Consumer-Centric System Planning

Power Session Webinar

25 July 2023

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Agenda

- Role of Customers in the Future Energy System
- State-of-the-Art Customer Behavior Forecasting
- Digitising Consumers, Behavior, Load, and Resource Potential
- State-of-the-Art Integrated Electricity System Planning
- Takeaways and Recommendations
- Next Power Session

Role of Customers in the Future Energy System

Impacts on Load

Impacts on Flexible Resources

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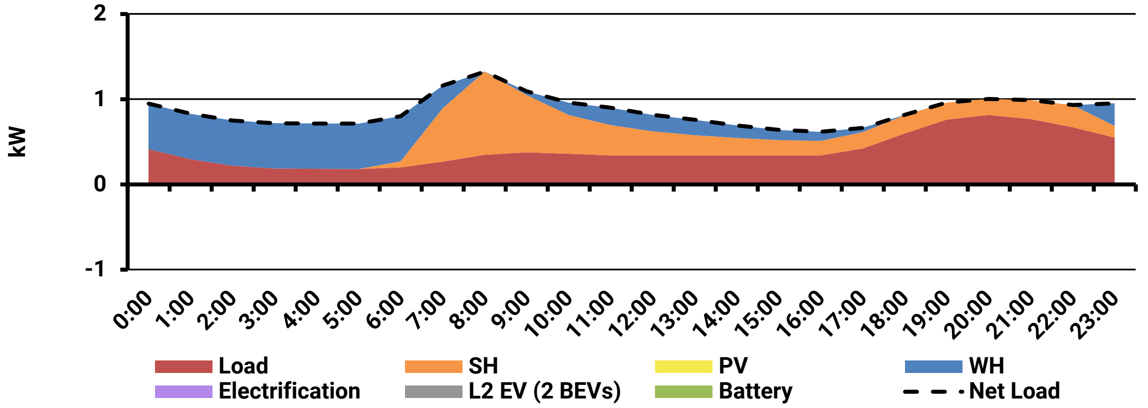
Consumer Decisions Impacting on System Planning

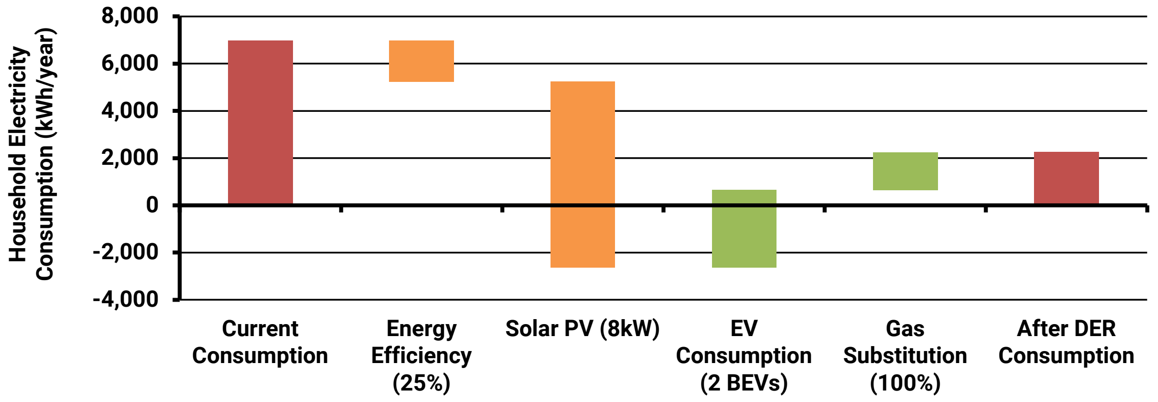
Average Winter Day Residential Customer Profile (Victoria)



Source: Energeia Modelling. Note: WH = Water Heating, SH = Space Heating

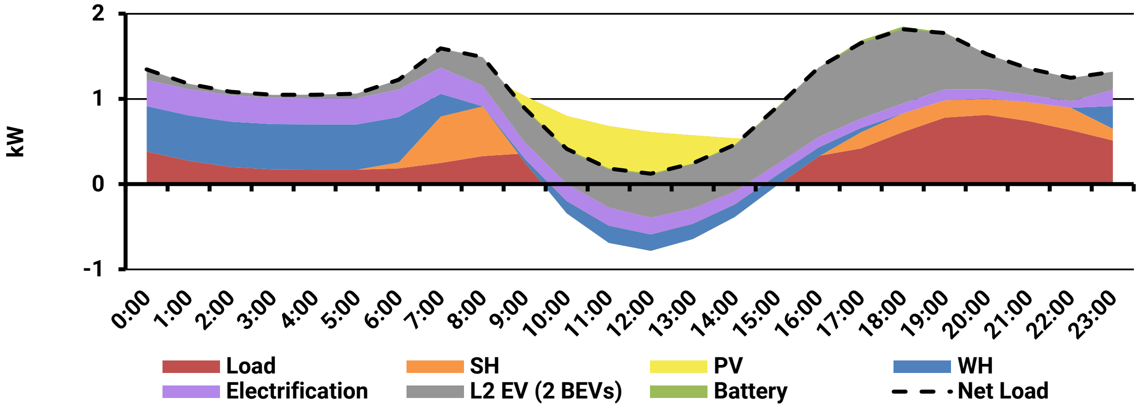
- Customer decisions will radically alter their service requirements and optimal grid and system plans
- Full electrification of transport and heating will increase premise consumption in Victoria by over 50%
- Solar photovoltaics (PV), storage and mobile storage could virtually offset that increase and more

Potential Customer Decisions (Example)



Source: Energeia Modelling

Illustrative Impacts of Customer Decisions on Load (Example)



Source: Energeia Modelling. Note: WH = Water Heating, SH = Space Heating

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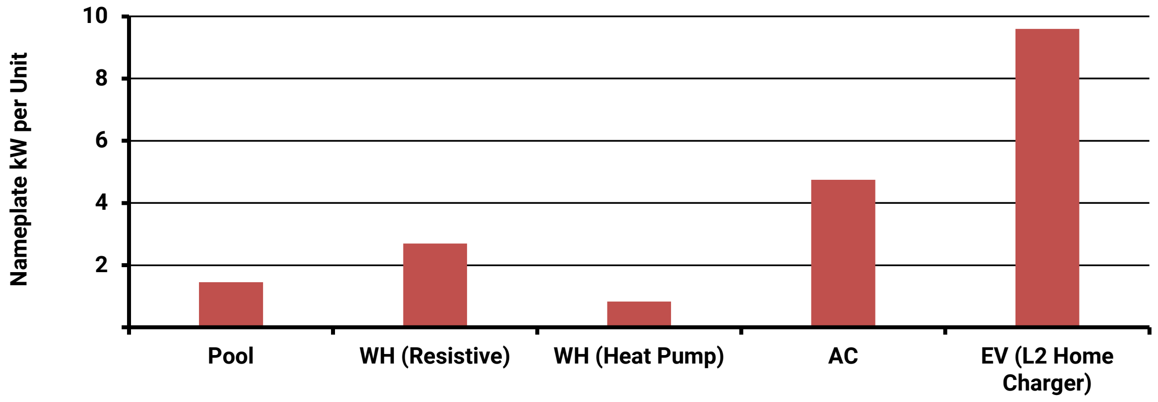
Consumer Decisions Impacting on System Planning

