Risk and Uncertainty in Building Portfolio Decarbonization

Macroeconomic Scenarios, Capital Costs, and Carbon Emissions

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COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

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Autocase

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- Economic analyses of building and site infrastructure projects
- Autocase is our cloud-based sustainable economic analysis tool

- Shane Minckley
- Senior Economist & Implementation Manager

Life Cycle Cost Analysis (LCCA)

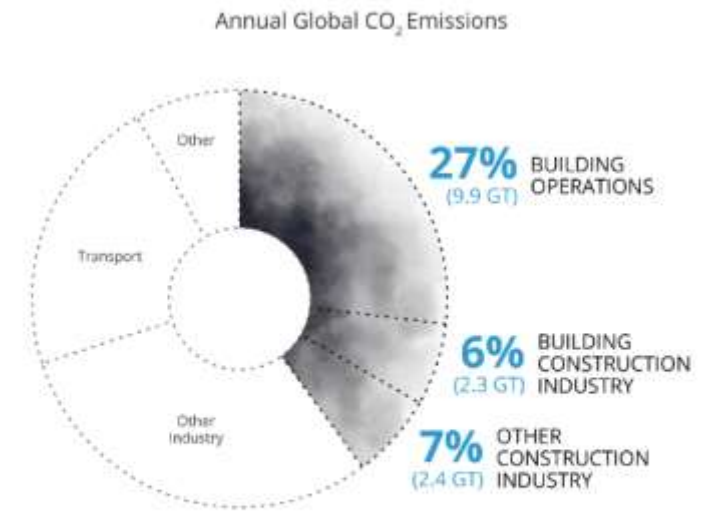
Why does Life Cycle Cost Analysis matter?

- LCCA provides decision-makers with a comprehensive and accurate view of the total cost of owning, operating, and disposing of a product or asset over its entire life cycle. LCCA matters because it enables decision makers to consider their total cost of ownership, as well as other effects like carbon emissions, and make more optimal decisions

LCCA indicators

- Net Savings = Total Savings - Total Cost
- Savings to Investment Ratio = Total Savings / Total Cost
- Simple Payback Period = Upfront Capital Cost / Annual Savings
- Discounted Payback Period = Upfront Capital Cost / [Annual Savings * (1+Discount Rate)]

Lifecycle Cost and Carbon Emissions



Building Construction Industry and Other Construction Industry represent emissions from concrete, steel, and aluminium for buildings and infrastructure respectively.

Why does building decarbonization matter?

- Buildings represent 40% of global carbon emissions

Leveraging scenario forecasts provided by the EIA, we can take United States based building portfolios and perform simulation to evaluate their exposure to both utility cost and grid emissions changes through time and their likelihood of hitting their decarbonization targets.

Dataset : Building Portfolio Data

Building Portfolio Data

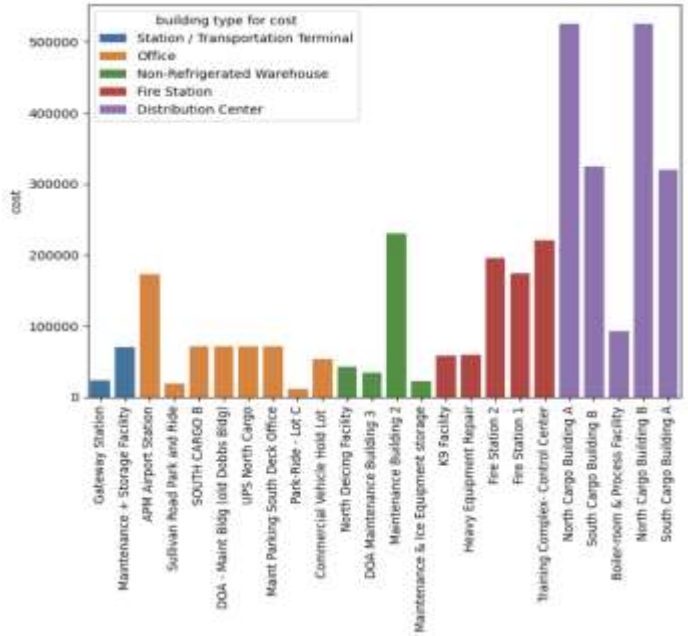
- Data source: building portfolio data is provided by Autocase from a project for Atlantic Airport
- It includes some fundamental information such as natural gas/electricity savings and rent/investment of 24 assets.

