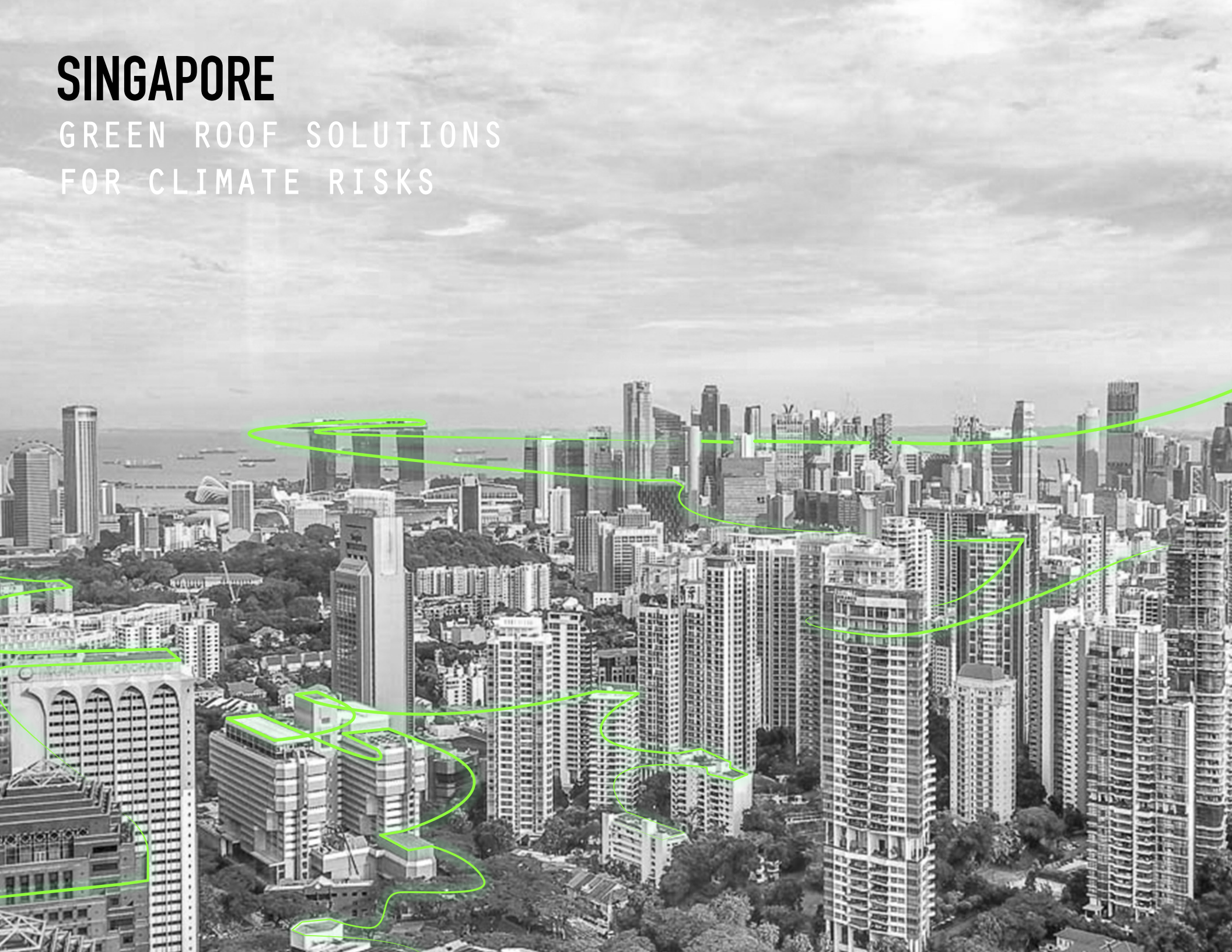
SINGAPORE

GREEN ROOF SOLUTIONS FOR CLIMATE RISKS



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1. Background

Singapore is an Asian city-state located south of Malaysia. Being near the equator, Singapore is subject to frequent precipitation, high heat, and high humidity.

