Energy, variability and weather finance engineering

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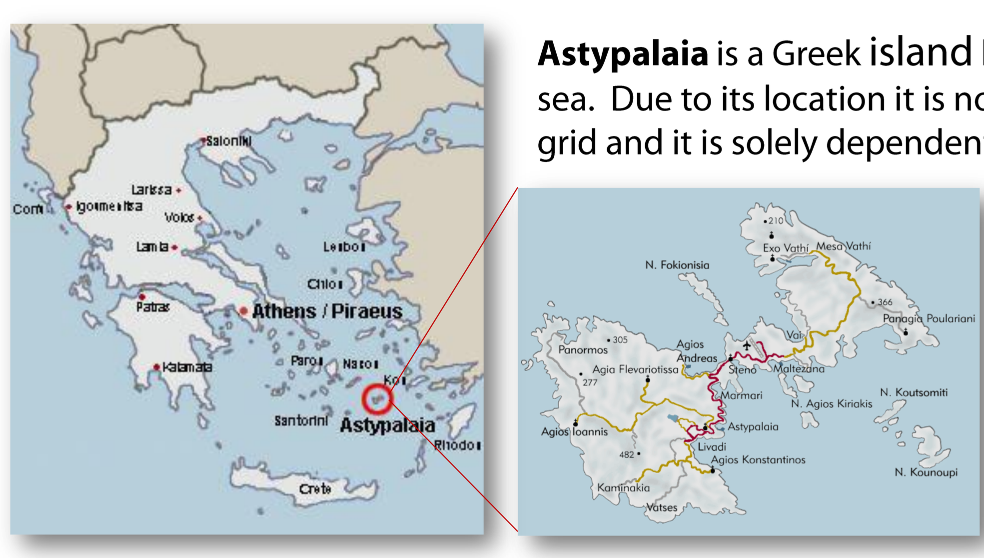
Project Description:

Many remote islands in Greece are not connected to the mainland energy grid and thus **fully dependent** on oil fired electricity generation in order to meet their energy demands [*Friedrich & Lavidas, 2015*]. The fossil fuels needed are imported and subsequently, the remote islands are **exposed** both to the international prices of oil and the extra margin imposed by the local suppliers. Difficulties lie along the costly transition to renewable sources of energy such as the present dependence on oil and the low predictability (or high variability) of hydrometeorological variables (e.g. rainfall, wind speed, temperature). **Weather derivatives** comprise mature financial tools which can safeguard against frequent hydrometeorological risks of low or medium impact, not covered by standard insurance contracts. In this context, we study the case of **Astypalaia**, a remote island in the area of South Aegean sea, facing all the aforementioned difficulties. In order to tackle these difficulties, we set a simple framework on the governing existing conditions and the potential use of weather derivatives as efficient tools in reducing the marginal price imposed by the local oil supplier, as it is constituted by factors such as the local **temperature** and the expected impact of tourism on the energy demand. Finally, we test the possible outcomes for both the public administration of the municipality of Astypalaia and the financial institution issuing the weather derivatives.

Contribution of the project

This project is part of a general attempt of the School of Civil Engineering, NTUA, focused on the **transition** from carbon-based energy to sustainable renewable forms in the case-study of Astypalaia. However, the transition is a costly process and the economic sustainability of renewable sources of energy is subject to the **fluctuations** of hydrometeorological variables. Even though the framework we set is simple, it is evident that weather derivatives have significant use in **integrating** the intermittent-load and base-load components of renewable energy sources into a **unified hybrid energy system**. Such energy systems could completely substitute the current ones which are heavily dependent on fossil fuels.

