

Maximizing Available Wind and Hydro Resources

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Agenda

- Thesis Focus
- Hydro and Wind Characterization Across Azores
- Difficulties Associated with Maximizing Wind and Hydro Resources
- Case Study: Flores
- Model Overview

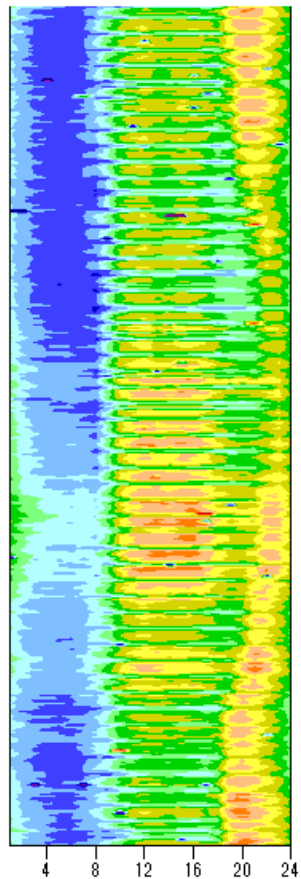
Thesis Focus

- Part 1: Characterize Wind and Hydro Resources
 - Are hydro and wind patterns complimentary or compounding?
- Part 2: Maximizing Available Wind and Hydro Resources
 - How much wind energy can be implemented on small islands without destabilizing the grid?
 - How does energy storage change this?
 - What price should islands be willing to pay for energy storage?

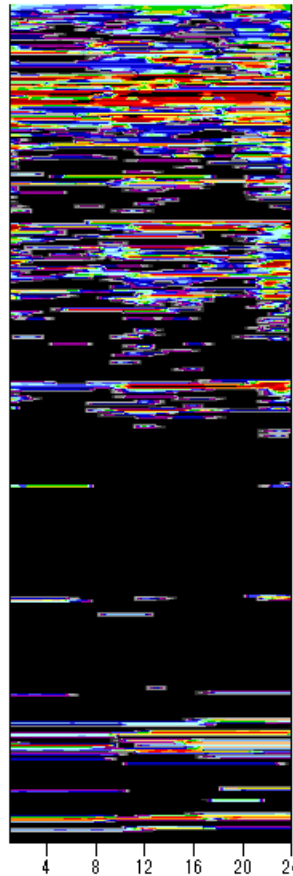
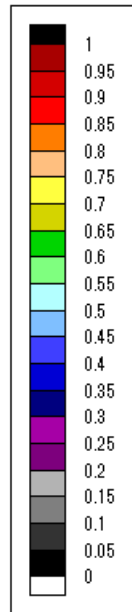
Part I - Wind and Hydro: Complimentary, or Compounding?

- Wind and Hydro:
 - Can they be used in tandem to balance one another?
 - OR
 - Do these resources display similar patterns and compound one another?
- How well do renewable resources match demand?
- Three islands utilize wind and hydro
 - Faial (run-of-river hydro)
 - Flores (small hydro dam)
 - Terceira (run-of-river hydro)