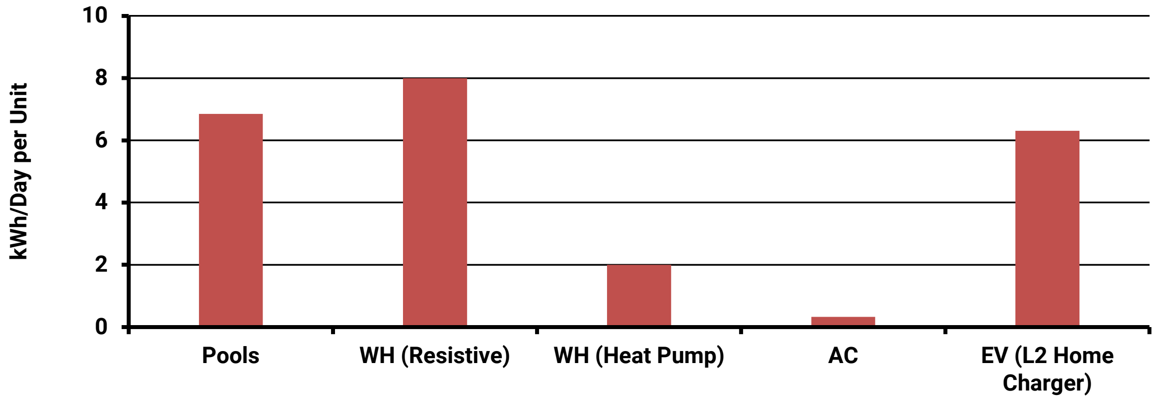
Load Demand Flexibility (kW)



Source: UTS (2023), Energeia Modelling

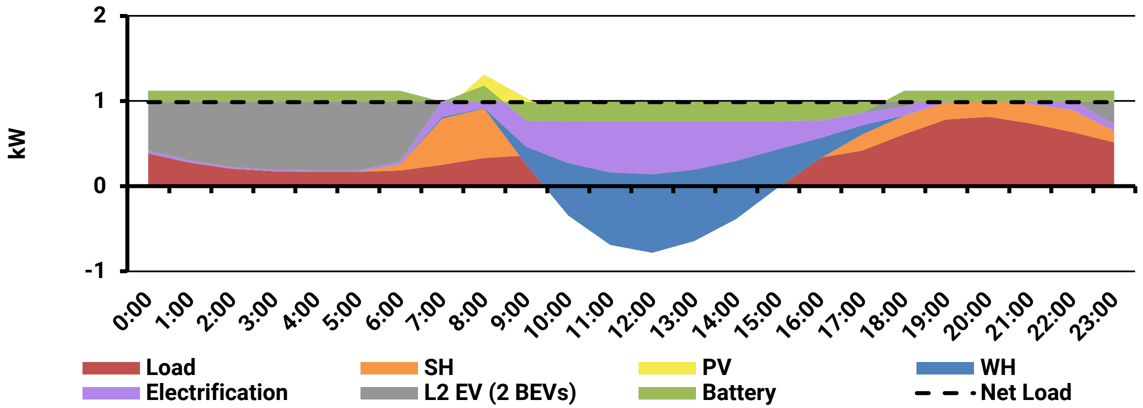
- Customer decisions regarding the devices or services they choose will radically alter their relationship to grid
- Understanding customer decision-making is therefore critical to effectively planning the future energy system
- It can also be used to ensure customers are integrated in an optimised way, maximising benefits overall

Load Energy Flexibility (kWh/Day)



Source: UTS (2023), Energeia Modelling

Illustrative Residential Load Profile Post Optimisation



Source: Energeia Modelling. Note: WH = Water Heating, SH = Space Heating

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State-of-the-Art Customer Behavior Forecasting

- Electricity Industry Trends
  - Trends in Consumer Behaviour Forecasting
  - Implications of Using Obsolete Techniques
  - Key Forecasting Techniques
- Agent-Based Simulation

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Trends in Consumer Behaviour Forecasting

Methodology	Demand Side Forecasting Variable				
	Max and Min Demand	Time Series Demand	DER Uptake	EV Uptake	Appliance Uptake
Linear Regression	WA, SMUD, Ireland, NZ	WA, SMUD, Ireland, NZ*	NEM, WA, LA, SMUD	NEM, WA, LA, SMUD	LA, SMUD
Non-Linear Regression	LA	LA			LA
Bass Diffusion			NEM	NEM	
Logit/Probit			LA		
ARIMA					
Extreme Value Theory	NEM				
Machine Learning	NEM				
Agent Based			LA		
Monte Carlo	LA	LA			
Linear Programming		NEM			
Non-Linear Programming					

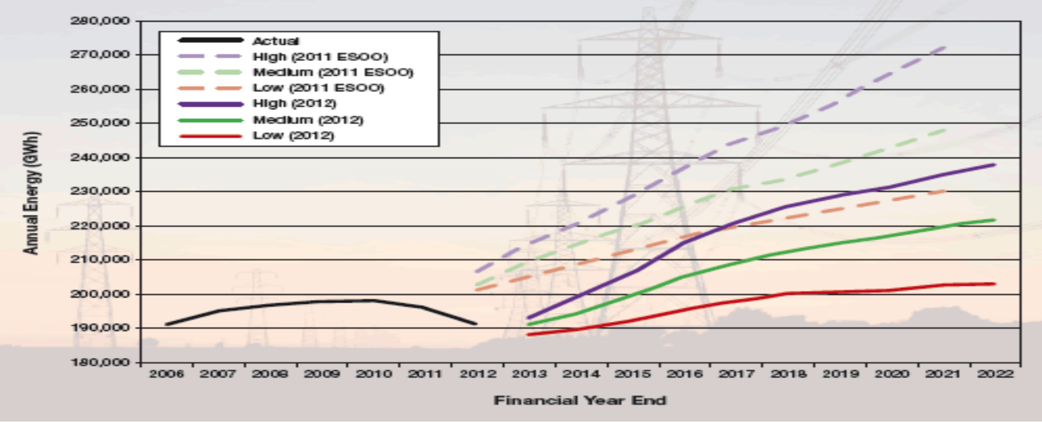
*NZ demand forecast was only annual resolution, whereas all other ISPs considered hourly or half-hourly resolutions. **Note**: SMUD: Sacramento Municipal Utility District, PG&E: PG&E Corporation. **Note:** ISPs are excluded if they did not model the variable or if their methodology was not found, most notably, PG&E's methodology was not found for any variable

Source: Energeia Research

- Demand-side forecasting typically uses linear regression
- More complex forecasting methods are used by the Australian Energy Market Operator (AEMO) for the National Energy Market (NEM) and Los Angeles Department of Water and Power (LADWP) for Los Angeles

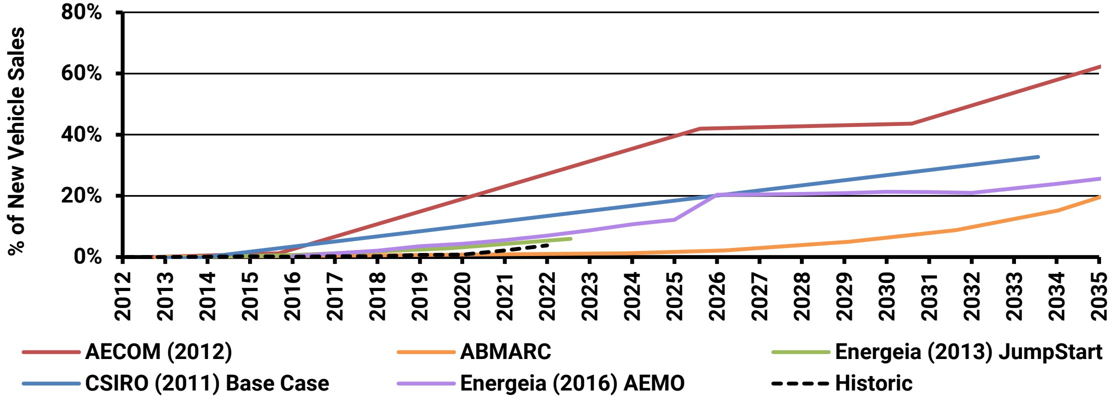
Implications of Using Obsolete Techniques