This city-state experiences two monsoonal periods separated by inter-monsoonal periods. With all this rain, Singaporeans are at high risk of floods. And due to poor drainage, an increase of precipitation in the future could be detrimental to Singaporean's health and financial state.

Singapore is also very hot all year. Current average annual temperatures reach about 28.4°C, a roughly 1°C increase over the past ten years.1 Climate change is increasing these numbers even further: an expected increase of 1.4°C - 4.6°C by the end of the century.[2] An increase this dramatic could lead to overall higher energy consumption, as Singaporeans will be using more energy to cool their buildings.

This city-state is currently emitting about nine tons of CO2 per capita, a small amount compared to the US whose emissions per capita are about double that of Singapore's.[2] Their goal is "... to introduce a carbon tax on the emission of greenhouse gases from 2019, in a move to maintain a high-quality living environment and do its part in fighting climate change."

1.1. Problems

This study aims to address certain questions regarding Singapore's climate risks and how the city-state will adapt to exacerbated climate conditions in the future. First, it is asked if there is a rising trend among the temperature data. If so, will a green roof be a viable option for cooling its building? Secondly, it is asked if the reduction in Singapore's carbon tax will be worth building a green roof. And finally, this study seeks to answer whether or not there is a trend in precipitation. If so, would a green roof be a viable option for reducing the cost of potential flood damage?

1.2. Solution

The study asks which potential adaptation and mitigation solutions green roofs can provide to Singapore, considering its above-stated climate risks. To begin, a green roof can aid a city in adapting to the threat of rising temperatures. A green roof insulates a building, which reduces mechanical cooling loads and also reduces the overall urban heat island effect.[4]

It can also aid a city in adapting to floods. A green roof captures storm water with its plants and growing medium. But due to the variability in green roof numbers, sizes, and types it is difficult to quantify the amount of rainfall that the roof can capture. In addition, a green roof can mitigate CO_2. This can be done indirectly through reducing energy use from reduced cooling loads, or directly through plant absorption.[4]

For this study, it is assumed that one type of green roof will be used for all roofs even though there are many methods used today. Calculation will be made based off of an extensive green roof with a soil medium of about six inches. This type is comprised of sedums and small grasses, which is low maintenance and requires little to no irrigation. This study is also only looking at commercial buildings to reduce variability.

1.3. Motivation

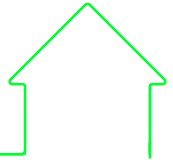
This study aims to conclude whether or not green roofs are a viable option for Singapore over a ten-year timescale given the rise in temperatures and rainfall.

2. Decision Problems

This paper takes a look at the three benefits of green roofs on which will be the focus: energy-use reduction, carbon mitigation, and flood mitigation.

2.1. Decision Problem 1: Energy-use

The energy-use decision problem consists of two outcomes: install a green roof or not install a green roof. The calculations for the cost of each plan over ten years are as follows:



Installation cost (125 SD/m²)[6] : 234,375 SD
Incentive (covering 50% of cost)[4]: 117,187.50 SD
Energy cost : 1,271,192.91 SD x 10 years
Energy Saving (12%) : 152,543.15 SD x 10 years

Cost Plan (Install): (Installation cost - Incentive) + (Energy cost - Energy savings)
Cost Plan (Install) = 11,304,000 SD

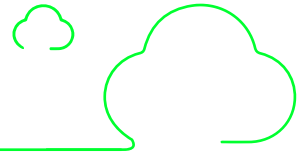
Cost Plan (Not install): Energy cost
Cost Plan (Not Install) = 12,712,000 SD

2.1.1 Results

Since the best option would be the one that is of lowest cost to the building owner, the choice would be to install the green roof. Calculating for Expected Utility (EU) produces the same result. For this decision problem the following assumptions were made: the energy consumption for all buildings is an average at 358 kWh/m²/yr and the typical building area is an average at 15,000 m² and seven stories[7].

