



CSD&MAsia 2016

2nd Asia-Pacific Conference

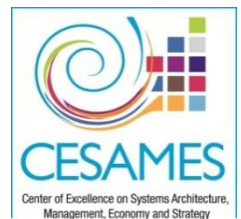
« Complex Systems Design & Management »

February 24-26, 2016 – Singapore University of Technology & Design

G. Matthew, WJ Nuttall, B Mestel, L Dooley and P Ferrão

**Renewable integration in
island electricity systems
*a systems dynamics study***

Event created and organized by





Renewables Deployment An EU imperative



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Island Systems provide a laboratory within which
to study larger issues

- ❑ We seek an island system
 - ❖ Electrically isolated
 - ❖ and of sufficient scale
- ❑ We build on prior work
 - ❖ By MIT and CMU
- ❑ The Azores are not economically isolated



Renewable Integration – Our Outlook



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**Our intention is neither:
Prediction
nor Optimisation**

*Rather, we seek to explore a range of possible
futures and elucidate possibilities and
scenarios that are neither obvious nor a simple
extrapolation from the present*



System Dynamics Modeling

Provides understanding of complex systems with non-linearities, feedbacks and time delays

- ❑ Quantitative insight into non-analytical mathematical problems
- ❑ Realistic processes can be simulated avoiding:
 - Pre occupations
 - Misinterpretations
 - Wrongly considered effectiveness



Renewable Integration – A Long-Term Infrastructure Investment Simulation considering:



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- ❑ Evolution of investments needed to achieve local renewable deployment and globally influenced CO₂ emissions targets
- ❑ Effects of supply (and demand) side changes on key policy goals
- ❑ Policy scenarios in which the rate of renewable integration is likely/not likely to be delayed, diluted, or defeated by unanticipated reactions and side effects



Renewable Integration – Sao Miguel Case Study



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- ❑ The Azores and archipelago of nine Portuguese islands about 1,500 km west of mainland Portugal
- ❑ Total population of about 245,000



Map courtesy <http://e2p.inegi.up.pt/>

This work is part of a more complete research study that involves a fossil fuel sub-model, this renewable sub-model, a forthcoming demand side model and an integrative synthesis of all three sub-models

