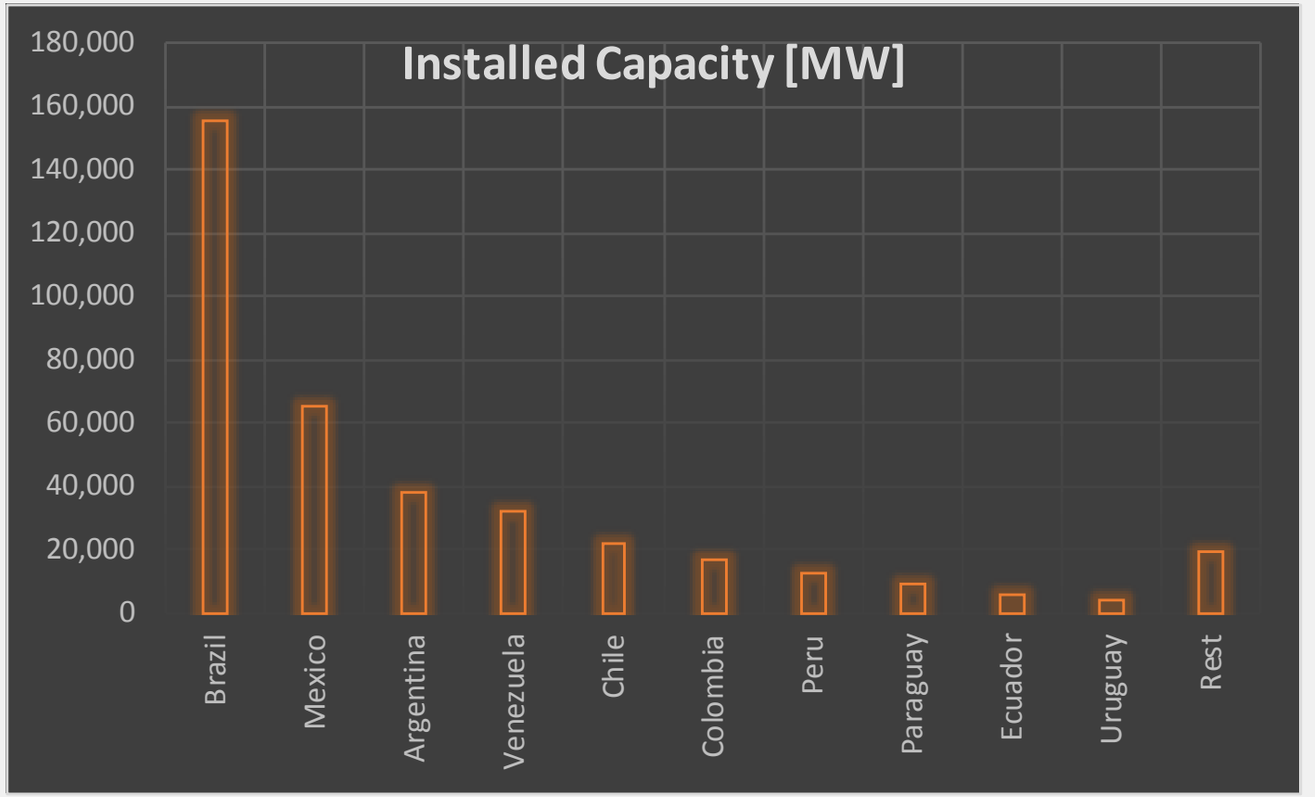




They need to increase 60% their current electricity generation

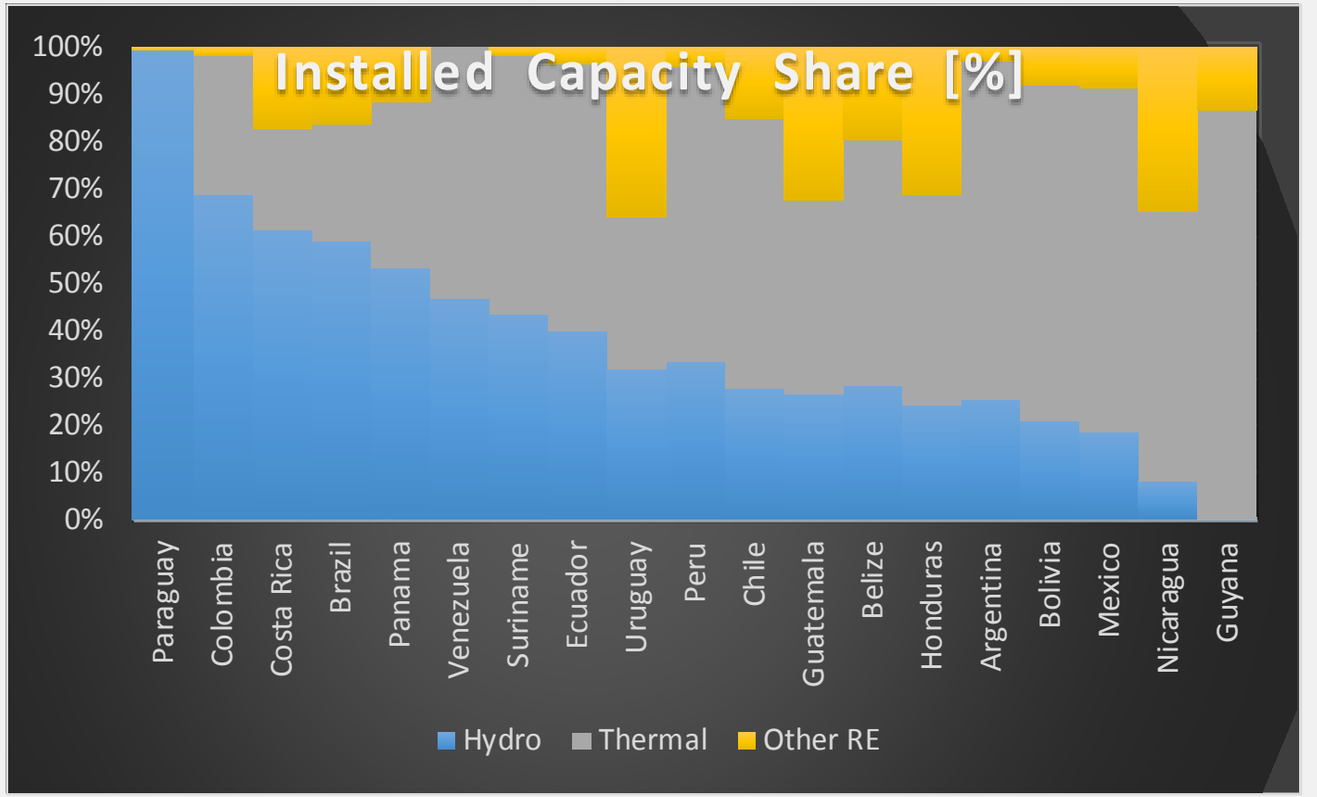
Sources: The World Factbook 2018. Washington, DC: Central Intelligence Agency, 2018.

Electricity Production Capacity



Source: The World Factbook 2018. Washington, DC: Central Intelligence Agency, 2018.

Electricity Production Capacity



Source: The World Factbook 2018. Washington, DC: Central Intelligence Agency, 2018.

How well interconnected the region is?