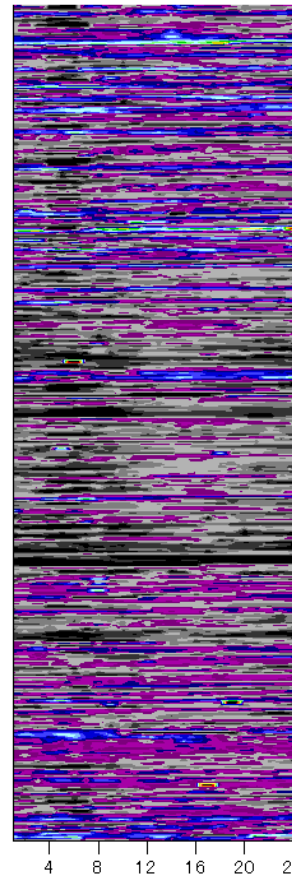
Faial: 2008 Wind and Hydro



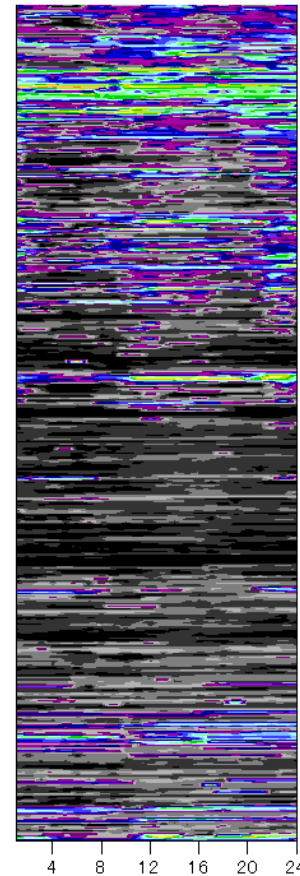
Total Generation



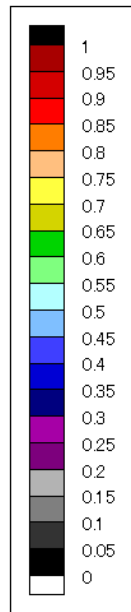
Hydro
Generation



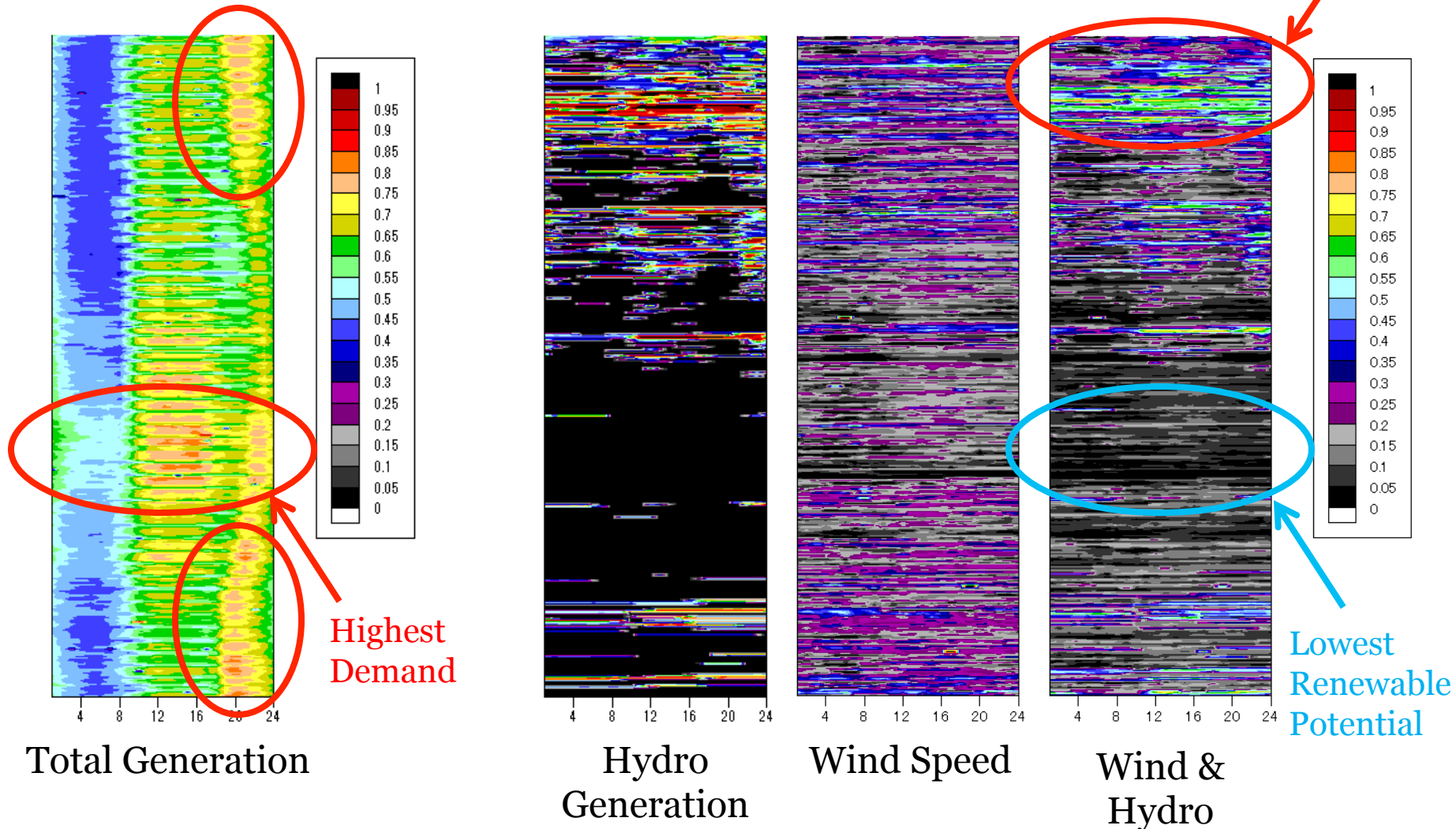
Wind Speed



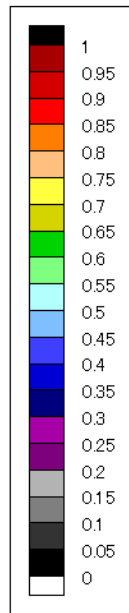
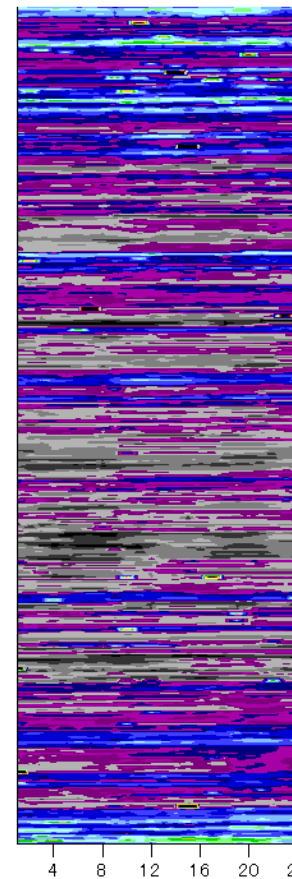
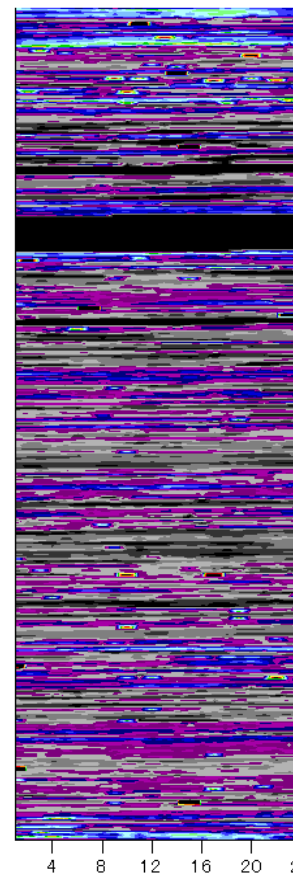
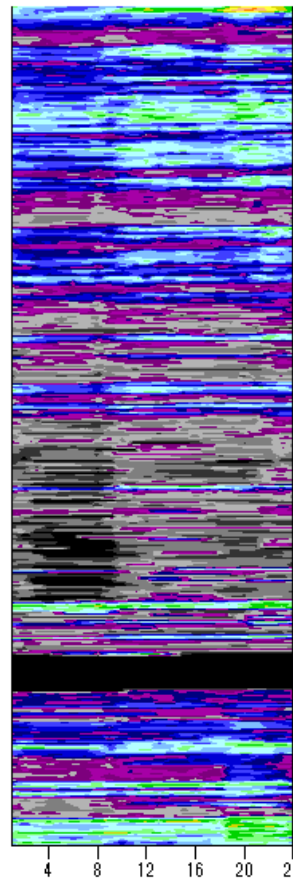
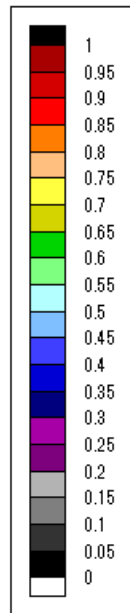
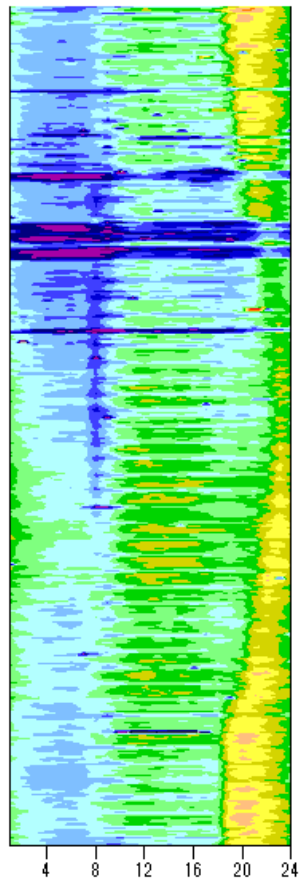
Wind &
Hydro



