Renewable Energy in Puerto Rico

Based on the Report "Achievable Renewable Energy Targets For Puerto Rico's Renewable Energy Portfolio Standard" sponsored by the Puerto Rico´s Energy Affairs Administration

Under contract number 2008-132009

October 2007 thru November 2008

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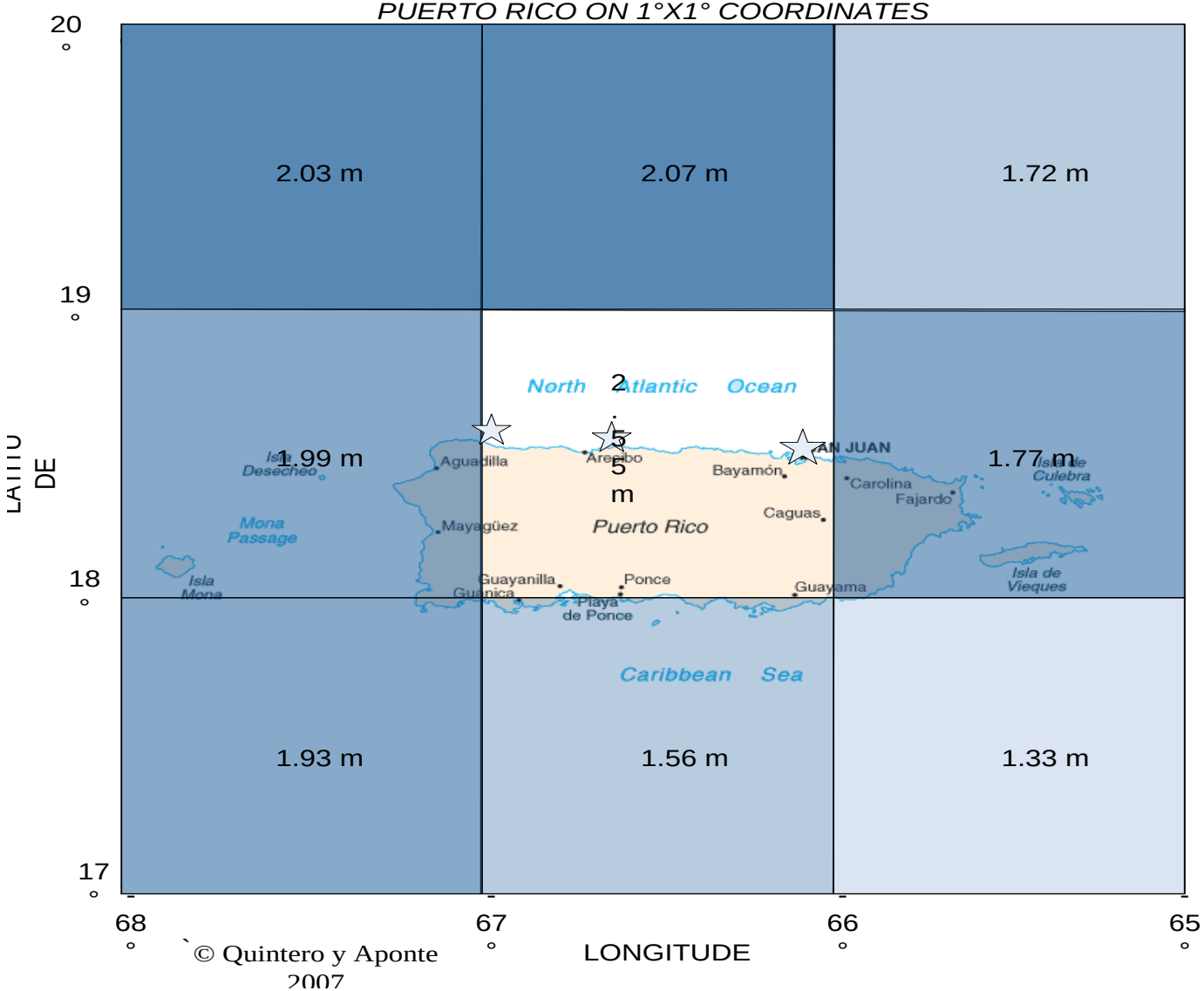
Objetive was to obtain an achievable estimate of the electricity that can be generated with renewable energy resources in Puerto Rico based on:

- Resource availability
- Required area (“foot print”),
- Climmate effects,
  - Seasonal, day or night
- Available Technology (commercial, prototype, etc),
- Cost (capital, mantenaince, operation)
- Grid interconnection
- Energy resources: Ocean, Solar, Wind, Biomass, Micro-hydro, Hydrogen (fuel-cells)

Ocean Energy Resource

ANNUAL AVERAGE WAVE HEIGHT IN METERS IN AREAS AROUND PUERTO RICO ON 1°X1° COORDINATES



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N

Annual average wave height in meters (m)

2.25-2.00
1.99-1.75
1.74-1.50
1.49-1.25

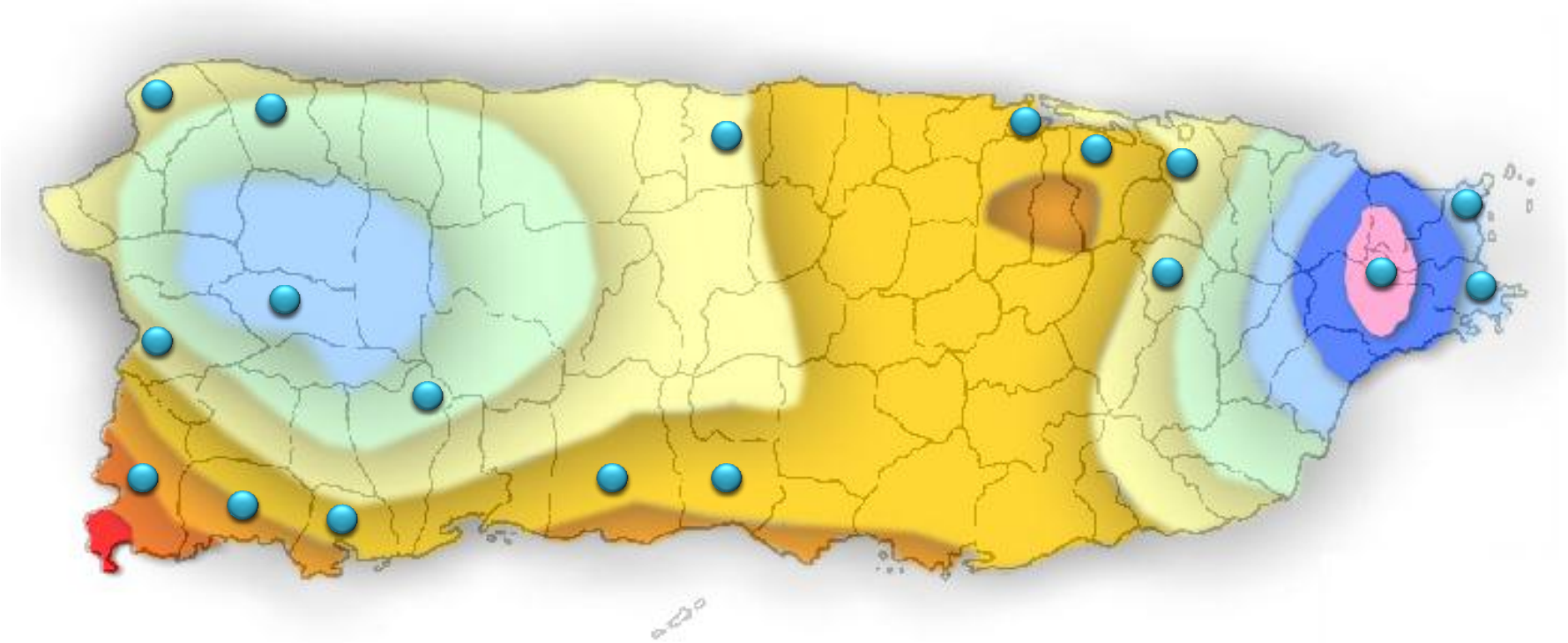
☆ 2.55m*

*Average of data obtained the measure of SBE 26 instrument and calculated by a SWAN model by Juan C. Ortiz Royero for his thesis work

Highest wave energy concentrates in the north coast.