1. The case-study of Astypalaia

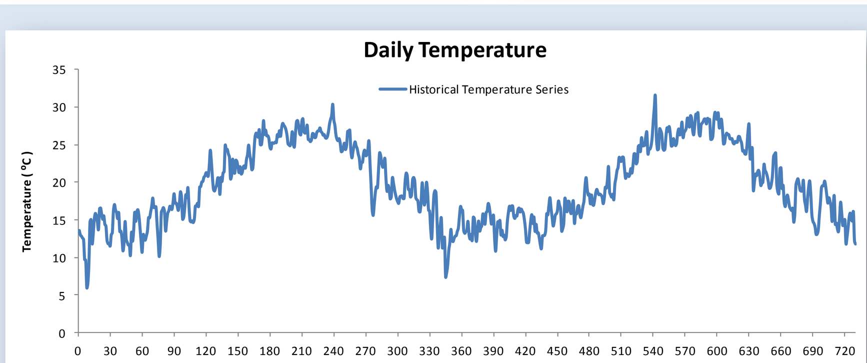


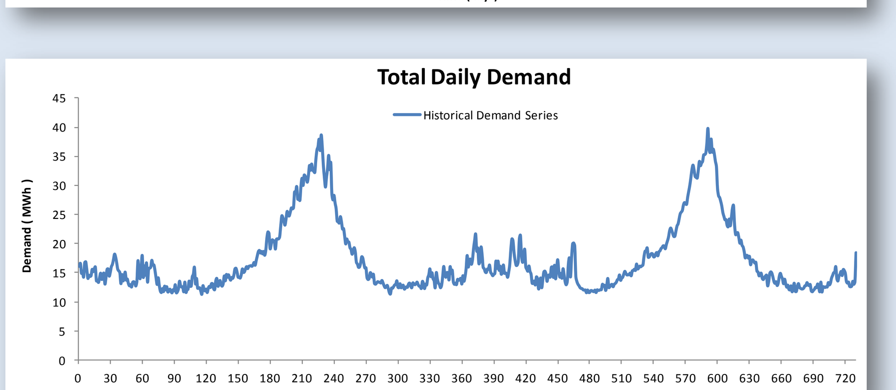
Astypalaia is a Greek island located in the southeastern Aegean sea. Due to its location it is not connected to the national power grid and it is solely dependent on oil fired electricity generation.

Capital: Chora

Population: 1334 residents

Area: 97 km²





Data Observations:

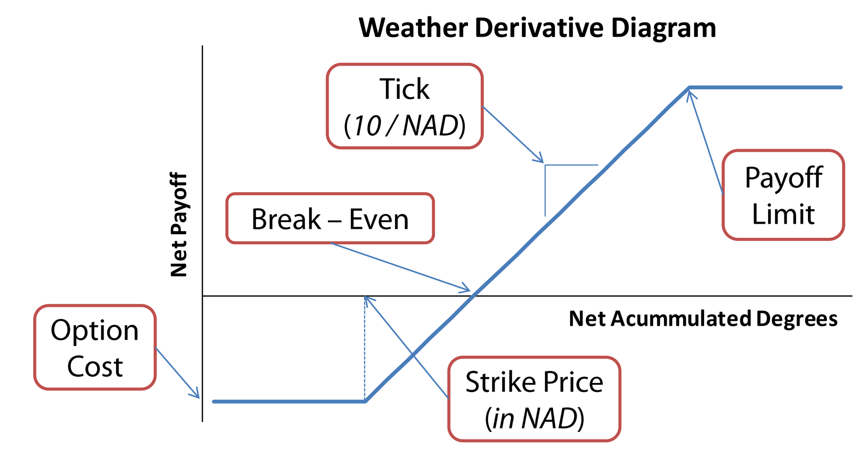
Generally, it appears that the increase in population due to *tourism* is **more strongly affecting demand** than a higher *temperature*. For example, on 26 June 2014, the island had a peak average daily temperature of 31.4 °C and a total daily demand of 20.89 MWh. However, in the two following months, an even higher demand can be observed, even reaching approximately 40 MWhr, *without* a corresponding increase in temperature.

