Improving Usability and Extensibility of the Energy Technology Uptake Simulation

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ABSTRACT
The recent increase in photo-voltaic (PV) technology adoption has left utility companies with a problem. As increasing numbers of consumers are flocking to solar panel adoption, how can the utility maintain a revenue stream without further encouraging the adoption of PV by more consumers? This question is the topic of much concern at many utility companies, as they attempt to predict the reaction of consumers to various novel pricing schemes. This project addresses the need for a tool with a clear and usable interface that can allow utility companies, researchers, and governmental agencies understand the economic, societal, and political implications of the changing energy distribution landscape.

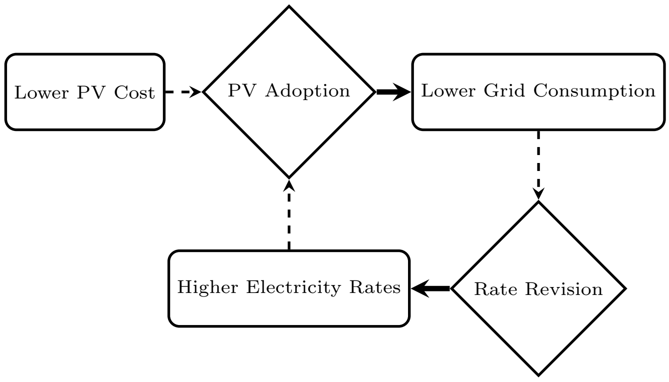
Keywords
Bass diffusion model, photo-voltaic, solar energy, renewable energy, death spiral

1. BACKGROUND
In recent years, rooftops laden with photo-voltaic (PV) panels have become a common sight in many American neighborhoods. These solar panels, as they are colloquially named, are indicative of a cultural and societal shift away from the established, centralized energy infrastructure, toward a more distributed power infrastructure.

This movement to adopt PV technology is being accelerated by many factors. Among the largest contributing factors are a mounting cultural reluctance to rely on fossil fuels and a government push (through tax incentives) towards the use of renewable energy sources.

1.1 Utility Companies
Although PV technology has been present for years, the speed and scale of the adoption by consumers was largely unforeseen by utility companies. These companies depend on certain levels of power consumption by their customers to subsidize the heavy investments required to maintain an extensive and reliable power infrastructure. As more households adopt PV as their primary or supplementary source of power, the utility company receives less revenue from the decreased demand of electrical power from the grid.

1.2 PV Uptake Feedback (The Death Spiral)



Currently, electrical utility companies charge a variable amount based, primarily, on a customers consumption of electricity. As the overall demand for electricity decreases due to customers' adoption of PV technology, the revenue for the utility also shrinks. Because the utility must ensure a level of revenue sufficient to maintain the existing distribution infrastructure, rates are increased to counteract the lost revenue. These higher rates, in turn, are a higher burden on the consumers and increase the economic incentive to adopt PV. This positive feedback effect is called "A Death Spiral" because of its circular effect on PV demand and rate pricing.

1.3 The Demand for Forecasting
The solution of raising rates on consumers to compensate for lost revenue is an unsustainable practice. Many utility companies (and consumer advocacy groups) recognize this problem and much research is currently being done by utility companies and academic institutions in order to find an optimal solution to the growing power utility problem.

1.4 Caltech and SCE
SCE has previously developed an in-house, 1-year forecasting tool to help predict PV adoption. This tool, however, is severely limited in scope and accuracy. For this reason, SCE has asked a Caltech research group, led by Desmond Cai and

Professor K. Mani Chandy to create a more accurate simulation of PV adoption that could, with greater accuracy, project multiple years or decades into the future.

2. PREVIOUS PROJECT PROGRESS

The aforementioned research group produced a simulation that proved accurate and useful for SCE. However, this simulation tool was poorly packaged, and the interface was difficult for industry forecasters to understand or use.

2.1 Tiers & Rate Structures

Southern California Edison, as well as many other utilities nationwide, utilize a tiered rate structure system. In this system, customers pay into tiers based on consumption, similar to the federal income tax tiered system. Because of the importance of electricity to a modern society, the electrical utilities are heavily regulated and must provide discounts to low-income households that satisfy certain government standards. Additionally, the utility companies cannot raise rates at will, but are constrained by a set of rules imposed by the government which cap the percentage increase allowed on the lowest two consumption tiers.

2.2 Other Factors

In addition to the aforementioned tier structure, the rate of PV adoption is also subject to political involvement in the form of government subsidies which are designed to promote the adoption of PV. The simulation must take into account the effect that this and other parameters will have on the demand for PV.