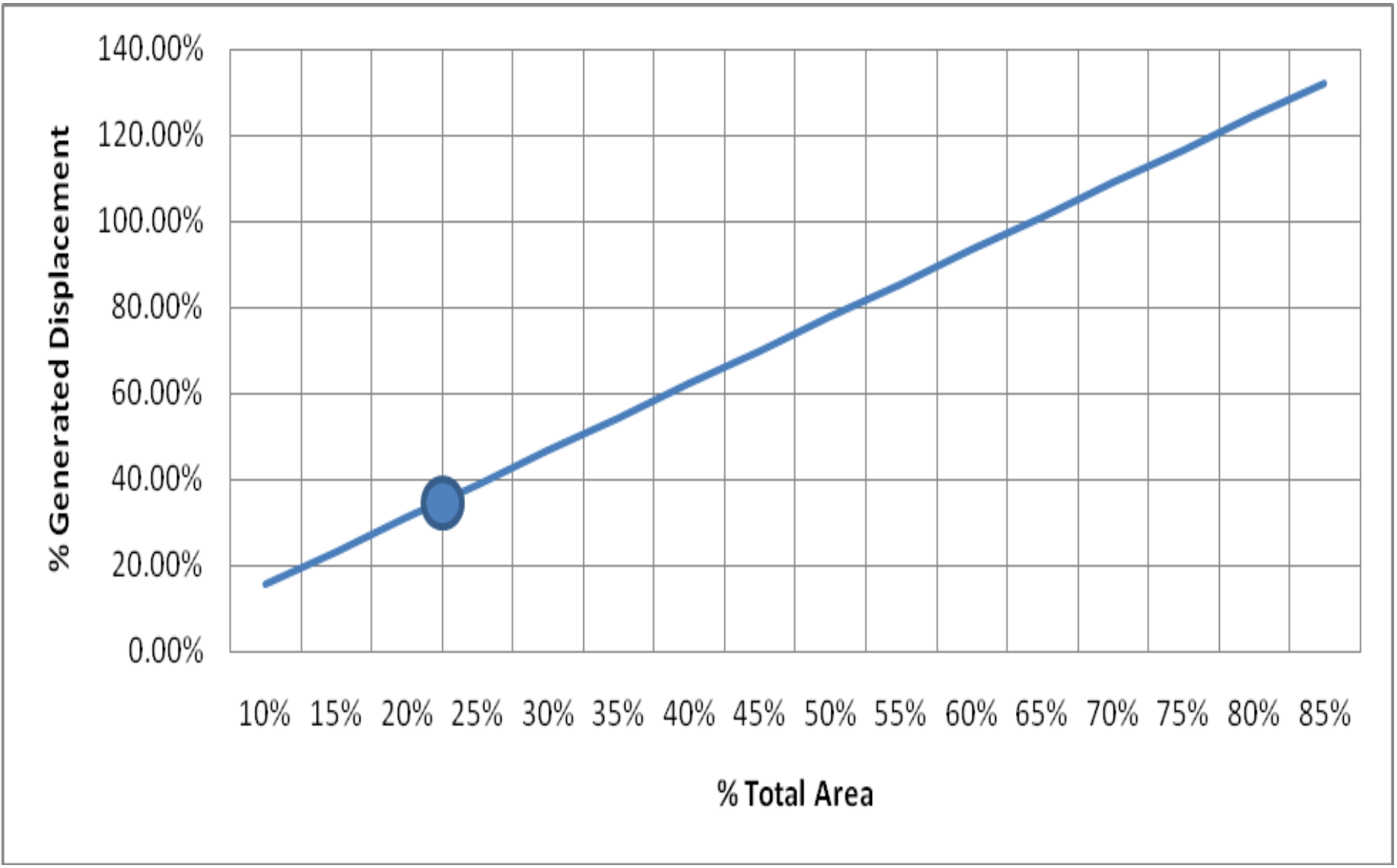
Solar Energy Resource

Average Insolation in Puerto Rico, kWh/m^2 per year



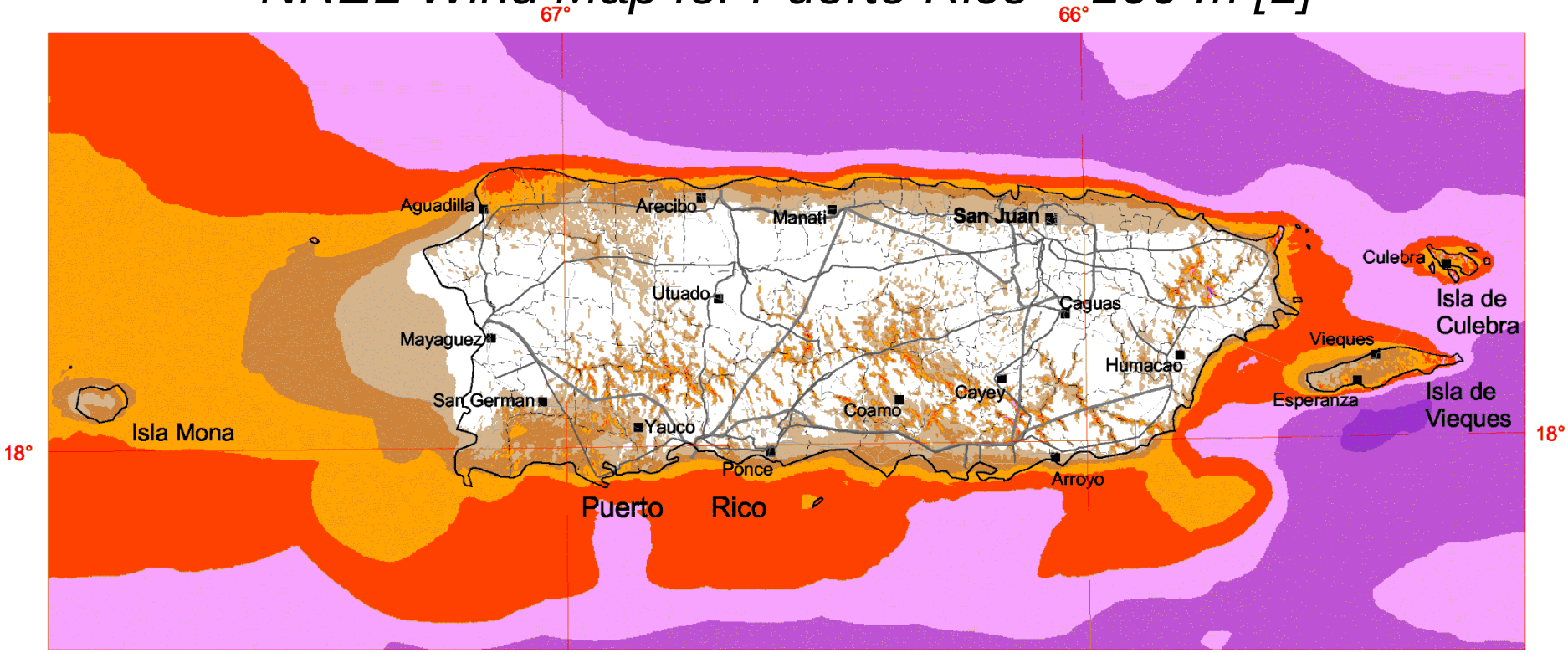
- 1419 – 1572
- 1267 – 1419
- 1115 – 1267
- 1876 – 2028
- 1724 – 1876
- 1572 – 1724
- 2332 – 2484
- 2180 – 2332
- 2028 – 2180

Annual Residential Energy Displacement



Wind Resource

NREL Wind Map for Puerto Rico – 100 m [1]



Wind Speed m/s	Capacity Factor percent*
9.0	
8.5	
8.0	39
7.5	35
7.0	30
6.5	27
6.0	23
5.5	
< 5.5	

* Net capacity factor assuming 12% energy losses.

Transmission Line
Voltage (kV)
38
115
230

The annual wind speed estimates for this map were produced by AWS Truewind using their Mesomap system and historical weather data.