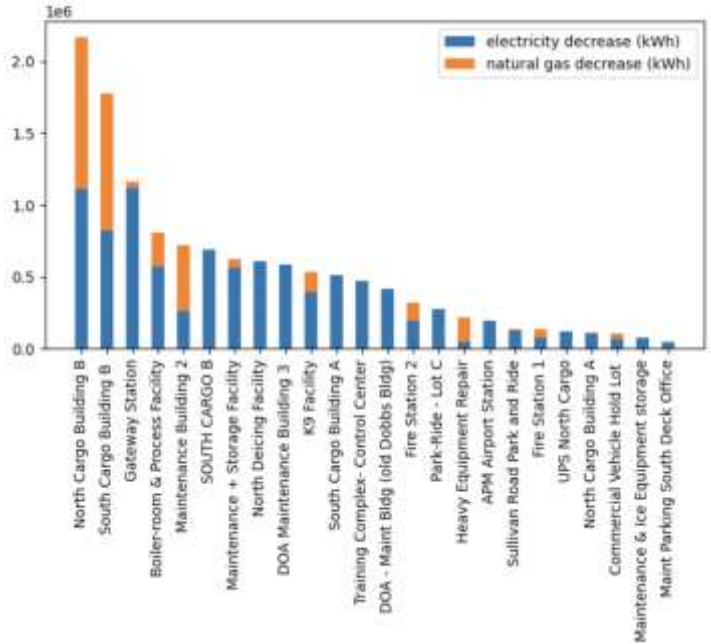
Asset Name	gross_floor_area (sqft)	electricity consumption (kWh)	natural gas consumption (kWh)	EUI (kBtu/sqft)	EUI reduction (kBtu/sqft)	% electricity	Electricity reduction (kBtu/sqft)	Natural gas reduction (kBtu/sqft)	new electricity consumption (kWh)	new natural gas consumption (kWh)	electricity decrease (kWh)	natural gas decrease (kWh)	building type for cost	cost
South Cargo Building A	125,524	909,052	483	24.72	13.92	99.95%	13.9167	0.0074	397,094	211	511,958	272	Distribution Center	$319,494
North Cargo Building A	206,582	714,943	48,330	12.61	1.81	93.67%	1.6927	0.1144	612,463	41,402	102,480	6,928	Distribution Center	$525,809
North Cargo Building B	206,582	1,447,578	1,376,905	46.65	35.85	51.25%	18.3748	17.4777	335,113	318,752	1,112,465	1,058,152	Distribution Center	$525,809
Boiler-room & Process Facility	36,414	651,025	273,366	86.62	75.82	70.43%	53.3976	22.4217	81,172	34,084	569,853	239,282	Distribution Center	$92,684
South Cargo Building B	127,331	1,006,964	1,172,708	58.41	47.61	46.20%	21.9948	25.6149	186,189	216,835	820,775	955,873	Distribution Center	$324,094
Training Complex- Control Center	26,561	1,062,912	10,063	137.84	60.68	99.06%	60.1149	0.5691	594,962	5,633	467,950	4,430	Fire Station	$220,228
Fire Station 1	21,000	331,445	277,809	98.99	21.84	54.40%	11.8805	9.9579	258,327	216,523	73,118	61,286	Fire Station	$174,119
Fire Station 2	23,526	512,342	338,898	123.46	46.31	60.19%	27.8708	18.4357	320,179	211,789	192,163	127,110	Fire Station	$196,063
Heavy Equipment Repair	7,191	81,688	296,575	179.49	102.33	21.60%	22.0990	80.2323	35,115	127,487	46,573	169,088	Fire Station	$59,823
Maintenance Building 2	40,671	387,083	675,740	89.17	60.47	36.42%	22.0221	38.4446	124,590	217,500	262,493	458,240	Non-Refrigerated Warehouse	$230,553
Commercial Vehicle Hold Lot	7,515	240,324	128,967	167.67	47.17	65.08%	30.6996	16.4746	172,710	92,683	67,614	36,284	Office	$53,108
Gateway Station	12,608	1,366,080	55,504	384.73	315.57	96.10%	303.2467	12.3209	245,571	9,978	1,120,509	45,526	Station / Transportation Termin	$23,185
K9 Facility	6,942	503,808	185,070	338.60	263.20	73.13%	192.4889	70.7091	112,189	41,212	391,619	143,858	Fire Station	$57,559
Maintenance + Storage Facility	37,915	1,061,064	112,532	105.62	56.02	90.41%	50.6504	5.3718	498,247	52,842	562,817	59,690	Station / Transportation Termin	$69,724
Sullivan Road Park and Ride	2,575	209,472	18,683	302.33	181.83	91.81%	166.9395	14.8894	83,490	7,446	125,982	11,236	Office	$18,197
DOA Airport Maintenance Div Snc	3,965	108,986		93.79	65.09	100.00%	65.0900	0	33,350	0	75,636	0	Non-Refrigerated Warehouse	$22,476
DOA Maintenance Building 3	6,072	638,654		358.89	330.19	100.00%	330.1894	0	51,072	0	587,581	0	Non-Refrigerated Warehouse	$34,421
North Deicing Facility	7,500	671,229		305.39	276.69	100.00%	276.6891	0	63,081	0	608,148	0	Non-Refrigerated Warehouse	$42,514
Park-Ride - Lot C - Office 1539 (Lo	1,539	325,725		722.17	601.67	100.00%	601.6706	0	54,350	0	271,375	0	Office	$10,878
DOA - Maint Parking South Deck I	9,999	402,074		137.21	16.71	100.00%	16.7071	0	353,115	0	48,959	0	Office	$70,662
UPS North Cargo	9,999	471,799		161.00	40.90	100.00%	40.9006	0	353,115	0	118,684	0	Office	$70,662
DOA - Maint Bldg (old Dobbs Bldg	9,999	765,804		261.33	140.83	100.00%	140.8292	0	353,115	0	412,688	0	Office	$70,662
SOUTH CARGO B : INTL CARGO M	9,999	1,040,133		354.94	234.44	100.00%	234.4436	0	353,115	0	687,018	0	Office	$70,662
APM Airport Station	24,514	1,066,847		146.96	26.46	100.00%	26.4638	0	865,721	0	190,127	0	Office	$173,241

Dataset : Building Portfolio Data

Building Portfolio Data

- Building cost = gross floor area * cost per square foot； High cost of distribution center is caused by large floor area
- Emission reduction more dependent on electricity than natural gas
- 9 assets have no gas decrease, warehouses or offices





Dataset : Utility Rate and Emission Factor

How do utility rate and emission factor connect to LCCA and greenhouse gas emission targets?