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Renewable Integration

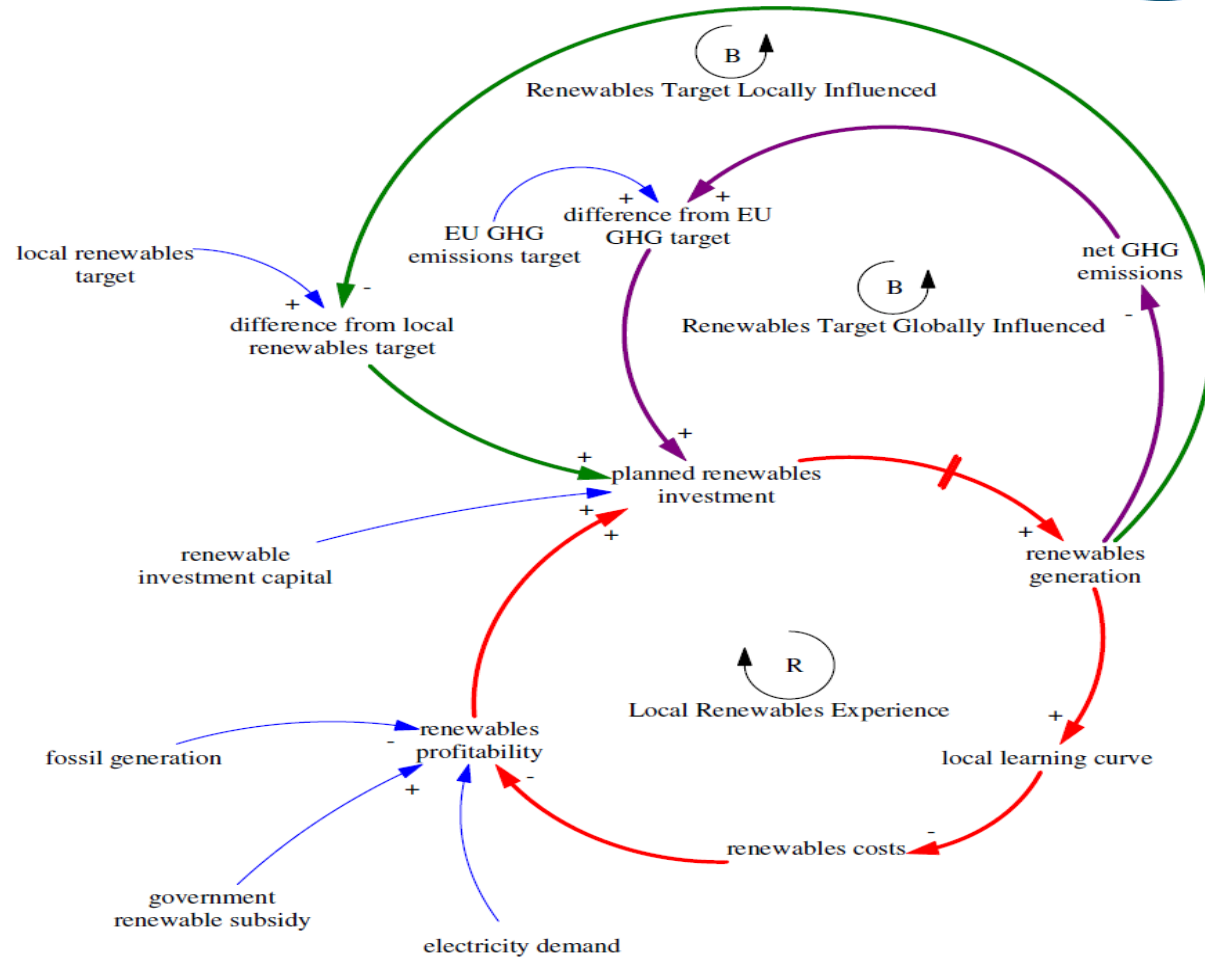
Key Literature



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- ❑ TIMES MARKAL analysis by Pina et al (2012) of the impact of demand side management for delaying new investments
- ❑ Other works using stochastic dynamic programming, least cost economic dispatch and unit commitment for electricity storage, electric vehicles for CO₂ emissions reductions and renewable integration: E.g. Ilic (2013 chp.20), Cross-Call (2013) and Parness (2007)
- ❑ Bildick (2015), Ford et al (2007, 2008, 2010), Black (2005) and Balnac et al (2009) show that SD can be applied to CO₂ emissions policies, renewable diffusion and demand management
- ❑ To the best of our knowledge no SD model exists for renewable integration considering local learning and renewable targets

SD Assessment for Renewable Integration



System's Mental Model Feedback Structure

SD Assessment for Renewable Integration



Local Learning Curve:

$$C_{t+\Delta t} = C_t \left(\frac{X_{t+\Delta t}}{X_t} \right)^{-e} \text{ where,}$$

C_t is the investment cost per MW at time t

X_t is the cumulative constructed capacity (including decommissions)

e is the learning curve parameter

We have $e = -\log_2(p)$, where p is the progress ratio with $0 \leq p \leq 1$

A progress ratio of 90% means that for each doubling of X_t there is a cost reduction of 10%

Influence of targets:

$$R = (S_* - S)/T_A \text{ where,}$$

T_A is the adjustment period.