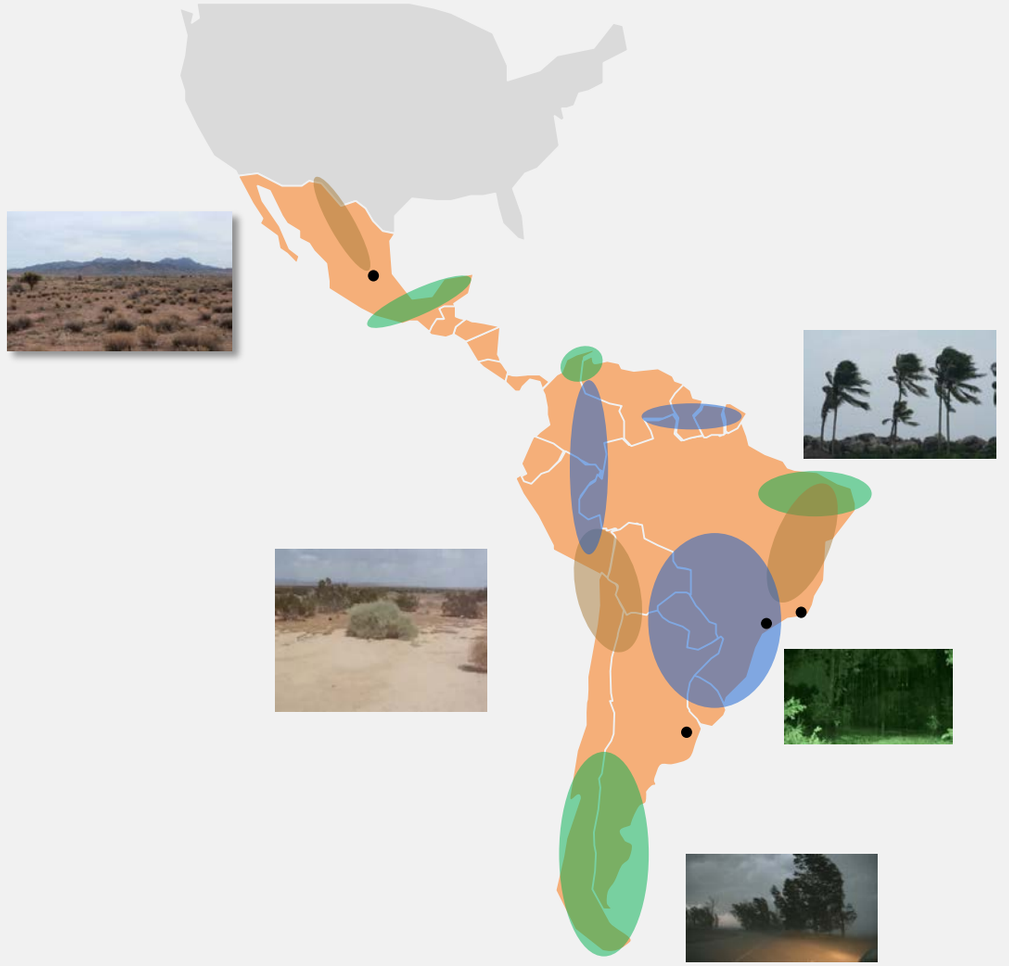
Country	Capacity Interchange [MVA]	As percentage of Installed Capacity [%]
Nicaragua	600	43.0%
ElSalvador	600	33.5%
Guatemala	1,100	26.6%
Belize	50	26.2%
Honduras	600	24.0%
CostaRica	600	19.2%
Panama	300	9.4%
Mexico	250	0.4%

*Mexico excludes interconnections with USA

How well interconnected the region is?

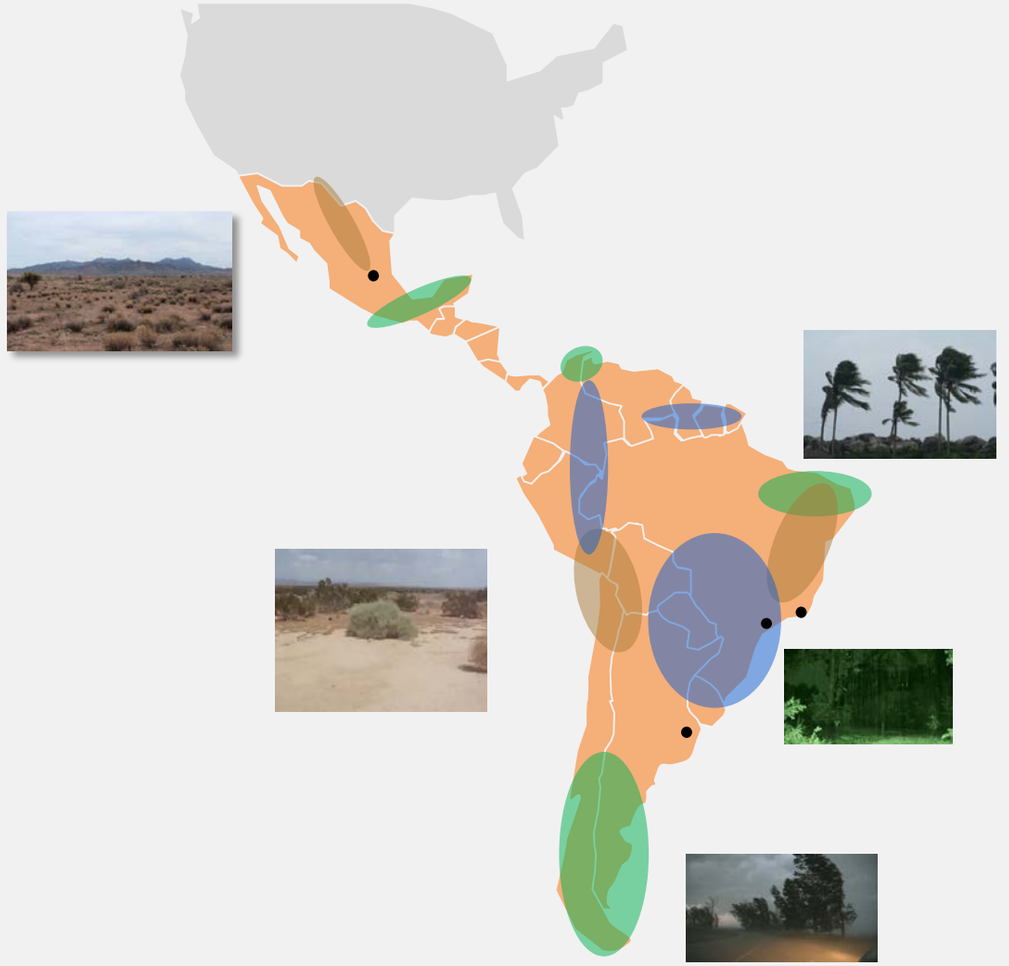
Country	Capacity Interchange [MVA]	As percentage of Installed Capacity [%]
Argentina	9,193	24.1%
Ecuador	832	13.9%
Colombia	670	4.0%
Peru	332	2.7%
Brazil	3,320	2.1%
Venezuela	450	1.4%