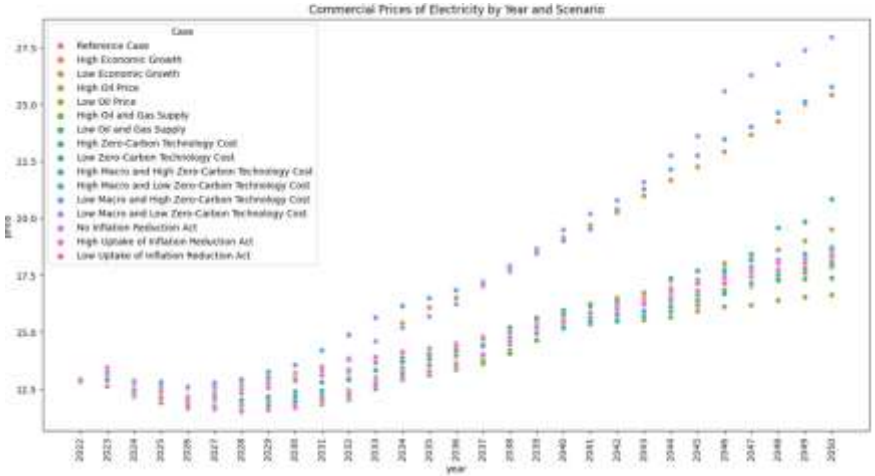
- Utility Rate: per unit of energy monetary costs, $/kWh
- Emission factor: per unit of energy pollutant emissions, MTCO2/kWh
- Utility and emission factor they together decide whether client can make their financial and environmental target
- Both are dynamic, varying with macroeconomic factors

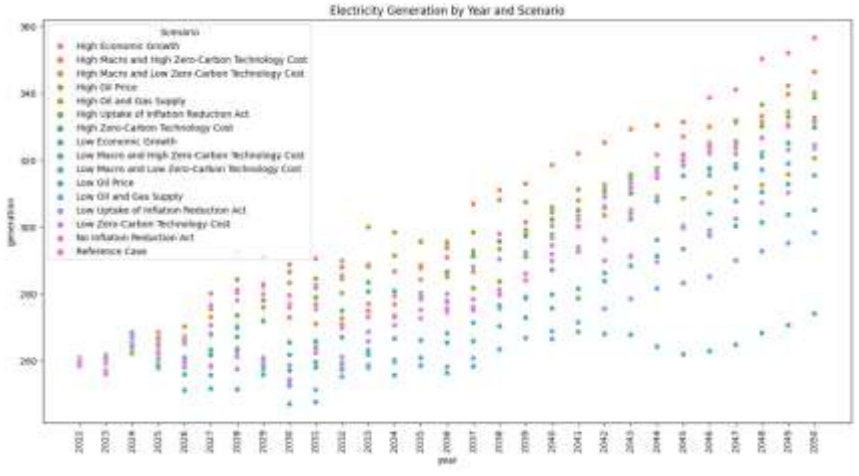
Metric Type	Indicator	Formula
LCCA	Net Saving	total cost - (energy reduction volume*energy price)
LCCA	Simple Payback Period	total cost/ (annual energy reduction volume*energy price)
LCCA	Discounted Payback Period	total cost / (annual energy reduction volume*energy price*(1+discount rate))
LCCA	Savings-to-investment Ratio	(energy reduction volume*energy price) / investment
Greenhouse Gas Emission	Carbon Dioxide Equivalent	energy consumption*(emission volume/energy generation)

Dataset : Scenario Data and Macroeconomic Fatcors

How can we deal with uncertainty in future utility rates and emission factors?

- Data Source: U.S. Energy Information Administration (EIA), a government agency providing energy data
- EIA summarizes the macroeconomic situation into 16 scenarios and predicts energy data for each scenario for the following 30 years.
- The energy data predictions from the EIA we used are energy generation and price for electricity and natural gas, which are varying with time and scenario





Simulation Concept

- There are two types of uncertainty assessment techniques: **Non-probabilistic & Probabilistic**
- **Probabilistic** assessment provides a more complete consideration of the uncertainty in inputs
- We use Monte Carlo Simulation based on scenario data to analyse uncertainty

APPROACHES TO UNCERTAINTY ASSESSMENT	
Non-Probabilistic	**Probabilistic**
Sensitivity Analysis	Input Estimates Using Expected Means (EM)
Break-Even Analysis	Decision Analysis (DA)
Risk-Adjusted Discount Rate (RADR)	Simulation
Certainty Equivalent (CE)	Mathematical/Analytical

Simulation Concept

- There are two types of uncertainty assessment techniques: **Non-probabilistic & Probabilistic**
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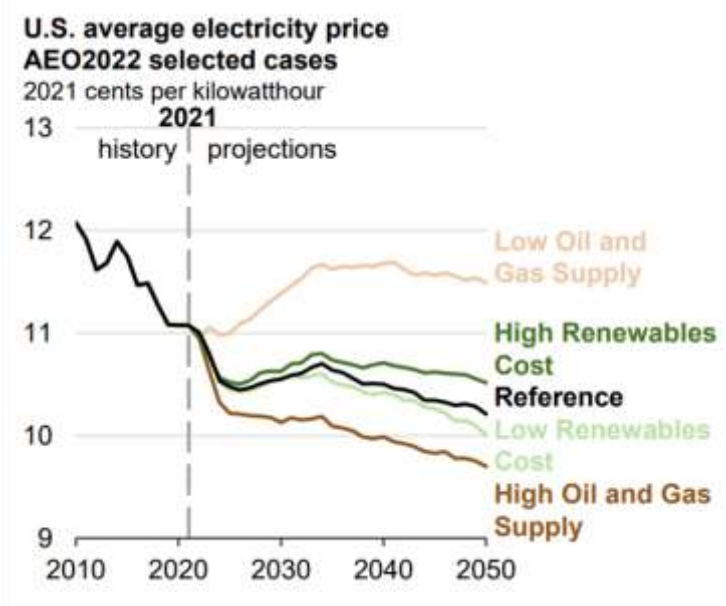
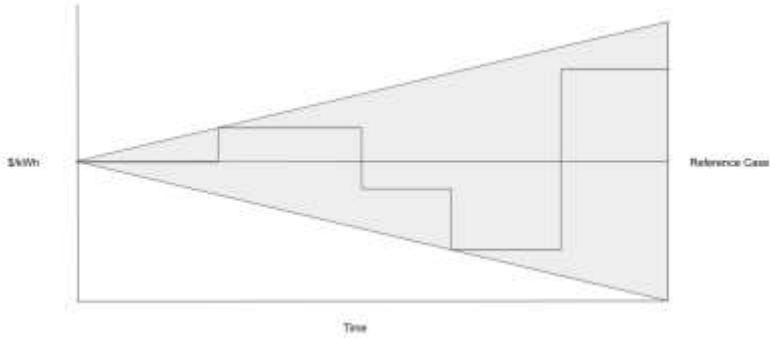
- We use Monte Carlo Simulation based on scenario data to analyse uncertainty