AEMO's Forecast of Peak Demand



Source: AEMO

Various Attempts at Forecasting EV Adoption in Australia



Source: AECOM (2012), ABMARC, Energeia, EV Council

- AEMO did not anticipate the emergence of behind-the-meter solar PV and its impact on consumption
- This outcome was typical for forecasters at the time, as most relied on regression models, which project the future using the past – and there was no PV in the past
- The situation for forecasting electric vehicle adoption was even worse, with a wide range of reputable organisations completely missing it – including Energeia
- We learned from this the perils of regression and even Bass Diffusion (a type of logit model) modelling, and pivoted to agent-based simulation methods

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Key Customer Behavior Forecasting Techniques

Modelling Category	Forecasting Method	Applications				Ease of Use				Robustness					Total
		Linear Variables	Non-Linear Variables	Binary Variables	Objective Optimisation	Human Effort	Data Requirement	Ease of Interpretation	Computational Intensity	Resistance to Lack of Independence	Resistance to Extraneous Variables	Resistance to Outliers	Resistance to Overfitting	Identifying Emerging Behaviours	
Statistical	Linear Regression	✓	✗	✗	✗	Good	Good	Good	Good	Poor	Average	Poor	Average	Poor	19
	Non-Linear Regression	✓	✓	✗	✗	Average	Good	Good	Average	Poor	Average	Poor	Poor	Poor	16
	Bass Diffusion	✓	✓	✗	✗	Average	Good	Good	Good	Poor	Average	Poor	Poor	Average	18
	Logit/Probit	✓	✗	✓	✗	Good	Good	Good	Good	Poor	Poor	Average	Average	Poor	19
	ARIMA	✓	✗	✗	✗	Good	Good	Good	Poor	Good	Poor	Poor	Average	Poor	18
	EVT	✗	✗	✓	✗	Good	Average	Good	Good	Good	Average	Good	Good	Poor	23
Statistical and Simulation	Machine Learning	✓	✓	✓	✓	Average	Poor	Poor	Poor	Good	Average	Average	Average	Good	17
	Monte Carlo	✓	✓	✓	✗	Good	Good	Good	Poor	Good	Good	Good	Good	Poor	23
Simulation	Agent-Based	✓	✓	✓	✓	Poor	Average	Good	Average	Good	Good	Good	Good	Good	23
	Linear Programming	✓	✗	✓	✓	Poor	Poor	Average	Poor	Good	Good	Good	Good	Good	20
	Non-Linear Programming	✓	✓	✓	✓	Poor	Poor	Average	Poor	Good	Good	Good	Good	Good	20

Source: Energeia Research. **Note**: ARIMA: Autoregressive Integrated Moving Average, EVT: Extreme Value Theory

Legend	Relatively Good	Relatively Average	Relatively Poor
Score	3	2	1

- Energeia ranked forecasting techniques by the ease of use and robustness under key modelling pitfalls
- Typically, simulation forecasting methods are the most challenging to apply but have a high resistance to unusual values in data, and a stronger ability to capture emerging trends

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Agent-Based Simulation 101

Overview

History

Strengths and Weaknesses

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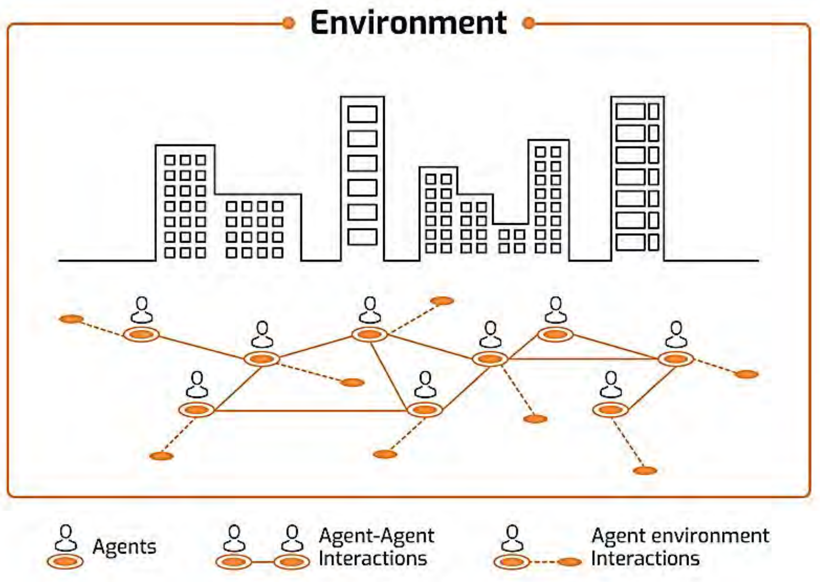
Definition of Agent Based Modelling

Agent-Based Modelling



Source: ResearchGate, Macro Galbiati, 2021

- Agent-Based Modelling (ABM) Definition:
  - ABM is a category of computational models that invoke dynamic action, reaction, and intercommunication protocols amongst the agents in their shared environment to derive insights about their behaviour and emergent properties
- Drivers for ABM in Electricity Sector Modelling are:
  - Increasing complexity of electricity system
  - Growing role of consumer behaviour in electricity system
  - Growing uncertainty, interdependency in electricity system

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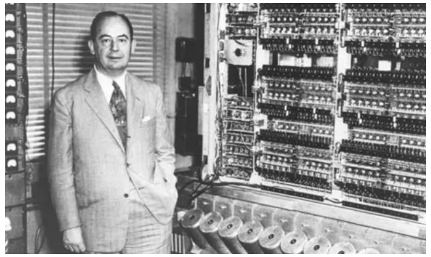
History of Agent Based Modelling

1940s

Origin Story

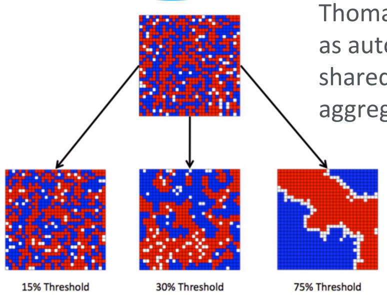
The idea of agent-based modelling was developed by Von Neumann as a simple concept a machine capable of reproduction



1970s

Early Development

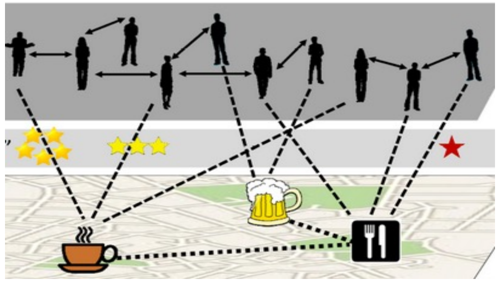
Thomas Schelling's segregation model as autonomous agents interacting in a shared environment with an observed aggregate, emergent outcome