2. Definitions and notations of weather finance

Weather Derivatives are financial tools that can be used by organizations or individuals as part of a risk management strategy to reduce the risk associated with adverse or unexpected weather conditions. Weather derivatives are index-based instruments that usually use observed weather data at a weather station to create an index on which a payoff can be based.

Option is a contract which gives the buyer (holder) the right, but not the obligation, to buy or sell an underlying asset or instrument at a specific strike price on a specified date. The seller has the corresponding obligation to fulfill the transaction – to sell or buy – if the buyer (owner) "exercises" the option.

Weather Derivatives ≠ Insurance contracts
Insurance contracts cover high risk – low probability events, while weather derivatives cover low risk – high probability events.



Quantification measurement indices of weather derivatives
So as to calculate the payoff of a weather derivative, we essentially need two indices: ***Accumulated HDDs/CDDs*** and the ***Strike Price*** of the contract. For each month period, we calculate the ***Net Accumulated Degrees (NAD)*** starting at day *(i)* by subtracting the degree index with the lower value.

$$HDD_i = \max(18.3 - T_i;0) \qquad H_{month} = \sum_{i=1}^{30} HDD_i \qquad C_{month} = \sum_{i=1}^{30} CDD_i$$

$$CDD_i = \max(T_i - 18.3;0) \qquad NAD_i = \max(H_{month} - C_{month}; C_{month} - H_{month})$$

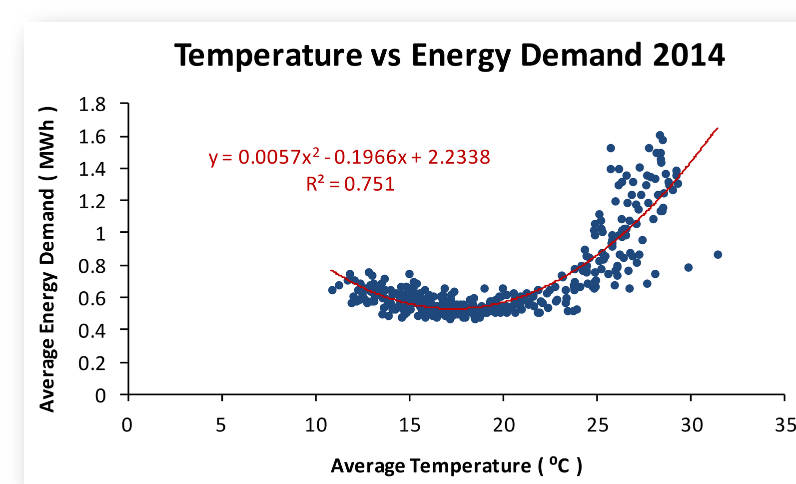
Determining strike price values to be used for the calculation of payoffs
Accumulated HDDs and CDDs can be modelled as a **log-normal distribution** [*Davis, 2001*]. However, a **normal distribution** can be hypothesized to fit approximately [*Harris, 2003*]. The ***Strike Price (SP)*** is the minimum value of ***Net Accumulated Degrees*** for the contract to have any payoff at all. The resulting payoff is calculated assuming a ***Tick***, which we assumed to have a constant value of 10 in the simulations.

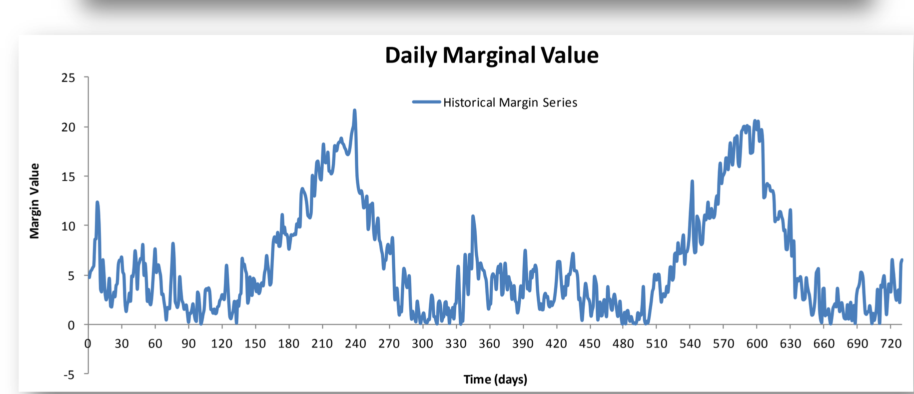
$$Payoff_i = Tick \cdot \max(NAD_i - SP;0)$$