20 0 20 40 60 80 Kilometers
20 0 20 40 Miles

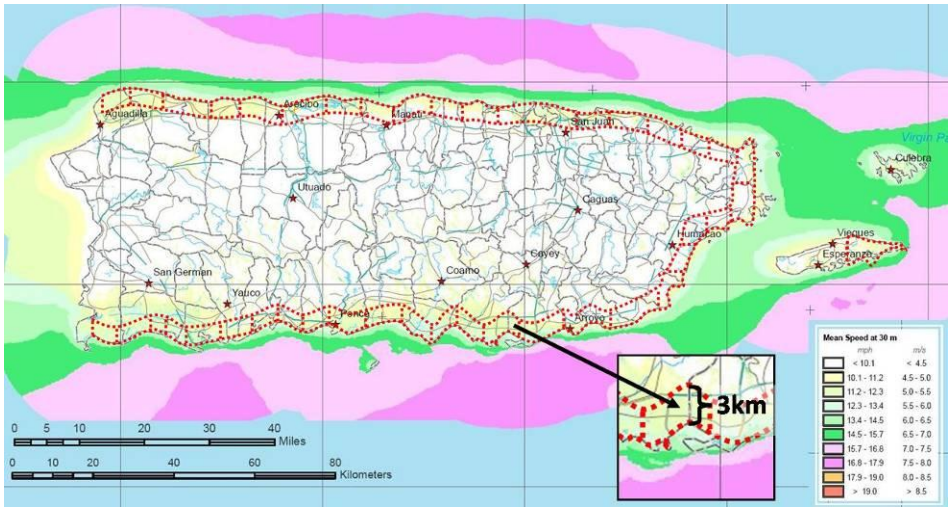
U.S. Department of Energy
National Renewable Energy Laboratory

How many large turbines? Available land vs. best wind

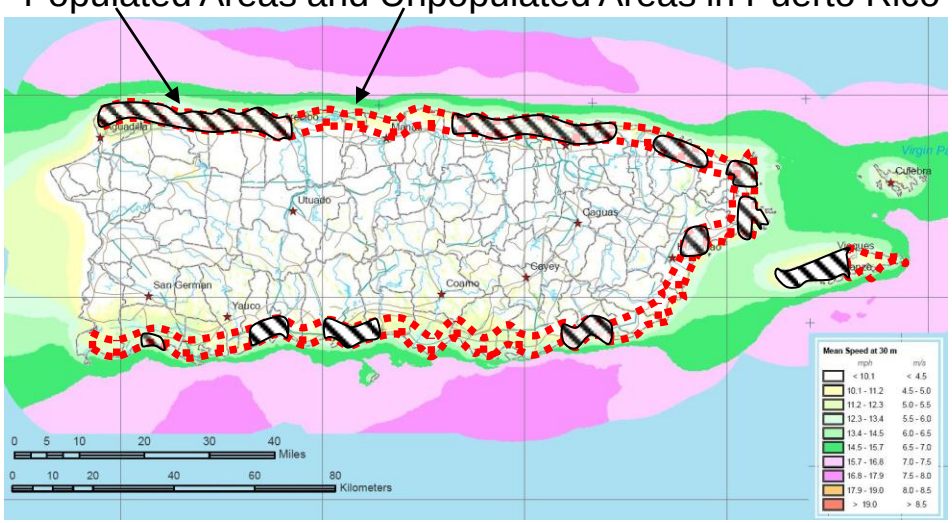
- Puerto Rico's area = 8,960 km²
  - 160 km x 56 km
  - approx. 2.24 million cuerdas

- Best wind, and best access to infrastructure, in a 3 km wide band along the north, east, and south coast
  - 960 km² (240,000 cuerdas)
  - 10.7% of PR total area
  - 50%, 480 km², of this area is heavily populated (to be used for small wind) and 50% is not populated, we assume it can be used for wind farms, large wind turbines. Do not compete (it complements) with Biorefinery efforts.

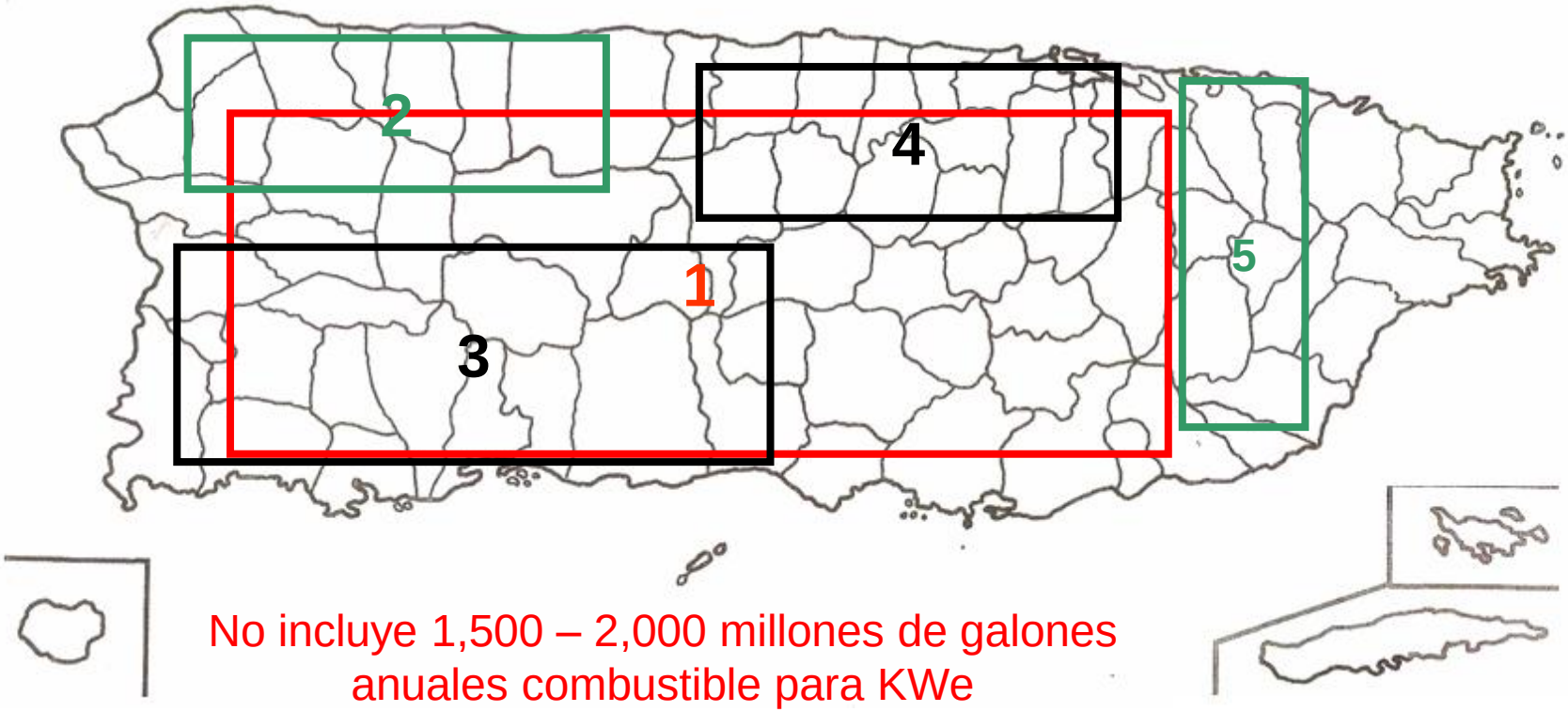
Selected Area with High Wind Speed Resources



Populated Areas and Unpopulated Areas in Puerto Rico



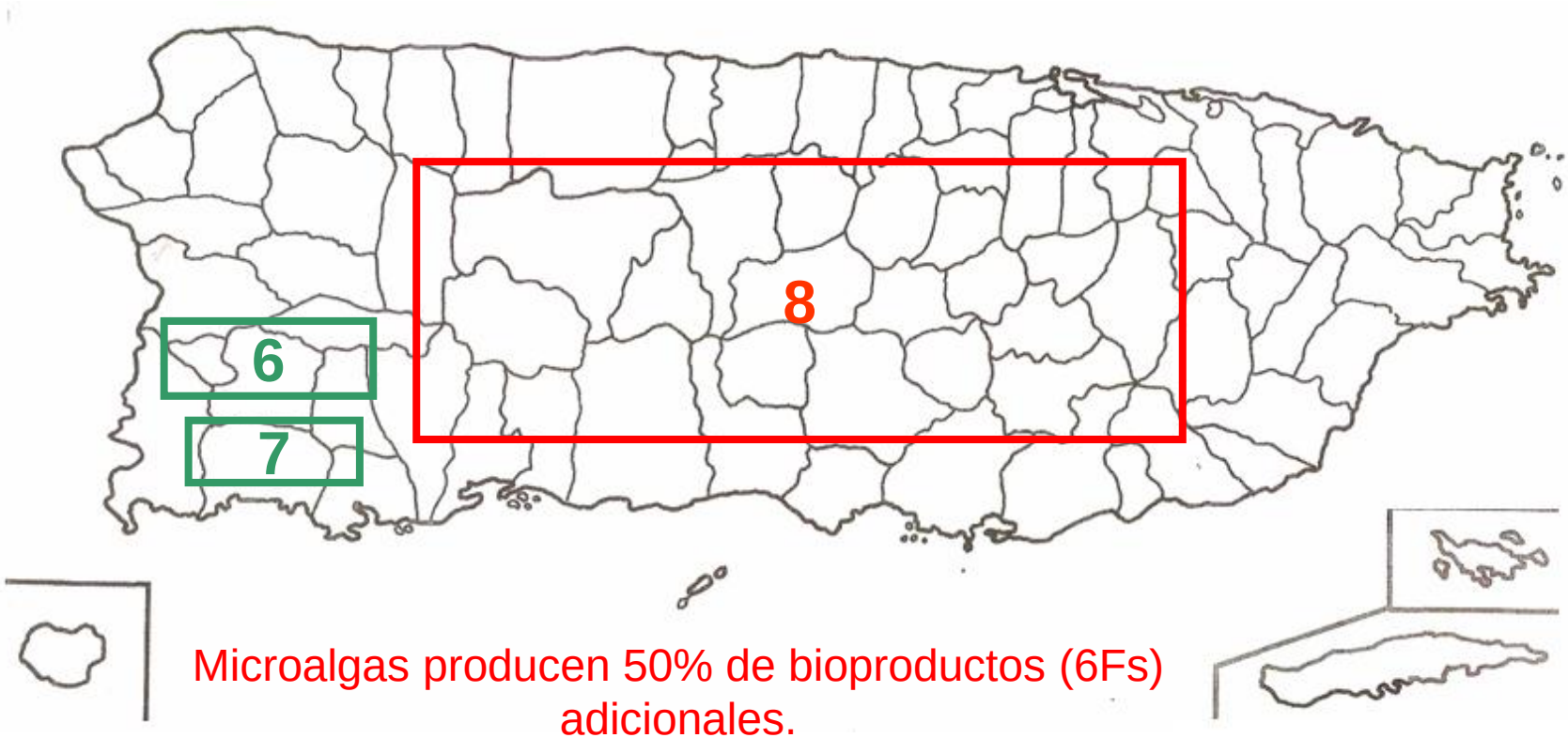
Area aprox. necesaria para la producción de Biogasolina 1,000 millones de galones anuales