Simulation Framework

Determine the annually min-to-max range based on scenario forecast

↓

Sample **uniformly** from the min-to-max range to generate pathway

↓

Smooth the pathway by constraining the possible maximum jump

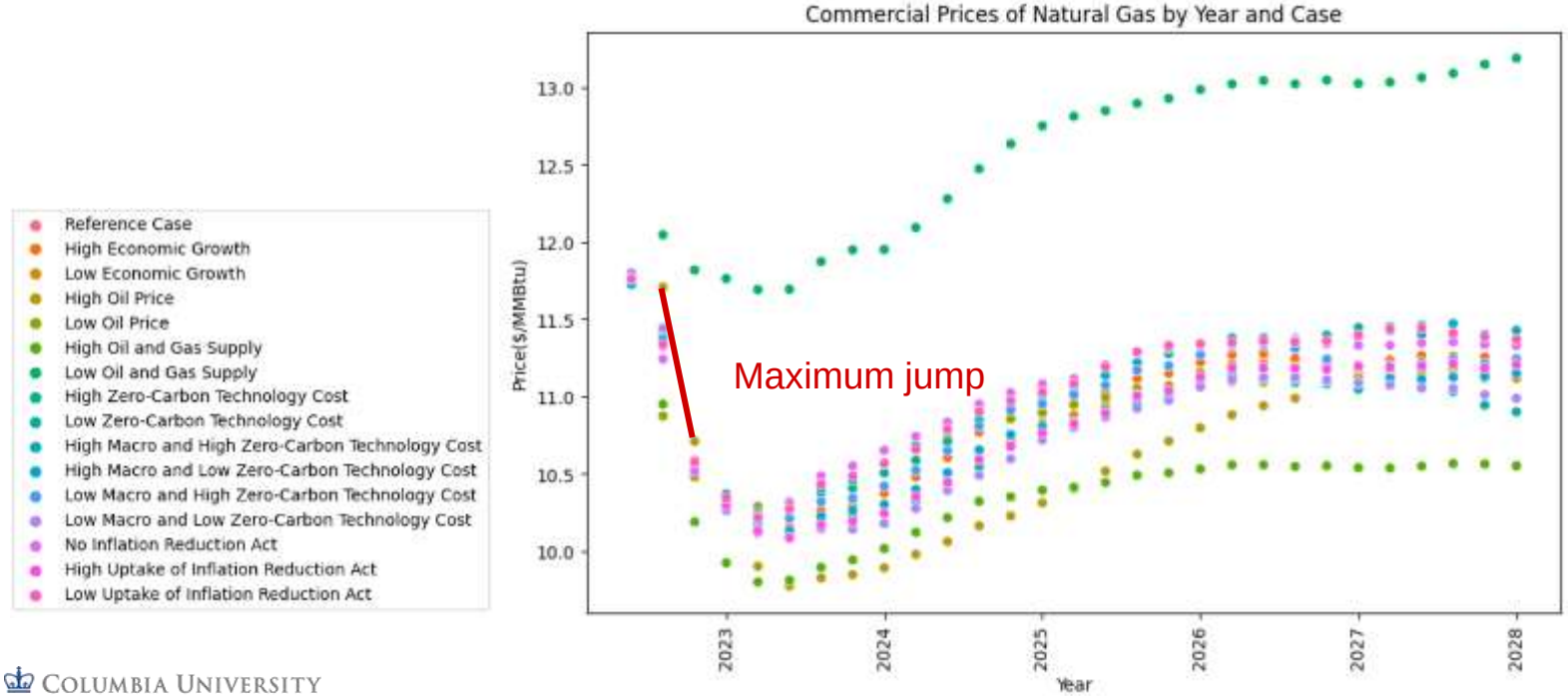
↓

Repeat the simulation process until we get consistent results

Simulation Framework

Scenario Forecasts

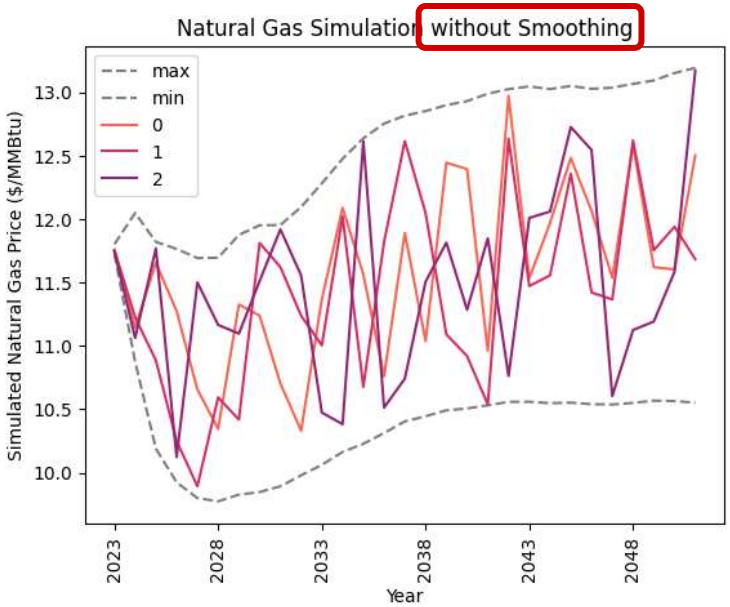
- Determine the annual min-to-max range