3. Modelling the market and the marginal price of oil

Assumptions:

- The international price of oil has an ***unpredictable behavior.***
- The oil necessary for energy production ***cannot be supplied directly*** to the municipality of Astypalaia from the international market and therefore a local supplier is needed.
- ***Stable supply*** is assumed and therefore the local supplier charges an added marginal value.



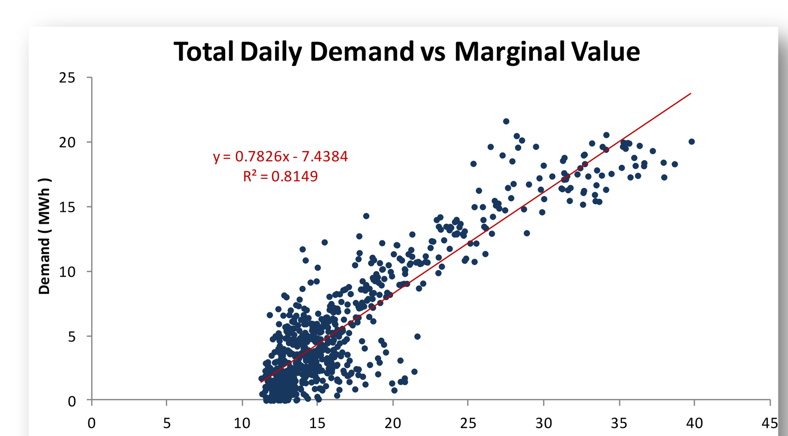


The interests of each counterpart:

- The ***municipality of Astypalaia*** is interested in maximizing the rate of potential payoff to the total marginal value for the **duration of the contract**.
- The ***financial institution*** is interested in fair-pricing the options and having a guaranteed profit on average.
- The ***local oil supplier*** is interested in covering various expenses and making a profit by supplying the municipality of Astypalaia.

Construction of an added Marginal Value model:

In order to construct the marginal value model, the *difference* between the **average daily temperature** and the **optimal comfort temperature** (*18.3°C*) is taken into account, as well as a *dummy variable* which corresponds to the **increase in population** of the island during tourist seasons and the analogous increase in energy demand. Thus, the constructed model of the marginal value must be closely correlated to the energy demand an it seems there can be a linear equation between the two.

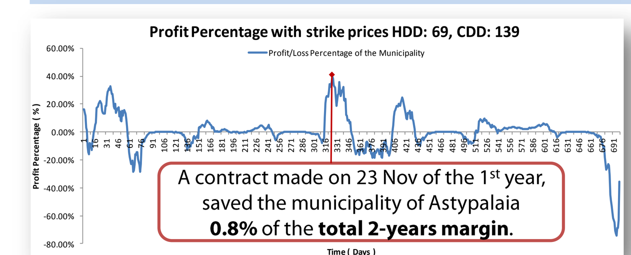


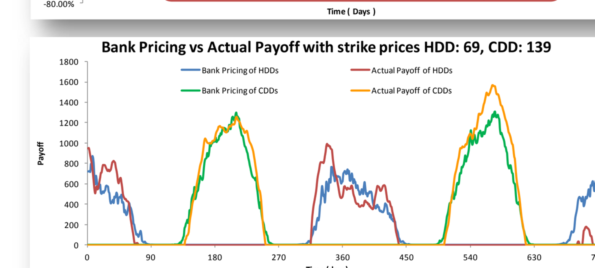
4. Valuation of weather derivatives' expected payoffs