2.2. Decision Problem 2: Carbon

The carbon decision problem also consists of two outcomes: install a green roof or not install a green roof. This problem involves temperature probabilities calculated from IRI data and we are assuming a 0.4% increase in energy costs for every 1°C temperature increase above the 28.1°C threshold. The calculations for the Expected Monetary Value (EMV) of each plan over ten years are as follows:



Carbon Tax[3]: 15 SD/ton CO_2* x 10 years

*The average building emits 6721 tons of CO_2 without a green roof, and 5915 tons of CO_2 with a green roof[7]

Probability (Above 28.1°C): 0.0088

Probability (Below 28.1°C): 0.9912

Cost Plan (Install): (Install Cost - Incentive) + (Energy Cost - Energy savings) + (Carbon Tax)

Cost Plan (Install | A): cost with 0.4% increase = 12,674,000 SD

Cost Plan (Install | B) = 12,191,000 SD

EMV (Install): 12,195,000 SD

Cost Plan (Not install): Energy Cost + Carbon Tax

Cost Plan (Not Install| A): cost with 0.4% increase = 14,386,000 SD

Cost Plan (Not Install| B) = 13,720,000 SD

EMV (Not Install): 13,726,000 SD

2.2.1 Results

Again, the best choice would be the lowest cost to the owner, which is evidently to install a green roof. Calculating for utility produces the same result. For this decision, the following assumptions were made: The CO_2 emissions for all buildings were averaged and that all carbon emissions are from cooling loads alone.

2.3. Decision Problem 3: Floods

The flood decision problem also consists of two outcomes: install a green roof or not install a green roof. This problem involves flood probabilities from IRI data as we are trying to determine the effects of future rainfall increase. These values are calculated based off of a U.S. case study. The calculations for the EMV of each plan are as follows:

Probability (Flood): 0.0018

Probability (No Flood): 0.9982

Incentive: 79,135,149.38 SD

Flood Damage Cost: 23,000,000 SD

Cost Plan (Install): (Install Cost - Incentive) + (Flood Damage Cost – Flood Damage Energy Savings)

Cost Plan (Not Install): Flood Damage Cost

2.3.1 Results

There was no conclusion to this decision problem as there was not enough data for flood damage savings after installing a green roof. Just as well, Singapore does not yet have any incentive in place for mitigating the effects of floods. Instead, this decision problem used values from a U.S. case study, which was not applicable to Singapore as the U.S. incentive (converted from USD to SD) is much larger than the actual flood-damage costs in Asia.

3. Results and Discussion

This study did find an upward trend in temperature and precipitation. This confirms that Singapore will be more dependent upon climate risk mitigation strategies. An analysis of three EMV decision problems resulted in two of the three pointing to install a green roof with one being inconclusive; the utility calculations also confirmed this. It is concluded that green roofs do insulate enough to reduce mechanical cooling loads enough to be worth the installation costs over ten years. Just as well, green roofs do absorb enough CO_2 to reduce the carbon tax enough to be worth the installation cost after ten years. This is not to mention the utility benefit of being a contributor to reaching the city-state's sustainability goals. Overall, it would be most beneficial to for the building owner to install green roofs to aid in both adaptation and mitigation of climate change effects on Singapore.

3.1 Study limitations

Singapore has a wide range of building types and because of this, an average height and area of all retail buildings was used for calculations. This resulted in an averaged emissions value, an averaged carbon tax value, and an averaged energy-use value. In addition, the lack of flood data for Singapore resulted in an inconclusive answer to the question of whether or not a green roof would be a viable option for reducing flood damage costs.

3.2 Benefits of Decision Analysis

By using EMV and EU, this study can be understood by anyone outside the climate community. These values are encouraged to be a method of convincing the building owner as to why a green roof would be a viable option for his/her building and city. Monetary values are well understood as opposed to probabilities of rainfall or tons of CO_2, for example.

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THANK YOU.