Resources Available



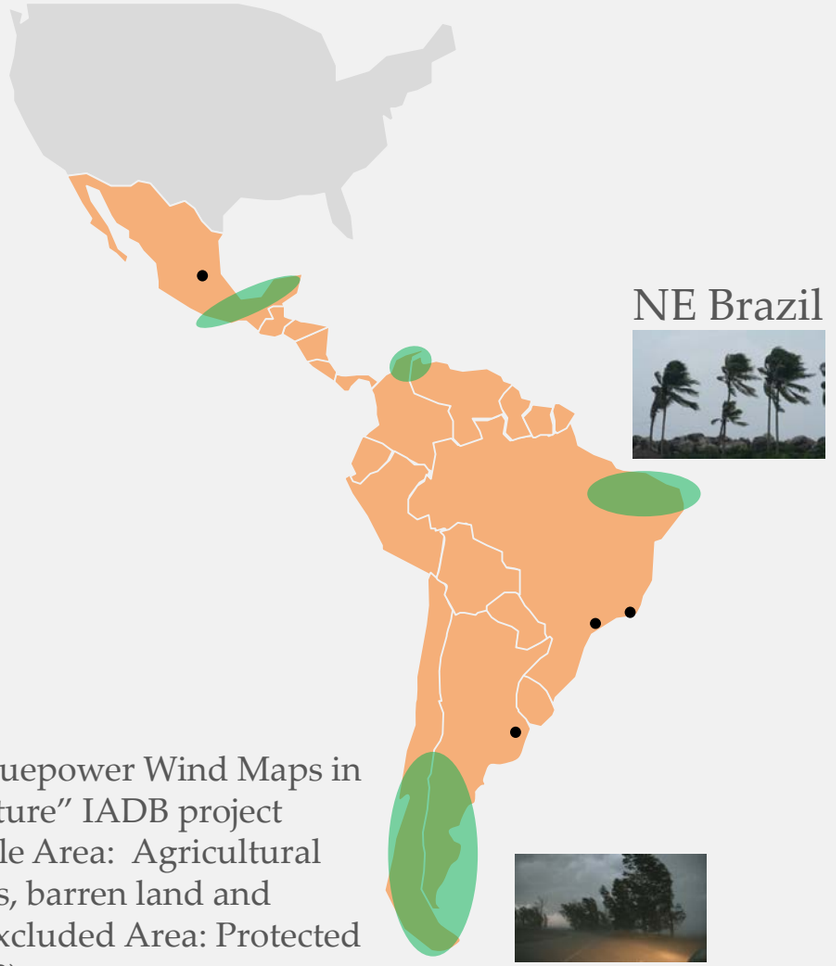
- ✓ Hydro Cascade Paraná river
- ✓ Entire Andes mountain range potential energy
- ✓ Barren areas: Mexico, Atacama, Altiplano
- ✓ Brazil NE wind and solar
- ✓ Patagonian & Caribbean coastal Wind

Resources Available

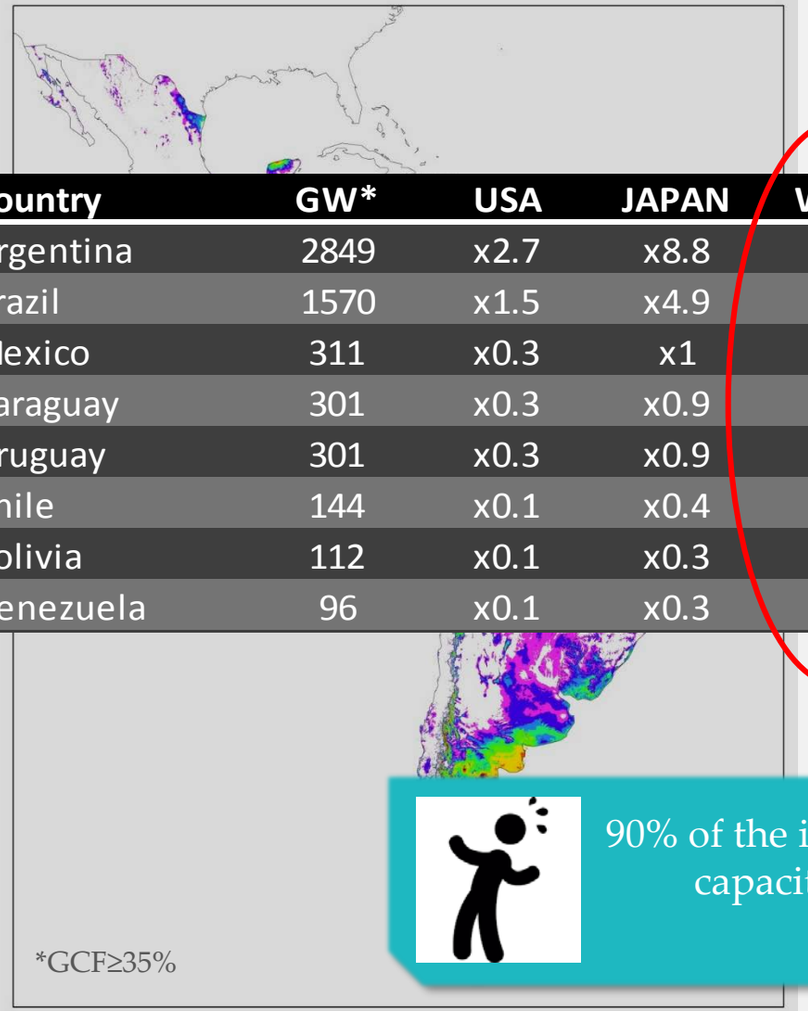


Country	Hydro [GW]	Small Hydro [GW]
Brazil	185	1.023
Colombia	118	25
Peru	60	1.6
Argentina	45	0.43
Bolivia	39	0.05
Venezuela	26	0
Chile	25	7

Resources Available: Wind Potential



Source: AWS Truepower Wind Maps in "Grid of the Future" IADB project
Notes: Allowable Area: Agricultural land, grasslands, barren land and slopes < 10%. Excluded Area: Protected Lands (by IADB)