Assuming the municipality would obtain an option with a period of one month for each day of the two years, a pricing method is needed to determine if the expected payoff (cost of option) calculated by the financial institution corresponds with the actual payoff. The most common method for valuing derivatives is the Black-Scholes model. However, it is not suitable for use in pricing individual weather derivatives [*Mircea & Cristina, 2012*]. Instead, a Monte-Carlo simulation [*Kung, 2010*] was used as follows:

1. Starting at each day, sampled a random path for daily temperature, by using an **AR(1) stochastic process** over the one-month period of the contract.
2. Calculated the **Net Accumulated Degrees** from the simulated temperature.
3. Calculated the payoff for each options contract, by setting **different strike prices**.
4. Repeated steps 1,2,3 to get many potential paths for the daily temperature and therefore **possible payoffs**.
5. Estimated the **expected payoff** for each day as the mean payoff of all samples.

5. Payoffs and profit percentages in relation to strike prices

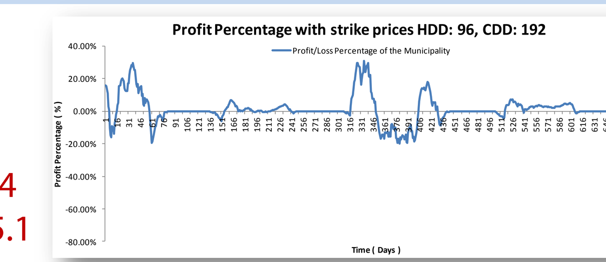


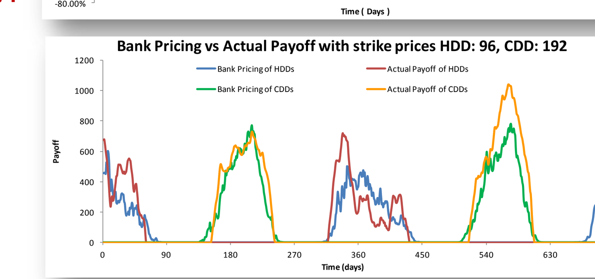


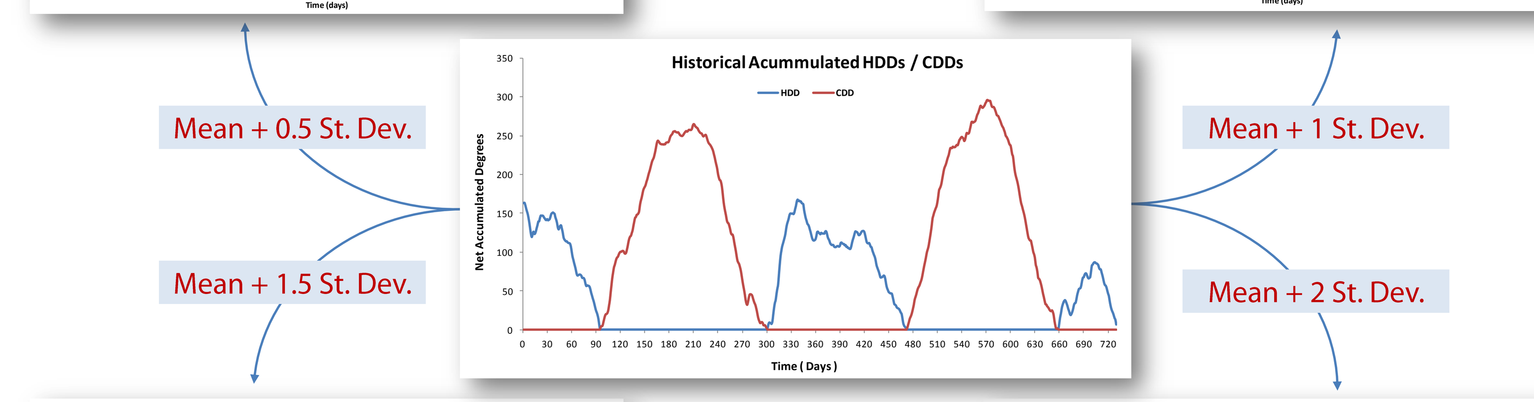
Mean HDD: 41.5
Mean CDD: 86.6

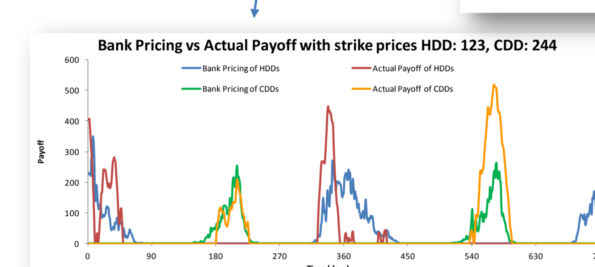
St. Dev. HDD: 54.4
St. Dev. CDD: 105.1

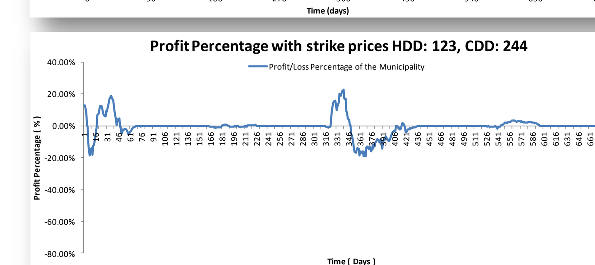
Strike Prices for each simulation are tested for various standard deviations from the mean of historical HDDs and CDDS.