1990s

ABM Expansion

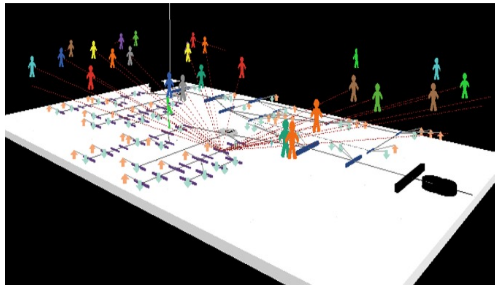
ABM Expanded to several fields Such as social and spatial dynamics of small-scale human societies and primates



1999

ABM in Electricity

First agent-based simulation of electricity by Visudhiphan modelled electricity demand as a price elastic demand curve



2010s

Application in Electricity

ABM has been applied in a wide range of simulation problem on market demand, supply, smart grids and energy storage

NREL National Renewable Energy Laboratory
DLR
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Key Strengths and Weakness

Forecasting Method	Applications				Ease of Use				Robustness			
	Linear Variables	Non-Linear Variables	Binary Variables	Objective Optimisation	Human Effort	Data Requirement	Ease of Interpretation	Computational Intensity	Resistance to Lack of Independence	Resistance to Extraneous Variables	Resistance to Outliers	Resistance to Overfitting
Agent-Based	✓	✓	✓	✓	Red (Relatively Poor)	Orange	Green (Relatively Good)	Red (Relatively Poor)	Green (Relatively Good)	Green (Relatively Good)	Green (Relatively Good)	Green (Relatively Good)

Legend
Relatively Good
Relatively Average
Relatively Poor

Strength	Weakness
• Identifies emergent properties • Easy to communicate, understand • Outcomes are traceable / auditable • Can model phase transitions, breaking points, perturbations • Can integrates w/regression, statistical and other techniques • Can model factor interdependencies • Can model wide range of agent attributes, incl. location and over time	• Setup and configuration can be resource intensive • Setup and configuration can be data intensive • Operation can be computationally intensive • Some interdependencies or agent attributes may not be known • Few examples of rigorously validated complex models (CSIRO validated Energeia model for Western Power)

Source: Energeia Research

- To conduct agent-based modelling, a number of key challenges must be overcome:
  - Sufficient and quality data must be available
  - Time and expertise required to implement

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Digitising Consumers, Behavior, Load and Resource Potential

Agent Design

Agent Mapping to Customers and Grid Assets

Agent Load and Sub-Load Profiles

DER Adoption and Operation

Resource Potential Analysis

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Agent Design Reflects Property Impact and Availability

Key Drivers of Customer Behavior and its Impacts (Example)

Category	Variable	Network Pricing	Demand Mgmt.	Customer Insights	Network Planning	Emerging Opp.	Data Avail.	Count
Location	Network (East, West, Mount Isa)	✓		✓	✓		✓	3
	Feeder Type (e.g. Long Rural)	✓	✓			✓	✓	3
	Network Region	✓			✓		✓	2
	LGA	✓						1
	Climate	✓		✓	✓			3
Customer	Type	✓	✓	✓	✓		✓	4
	Size (MWh)	✓	✓	✓	✓		✓	4
	Network Tariff	✓	✓				✓	2
	ANZSIC Class	✓	✓			✓	✓	3
	Income	✓	✓	✓	✓	✓	✓	5
Premise	Premise Type		✓	✓	✓	✓	✓	4
	Number of Occupants	✓	✓	✓	✓		✓	4
	Number of Bedrooms		✓		✓		✓	2
Appliances	Access to mains gas		✓			✓	✓	2
	Space Conditioning (AC)	✓	✓	✓		✓	✓	4
	Water Heater	✓	✓	✓		✓	✓	4
	Pool	✓	✓	✓		✓	✓	4
	Distributed Energy Resources (DER)	✓	✓	✓	✓	✓	✓	5
	Controlled Load	✓	✓	✓	✓	✓	✓	5

Source: Energeia

- Agent design focuses on agreeing on the set of customer characteristics that drive behavior and impact outcomes
- They can vary a little or a lot depending on the application, as shown in the example to the left
- The resulting characteristics are used to develop a table of customers by segment and their statistical properties
- Energeia then uses a sample design to generate agents that reflect each customer segment of interest
- Segment variables include:
  - Rate, appliance, and flexible resource configuration
  - Load and flexible resource load profiles over the year
  - Technology, tariff, and program adoption propensities
  - Map to grid assets and market pricing areas

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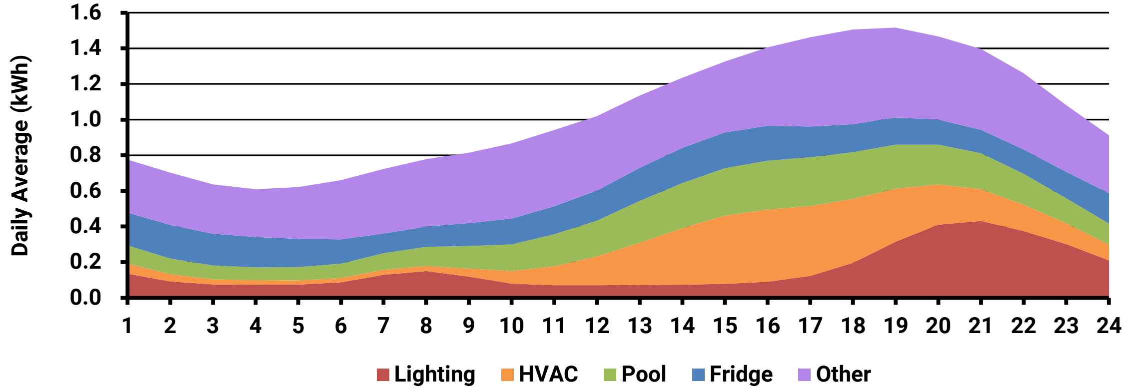
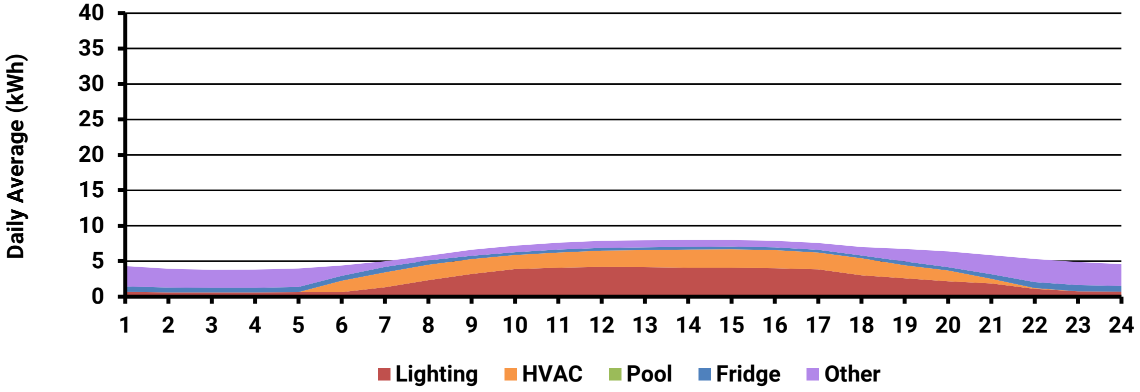
Example Estimation of Agent Loads and Sub-Loads