3. WORKING WITH SCE

In order to increase the simulation's traction with industry forecasters, we met with an engineer who regularly used the previous release of the simulation. Muhammad Dayhim is a Forecasting Analysis Project Manager at Southern California Edison, and we scheduled weekly meetings to discuss how we could improve the simulation. Dayhim provided us with several user-facing issues, as well as insight into what features and use cases are interesting to a forecaster.

3.1 Interface

Dayhim found the simulation interface confusing, with many more input parameters displayed than actually interested him. Additionally, the simulation outputs did not exactly match the results he is trying to evaluate. We determined that a forecaster wants to be able to control inputs and obtain outputs through one consolidated view, and we scheduled follow-up meetings with Dayhim to iterate on interface designs.

3.2 Packaging

The simulation's packaging - software requirements, how a user obtains accesses the interface, and what processes take place when the simulation executes - has a large impact on how many forecasters will use the simulation. The simulation used to be accessible online, hosted on the Google App Engine, but SCE forecasters did not want sensitive data transferred online. Therefore, Dayhim ran the previous simulation locally, through a complicated series of steps that he had memorized. Dayhim agreed that improved packaging could significantly change his ability to share scenarios with his coworkers or recommend the simulation to other forecasters. Dayhim also warned us that some industry forecasters would not have administrator permissions on their computers, so we would have to think carefully about any local software dependencies we created.

3.3 Understanding

Dayhim's final issue with the simulation was that he did not understand its inner-workings very well, which caused some friction when he would not know which parameters to change or what certain inputs really signified. We took this as a cue to document the simulation, produce a documentation website, and schedule meetings with both Cai and Dayhim to clarify points of confusion and disagreements over how the simulation should handle certain inputs.

3.4 Sensitivity Analyses

Through our meetings, we realized that Dayhim's primary use case for the simulation was to perform sensitivity analyses across multiple scenarios, rather than to determine the outcomes of any particular scenario. In order to tailor the simulation and interface for sensitivity analyses, it needed to be easier to run multiple similar scenarios in quick succession. The old interface allowed for a user to create multiple input files, run the simulation multiple times, and compare the results across output files, but we decided to make it even easier to make those comparisons.

4. WORKING WITH CALTECH

We also met regularly with the Caltech ETechUptake research team, in order to learn about the simulation and provide feedback for how the internals could be improved.

4.1 End-User Needs

The weakest aspect of the simulation was its ability to address the needs of industry forecasters like Dayhim. In order to fix this deficiency, we scheduled meetings for Dayhim, Cai, and Mani Chandy to discuss simulation use cases and the relative importance of each parameter. From these meetings, the project gained a stronger focus on which scenarios the simulation and interface should support.

4.2 Extensibility

A secondary problem with the simulation was that its codebase was not very extensible. Without significant documentation and test coverage, and with several non-standard implementations of major simulation components, it would be difficult for future developers to improve the simulation or shift its focus toward different forecasting goals. We discussed some implementation alternatives with Cai, who then re-wrote a more extensible simulation core from scratch. We believe the changes made during this renovation will prove valuable to both future developers and advanced users.

5. THE NEW INTERFACE

After considering the many criteria for the new interface, including the ability to easily perform sensitivity analyses and minimal reliance on third-party software that would require IT department approval, we settled on a combination of Excel and Python through `xlwings`, an open-source Python li-

	A	B	C	D	E	F	G	H	I	J	K
1–2				Run Scenario							
3–4				Inputs					Outputs		
5–6				Constants					Constants		
7		Start Year	End Year	Revision Year	Innovator Coefficient	Imitator Coefficient		Total Adopters	Fixed Charge	PV Price	
8		2016	2020	2018	0.01	0.01		133625	1.3	$ 4,991.00	
9–10				Tiers					Tiers		
11		Upper Usage Limit	Variable Charge ($/kWh)	Annual Increase	Tier Delta			PV Price			
12	Tier 1	1	$ 0.13	3.00%			Tier 1	$ 0.13			Tier 1
13	Tier 2	1.33	$ 0.16	3.00%			Tier 2	$ 0.16			Tier 2
14	Tier 3	2	$ 0.24		$ 0.04		Tier 3	$ 0.27			Tier 3
15	Tier 4		$ 0.30		$ 0.04		Tier 4	$ 0.31			Tier 4
16											
17–18				Years					Years		
19		Minimum Charge	Fixed Customer Charge	PV Price ($/kW)	Annual PV Discount			PV Customers	PV Production (kW)	Average Savings	
20	2018	0.02	1.5	5	5.00%		2016	58895	311260	$ 4,019.62	2016
21	2019	0.03	1.4	4.8	5.00%		2017	63032	332387	$ 4,019.62	2017
22	2020	0.04	1.3	4.6	5.00%		2018	67420	354792	$ 4,019.62	2018
23	2021	0.05	1.2	4.4	5.00%		2019	72070	378529	$ 4,019.62	2019
24	2022	0.06	1.1	4.2	5.00%		2020	76992	403646	$ 4,019.62	2020
25											