- Find the maximum jump between two years in one scenario

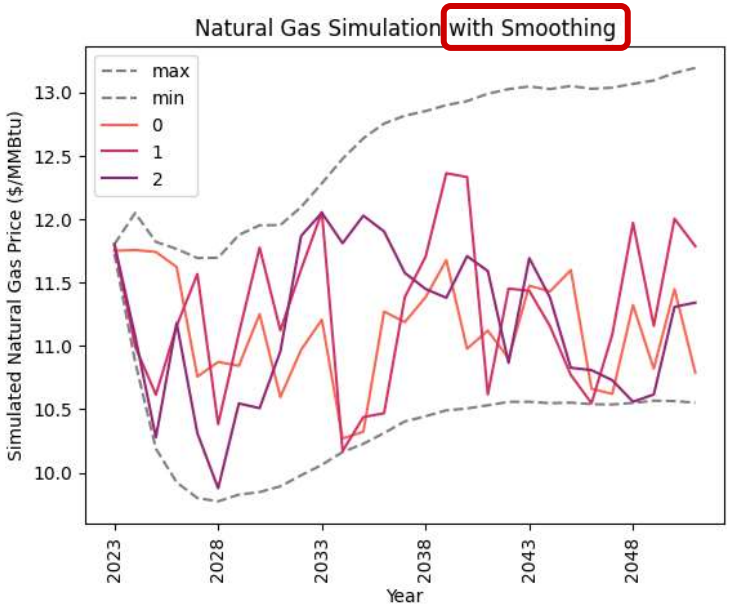


Simulation Framework

Simulation

- For each year, sample uniformly from the annual range to generate pathway
- Smooth the pathway by constraining the possible maximum jumps between two consecutive years

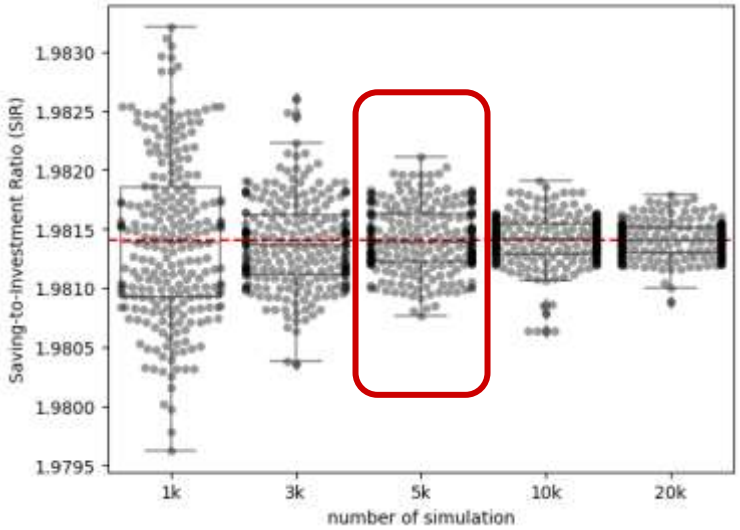


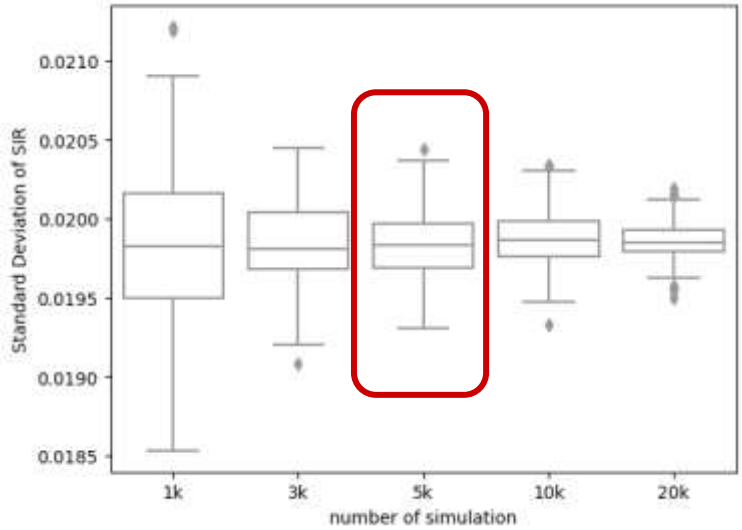


How Many Simulations for Consistent Results?