Residential – Single Family – Zone 2



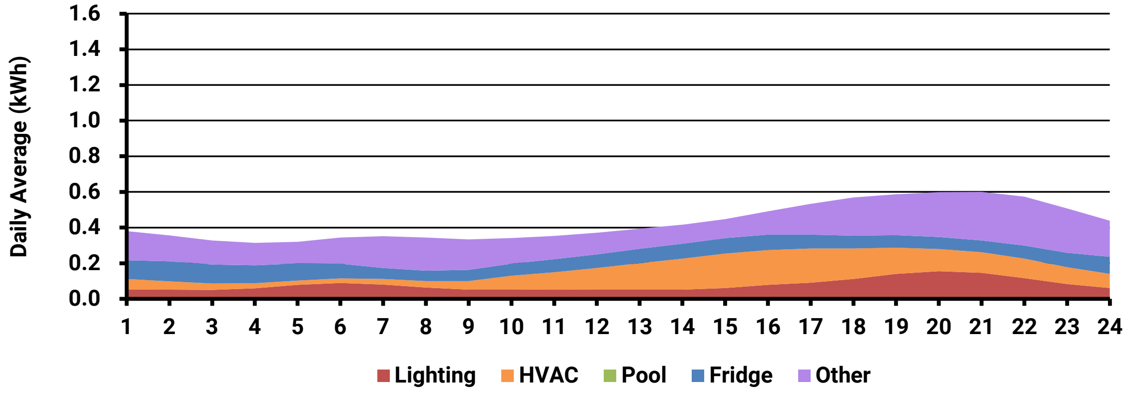
Source: LADWP, Energeia, Open EI / DOE and Building America House Simulation Protocols

Commercial – Retail



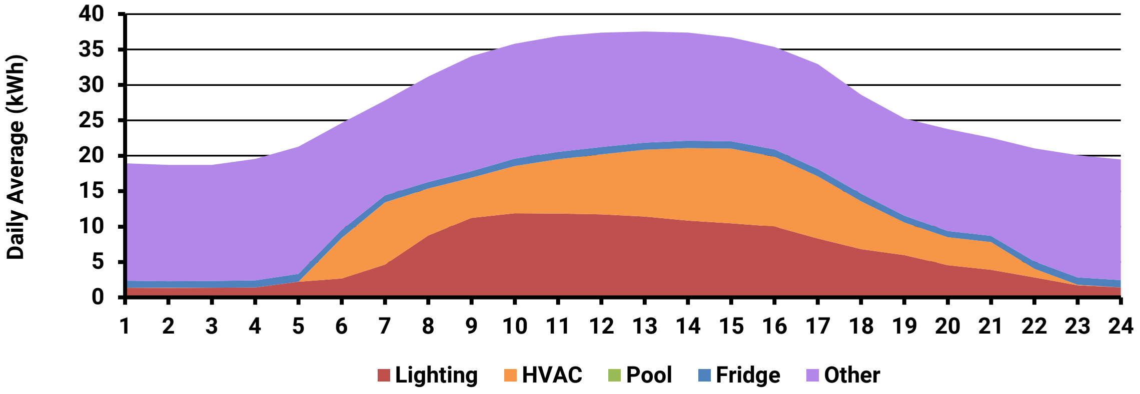
Source: LADWP, Energeia, Open EI / DOE and Building America House Simulation Protocols

Residential – Single Family – Zone 1



Source: LADWP, Energeia, Open EI / DOE and Building America House Simulation Protocols

Commercial – Office



Source: LADWP, Energeia, Open EI / DOE and Building America House Simulation Protocols

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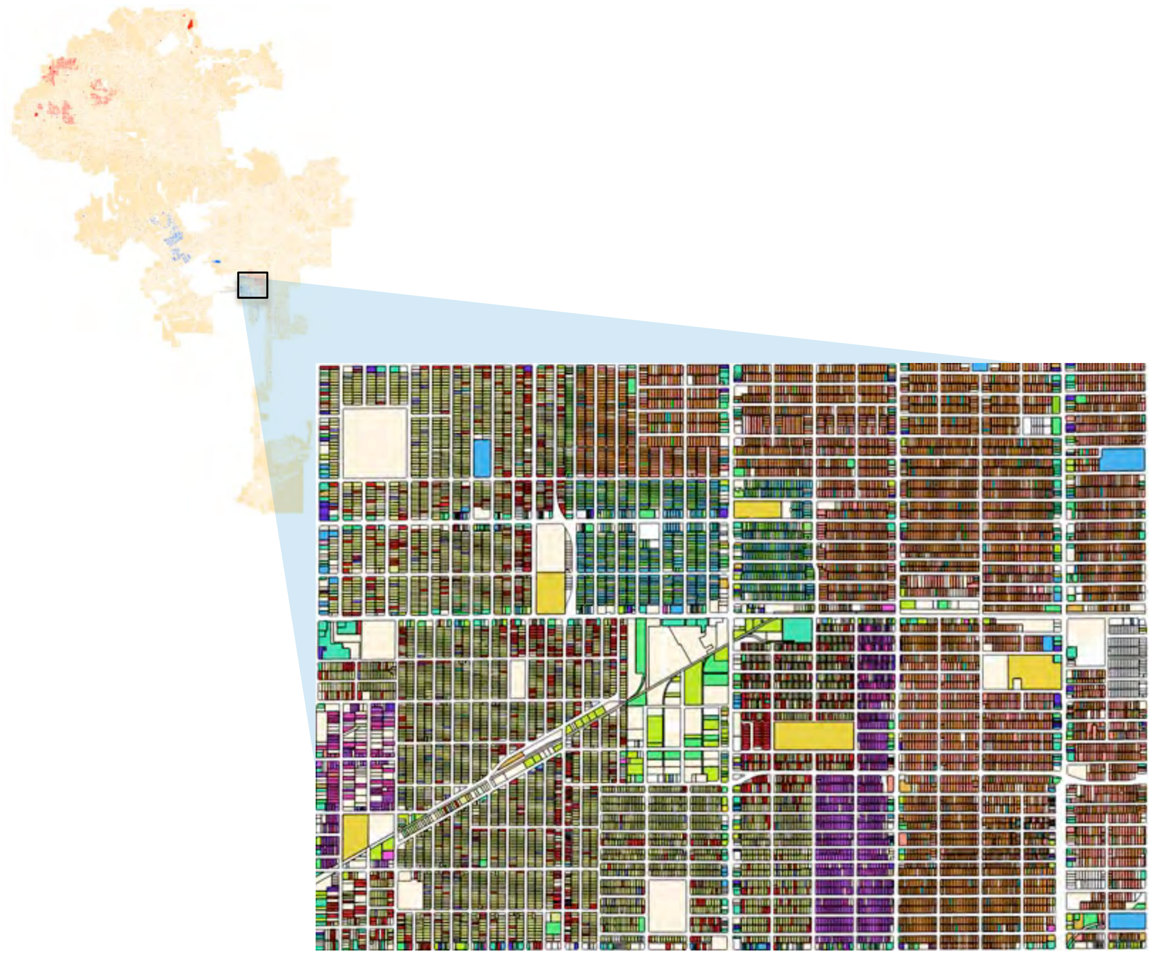
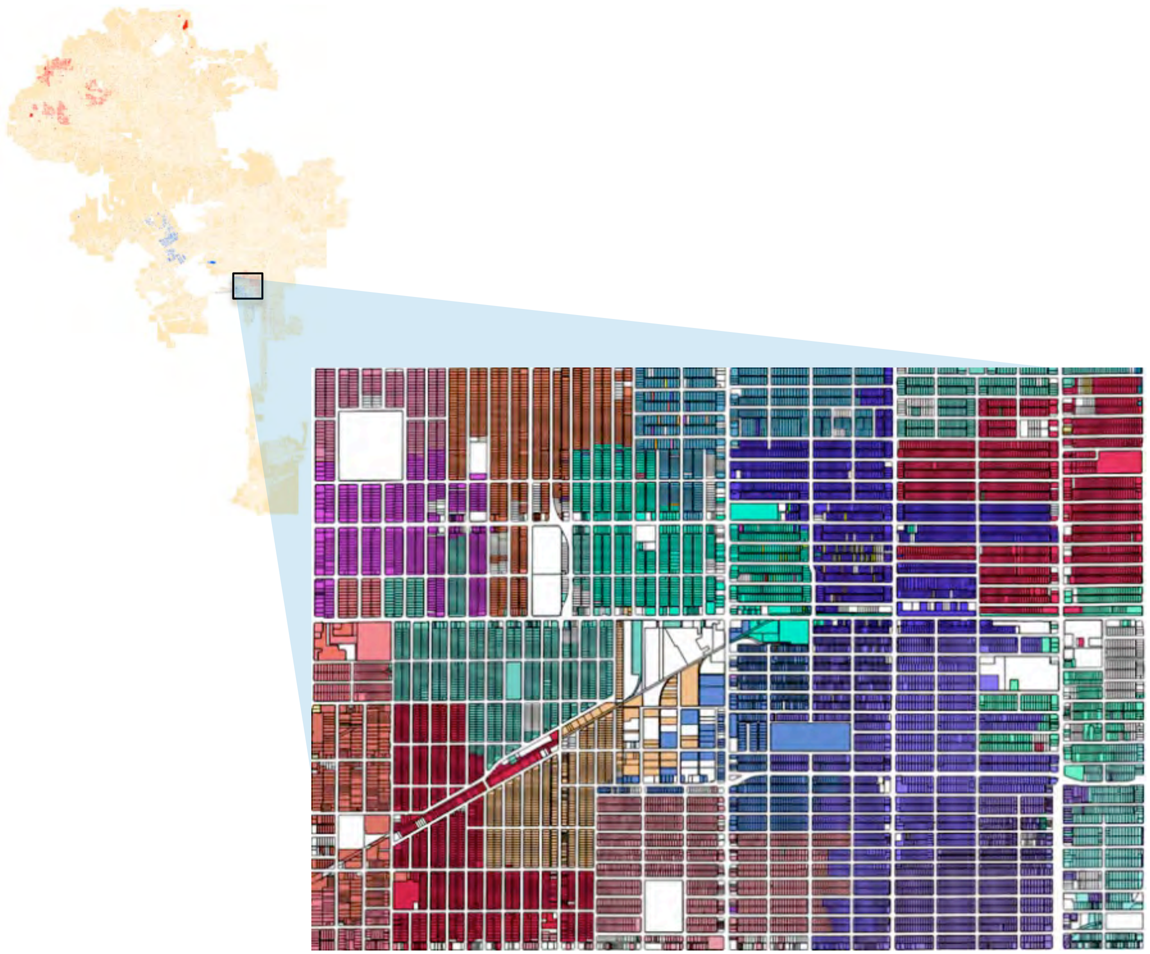
Agents Mapped to Customers and to the Grid