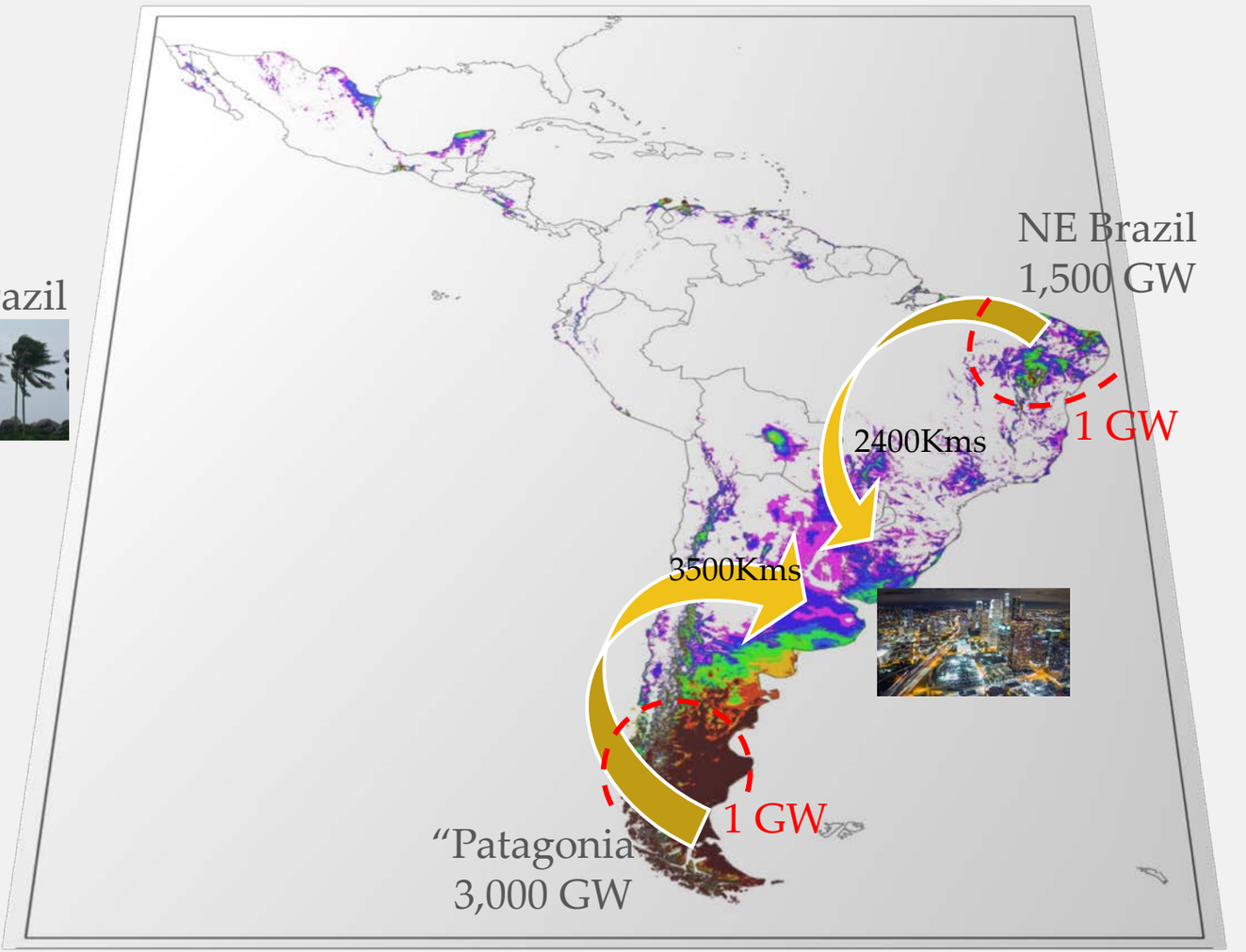


Country	GW*	USA	JAPAN	WORLD
Argentina	2849	x2.7	x8.8	45%
Brazil	1570	x1.5	x4.9	25%
Mexico	311	x0.3	x1	5%
Paraguay	301	x0.3	x0.9	5%
Uruguay	301	x0.3	x0.9	5%
Chile	144	x0.1	x0.4	2%
Bolivia	112	x0.1	x0.3	2%
Venezuela	96	x0.1	x0.3	2%

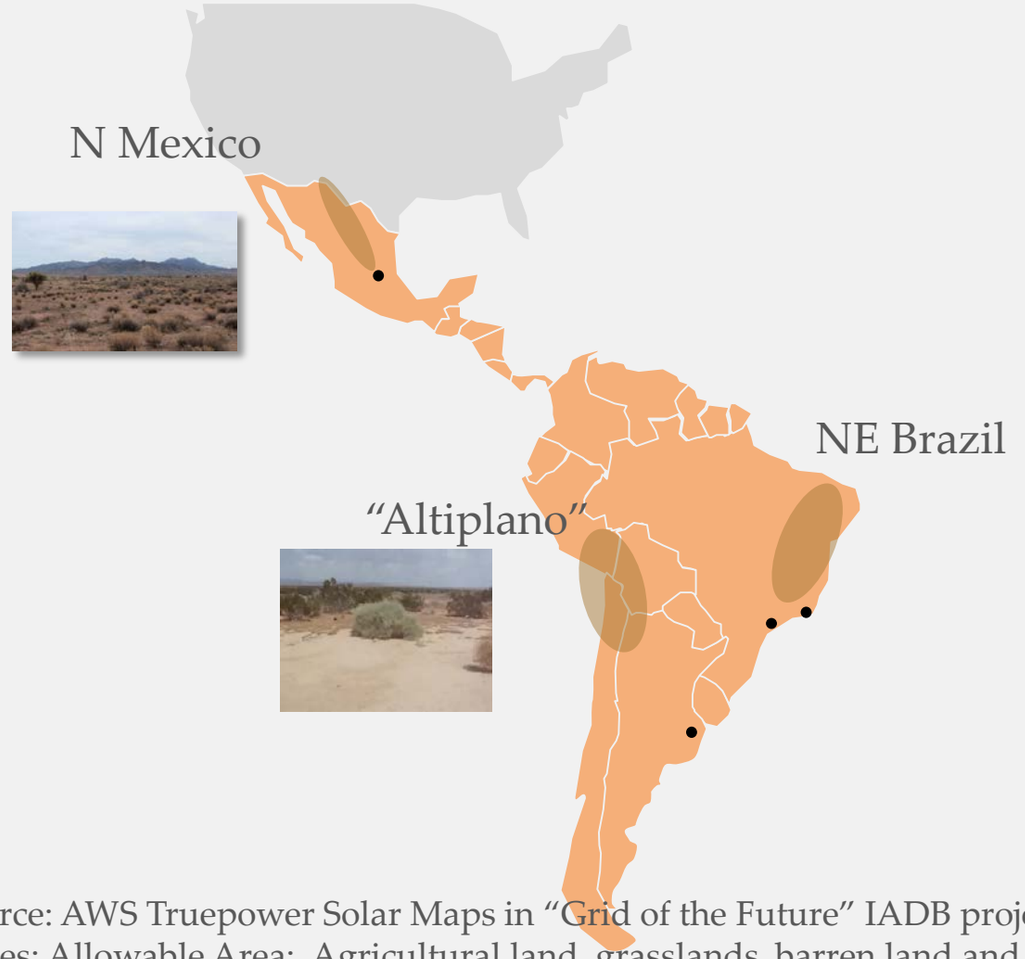
90% of the installed capacity of the World!