Faial: 2008 Wind and Hydro



Flores: 2008 Wind and Hydro



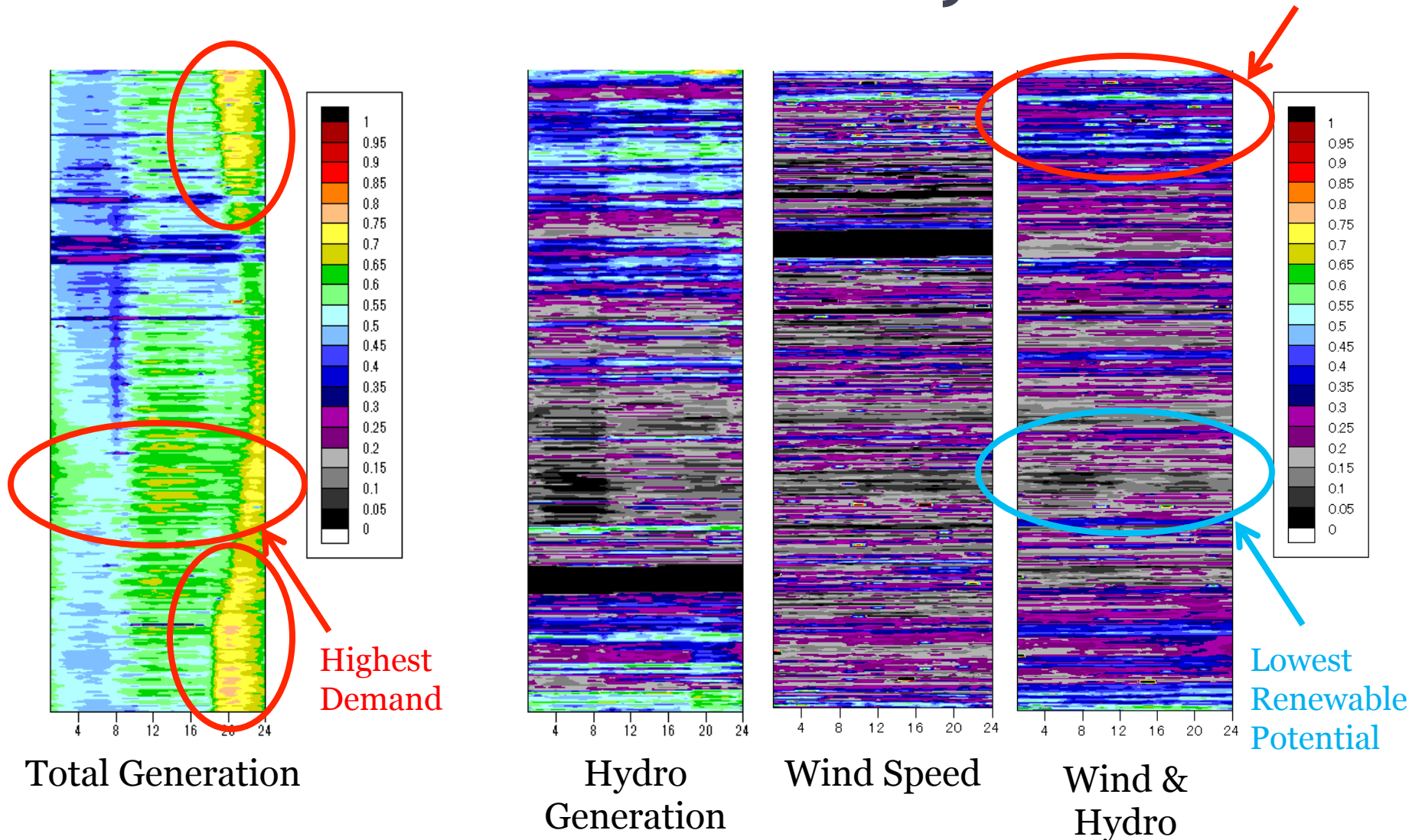
Total Generation

Hydro
Generation

Wind Speed

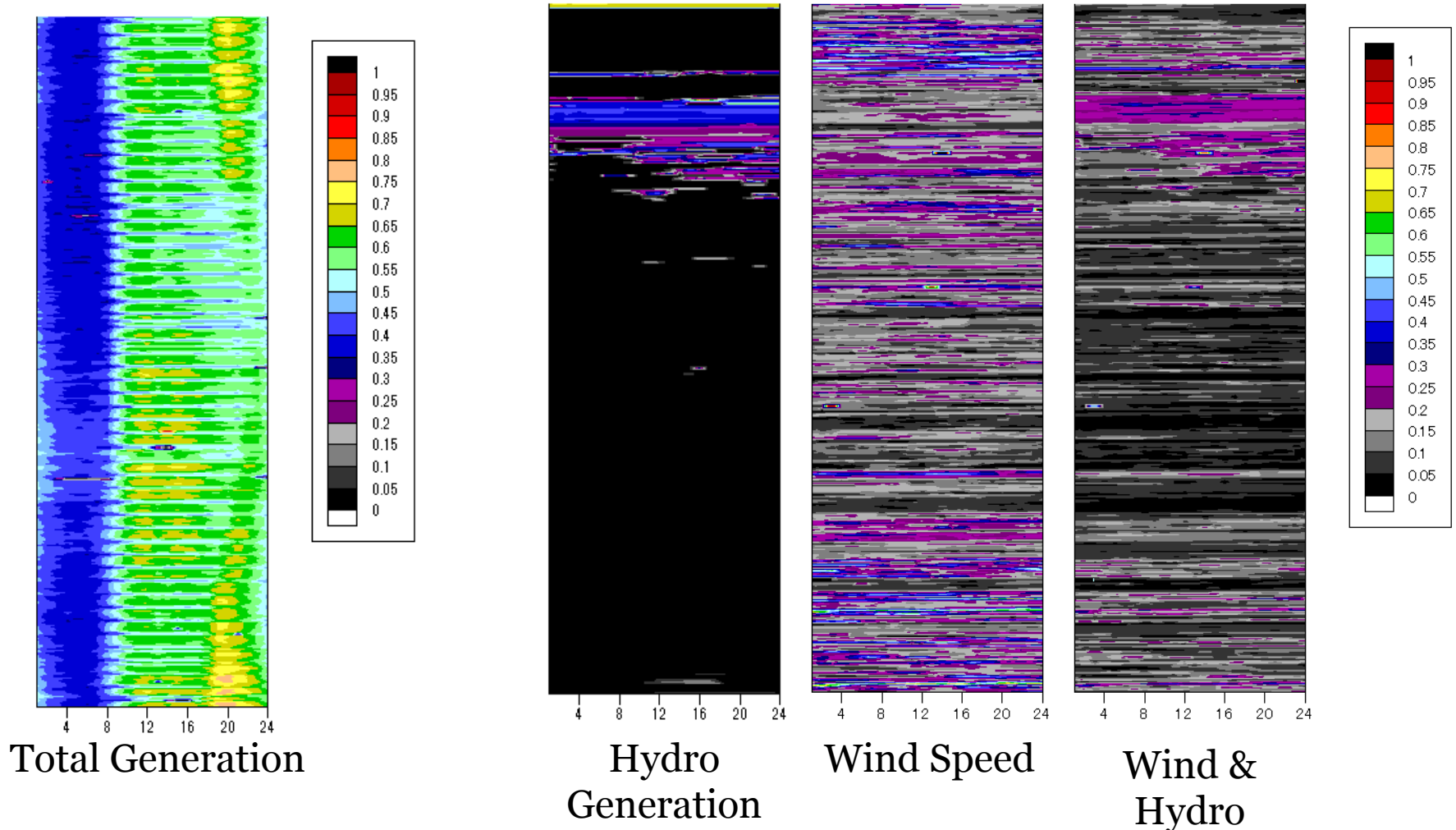
Wind &
Hydro

Flores: 2008 Wind and Hydro



Terceira: 2009* Wind and Hydro

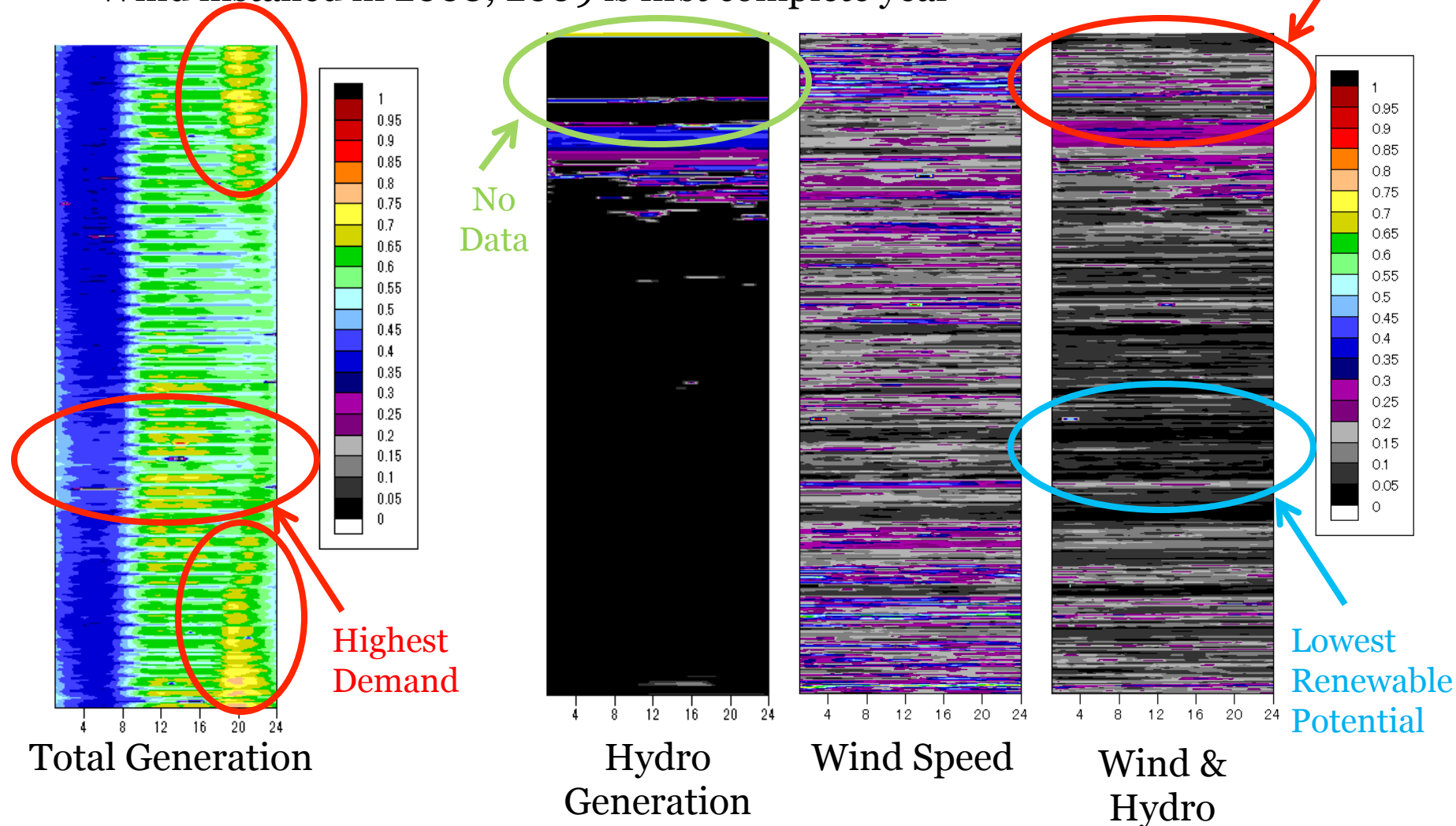
*Wind installed in 2008; 2009 is first complete year



Terceira: 2009* Wind and Hydro

*Wind installed in 2008; 2009 is first complete year

Highest
Renewable
Potential



Wind and Hydro: Results

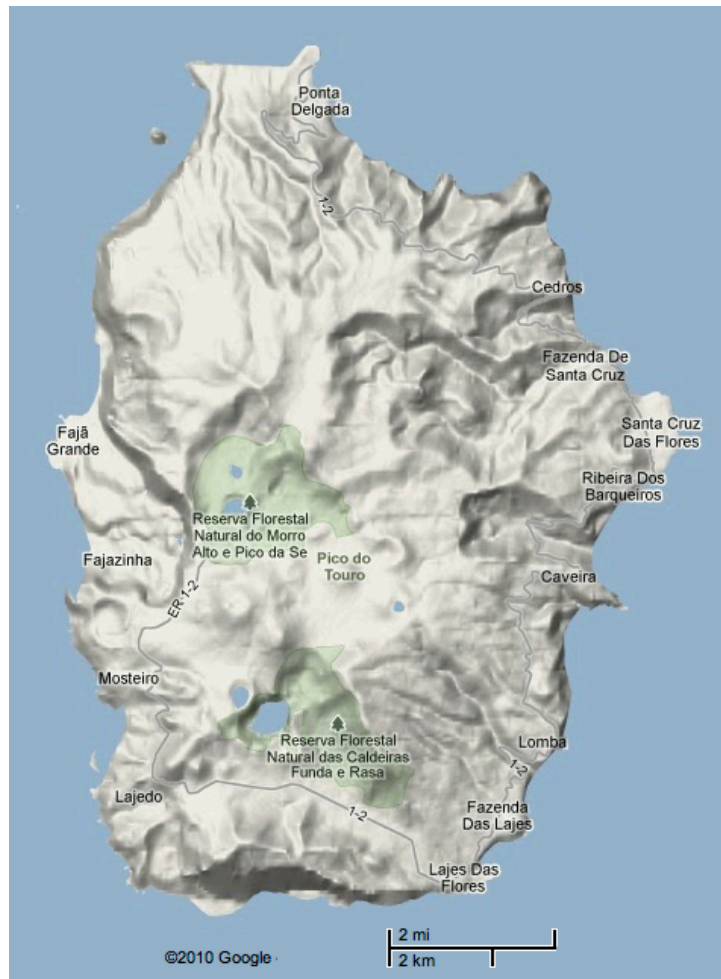
	Demand	Renewable Resources
Diurnal Patterns	Highest after sunset in winter	No significant matching pattern
Diurnal Patterns	Lowest in early morning, year-round	No significant matching pattern
Seasonal patterns: Winter	2 nd Lowest demand - all islands	Highest renewable resources – all islands
Seasonal patterns: Spring	Lowest demand - all islands	2 nd highest renewable resources – all islands
Seasonal patterns: Summer	Highest demand - all islands	Lowest renewable resources – all islands
Seasonal patterns: Fall	2 nd highest demand - all islands	2 nd lowest renewable resources – all islands

- Flores has hydro generation throughout the year
- Terceira and Faial have limited generation in summer and fall

Part II - Maximizing Resources for Electricity Generation

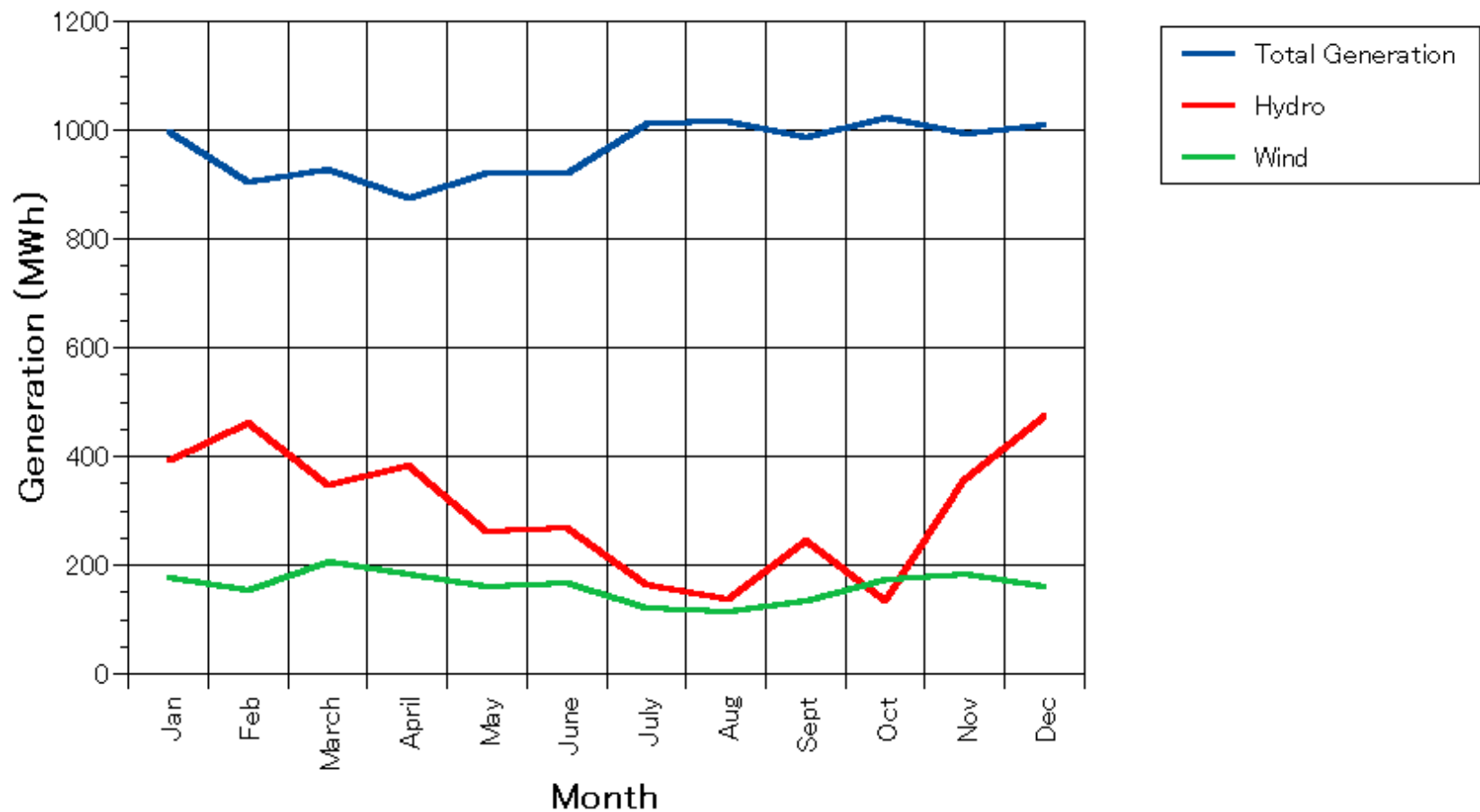
- Complexities of Small Island Energy Systems
 - Renewable sources often fluctuate quickly
 - Especially true of wind
 - Mostly unpredictable
 - Ramping wears thermal generators
 - Thermal generators need to back up renewable sources
- Storage potentially reduces both of these needs