Agent Segments Mapped to Each Premise



Source: Energeia modeling

Premises Mapped to Grid



Source: Energeia modeling

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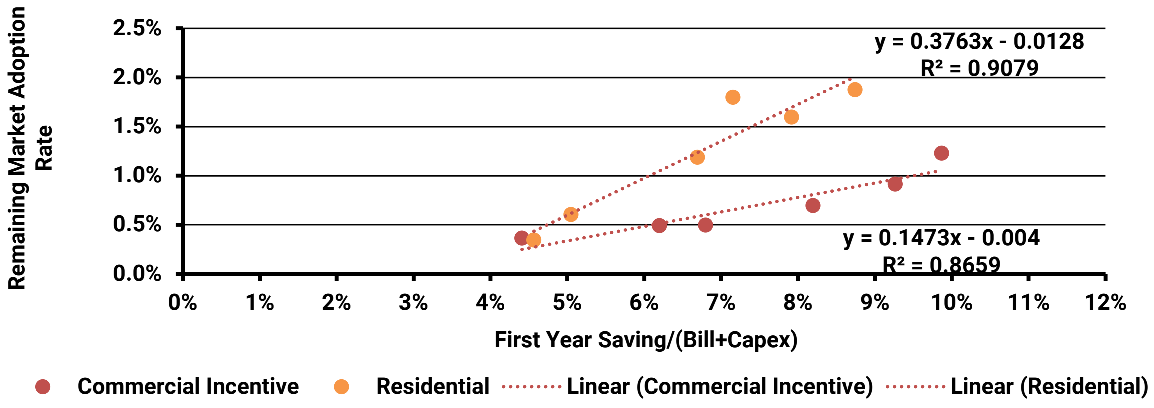
Key Agent Behavior Functions

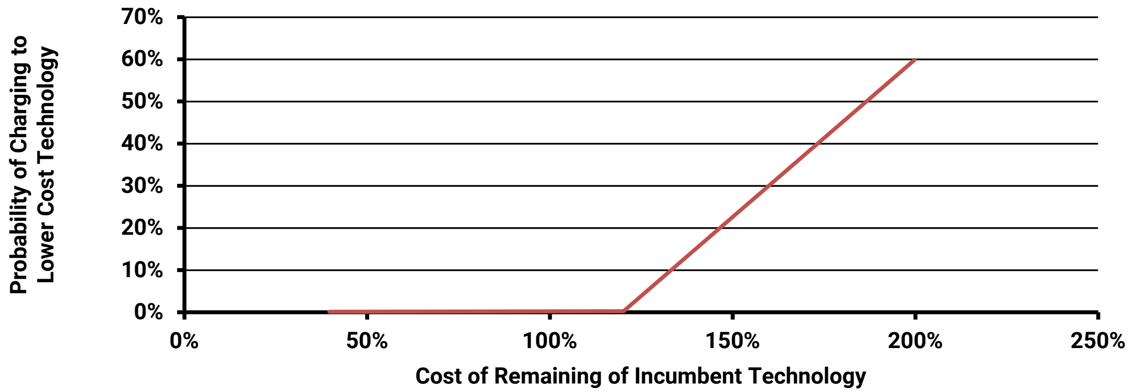
Adoption Involving Significant Investment



Source: Energeia Modelling

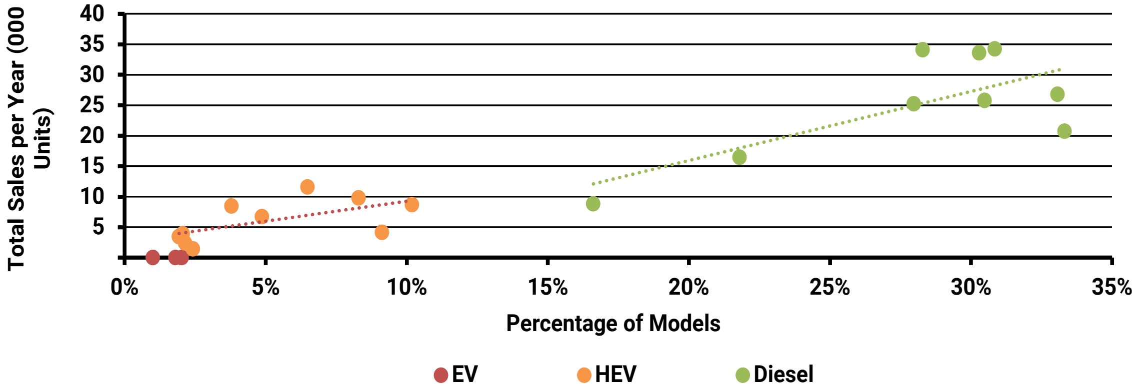
- Energeia has spent considerable time refining its customer behavior models over the past 10 years
- We have developed three different types of behavior models, which are robust across jurisdictions
- The models are parameterised for a given jurisdiction based on historical behavior