*GCF≥35%

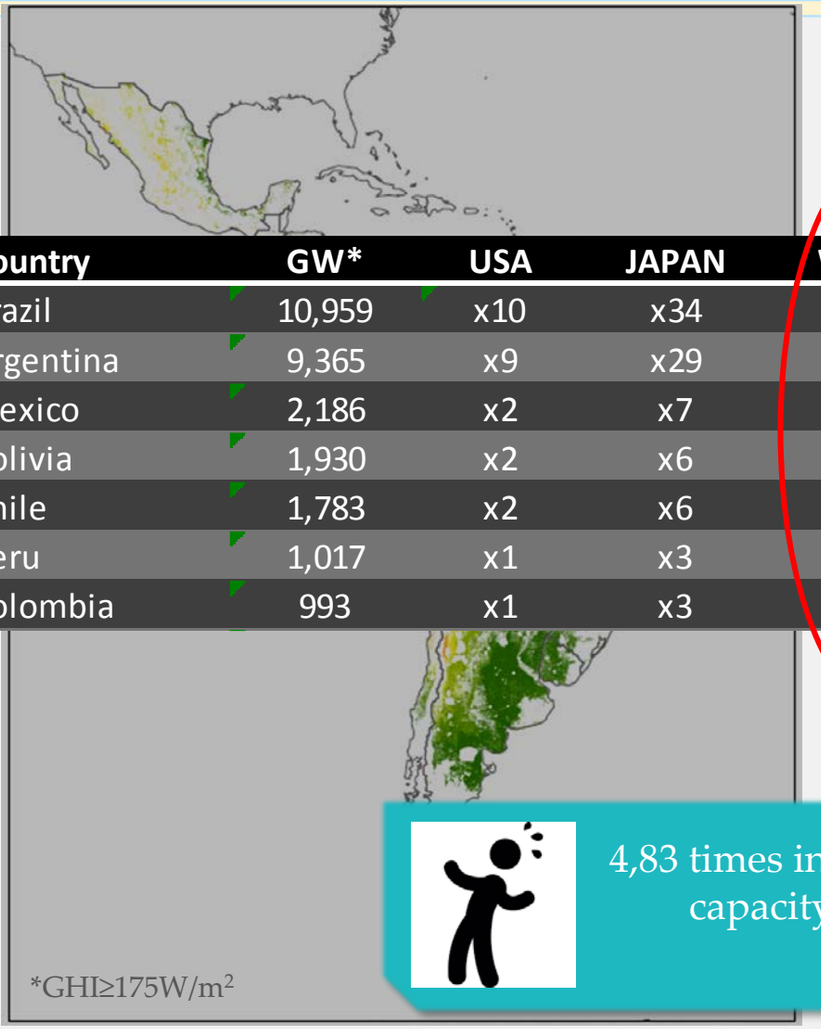
Resources Available: Wind Potential



Resources Available: Solar Potential



Country	GW*	USA	JAPAN	WORLD
Brazil	10,959	x10	x34	171.7%
Argentina	9,365	x9	x29	146.7%
Mexico	2,186	x2	x7	34.2%
Bolivia	1,930	x2	x6	30.2%
Chile	1,783	x2	x6	27.9%
Peru	1,017	x1	x3	15.9%
Colombia	993	x1	x3	15.6%



4,83 times installed capacity of the World!

Source: AWS Truepower Solar Maps in "Grid of the Future" IADB project
Notes: Allowable Area: Agricultural land, grasslands, barren land and slopes < 10%. Excluded Area: Protected Lands (by IADB)

Resources Available: Solar Potential

Summary

- +Growth of electricity demand (60% increment in few years!)
- Clean already (65%)
- Vast Renewable Resources (wind 5 x USA, solar 29 x USA)
- Poorly interconnected
- Coupling with Hydro Existent
- Sparse Load Centers

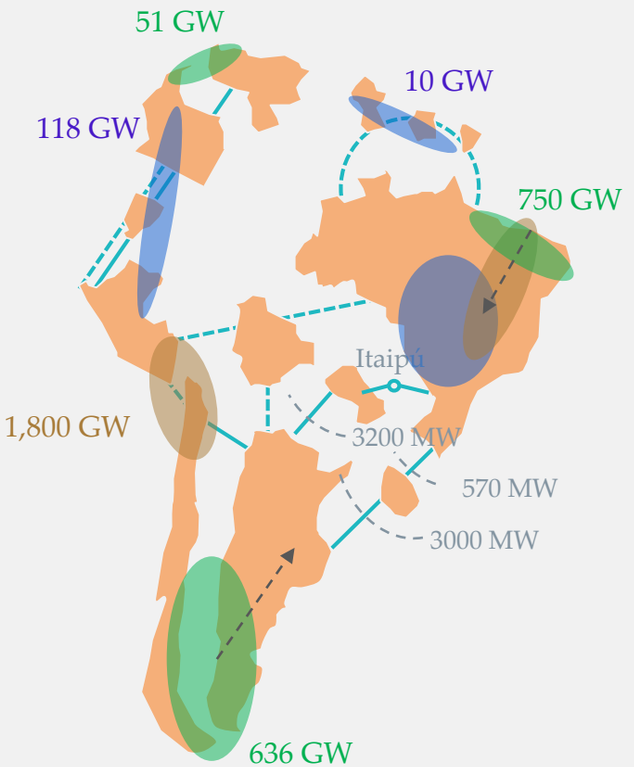
Role of transmission development in Complementarity… It's a developing need more than a target…

Cost/Benefits of Complementarity

Base
Scenarios
Results

Methodology Framework

LET'S FOCUS ON SOUTH AMERICA ONLY :



What is the best scenario for South America?

- Guyanas hydro and Arco Norte?
- Colombian [hydro or Wind] for Andean Countries?
- Patagonian, Brazil-NE Wind and internal re-enforcements?
- Solar Altiplano with Bolivia interconnections development?

Methodology Framework

¿How to approach Grid of the Future objectives?

- Capacity Expansion: **Fundamental** modelling to the generation and transmission **optimal** expansion. <-Mathematical!
- For 3 different main scenarios:
  - BAU-oriented (as reference) **[Base]**
  - High RE penetration **[RE]**
  - High RE penetration + Transmission Expansion **[CORE]**

Complementarity!

Methodology Framework

¿How to approach Gri

Base scenario (low Renewable Energy penetration, low integration):

Business as usual:
- No overall RE targets are defined (cost-effective penetration);
- Construction of new interconnections is limited to a reduced list of firm candidate projects.
- Optimal construction of generation candidates is allowed with annual limits per country:

RE-Optimistic scenario (high REs penetration, low integration):

Base Scenario with RE additions:
- Same as Base
- Renewable Energy: full potential and optimistic generation construction annual limits
- A 2030 target constraint:
  $\sum$ Generation (REs) $\geq 0.86 \sum$ Load

Core-Optimistic scenario (high REs penetration, high integration):

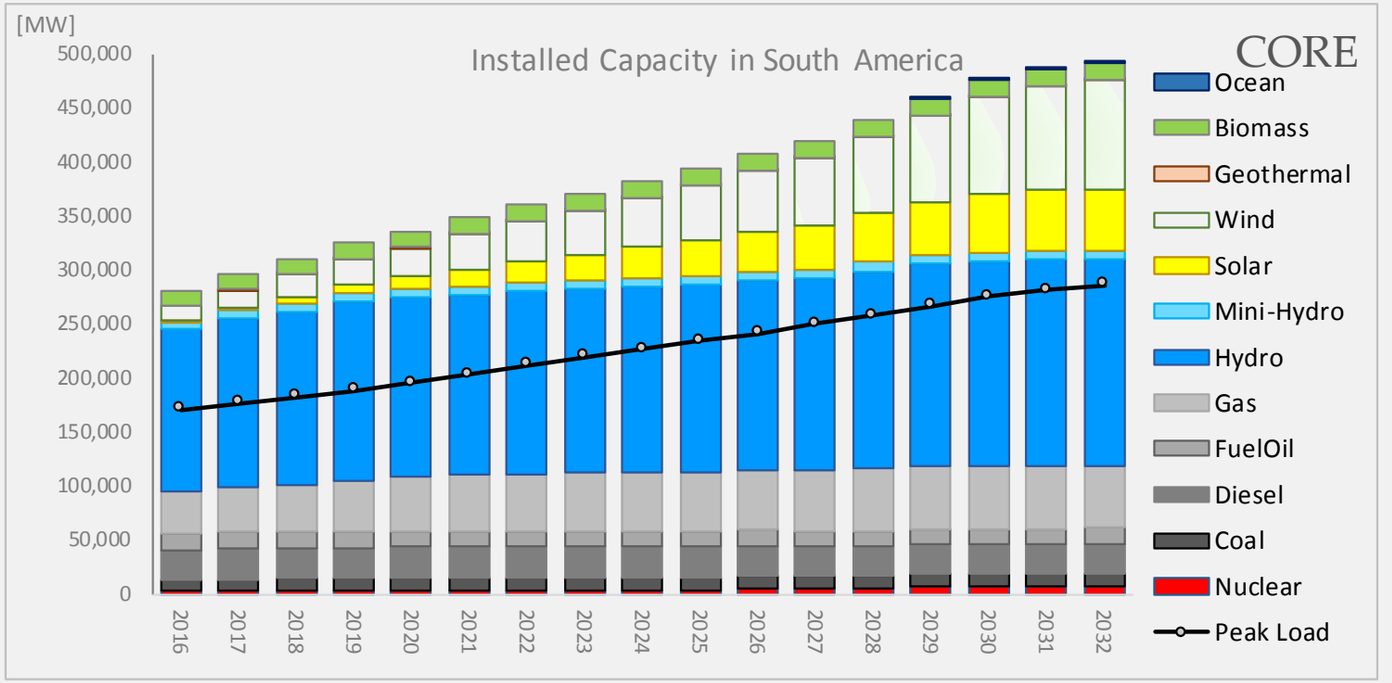
RE-Optimistic scenario with Transmission additions:
- Same as RE
- All international interconnection projects (candidates) available for expansion.