No incluye 1,500 – 2,000 millones de galones anuales combustible para KWe

	Consumo de gasolina anual en PR	1,000,000,000	Unidades	Hectáreas de PR	Und.	% Hectáreas de PR
	Biomasa	Productividad por hectárea	gal *año	906,500	gal	100%
1	Bioetanol de almidón	2,000	gal / ha*año	500,000	ha	55.2%
2	Bioetanol de lignocelulosa (agresivo)	10,000	gal / ha*año	100,000	ha	11.0%
3	Bioetanol de lignocelulosa (moderado)	5,000	gal / ha*año	200,000	ha	22.1%
4	Gasolina de microalgas en charcas por Fisher Tropsch (+50% de productos adicionales)	10,000	gal / ha*año	100,000	ha	11.0%
5	Gasolina de microalgas en biofotoreactores por Fisher Tropsch (+50% de productos adicionales)	15,000	gal / ha*año	66,667	ha	7.4%

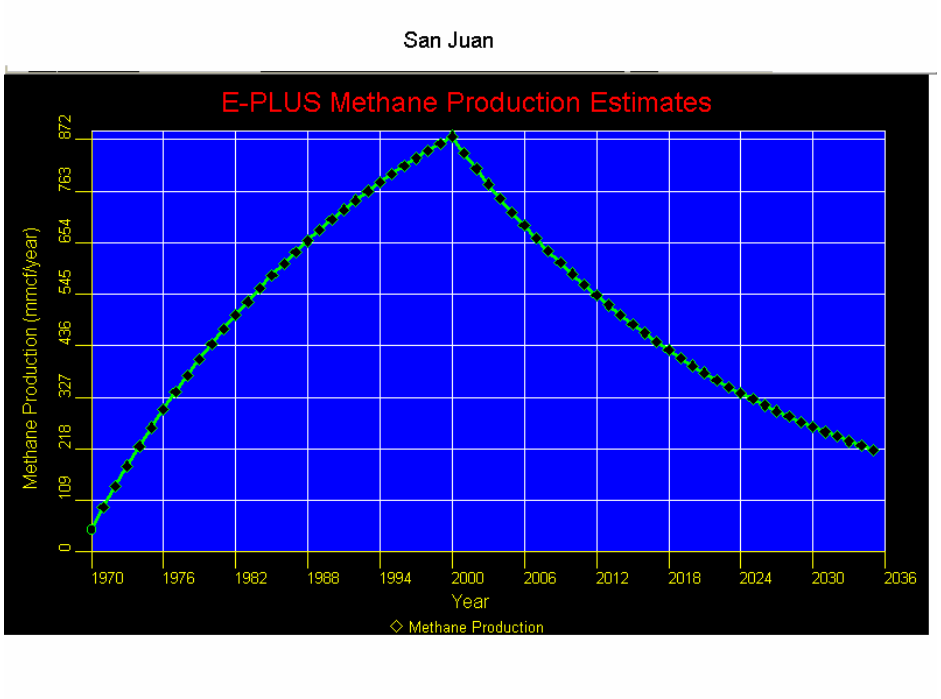
Area aprox. necesaria para la producción de Biodiesel 500 millones de galones anuales



Microalgas producen 50% de bioproductos (6Fs) adicionales.

	Consumo de diesel anual en PR	500,000,000	Unidades	Hectáreas de PR	Und.	% Hectáreas de PR
	Biomasa	Productividad por hectárea	gal *año	906,500	gal	100%
6	Biodiesel de microalgas en charcas (+50% de productos adicionales)	20,000	gal / ha*año	25,000	ha	2.8%
7	Biodiesel de microalgas en biofotoreactores (+50% de productos adicionales)	30,000	gal / ha*año	16,667	ha	1.8%
8	Biodiesel terrestre	1,500	gal / ha*año	333,333	ha	36.8%

Vertederos, KWe & Landfill Diesel



	Total Tons Accumulated	Peak Electric Capacity, kW
Toa Baja	13,353,888	6,100
San Juan	10,411,343	4,940
Ponce	8,151,993	4,076
Carolina	6,730,869	3,365
Humacao	5,430,701	2,715
Guaynabo	2,970,383	1,485
Bayamón	2,886,982	1,443
Mayagüez	2,802,919	1,401
Arecibo	2,743,373	1,372
MOCA	2,287,417	1,144
Others	23,921,419	11,961
Total Top 10	57,769,868	28,042
Total	81,691,287	40,003

San Juan Landfill Diesel Potential: 2 – 4 Million Gallons/year

Conclusion

- We recommend wind, PV and ocean waves to be targeted in PR in the immediate future. Only 10% use of these resources supply all the ***ENERGY*** demand of PR (2006 level)
- The question should not be how to best integrate renewable resources into the existing energy infrastructures, but how the latter should change or *transition* in order to make way for the maximum penetration possible (technologically, economically, environmentally and socially) of renewable energy sources.
- Need to have systems thinking, beyond our disciplinary or sector bounds

Alice in Wonderland

- "Scientific research results do not play an important role in the agenda-setting process."
  - Dearing and Rogers (1996)
- Research ***<u>DOES NOT</u>*** translate immediately into social actions or policy changes

Achievable RETs vs. Socially Acceptable RETs

Parameters for achievability:

- Surface area, or "footprint"
- Capital costs and potential electric energy contribution from each resource.
- Estimated availability and variability the resource
- The state of the technologies used to harvest their energy

(Irizarry, O'Neill and Colucci, 2009)