Adoption Involving a 'Hassle' Factor



Source: Energeia Modelling

Adoption Involving Non-Financial Drivers



Source: Energeia Modelling

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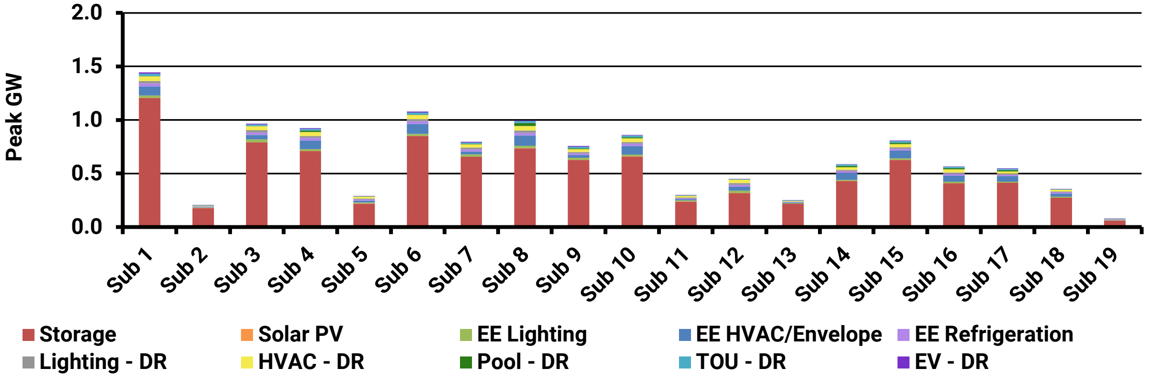
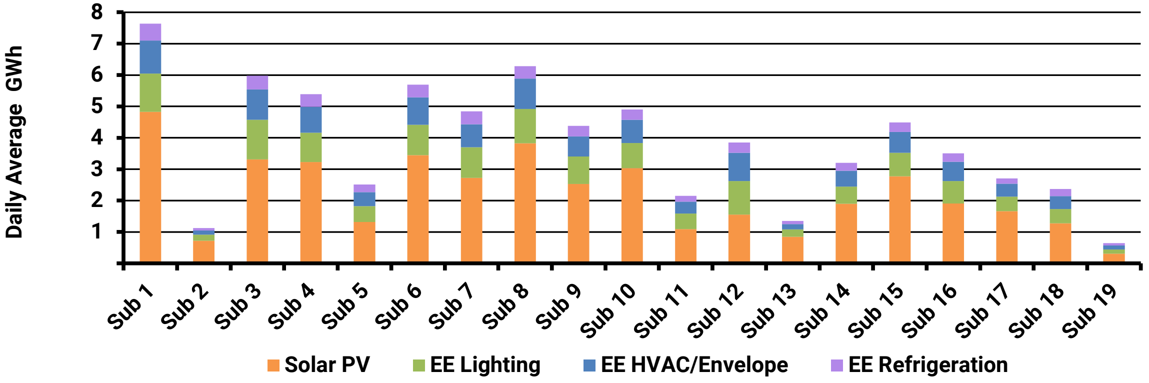
Estimation of Technical, Market and Achievable Potential

Estimation of Achievable Peak Reduction Potential (Example)



Source: Energeia
Note: Peak capacity is defined as 6:00 PM August 21, 2027

Estimation of Achievable Consumption Reduction Potential (Example)



Source: Energeia Modelling

- Customer digitisation can be applied to estimate:
  - **Technical Potential** – Based on physical space limitations
  - **Economic Potential** –Based on relative economics, consumer behavior set to perfectly rational
  - **Market Potential** – Based on consumer behavior and incentives
  - **Achievable Potential** – Based on consumer behavior and optimized incentives
- Potential analysis is a key input into grid and system planning
- Achievable potential dependent on scenario assumptions, including incentives and timelines
- Foresight of achievable potential enables the timely development of incentives and market arrangements

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State-of-the-Art Integrated Electricity System Planning

System Planning Methods

Benefits of Truly Integrated System Planning

Benchmarking ‘Integrated’ System Plans

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System Planning Definitions

- **System Planning –** Providing an evidence base of quantitative analysis to guide strategic investment decisions to achieve a set objectives[1]

- **Transmission Network Planning –** Facilitating new and replacement transmission assets at the least cost to consumers by considering forecasts of generation, demand and asset condition to identify emerging constraints[2]

- **Distribution Network Planning –** Delivering efficient investment options to ensure the network can function by forecasting max/min demand for the relevant network assets and identifying emerging system limitations[3]

- **Integrated System Planning –** Using a holistic approach across customers, networks, resource providers and energy suppliers to find an integrated, optimised solution to electricity system objectives at an acceptable level of risk[4]

- While all the above are examples of system planning, an integrated system plan must explicitly consider *all* aspects of the energy system

1: IRENA, Long-Term Energy Planning https://www.irena.org/Energy-Transition/Planning
2: AEMC, Network planning, https://www.aemc.gov.au/energy-system/electricity/energy-system. TransGrid (2022), TAPR (Page 2), https://www.transgrid.com.au/media/jn4klv4s/tgr12164-tapr-2022-v5-4-final.pdf
3: AEMC, Network planning, https://www.aemc.gov.au/energy-system/electricity/energy-system. AusGrid (2022), DAPR (Page 5), https://cdn.ausgrid.com.au/-/media/Documents/Reports-and-Research/Network-Planning/DTAPR-2022.pdf?rev=313ff97b28e94dc98fa8a5a0c0a8d581&hash=C19577C6FE6E7AEF5F8F5B61EA74D87A
4: AEMO ISP, https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp#:~:text=The%20Integrated%20System%20Plan%20(ISP,next%2020%20years%20and%20beyond. Berkely Lab Integrated Energy Systems (2021), https://eta.lbl.gov/integrated-energy-systems

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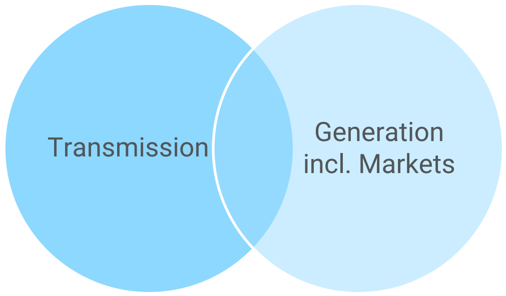
Illustrative Value of Truly Integrated System Planning

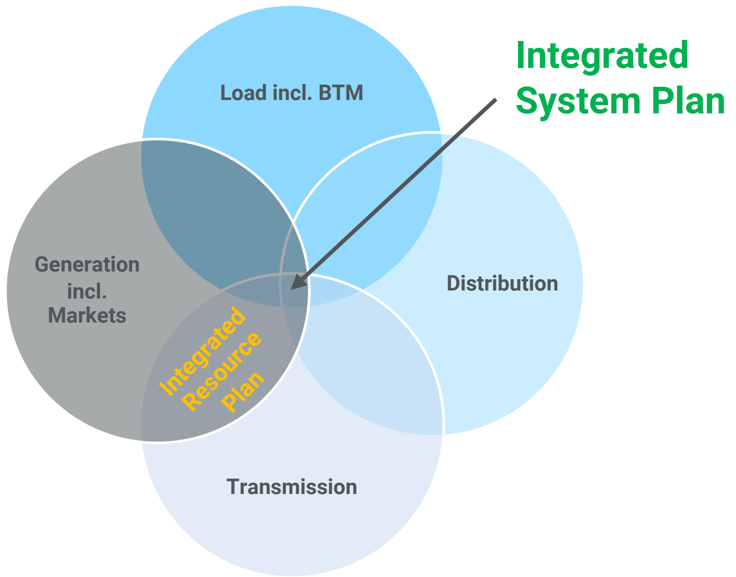
Typical Integrated Resource Plan



Source: Energeia

- Net load and BTM resources by scenario assumed fixed inputs
- Distribution network impacts typically not considered
- Transmission and generation assumed variable in the optimisation process