R is the rate of adjustment of a variable S to a target S_*

- ✓ Important exogenous inputs: local renewable targets, EU CO₂ emissions targets, electricity price and electricity demand

- ✓ CO₂ emissions tax is excluded from this model

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Policy Scenarios

Reference scenario: The “business as usual” case; what is most likely to occur under a mid-term goal of 50% reduced CO₂ emissions and 50% installed renewable capacity targets by 2030

Less-aggressive renewable scenario: The renewable policy that have a goal of 50% reduced CO₂ emissions and 50% installed renewable capacity targets by 2050

Aggressive renewable scenario: The renewable policy with the goal of 50% reduction in CO₂ emissions and 75% installed renewable capacity by 2018

- ❑ **Model calibration is done from January 2005 up to December 2014**
- ❑ **Total simulation period goes from 2005 up to 2049**



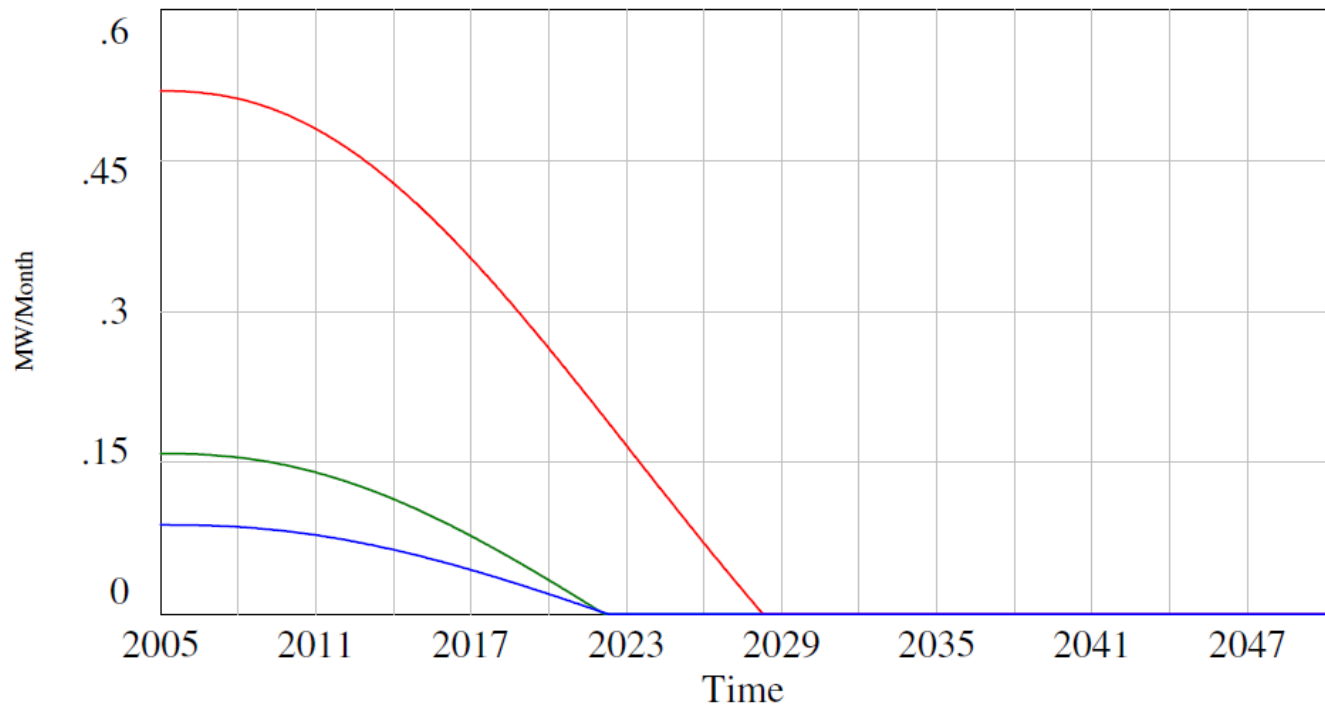
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Model Results

Difference from local renewable target



difference from local renewable target : 50percent 2050scenario —————
difference from local renewable target : 75percent 2018scenario —————
difference from local renewable target : bau_50percent 2030scenario —————