Project

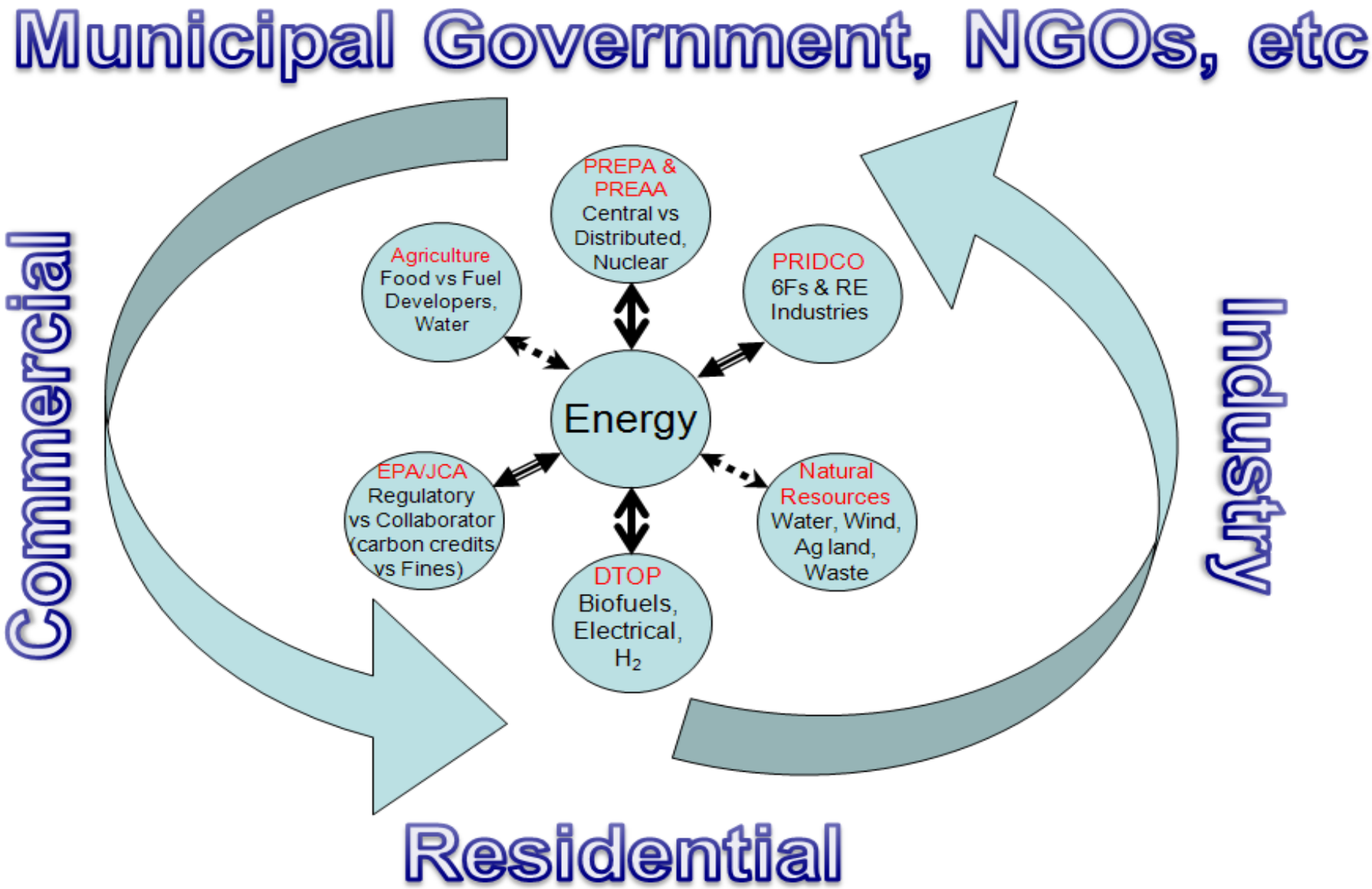
Success

Parameters for acceptability:

- Perception of procedural justice in the decision-making process
- Perception of equity in the distribution of costs and benefits associated with the project.
- Perceived of economic, environmental and aesthetic consequences

(Ortiz and Perez, 2008)

Puerto Rico's Energy Challenge



Renewable Energy Alternatives

Based on the Report "Achievable Renewable Energy Targets For Puerto Rico's Renewable Energy Portfolio Standard" sponsored by the Puerto Rico´s Energy Affairs Administration

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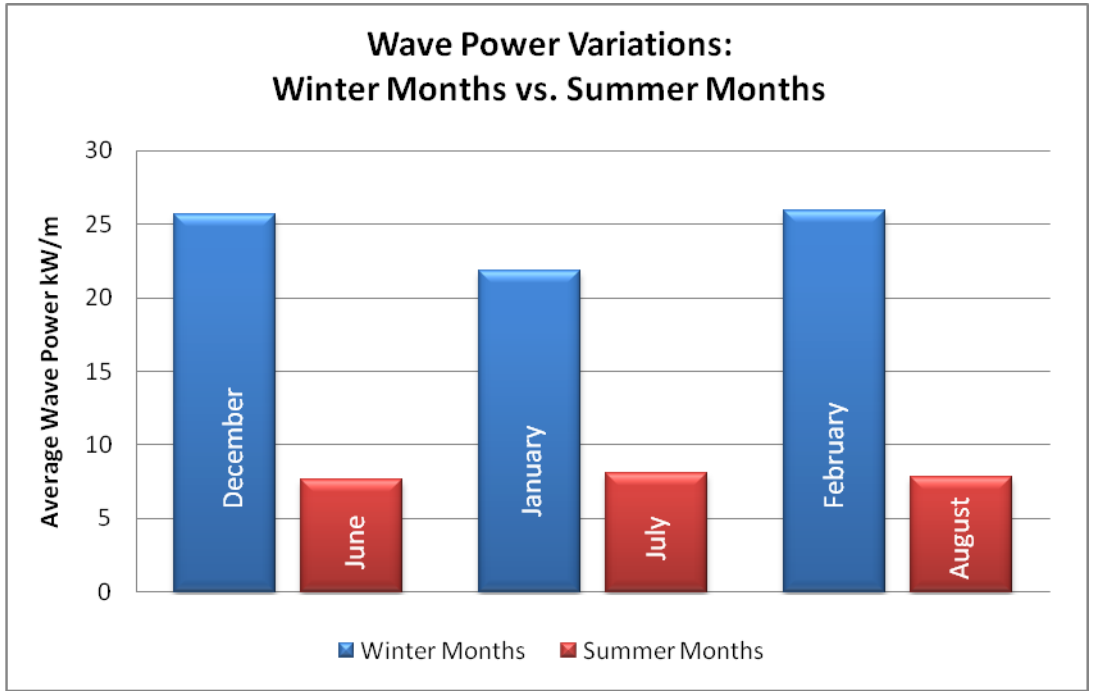
Variability of Ocean Wave Energy

- Scatter diagrams were used to analyze the data.
- Major variability occur with: season of the year and the climate conditions.
- Winter shows highest wave heights, summer shows the lowest.

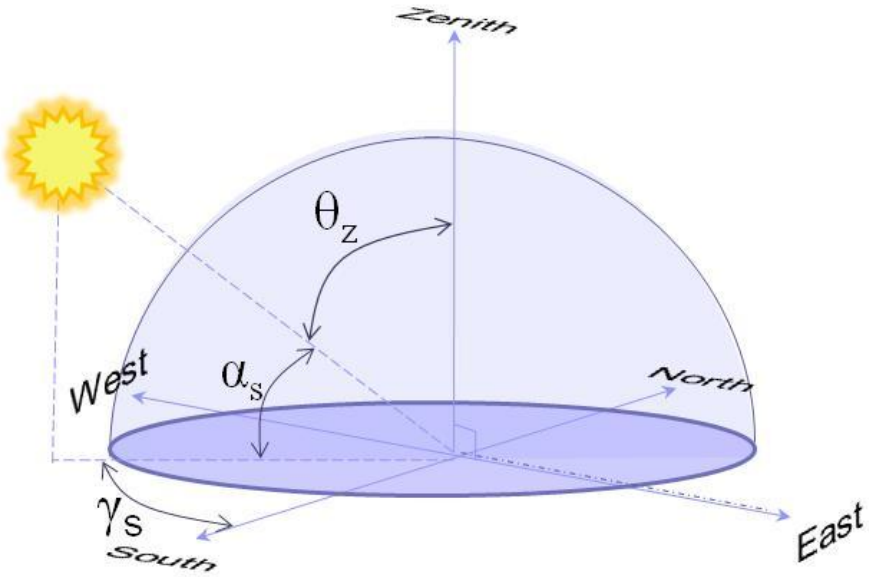


Data from station L1-9 of the WIS model located at the north east of Puerto Rico for the year of 1999.