We experiment with simulation counts from 1k to 20k, and repeat each count 240 times (24 buildings with 10 iterations each)

- **For LCCA metrics, we use Saving-to-Investment (SIR) ratio as output**
- **5k simulations** provides reliable result with relatively low computational power required

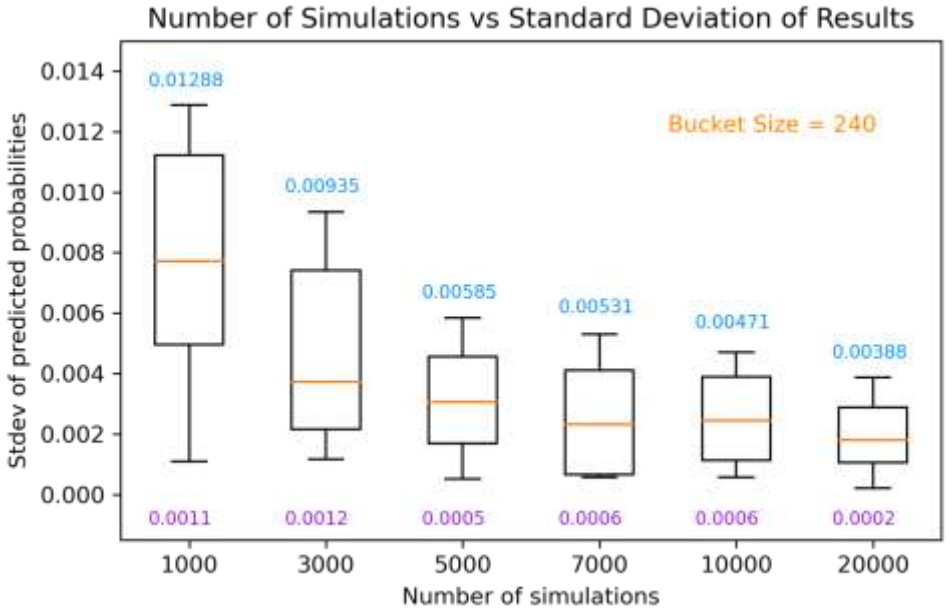




How Many Simulations for Consistent Results?

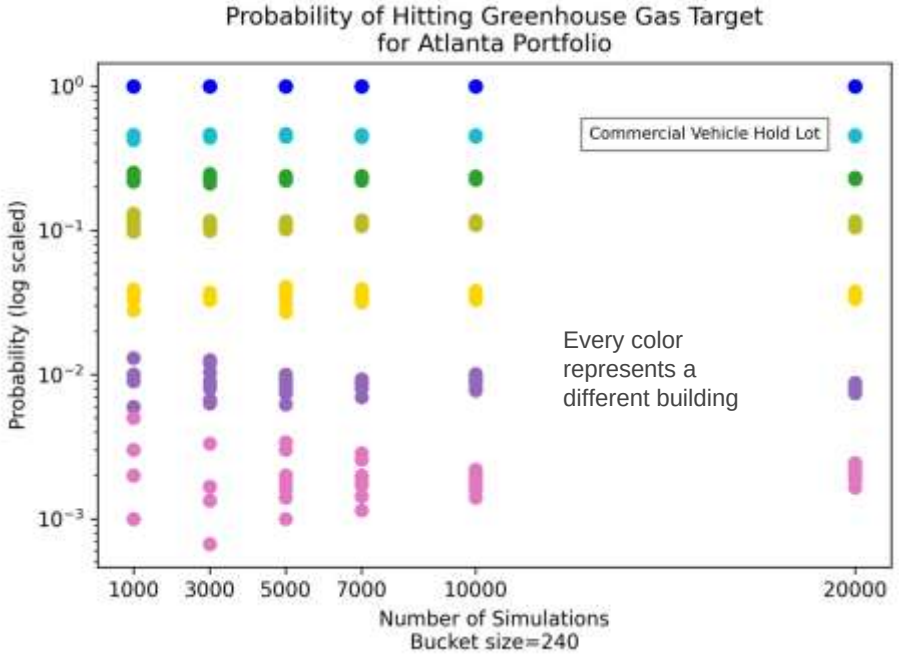
We experiment with simulation numbers from 1k to 20k, and repeat each number 240 times (24 buildings with 10 iterations each)

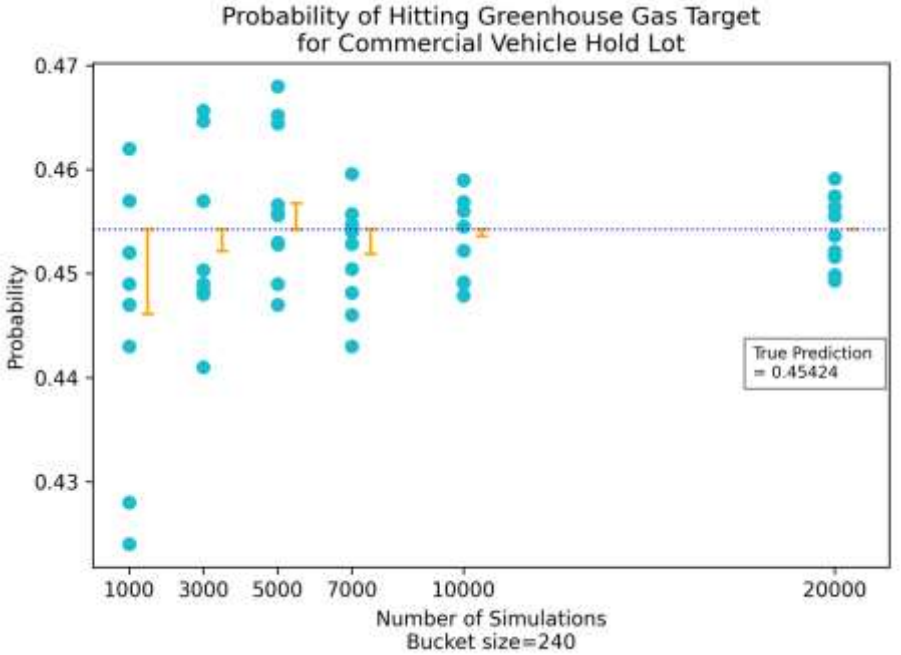
- **For Greenhouse gas emission, we output the probability of reducing x% of our emissions by 2050.**
- 5k simulations provides good reliable with relatively low computational power required



How Many Simulations for Consistent Results?