Complementarity!

Cost/Benefits of Complementarity: Installed Capacity

TOTAL INSTALLED CAPACITY IN SOUTH AMERICA IN 2032 [MW]

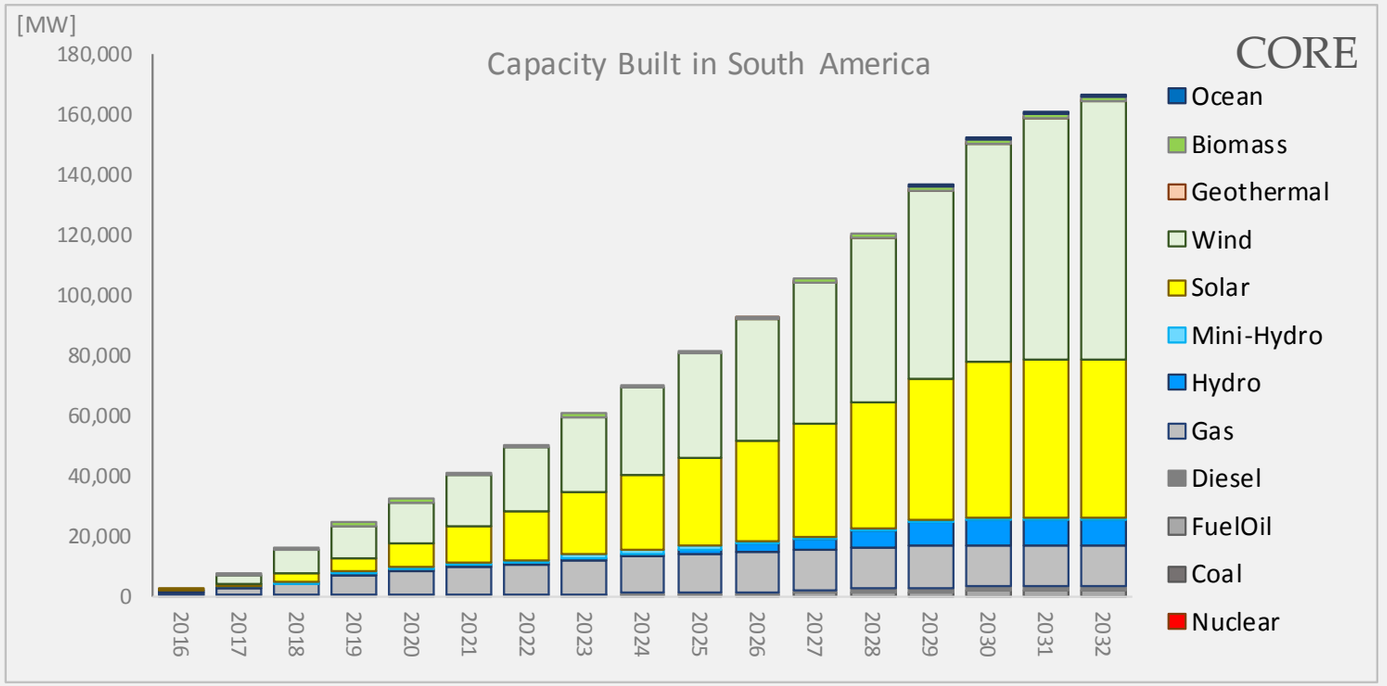
Scenario	Peak Load	Coal	Gas	FuelOil	Diesel	Nuclear	Hydro	Mini-Hydro	Solar	Wind	Geo-thermal	Biomass	Ocean	Total
Base	286,202	11,077	69,104	14,534	30,097	7,324	185,890	8,053	37,169	76,349	284	15,916	3	455,800
RE	286,202	11,077	54,775	14,359	28,549	7,324	187,351	9,913	63,727	104,571	284	15,916	4	497,850
CORE	286,202	11,077	57,392	14,534	28,252	7,324	191,651	8,130	56,180	101,821	181	15,916	3	492,460



Cost/Benefits of Complementarity: Installed Capacity

TOTAL INSTALLED CAPACITY IN SOUTH AMERICA IN 2032 [MW]

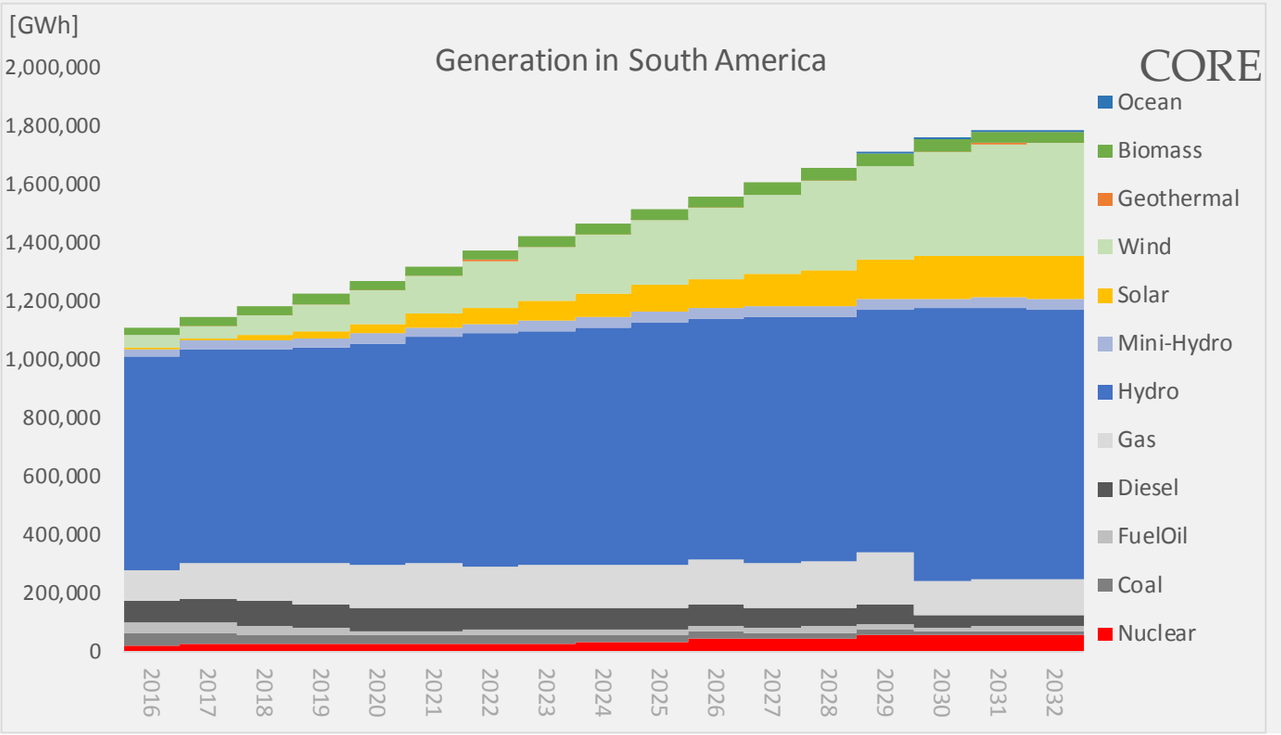
Scenario	Peak Load	Coal	Gas	FuelOil	Diesel	Nuclear	Hydro	Mini-Hydro	Solar	Wind	Geo-thermal	Biomass	Ocean	Total
Base	286,202	11,077	69,104	14,534	30,097	7,324	185,890	8,053	37,169	76,349	284	15,916	3	455,800
RE	286,202	11,077	54,775	14,359	28,549	7,324	187,351	9,913	63,727	104,571	284	15,916	4	497,850
CORE	286,202	11,077	57,392	14,534	28,252	7,324	191,651	8,130	56,180	101,821	181	15,916	3	492,460