Case Study: Flores

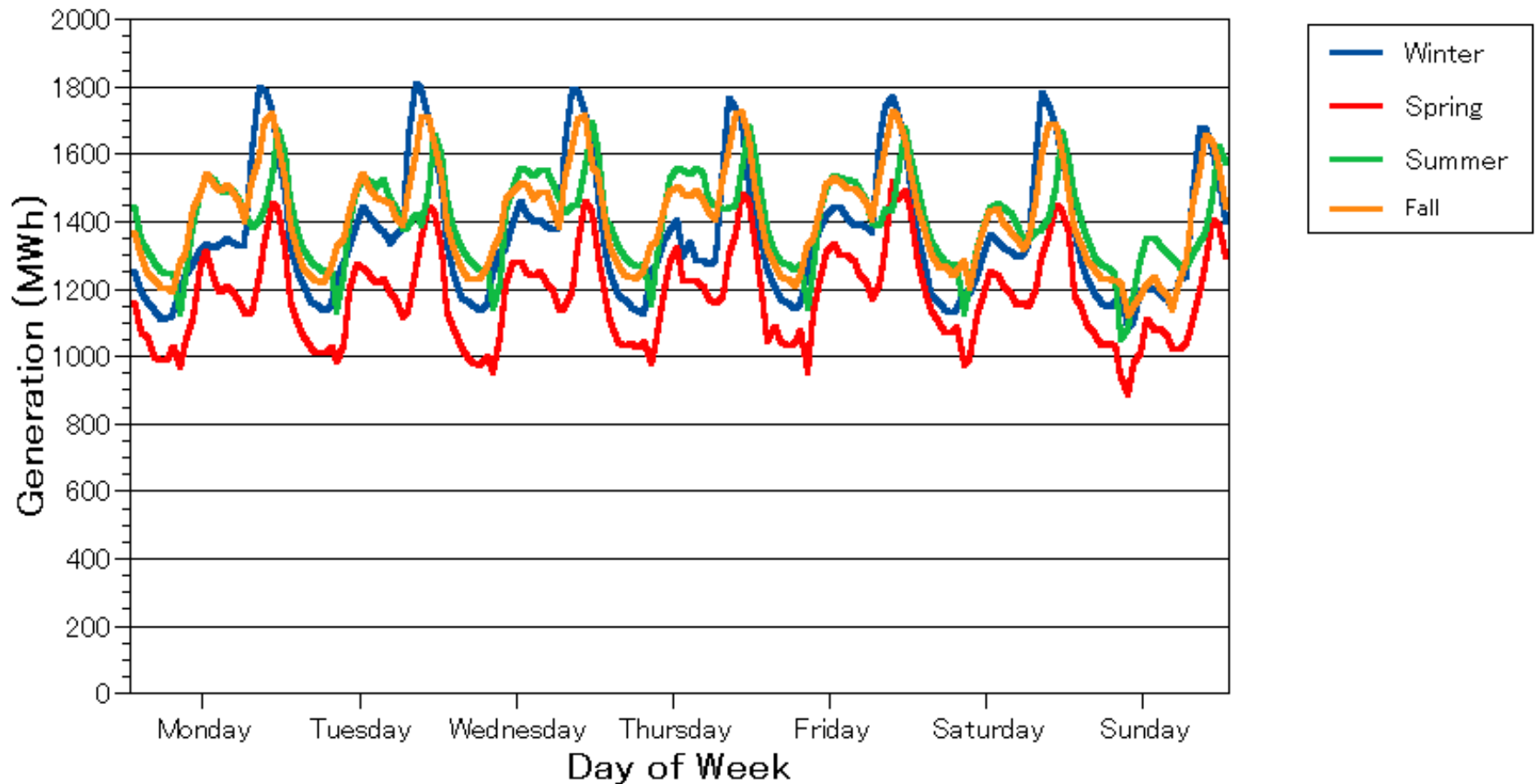


- Population: 4,000 (2%)
- Highest utilization of renewable energy (48%)
- Installed Capacity:
 - 2.2 MW thermal
 - 1.5 MW hydro
 - 0.6 MW wind
- Small hydro dam
 - ~ 6 MWh