- The average from 5k simulations is a good estimate for the average from 20k simulations, our true prediction.
- We eliminate 3k from consideration after observing its large spread for the buildings in pink and purple.





Project Example Outcome

LCCA benchmark in practice

- Simple Payback Period < 7 (years)
- Saving-to-Investment Ratio > 2

Asset Name	Electricity Decrease (kWh)	Natural Gas Decrease (kWh)	Cost	Net Saving	Simple Payback Period	Discounted Payback Period	Saving-to-Investment Ratio	Decision
South Cargo Building A	511,958	272	$319,494	1,150,228	4.17	5.0	4.6	Accept
North Cargo Building A	102,480	6,928	$525,809	-216,448	32.48	33.45	0.59	Reject
Fire Station 1	73,118	61,286	$174,119	170,892	10.33	10.99	1.98	Reject

User Interface for LCCA Indicators

```
Test a portfolio? [y/n]y

Select from the following buildings:
0 South Cargo Building A
1 North Cargo Building A
2 North Cargo Building B
3 Boiler-room & Process Facility
4 South Cargo Building B
5 Training Complex- Control Center
6 Fire Station 1
7 Fire Station 2
8 Heavy Equipment Repair
9 Maintenance Building 2
10 Commercial Vehicle Hold Lot
11 Gateway Station
12 K9 Facility
13 Maintenance + Storage Facility
14 Sullivan Road Park and Ride
15 DOA Airport Maintenance Div Snow & Ice Equipment Storage - Building #5
16 DOA Maintenance Building 3
17 North Deicing Facility
18 Park-Ride - Lot C - Office 1539 (Lot C Management bld)
19 DOA - Maint Parking South Deck Office
20 UPS North Cargo
21 DOA - Maint Bldg (old Dobbs Bldg)
22 SOUTH CARGO B : INTL CARGO MKTG CONS INC , DBA ALLIANCE AIRLINES
23 APM Airport Station
Enter numbers seperated by comma (enter "all" to select all buildings): 0,1,2,3

Estimated Net Saving: $8005145.88
Estimated Simple Payback Period: 2 years and 11 months
Estimated Discounted Payback Period: 3 years
Estimated Saving-to-Investment Rate: 6.47
```

Portfolio Testing

- User select the buildings they want to use to build their portfolio
- Output the four LCCA indicators based on the selections
- Calculations take all the buildings in the portfolio as one “giant building” (add up their electricity decrease, gas decrease, and cost together)

User Interface for LCCA Indicators

```
Input target indicators? [y/n]y

Select from the following buildings:
0 South Cargo Building A
1 North Cargo Building A
2 North Cargo Building B
3 Boiler-room & Process Facility
4 South Cargo Building B
5 Training Complex- Control Center
6 Fire Station 1
7 Fire Station 2
8 Heavy Equipment Repair
9 Maintenance Building 2
10 Commercial Vehicle Hold Lot
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22 SOUTH CARGO B : INTL CARGO MKTG CONS INC , DBA ALLIANCE AIRLINES
23 APM Airport Station
```

```
Enter numbers seperated by comma (enter "all" to select all buildings): all

Choose indicators you want to test:
Net Saving (ns)
Simple Payback Period (spp)
Discounted Payback Period (dpp)
Saving-to-Investment Ratio (sir)
Enter abbreviations seperated by commas or "all" to select all indicators: all

Enter minimum net saving (unit: $): 2000000
The probability of hitting the target is 1.0

Enter maximum simple payback period (unit: year): 2
The probability of hitting the target is 0.9946

Enter maximum discounted payback period (unit: year): 2
The probability of hitting the target is 0.4168

Enter minimum saving-to-investment ratio: 10
The probability of hitting the target is 0.1558
```

Probability of Hitting Indicator Targets

- User select the buildings in their portfolio
- User input their desired indicator targets
- Run simulations based on the selected buildings, then calculate the proportion of the simulation results that meet the user targets