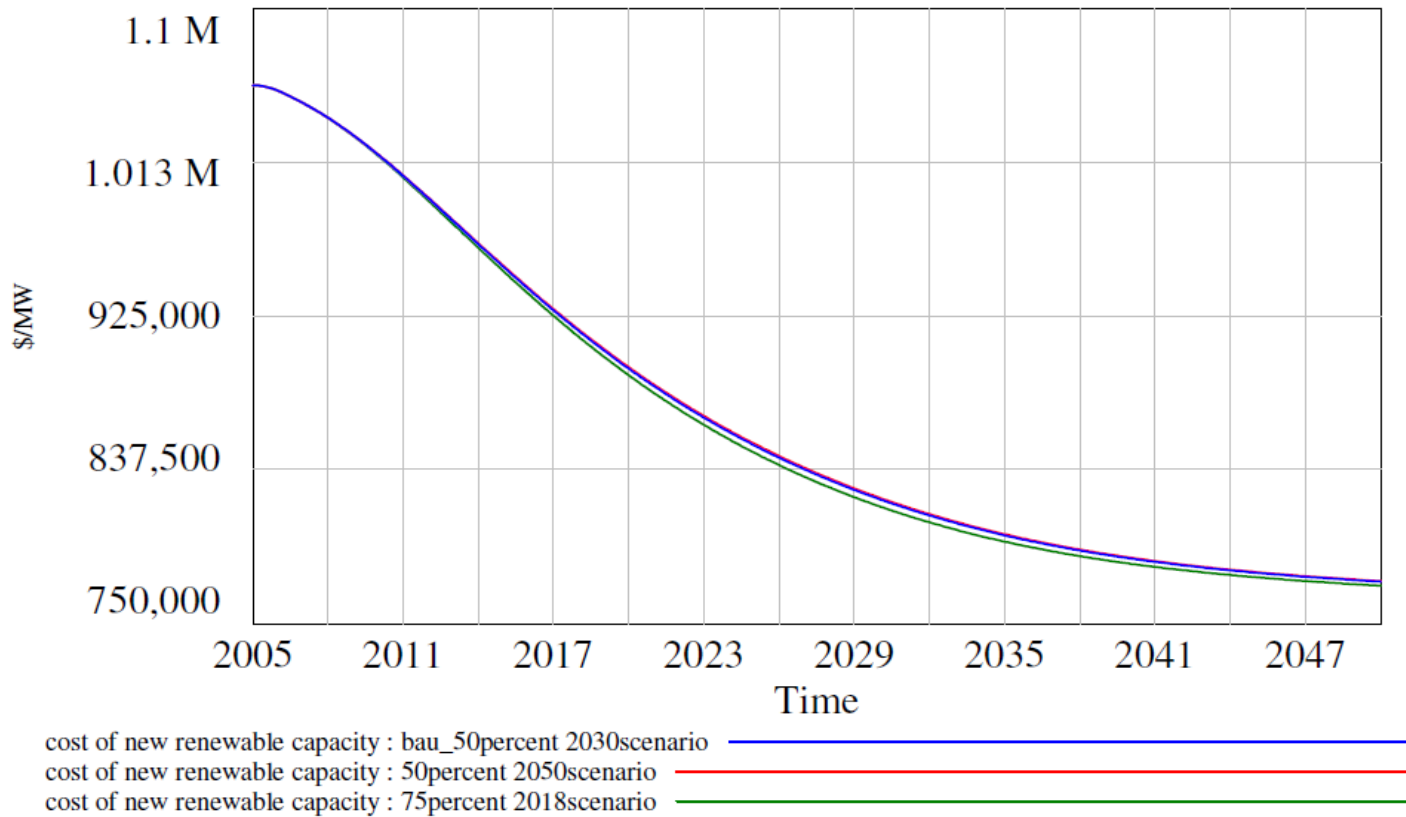
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Model Results



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Cost of new renewable capacity