2008 Monthly Generation

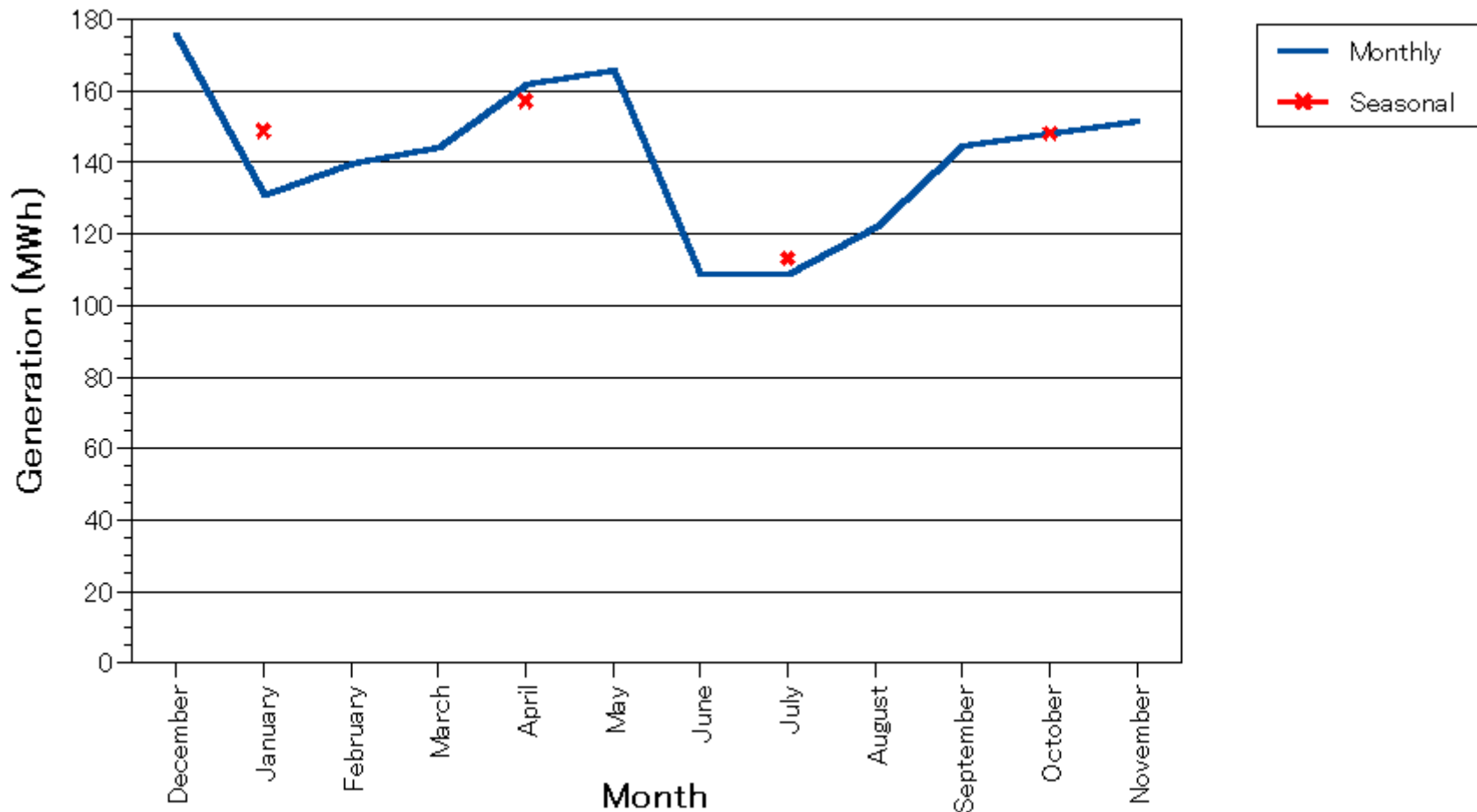


2008 Seasonal Variation in Generation



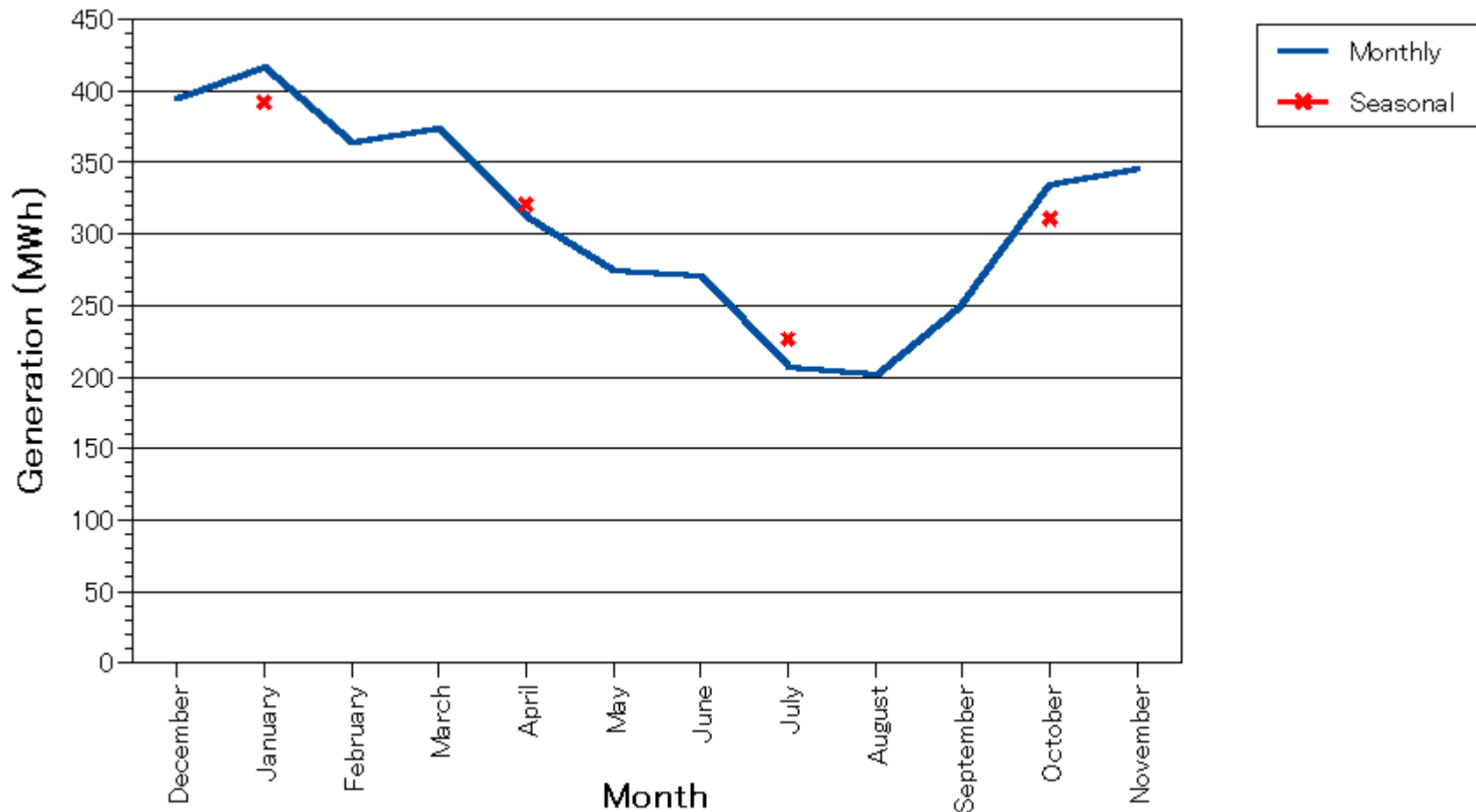
Renewable Generation Patterns - Wind

Total Monthly Generation – Wind, 6 Year Average



Renewable Generation Patterns - Hydro

Total Monthly Generation - Hydro, 18 Year Average



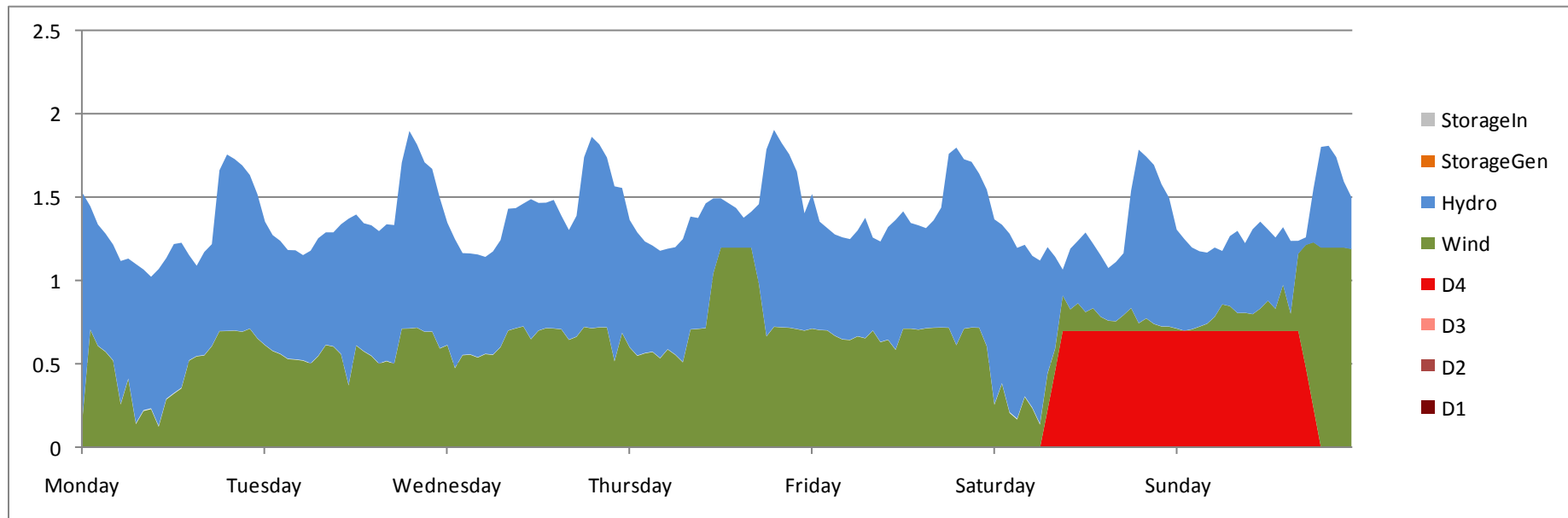
Model Overview

- 7-day hourly unit commitment
- Stochastic wind, hydro;
 - 9 Possibilities
- Model outputs generation in all scenarios
- Expected Value Solution
 - Cost of Running System
 - Deterministic optimization solution using weighted average of randomized wind, hydro
 - Wind, hydro result in lower value

Scenarios

- Seasons:
 - Winter (Dec.-Feb.)
 - Spring (March-May)
 - Summer (June-Aug.)
 - Fall (Sept.-Nov.)
- Years:
 - 2008 - Base
 - 2012 - Planned generation increase completed
 - **2018 - 75% renewable goal**
 - 1) No additional generation
 - 2) Various wind amounts
 - 3) Adding in storage

Sample Model Output - No Battery



Input:

January 1 – 7 2008

Demand, Wind, Hydro

Wind: 2.3 generated levels

Hydro: 1.25 generated levels

Results:

Total Cost

€ 26,052

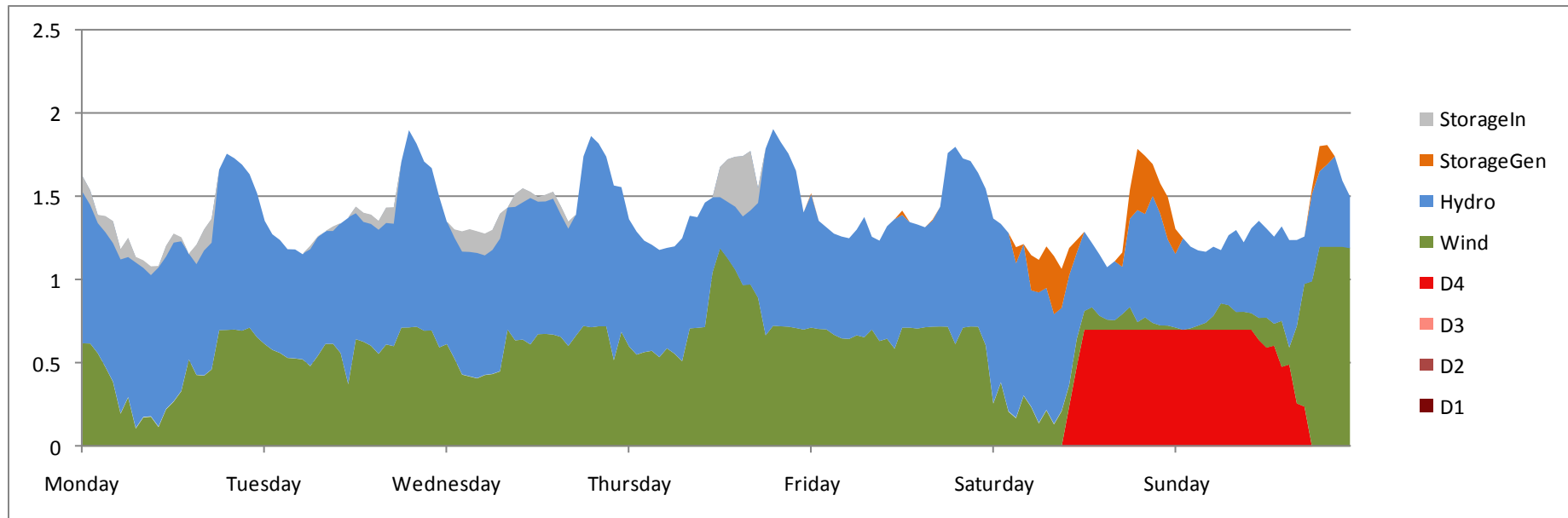
Total Diesel

22.81 MWh

Storage Gen

0 MWh

Sample Model Output - Battery



Input:

January 1 – 7 2008

Demand, Wind, Hydro

Wind: 2.3 generated levels

Hydro: 1.25 generated levels

Results:

Total Cost € 25,698

Total Diesel 20.12 MWh

Storage Gen 3.68 MWh

Questions?