User Interface for Greenhouse Gas Emissions

```
Test a case? (y/n):
y

--------------------------------------------------------------------------------

Which set of buildings would you like to consider?

0                                South Cargo Building A
1                                North Cargo Building A
2                                North Cargo Building B
3                          Boiler-room & Process Facility
4                                South Cargo Building B
5                       Training Complex- Control Center
6                                          Fire Station 1
7                                          Fire Station 2
8                                Heavy Equipment Repair
9                                Maintenance Building 2
10                         Commercial Vehicle Hold Lot
11                                       Gateway Station
12                                          K9 Facility
13                         Maintenance + Storage Facility
14                           Sullivan Road Park and Ride
15    DOA Airport Maintenance Div Snow & Ice Equipme...
16                           DOA Maintenance Building 3
17                                North Deicing Facility
18    Park-Ride - Lot C - Office 1539 (Lot C Managem...
19                  DOA - Maint Parking South Deck Office
20                                       UPS North Cargo
21                        DOA - Maint Bldg (old Dobbs Bldg)
22    SOUTH CARGO B : INTL CARGO MKTG CONS INC , DBA...
23                                     APM Airport Station
Name: Asset Name, dtype: object

Enter chosen buildings:
    e.g. "0 1 2" for South Cargo Building A, North Cargo Building A,
and North Cargo Building B.    Enter "all" to select whole portfolio
0 1 2

--------------------------------------------------------------------------------

Target greenhouse gas reduction (0.5 for 50% reduction):
0.7

--------------------------------------------------------------------------------
```

```
Probabilities of Successfully reducing greenhouse gas emission by 70.0%:
                    Building Probability
0  South Cargo Building A         1.0
1  North Cargo Building A      0.0086
2  North Cargo Building B         1.0

Most to Least Problematic:
                    Building Probability
1  North Cargo Building A      0.0086
0  South Cargo Building A         1.0
2  North Cargo Building B         1.0
--------------------------------------------------------------------------------

With same buildings, test another target? (y/n):
y

--------------------------------------------------------------------------------

Target greenhouse gas reduction (0.5 for 50% reduction):
0.5

--------------------------------------------------------------------------------

Probabilities of Successfully reducing greenhouse gas emission by 50.0%:
                    Building Probability
0  South Cargo Building A         1.0
1  North Cargo Building A         1.0
2  North Cargo Building B         1.0

Most to Least Problematic:
                    Building Probability
0  South Cargo Building A         1.0
1  North Cargo Building A         1.0
2  North Cargo Building B         1.0
--------------------------------------------------------------------------------
```

User Interface for Greenhouse Gas Emissions

Target greenhouse gas reduction (0.5 for 50% reduction):
0.5

Probabilities of Successfully reducing greenhouse gas emission by 50.0%:

	Building	Probability
0	South Cargo Building A	1.0
1	North Cargo Building A	1.0
2	North Cargo Building B	1.0
3	Boiler-room & Process Facility	1.0
4	South Cargo Building B	1.0
5	Training Complex- Control Center	1.0
6	Fire Station 1	1.0
7	Fire Station 2	1.0
8	Heavy Equipment Repair	1.0
9	Maintenance Building 2	1.0
10	Commercial Vehicle Hold Lot	1.0
11	Gateway Station	1.0
12	K9 Facility	1.0
13	Maintenance + Storage Facility	1.0
14	Sullivan Road Park and Ride	1.0
15	DOA Airport Maintenance Div Snow & Ice Equipme...	1.0
16	DOA Maintenance Building 3	1.0
17	North Deicing Facility	1.0
18	Park-Ride - Lot C - Office 1539 (Lot C Managem...	1.0
19	DOA - Maint Parking South Deck Office	1.0
20	UPS North Cargo	1.0
21	DOA - Maint Bldg (old Dobbs Bldg)	1.0
22	SOUTH CARGO B : INTL CARGO MKTG CONS INC , DBA...	1.0
23	APM Airport Station	1.0

Probability of Hitting Greenhouse Gas Target

- We project that our entire Atlanta portfolio can reduce 50% of its greenhouse gas emission by 2050.
- In fact, this prediction holds up to 61%.
- These projections become important for customers once they meet their LCCA indicator targets.

Results and Suggestions

	Building	NS	SIR	SPP	DPP
0	0	1150264.27	4.60	4.17	5.00
1	1	-216444.85	0.59	32.48	33.45
2	2	5000229.99	10.51	1.03	1.96
3	3	2070319.68	23.34	0.00	0.00
4	4	4139323.63	13.77	1.00	1.00
5	5	1132411.08	6.14	3.00	3.00
6	6	170864.83	1.98	10.33	11.00
7	7	636708.67	4.26	4.99	5.00
8	8	446928.10	8.50	2.00	2.00
9	9	1533307.09	7.65	2.00	2.00
10	10	220942.48	5.16	4.00	4.00
11	11	3292724.93	143.02	0.00	0.00
12	12	1383524.14	25.04	0.00	0.00
13	13	1677022.15	25.05	0.00	0.00
14	14	368111.22	21.23	1.00	1.00
15	15	194575.53	9.66	2.00	2.00
16	16	1651751.63	48.99	0.00	0.00
17	17	1702679.45	41.05	0.00	0.00
18	18	767884.88	71.60	0.00	0.00
19	19	69834.93	1.99	11.00	11.02
20	20	269923.75	4.82	4.00	4.00
21	21	1113622.74	16.76	1.00	1.00
22	22	1900863.54	27.90	0.00	0.00
23	23	372363.68	3.15	7.00	7.00

Most to Least Problematic:

	Building	Probability
19	DOA - Maint Parking South Deck Office	0.0012
1	North Cargo Building A	0.0068
23	APM Airport Station	0.0344
6	Fire Station 1	0.109
20	UPS North Cargo	0.2256
10	Commercial Vehicle Hold Lot	0.4538
21	DOA - Maint Bldg (old Dobbs Bldg)	1.0
18	Park-Ride - Lot C - Office 1539 (Lot C Managem...	1.0
17	North Deicing Facility	1.0
16	DOA Maintenance Building 3	1.0
15	DOA Airport Maintenance Div Snow & Ice Equipme...	1.0
14	Sullivan Road Park and Ride	1.0
13	Maintenance + Storage Facility	1.0
0	South Cargo Building A	1.0
22	SOUTH CARGO B : INTL CARGO MKTG CONS INC , DBA...	1.0
9	Maintenance Building 2	1.0
8	Heavy Equipment Repair	1.0
7	Fire Station 2	1.0
5	Training Complex- Control Center	1.0
4	South Cargo Building B	1.0
3	Boiler-room & Process Facility	1.0
2	North Cargo Building B	1.0
12	K9 Facility	1.0
11	Gateway Station	1.0

Thank you for your time!

Questions?