Franchesca Aponte & Magaby Quintero

Resource Variability

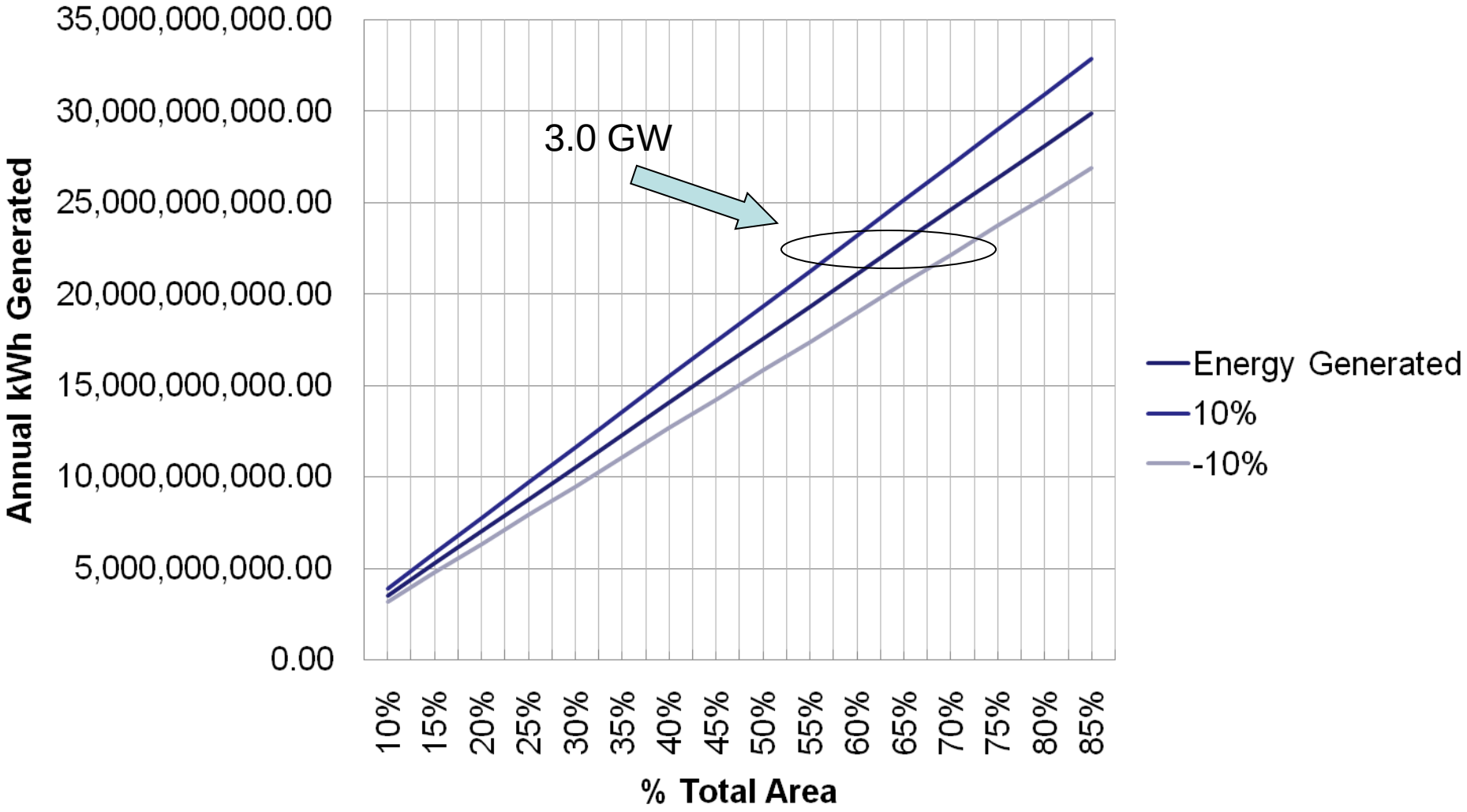
- Solar variations are changes in the amount of radiant energy emitted by the Sun. It has been typically attributed to factors such as seasons, Earth-Sun distance, atmospheric conditions, location, time of day
- Common cost estimates figures are 8,000 $/kW for grid-tied systems, and 14,000 $/kW for stand-alone systems



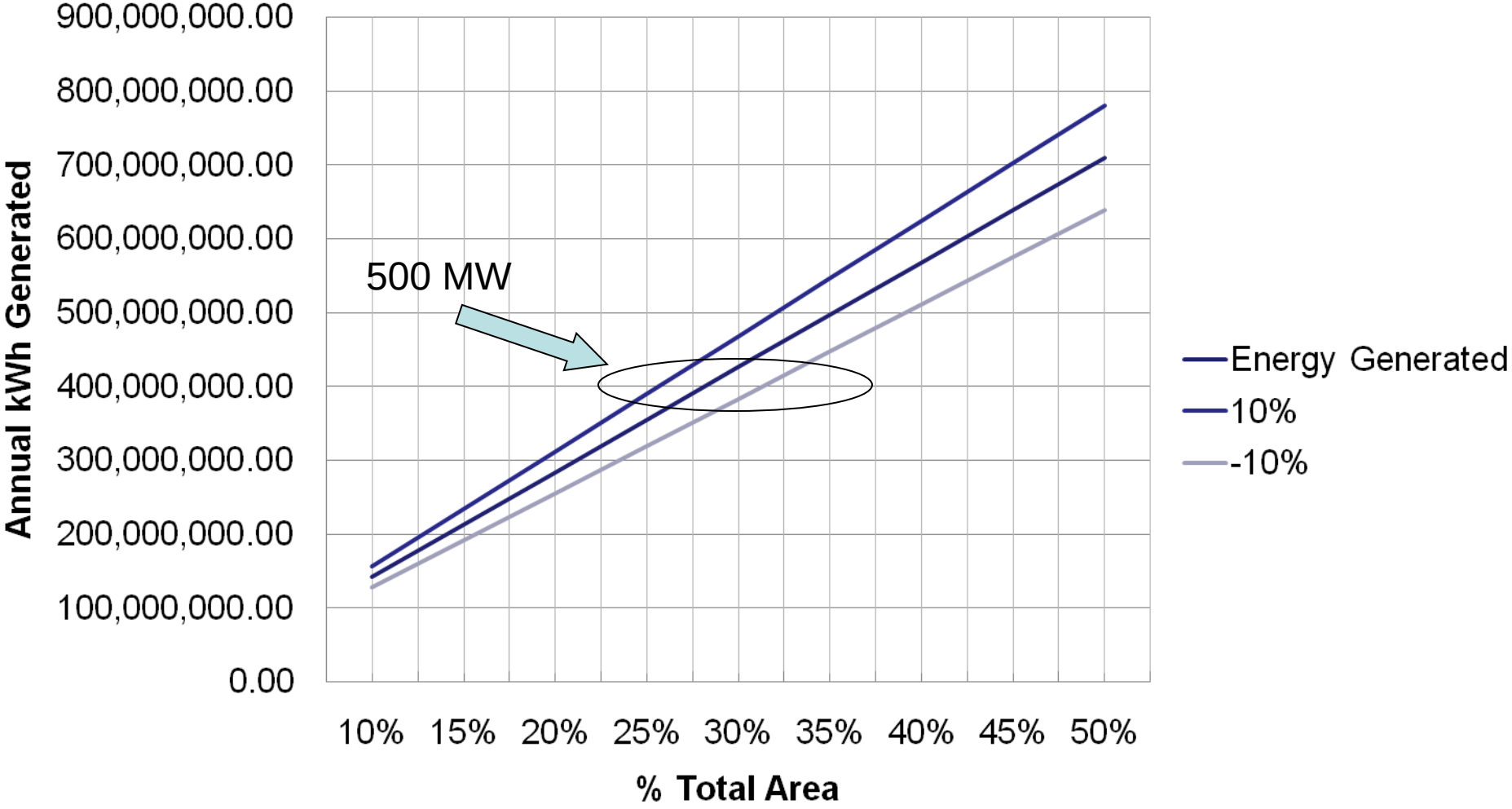
Conversion Technology: Residential, Commercial and Industrial Footprint

- There are 1,254,318 residences with an average size of 152m^2
- Only single (994,754 units) and contiguous unit (194,813 units) types considered to account for uncertainties
- Total estimated available area for this sector is 180,814,184.00m^2
- The total available commercial and industrial area in the island is 7,300,000.00 m^2 and 2,702,545.45m^2 respectively.