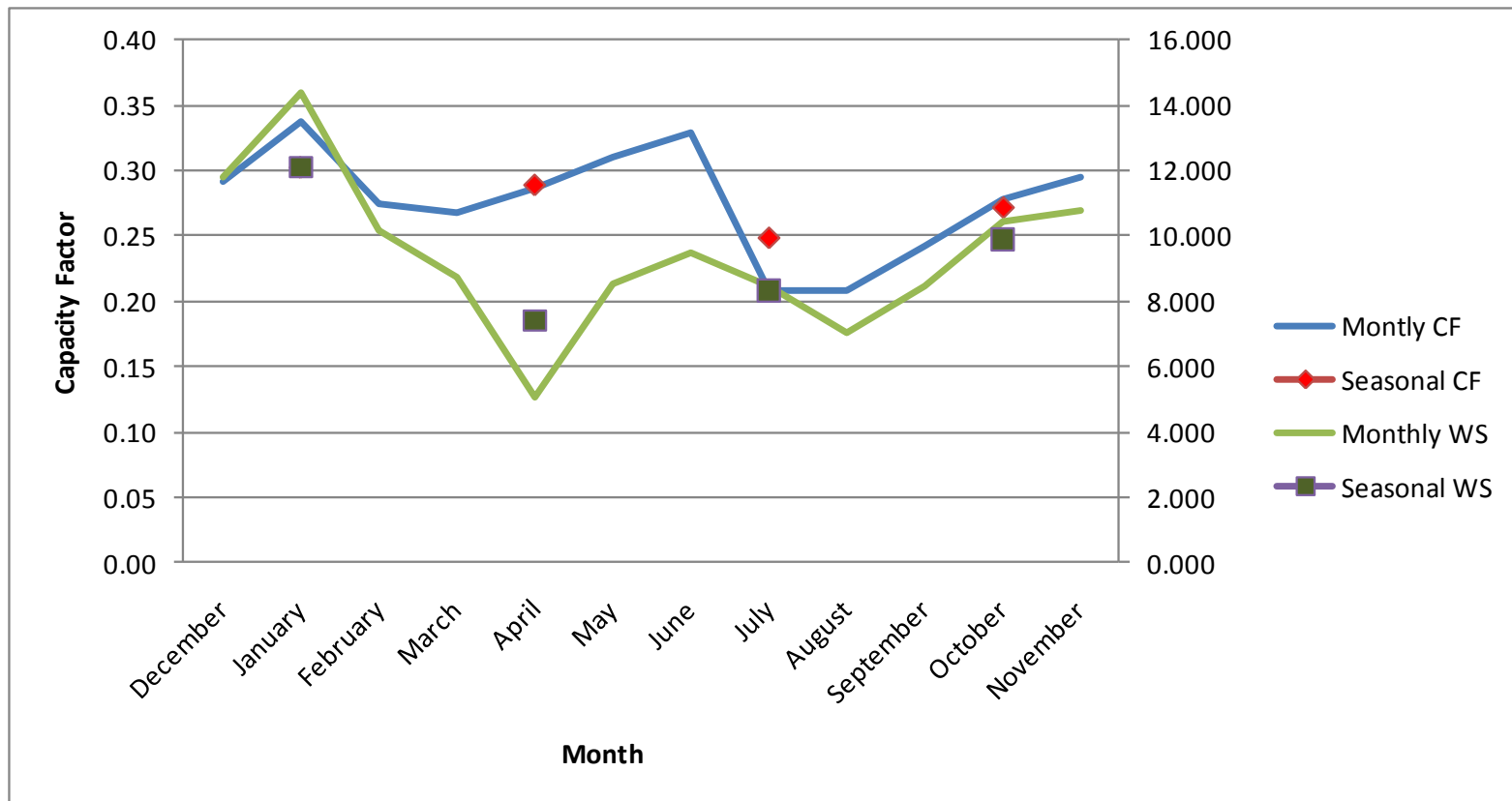
Back-Up Slides

Wind and Hydro: Results Continued

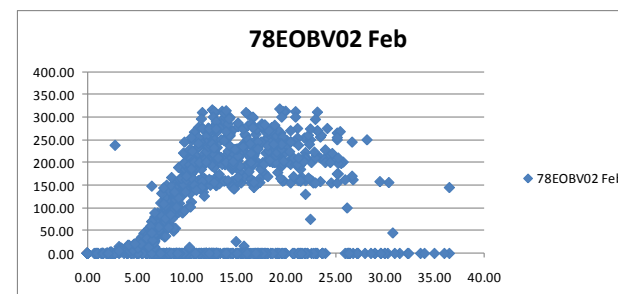
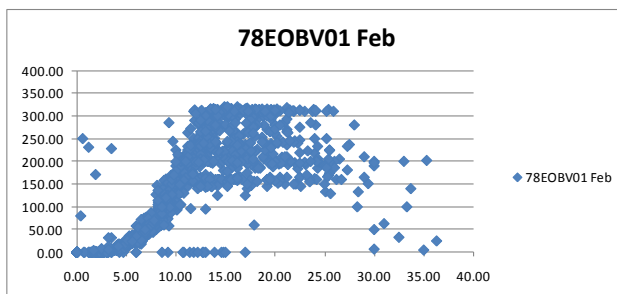
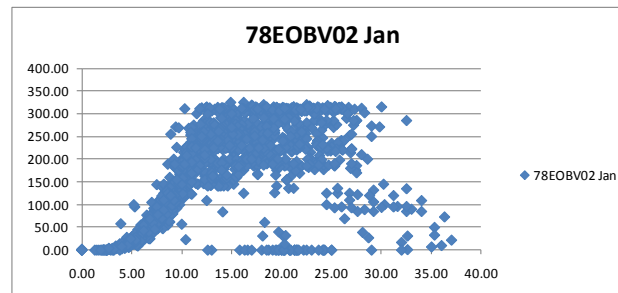
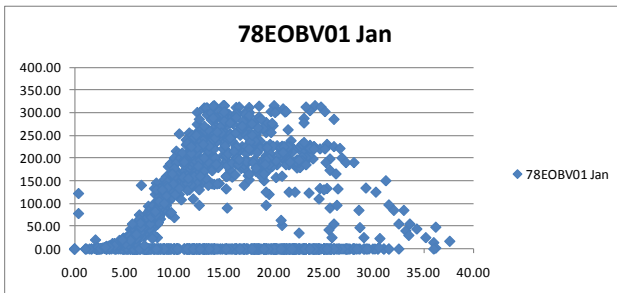
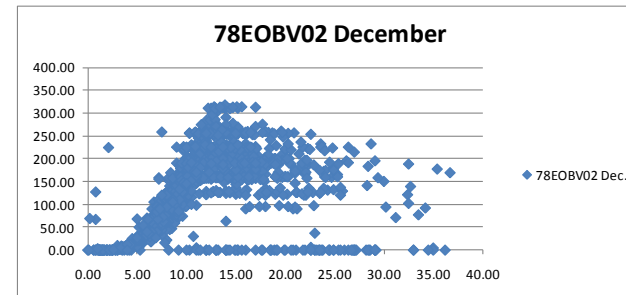
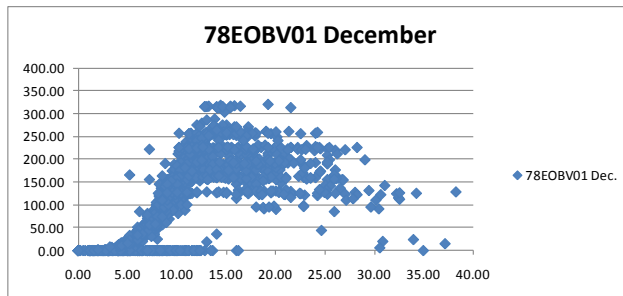
2008						2009					
		Demand	Wind	Hydro	Combined			Demand	Wind	Hydro	Combined
Flores	Winter	0.56	0.30	0.41	0.36	Flores	Winter	0.69	0.21	0.46	0.33
	Spring	0.48	0.18	0.31	0.25		Spring	0.25	0.14	0.13	0.13
	Summer	0.58	0.21	0.18	0.19		Summer	0.00	0.00	0.00	0.00
	Fall	0.58	0.25	0.17	0.21		Fall	0.22	0.01	0.01	0.01
2008						2009					
		Demand	Wind	Hydro	Combined			Demand	Wind	Hydro	Combined
Faial	Winter	0.58	0.24	0.35	0.30	Faial	Winter	0.68	0.20	0.08	0.14
	Spring	0.56	0.20	0.19	0.20		Spring	0.63	0.16	0.00	0.08
	Summer	0.62	0.14	0.05	0.10		Summer	0.68	0.11	0.00	0.06
	Fall	0.60	0.19	0.01	0.10		Fall	0.67	0.17	0.04	0.10
2008						2009					
		Demand	Wind	Hydro	Combined			Demand	Wind	Hydro	Combined
Terceira	Winter	0.50	0.08	0.32	0.20	Terceira	Winter	0.53	0.22	0.06	0.14
	Spring	0.47	0.00	0.24	0.12		Spring	0.50	0.18	0.07	0.13
	Summer	0.52	0.07	0.00	0.04		Summer	0.52	0.13	0.00	0.07
	Fall	0.51	0.21	0.00	0.11		Fall	0.53	0.19	0.00	0.10

Renewable Generation Patterns - Wind

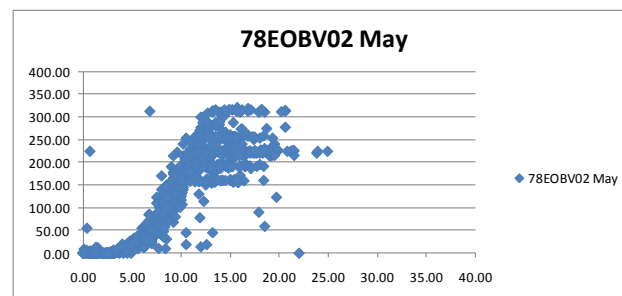
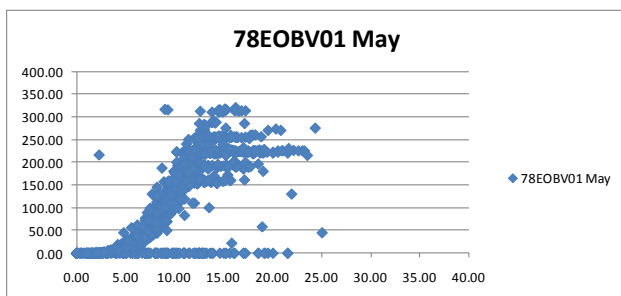
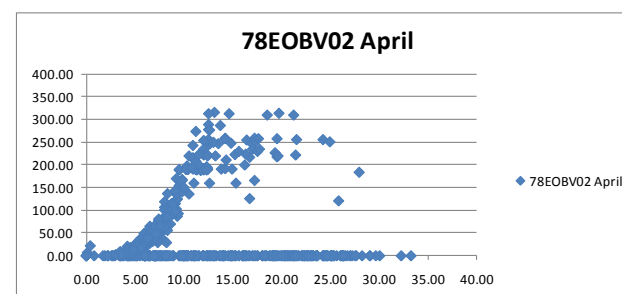
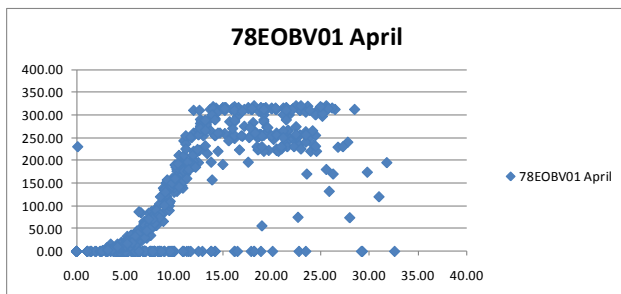
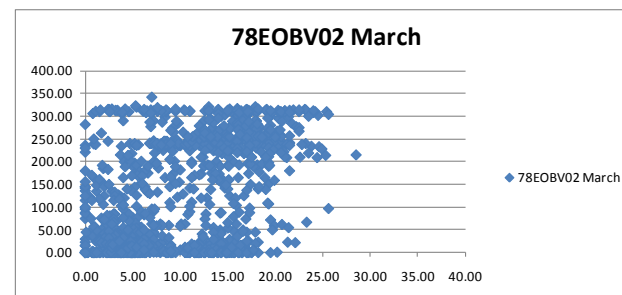
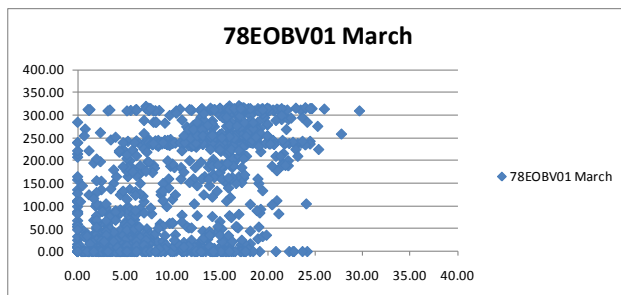
Total Monthly Generation – Wind, 6 Year Average
Average Monthly Wind Speed – 2008 Only