Cost/Benefits of Complementarity: Generation

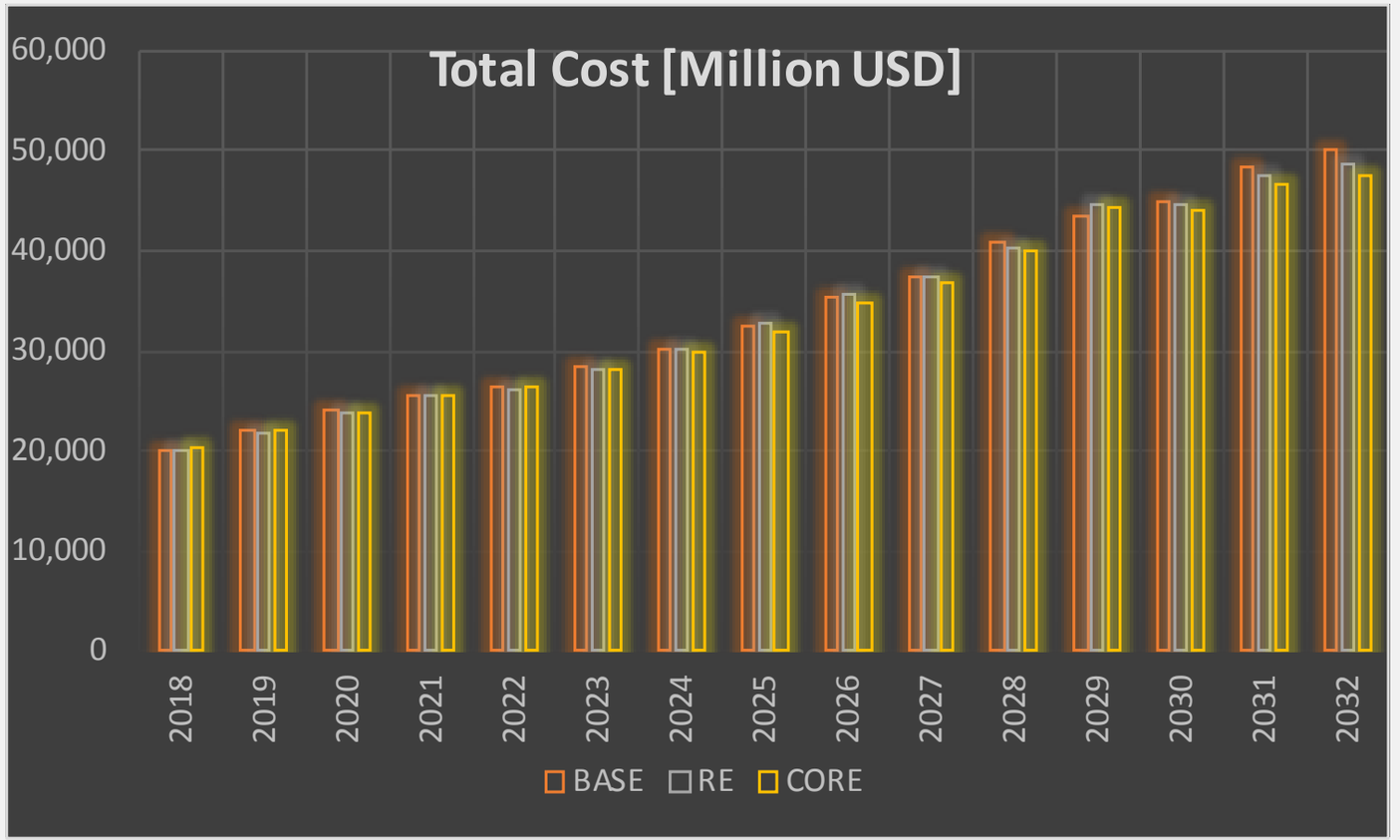
GENERATION BY SOURCES IN SOUTH AMERICA IN 2032 [MW]

Scenario	Load [TWh]	Coal	Gas	FuelOil	Diesel	Nuclear	Hydro	Mini-Hydro	Solar	Wind	Geothermal	Biomass	Ocean	%VRE	%RE Total
Base	1,778	20,092	288,538	24,298	91,271	57,072	825,134	34,140	99,690	292,877	1,906	41,414	17	24.0%	72.9%
RE	1,778	13,465	112,485	17,692	44,965	55,924	889,188	41,844	163,767	396,243	1,881	39,678	22	33.9%	86.2%
CORE	1,778	13,926	122,208	14,479	38,677	56,782	925,549	34,291	146,273	386,181	1,222	37,926	17	31.9%	86.2%



Cost/Benefits of Complementarity: Total Cost

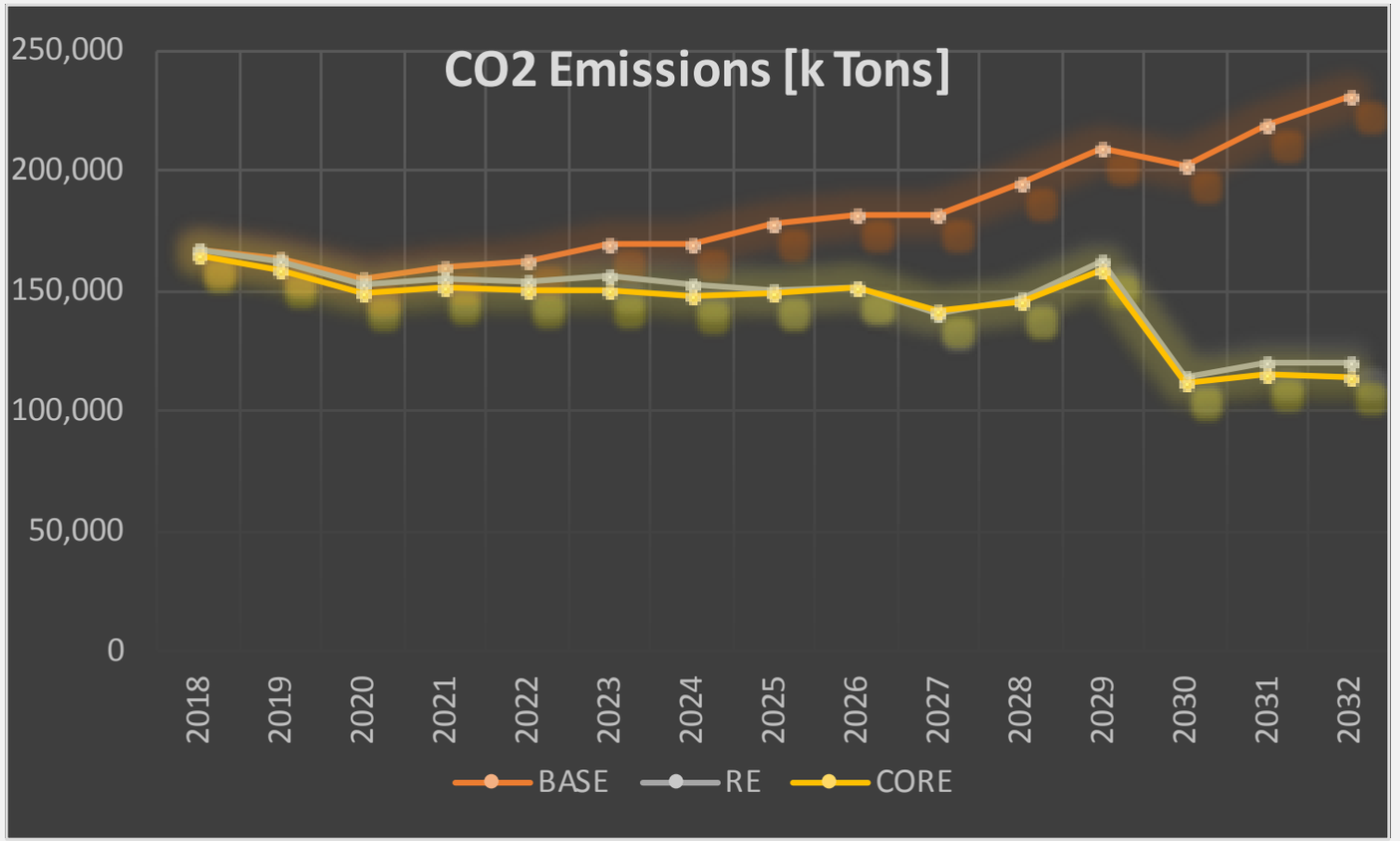
TOTAL COST IN SOUTH AMERICA [B USD]