Estimate of potential electric energy residential contribution

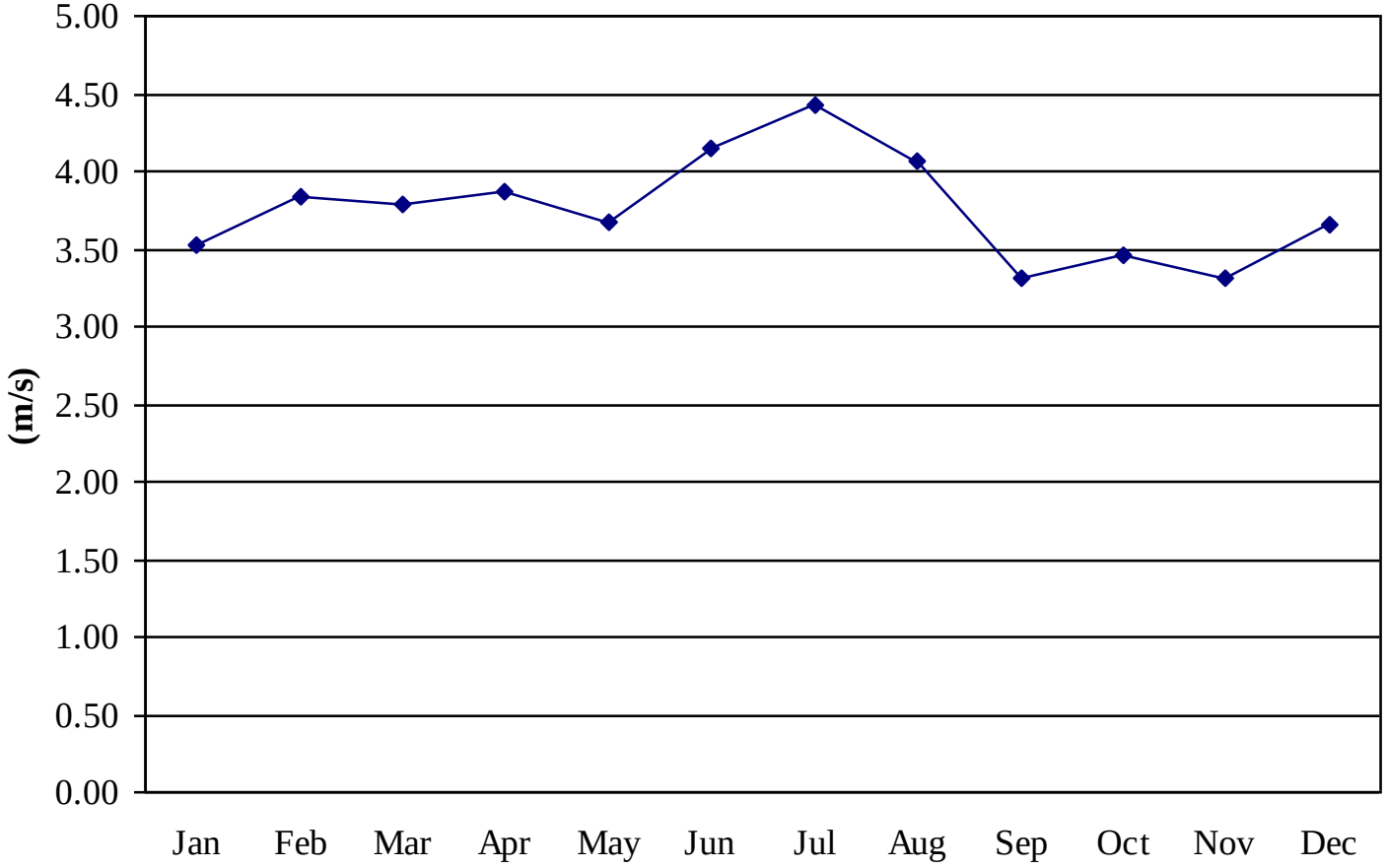


Estimate of potential electric energy commercial contribution



Variability of Wind by month

More wind in summer, based on "Monthly Distribution of mean wind velocity in (m/s)".



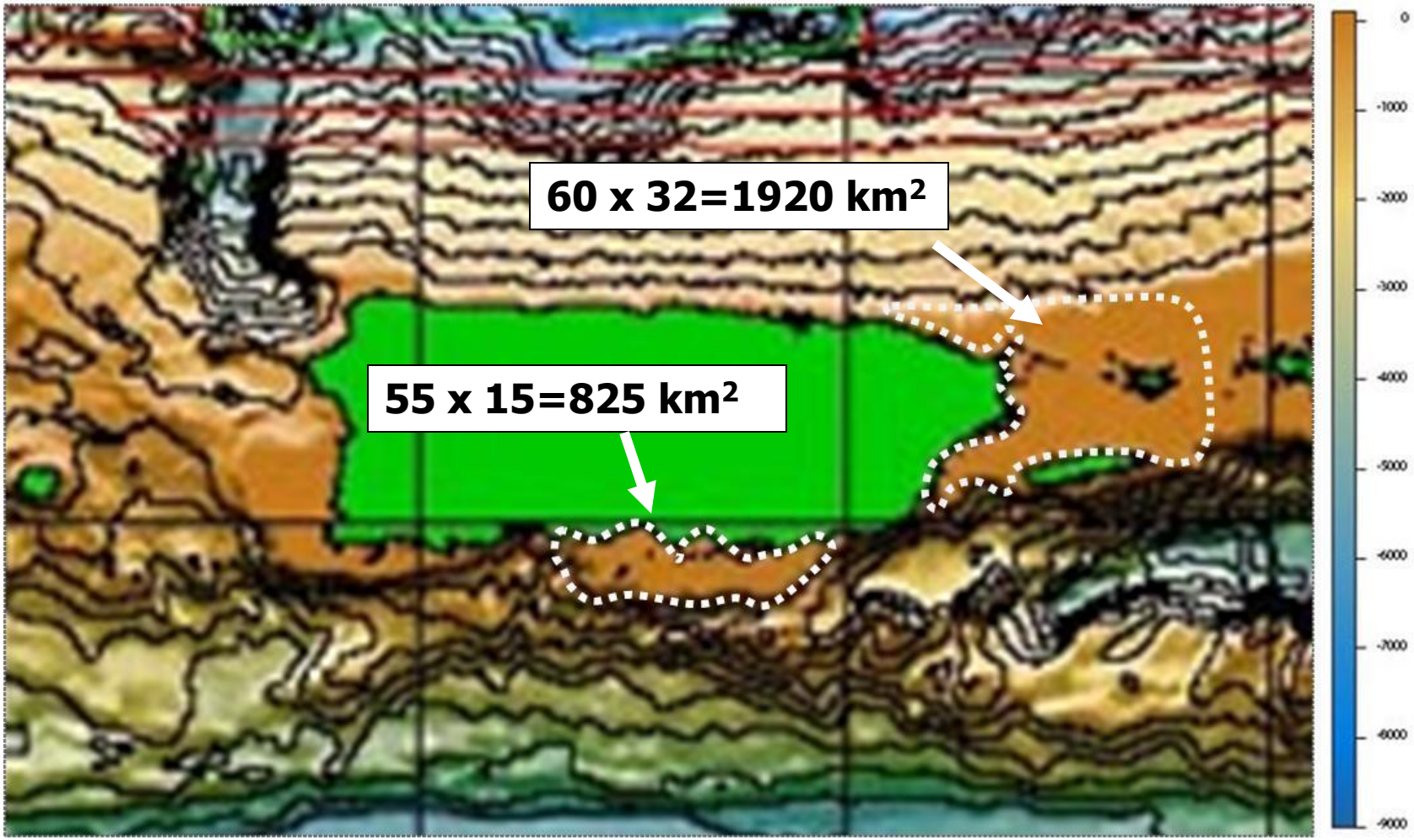
Average Monthly Wind Speed

MW of installed capacity large wind turbines

Turbine	Power capacity [MW]	Rotor diameter [m]	k=10	k=8	k=10	k=8	k=10	k=8
			MW in 480 km^2		MW in 240 km^2		MW in 48 km^2	
Enercon E53	0.81	53	2768	4325	1384	2163	277	433
Vestas V52	0.85	52	3018	4715	1509	2358	302	472
Gamesa G58	0.85	58	2426	3790	1213	1895	**243**	**379**
AAER A1000	1.00	58	2854	4459	1427	2229	285	446
Enercon E 70	2.30	70	4506	7041	2253	3520	451	704
GE 2.5xl	2.50	100	2400	3750	1200	1875	**240**	**375**

Is it better to install less very large turbines or more smaller turbines? Wind turbines are not power producers, they are energy producers. The answer is install turbines that produce the most amount of energy, turbines that <u>match</u> the wind regime. Use the turbine power curve and wind distribution.

Off-shore wind turbines

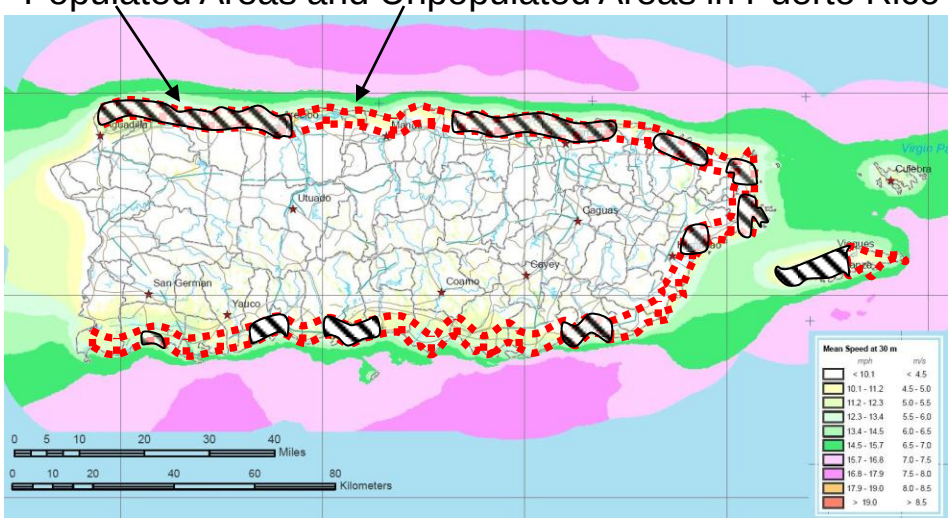


With a density of 5 MW/km^2 the 2,745 km^2 can accommodate 13,725 MW of installed wind capacity. If only 10% is used we still have 1,372 MW.