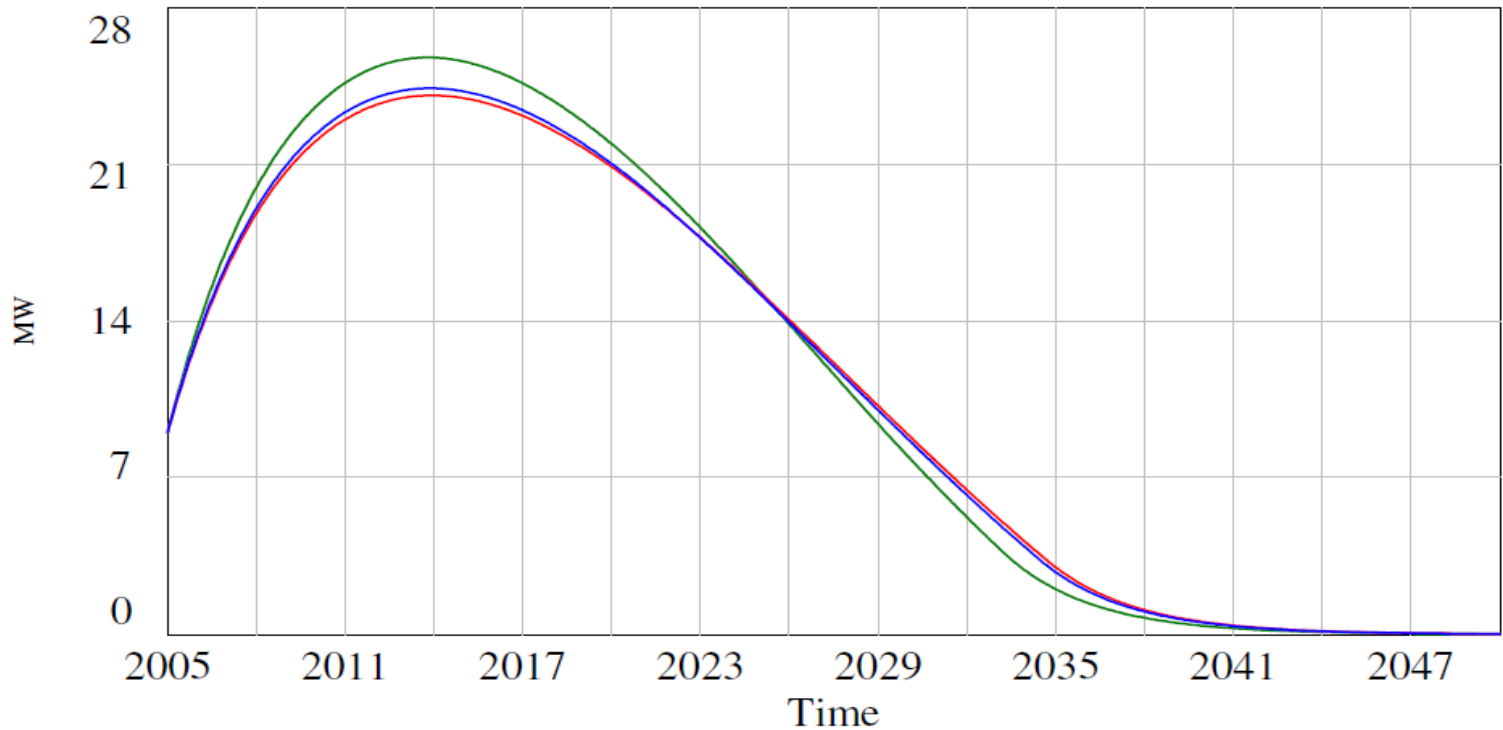
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Model Results



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Planned renewable investments