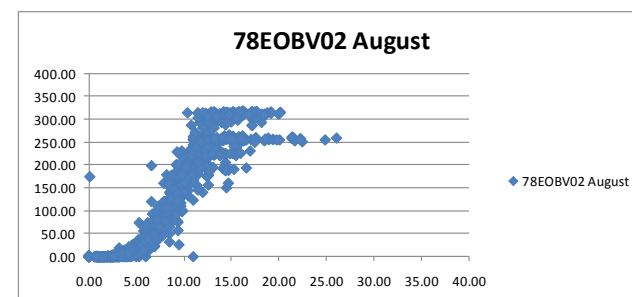
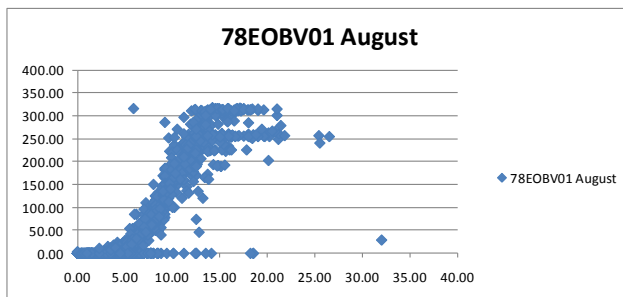
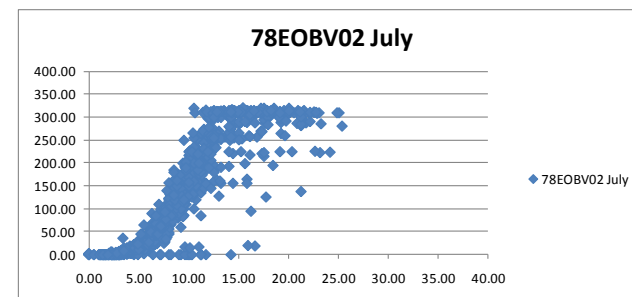
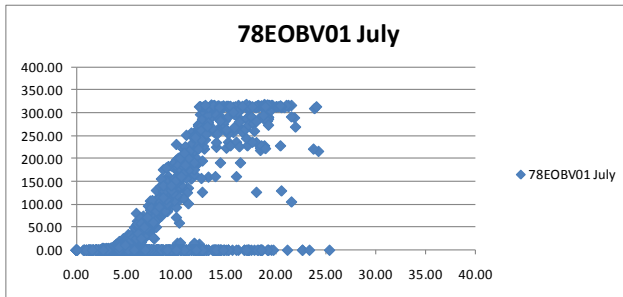
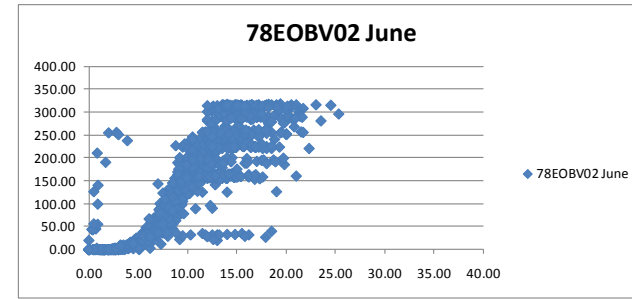
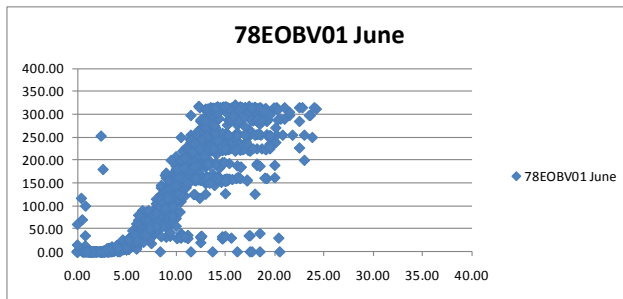
Wind Speed vs. Generation - Winter



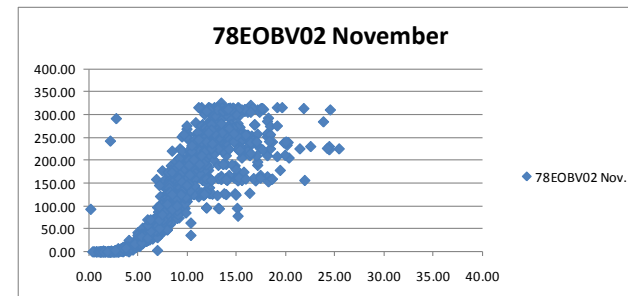
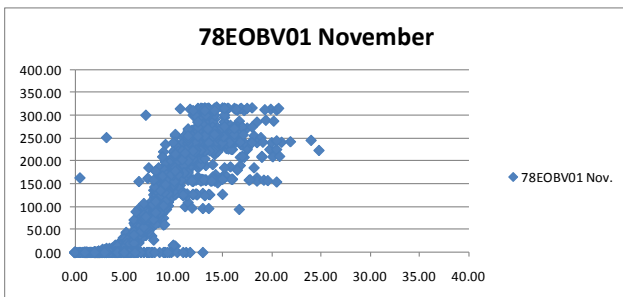
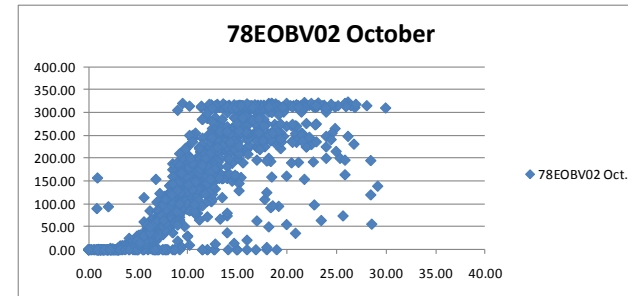
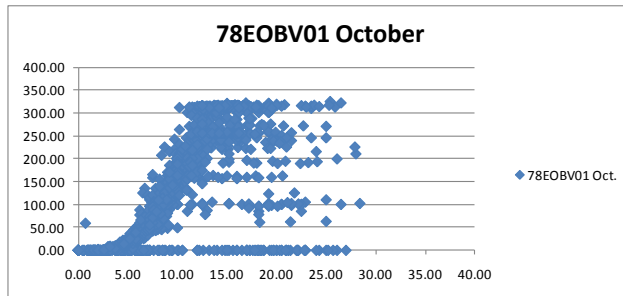
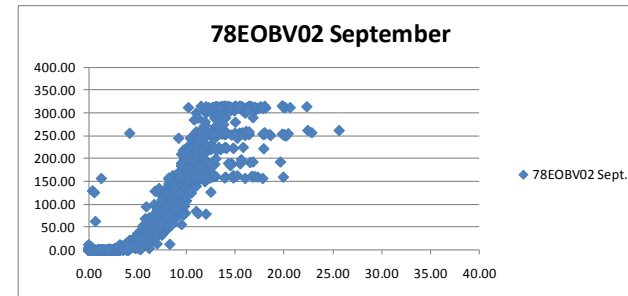
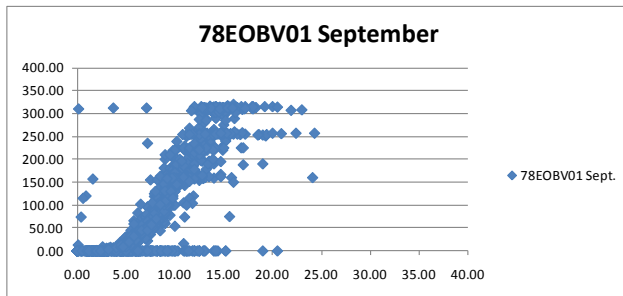
Wind Speed vs. Generation - Spring