How many small turbines?

- Best wind, and best access to infrastructure, in a 3 km wide band along the north, east, and south coast
  - 50% (480 km²) heavily populated thus to be used for small wind.
  - 1 km² = 250 cuerdas
  - 480 km² = 120,000 cuerdas
- Assume one small turbine per residence, the question is; How many residences per cuerda (km²)?
  - One residence per cuerda = 120,000 small turbines
  - 10% of this? 12,000 small turbines (10 – 50 MW)

Populated Areas and Unpopulated Areas in Puerto Rico



Disponibilidad de Recursos, Desperdicios

			Proyección de generación de desperdicios sólidos (Toneladas/día)		Productos Químicos MMGPY	
Categoría		**% del peso**	**2010**	**Generación eléctrica MW*****	**25%**	**50%**
Platico	Polietileno tipo 1	1.1	123	4	3	6
	Polietileno de alta densidad (HDPE) tipo 2	2.9	325	10	8	17
	Tipo 3-7 (PVC, LDPE, PP, PS, Mezclado)	6.5	728	22	19	38
Papel-Cartón	Papel de alta calidad	1.3	146	4	4	8
	Papel de baja calidad	8.7	975	29	25	51
	Cartón Ondulado	9.3	1,042	31	27	54
Metal	Metal ferrosos	9.4	1,053			
	Metales no-ferrosos	1.1	123			
Jardinería	**Material vegetal**	**20.4**	**2,286**	**69**	**60**	**119**
Orgánico	**Material orgánico**	**12.9**	**1,445**	**43**	**38**	**75**
C&D	Escombro de contracción y demolición	17.1	1,916			
Vidrio	Todo tipo de vidrio	2.4	269			
HHW	Desperdicio peligroso caseros	0.5	56	2	1	3
Otros	No definido de otra manera	6.4	717	22	19	37
Total		100%	11,204	235	204	409

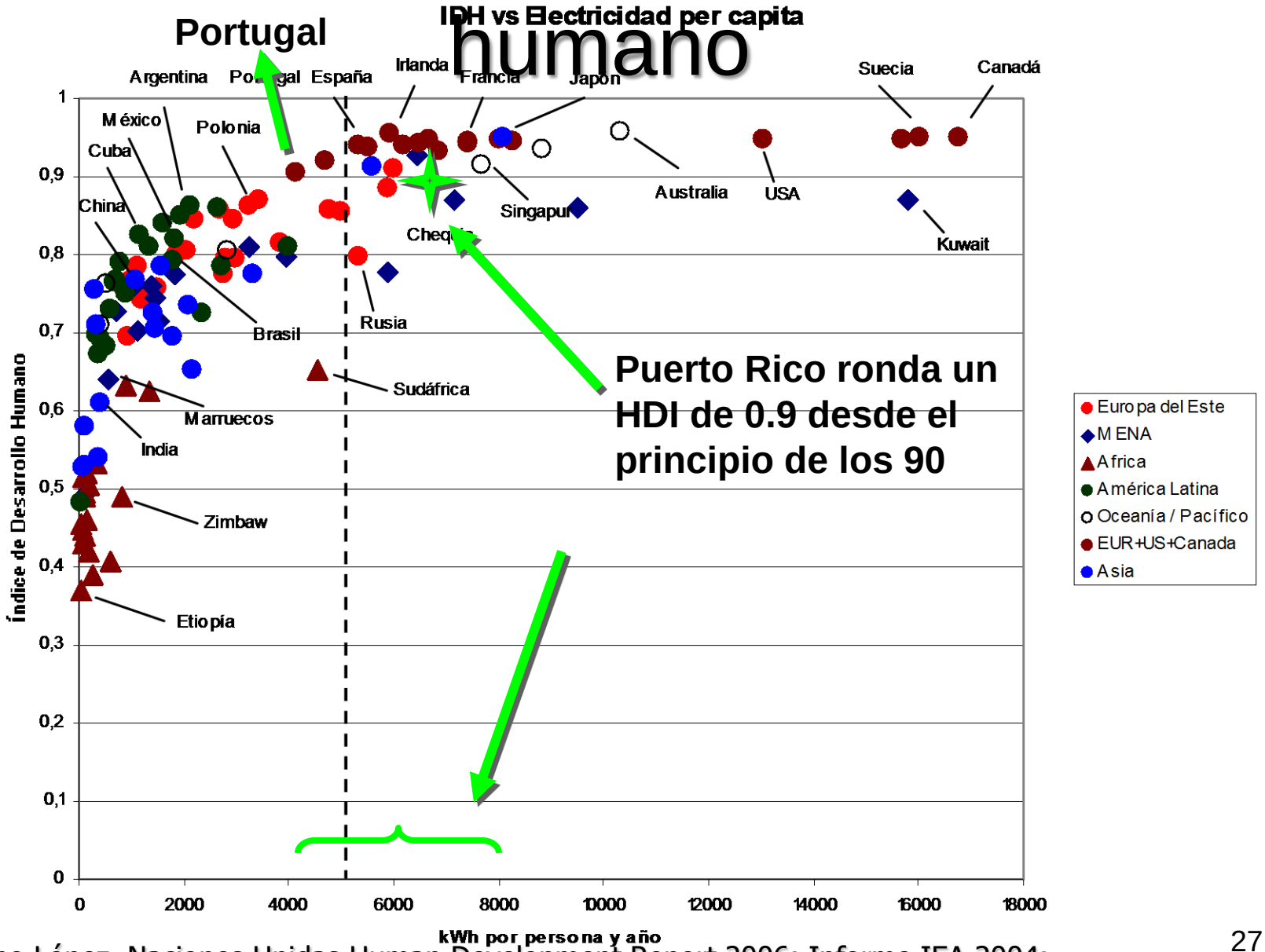
Fuente: Itinerario Dinámico, 2007

*** 1000 Toneladas al dia de desperdicio equivale a 30 MW

Conservación y eficiencia: reducción en consumo

- El consumo en PR en el 2005 fue de unos 24,960,000,000 kWh, lo que equivale a unos 6,568 kWh por persona por año
- Bajar el consumo anual a 4,900 kWh por persona equivale a una reducción de un 25% usando los niveles de 2005.
- Esto ES POSIBLE, si usamos de comparación a Portugal (consumo anual por persona fue de unos 4,000 kWh). Nadie puede decir que Portugal es un país sub-desarrollado, de hecho, es uno de los países con uno de los índices de desarrollo humano más alto del Mundo (Naciones Unidas)

Consumo de energía y desarrollo humano



Dr. Cayetano López, Naciones Unidas Human Development Report 2006; Informe IEA 2004; Pablo Espinoza, **Índice de Desarrollo Humano:Estimado para Puerto Rico**, Tesis UPR

Uso de Recursos Renovables

- La AEE ha establecido una meta de 15% de uso de renovables (2024). El DDEC ha establecido un 25% (2025). Estas metas se relacionan mayormente a proyectos GRANDES de energía renovable.
- El estudio ARET auspiciado por la AAE demostró que usando el viento, el sol y las olas, PR tiene disponibles recursos de energía renovable mucho mayores.
- Siendo conservadores, y también considerando que se establezcan mecanismos para que a nivel pequeño y distribuido tengamos una penetración entre 10 y 15% de renovables, una meta realista es 30% de energía renovable

Renewable Portfolio Standards

- Es una política pública estatal que le requiere a los proveedores de electricidad que obtengan, de fuentes renovables, cierto por ciento mínimo de la potencia que venden para una fecha específica.

Renewable Energy Credits (REC)

- Es un certificado de que un kWh de electricidad fue generado usando una fuente renovable y fue vendido a un abonado en el estado.
  - Certificado de generación y venta <u>no de capacidad</u>.
  - El REC es un producto separado del kWh mismo.

Renewable Energy Credits (REC)

- El RPS se ejecuta con el requisito a cada generador o vendedor de que posea una cantidad de créditos (REC) equivalente a cierto por ciento de su generación (o venta) anual en kWh.

Ejemplo: RPS = 5%, Si el generador vende 100,000 kWh en un año, necesita poseer 5,000 REC al final del año.

Renewable Energy Credits (REC)

- El generador de electricidad renovable es el dueño de los REC y puede venderlos junto con los kWh o puede vender los kWh a un comprador y los REC a otro, cada cual al valor de su propio mercado.
  - Se limita al valor de los REC, digamos, 2.5 ¢/KWh