YEAR	BASE	RE	CORE
2018	20,101	20,047	20,260
2019	22,018	21,891	22,065
2020	24,025	23,871	23,907
2021	25,643	25,486	25,626
2022	26,383	26,089	26,300
2023	28,403	28,233	28,233
2024	30,186	30,136	29,824
2025	32,568	32,642	32,044
2026	35,362	35,544	34,883
2027	37,351	37,523	36,843
2028	40,754	40,423	40,084
2029	43,487	44,720	44,359
2030	44,823	44,514	44,065
2031	48,409	47,626	46,569
2032	50,234	48,659	47,618
Total	**509,748**	**507,405**	**502,679**

Cost/Benefits of Complementarity: Emissions

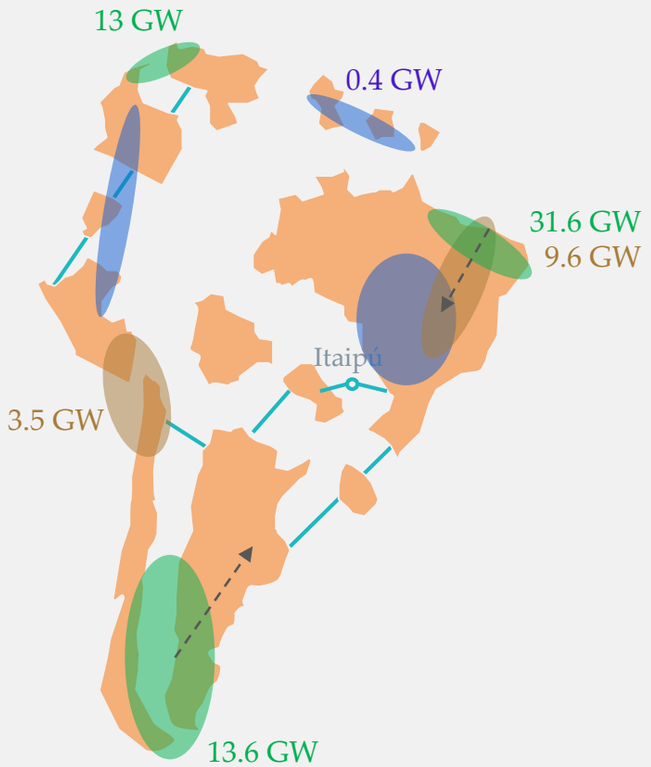
TOTAL CO2 EMISSIONS IN SOUTH AMERICA [K TONS]



YEAR	BASE	RE	CORE
2018	167,416	167,122	164,352
2019	163,447	162,053	158,716
2020	155,458	152,444	149,460
2021	160,052	155,260	151,355
2022	162,980	154,561	150,133
2023	169,148	156,177	150,397
2024	170,135	153,048	147,603
2025	177,803	150,885	149,150
2026	182,128	151,844	151,936
2027	181,174	140,528	142,317
2028	195,360	146,524	146,043
2029	210,050	162,534	159,008
2030	202,210	113,751	111,317
2031	219,342	120,052	116,063
2032	231,231	120,238	114,534
Total	**2,747,932**	**2,207,020**	**2,162,383**

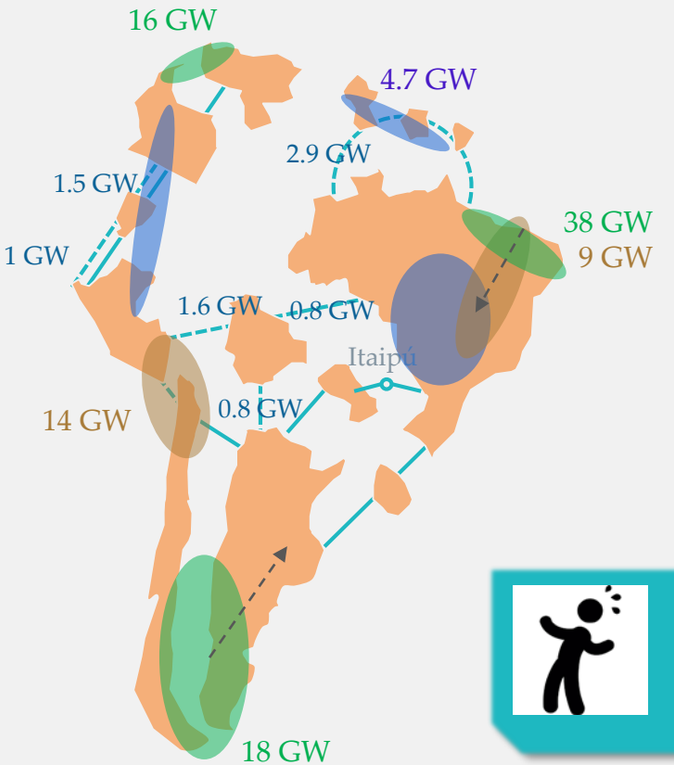
Cost/Benefits of Complementarity: Transmission

Base Scenario



TOTAL COST: 512.6 bUDS
(2.8bUSD in transmission)

CORE Scenario



All Transmission Candidates built!

TOTAL COST: 510.9 bUDS
(8.2bUSD in transmission)

Findings and Conclusions

- Complementarity is not a requirement, but Smart…
- Transmission investments of +5 bUSD can reduce 7 bUSD in Generation Costs while achieving 86% renewable
- Same (high) levels of RE penetration can be achieved more efficiently with (discrete) interconnection expansions
- RE-Optimistic scenarios produce economic benefits! Surprise: Optimistic refers penetration rates and targets. Not costs!
- Complementarity in South America reduces costs (5 bUSD), emissions (2%), need for capacity (7,884 MW)*

*by 2032 comparing RE with CORE