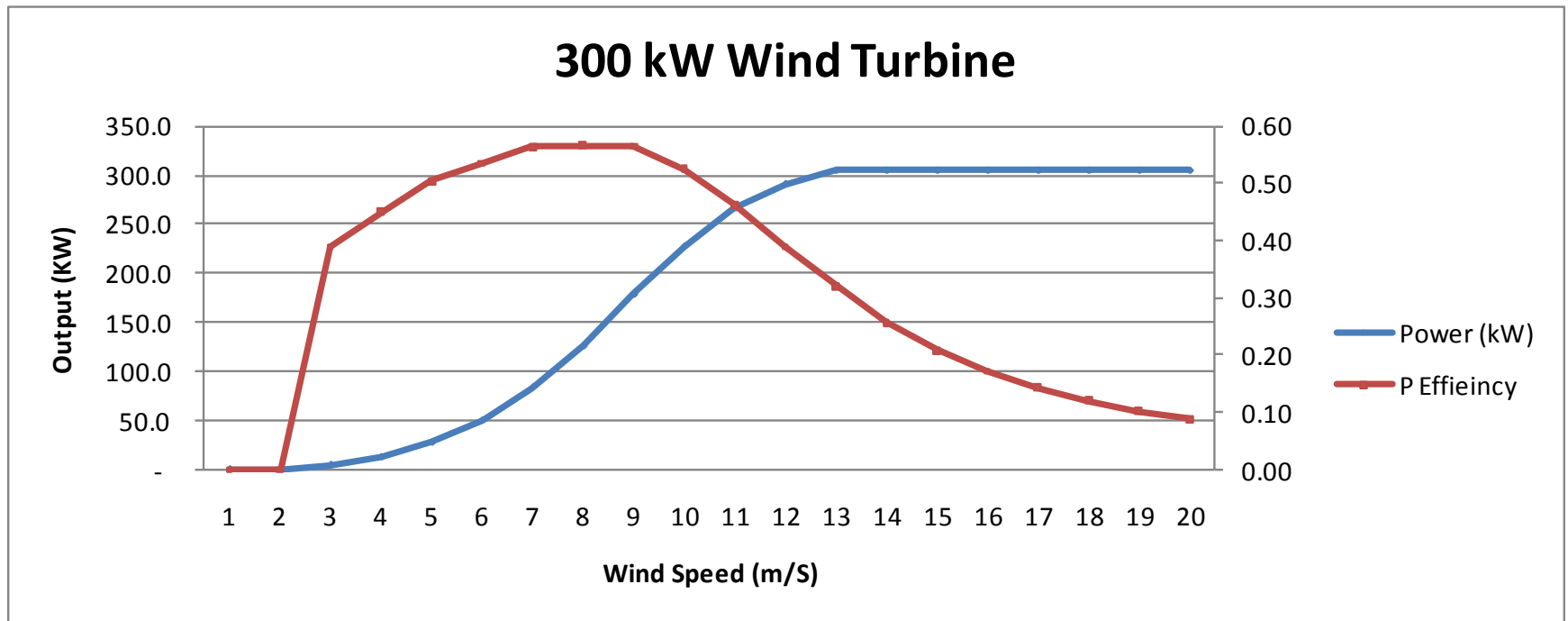
Wind Speed vs. Generation - Summer



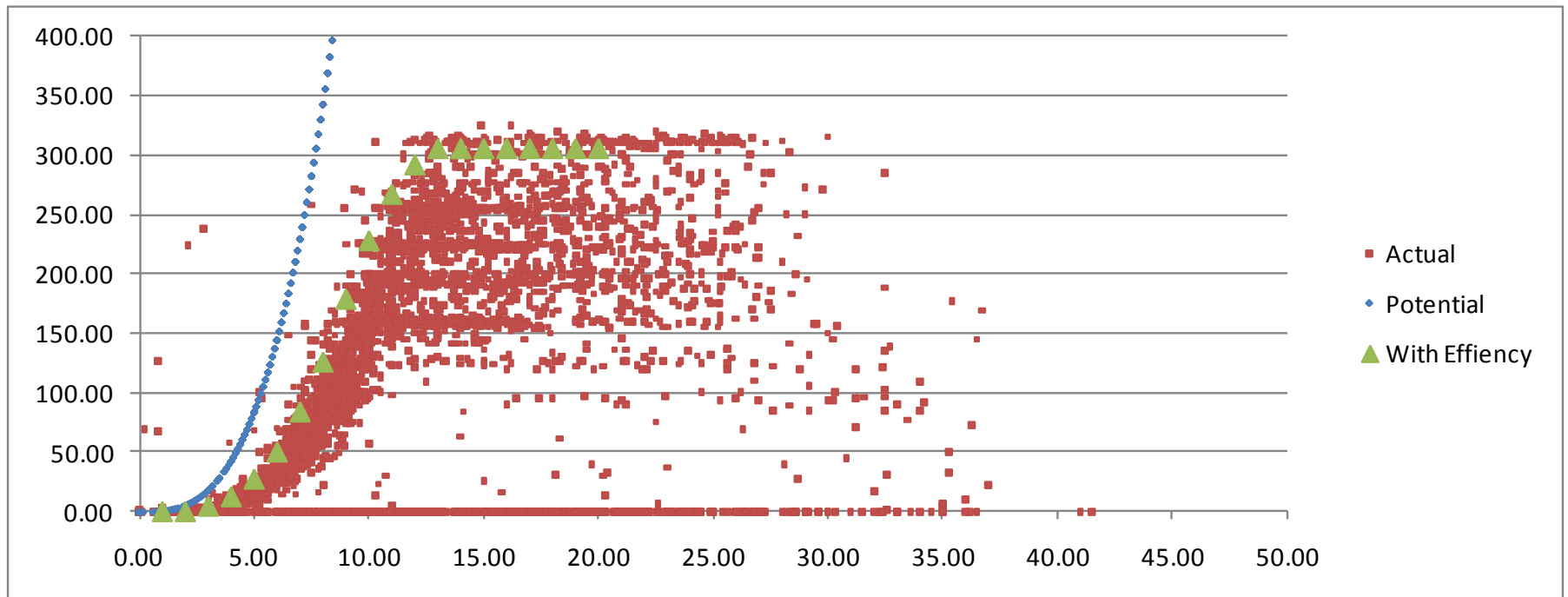
Wind Speed vs. Generation - Fall



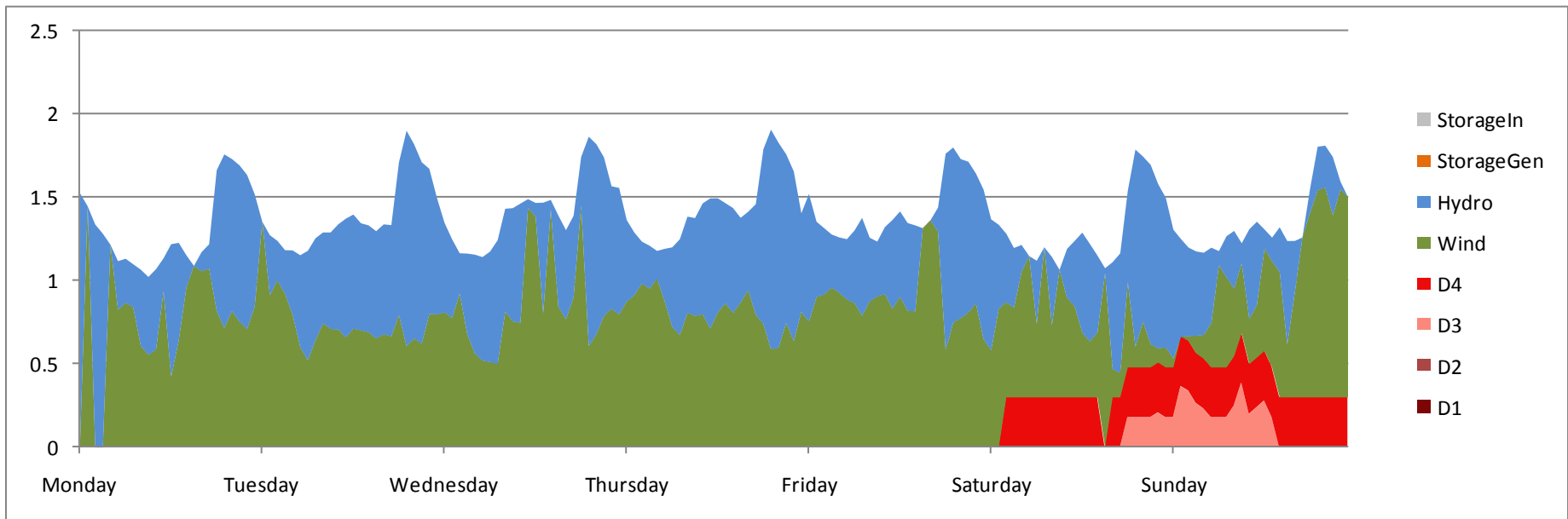
Wind Turbine Efficiency Curve



Winter 2008 Power Curve



Sample Model Output - No Battery



Input:

January 1 – 7 2008

Demand, Wind, Hydro

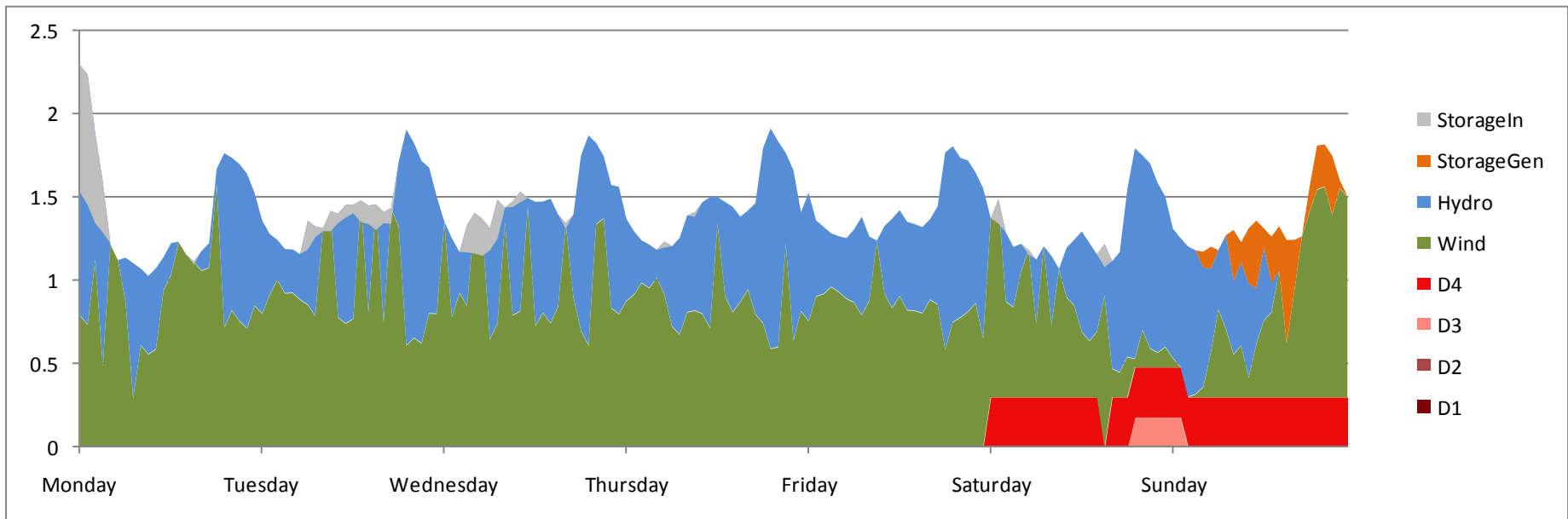
Wind: 1.8 MW (3 X current)

Hydro: 1.2 MW (1 X current)

Results:

Total Cost	€ 25,583
Total Diesel	18.06 MWh
Storage Gen	0 MWh

Sample Model Output - Battery



Input:

January 1 – 7 2008

Demand, Wind, Hydro

Wind: 1.8 MW (3 X current)

Hydro: 1.2 MW (1 X current)

Results:

Total Cost € 26,125

Total Diesel 15.36 MWh

Storage Gen 4.05 MWh