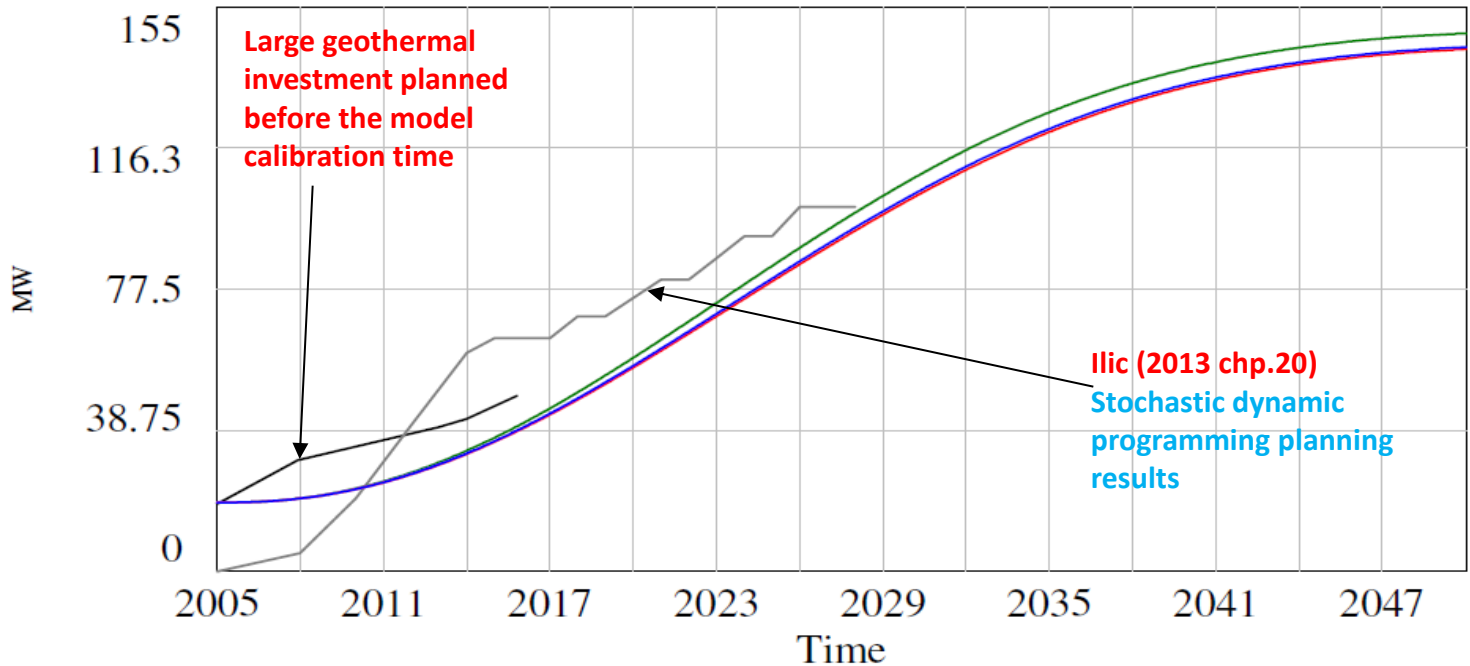
planned renewable investments : bau_50percent 2030scenario
planned renewable investments : 50percent 2050scenario
planned renewable investments : 75percent 2018scenario

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Model Results



Installed renewable capacity



installed renewable capacity : bau_50percent 2030scenario —————

installed renewable capacity : 50percent 2050scenario —————

installed renewable capacity : 75percent 2018scenario —————

"stochastic dynamic optimization model: Ilic Results" : bau_50percent 2030scenario —————