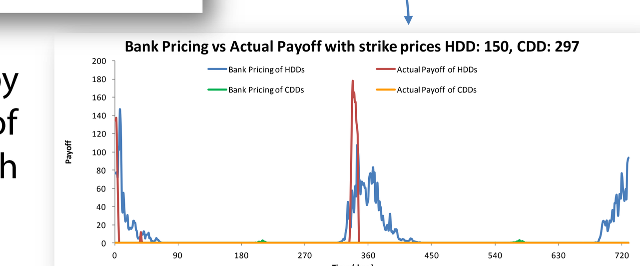


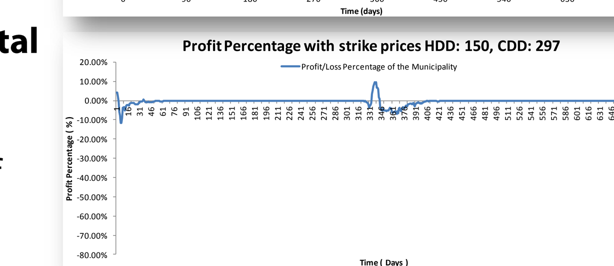






The profit made by the municipality of Astypalaia for each contract is calculated in relation to the **total marginal value over the one-month period** of the contract.





6. Conclusions

- ✓ The derivatives were priced accurately in overall, but the financial institution was **exposed** to a considerable degree at the following approximate intervals:
  - 20 Jan – 15 Feb of the 1st year
  - 15 Nov – 10 Dec of the 1st year
  - 10 Feb - 25 Feb of the 2nd year
  - 5 Jul – 30 Aug of the 2nd year
- ✓ Instead of utilizing a savings account based on a risk-free interest rate, **the municipality of Astypalaia could actually achieve a larger profit by purchasing weather derivative contracts** and particularly with HDDs as the underlying index, on the above intervals.
- ✓ The financial institution would prefer issuing **HDD-based** contracts over **CDD-based** ones. Also, it would not prefer to set particularly high strike prices.
- ✓ In our case-study, we can clearly see that as we increase the standard deviations used to determine the strike prices, **weather derivatives become less useful** as a financial tool for hedging the risk. In particular, the **exposure** of the financial institution **increases** and the percentage of **profit** made by the municipality of Astypalaia **decreases**.

About the Authors

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