Figure 1: The one-page simulation dashboard

brary. This new interface provides significant improvement in several ways.

5.1 Consolidated

All of the important inputs and outputs are presented on one page, where the user can simply change the input cell values, click a button, and instantly view the results in the output cells. A second page expands upon the less-frequently-used inputs, so that a user can easily reference or tweak these values. Similarly, a third page expands upon the less-frequently-examined and high-fidelity outputs, so that a user can occasionally grab a complete scenario report.

5.2 Designed for the End-User

This interface is designed to enhance a forecaster's ability to draw meaningful conclusions by changing the input assumptions. The inputs are more aligned with the interests of industry engineers like Dayhim, and the outputs are simplified to more quickly point out what has changed. Users will get much more use out of this interface, and they will be much more likely to share the tool with other forecasters.

5.3 Extensible

A major goal of the new user interface design was to allow the interface to be dynamic and extensible. This was achieved by creating a clear structure of parameters that vary by year, and parameters that vary by customer consumption tier. Our interface allows the user to simply manually insert an additional parameter and its corresponding values and the simulation will parse the input and behave accordingly. This feature allows the user interface to contain only the values that the end user, in this case, Dayhim at Southern California Edison.

class `simulation.utility.`**`Utility`**(*name, simulator, start_period, revision_period*) [source]

A utility agent revises electricity rates regularly as customer usage patterns change so as to recover its operating and infrastructure costs.

A utility agent revises its rates every 36 months.

Parameters:
- **name** (*str*) – Utility name.
- **simulator** (*Simulator*) – Simulator object.
- **start_period** (*Period*) – First period to simulate.
- **revision_period** (*Period*) – First period in which there is a rate revision.

Variables:
- **start_period** (*Period*) – First period of the simulation.
- **revision_period** (*Period*) – First period in which there is a rate revision.
- **year_region_baseline_percent** (*dict*) – Dictionary that maps year to percentage of aggregate consumption to allocate baseline. Each value is a dictionary that maps the region name to its percentage baseline allocation for that year.
- **year_expense_cost** (*dict*) – Dictionary that maps year to costs. Each value is a dictionary that maps the name of the expenses to the cost objects for that year.
- **year_schedule_rule** (*dict*) – Dictionary that maps year to rules for revising rates. Each value is a dictionary that maps schedule names to rate rule objects for that year.
- **category_usage** (*dict*) – Dictionary that maps category name to its usage profile.
- **category_bills** (*dict*) – Dictionary that maps category name to its utility bills under current rates. Each value is a 12-element tuples where the entries are the bills from Jan to Dec (inclusive).
- **regions** (*list*) – List of all region names.
- **schedules** (*list*) – List of all rate schedule names.
- **categories** (*list*) – List of all customer category names.

Figure 2: Documentation from the `Utility` class

6. RESULTS

6.1 Interface

We created a more extensible and intuitive interface to allow the engineers and managers at SCE to utilize the simulation to visualize the effect various parameters have on the overall adoption of PV technology. Our interface allows the user to call the simulation from within the excel file, using Visual Basic macros, greatly simplifying and accelerating the process by which the user can see results to input parameter stimulus.

6.2 Documentation

We worked with Cai to document the major simulation components, and we added an auto-updating set of HTML pages to the repository. As these docs were able to clarify some simulation components for Dayhim, they will likely prove useful to both developers and users in the future.

6.3 Foundation for the Future

The interface we have developed in conjuction with Desmond Cai, Professor K. Mani Chandy, and Muhammad Dayhim represents the blending of use-cases most helpful to the visualization needed by SCE to forecast PV adoption generations into the future.

The clean interface and well-documented code will allow future improvements to be easily implemented by later users. This ability will help the underlying simulation demonstrate its capabilities and allow future users, whether engineers at utility companies, politicians in charge of policy decisions, or everyday people to see the long term effect that PV adoption will have on our nations energy distribution infrastructure.

7. ACKNOWLEDGMENTS

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