installed renewable capacity real data : bau_50percent 2030scenario —————

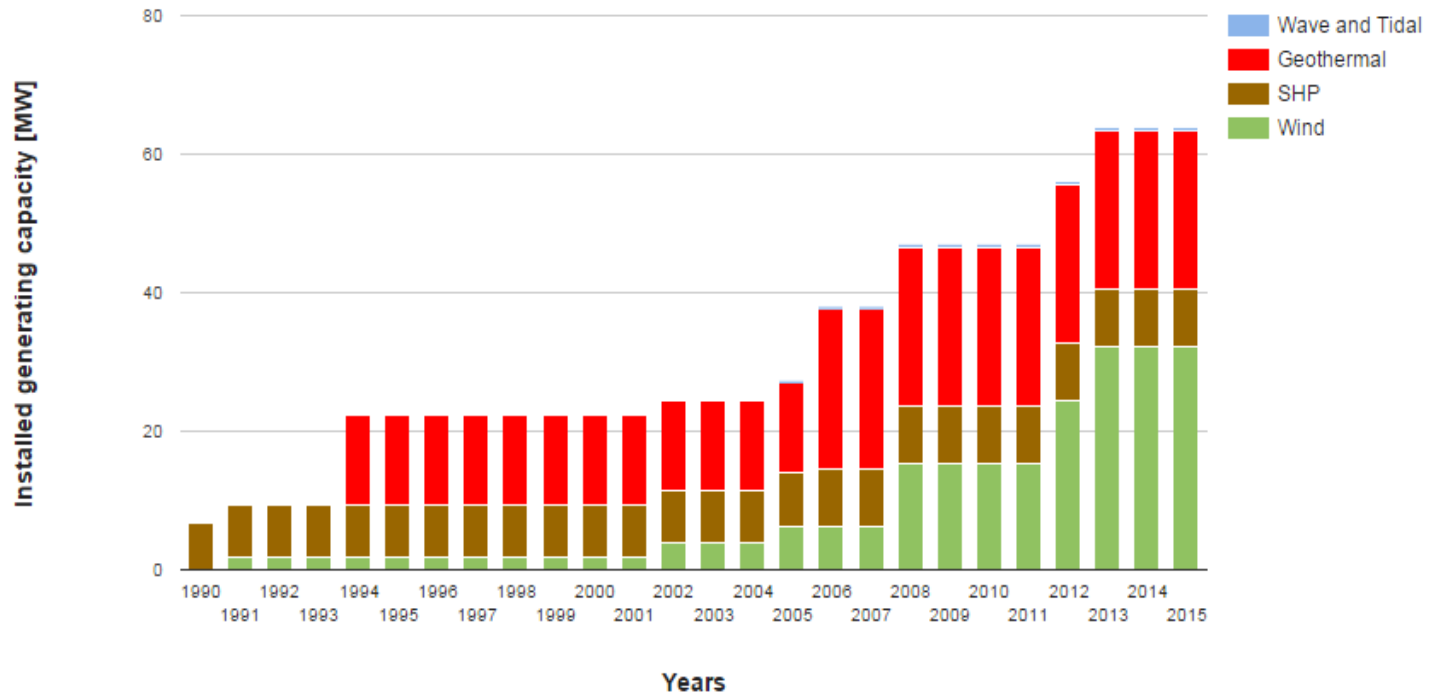


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Further Confidence in Model Results



Historical installed renewable capacity in Azores

Source: INEGI/APREN | Nov 2015

Conclusions



- ❑ For all scenarios there is no major long-term shortfall (by 2050) **i.e. targets are eventually achieved**
- ❑ Overly aggressive renewable target policy could lead to short-term over-investment at high cost.
- ❑ Renewable investment cost does not decrease significantly with time in any scenario
 - Limited electricity demand carrying capacity
 - No grid interconnection so investment is curtailed
 - Multiple doubling of capacity does not occur in a small island system



Next Steps and Future Work



- ❑ Disaggregating renewable technologies for greater resolution and ensuring the demand forecast is endogenous to the model
- ❑ Further sensitivity analysis
- ❑ Inclusion of energy efficiency/demand side response mechanisms
 - How much renewable is too much for the grid to handle
 - Energy security concerns
- ❑ Synthesis of all three sub-models



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Thoughts and Questions

Thank you for your attention

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