Truly Integrated System Plan



Source: Energeia

- All sources of demand and supply variable
- Interdependencies and synergies integrated
- Least cost achieved across <u>all</u> domains
- Net end-to-end costs 20-30% lower

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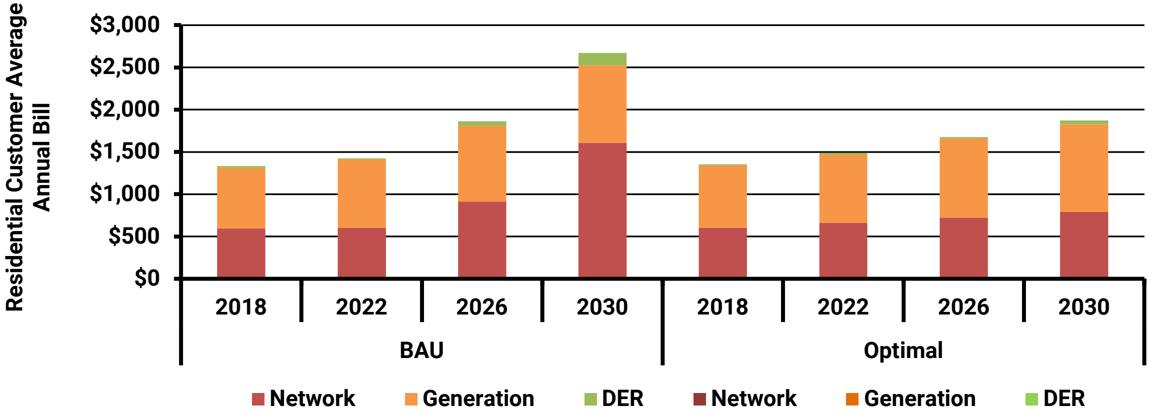
Economic Impacts of True, Consumer-Centric Planning

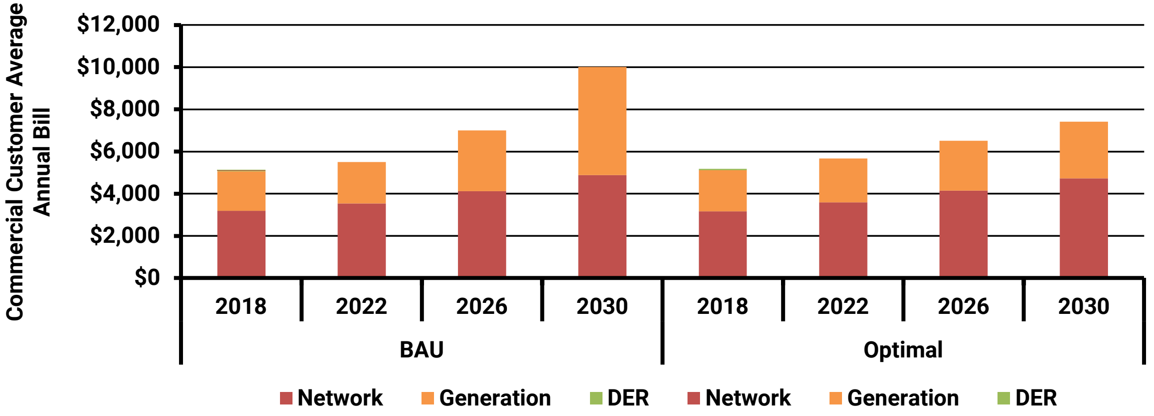
Residential Customer Average Annual Bill (example)



Source: Energeia Modelling

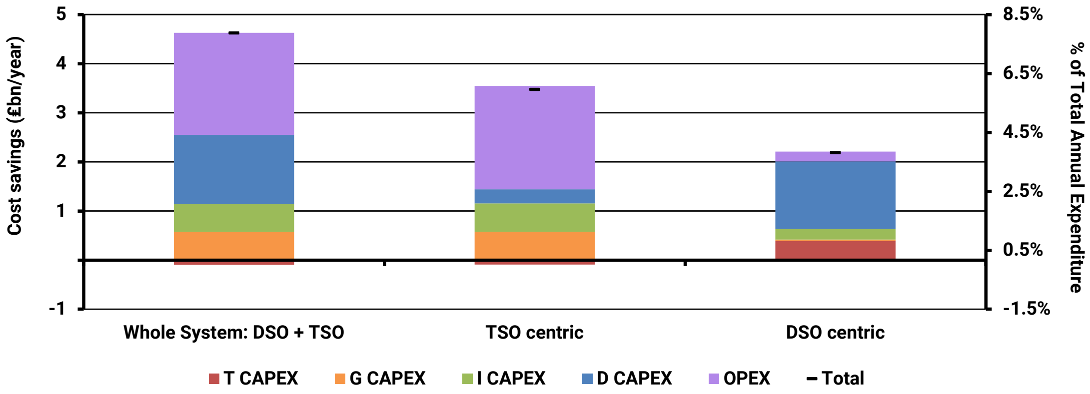
- Truly integrated, whole-of-system planning can deliver a significantly lower costs overall, due to effect of feedback loops with consumer behavior
- The examples to the left compare a Business as Usual, Integrated Resource Plan (IRP), with an optimized, truly Integrated System Plan (ISP)
- The ISP actually has less consumer resource investment than the IRP, and significantly lower grid costs and resource costs
- The difference grows over time, as more consumer located resources are invested in, and increasingly leveraged across upstream asset constraints

Commercial Customer Average Annual Bill (example)



Source: Energeia Modelling

Potential Benefits of Improved T&D Control Interface



Source: Imperial College London (2019)

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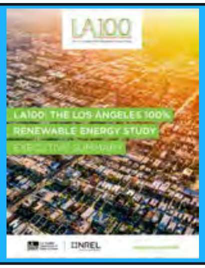
Integrated System Plans (ISPs) Assessed

Integrated System Plans							
Jurisdiction	National Energy Market (NEM), Australia	Western Australia (WA), Australia	Los Angeles, California, USA	Sacramento, California, USA	Northern California, USA	Republic of Ireland + Northern Ireland	New Zealand
ISP Name	2022 Integrated System Plan (ISP)	Whole of System Plan (WOSP)	Los Angeles 100% Renewable Energy Study (LA100)	Resource Planning Report	Integrated Resource Plan	Shaping Our Electricity Future	Net Zero Grid Pathways (NZGP)
Conducted By	ISO	Government Authority	Vertically Integrated Utility	Vertically Integrated Utility	Vertically Integrated Utility	TSO + ISO	Transmission Network
Year Conducted	2022	2022	2021	2019	2022	2022	2022
Frequency Conducted	2 years	<= 5 years	5 years (required) 2 years (planned)	5 years (required)	5 years (required) 2 years (planned)	Only 1 to date. 1 year planned	Only 1 to date
Number of Customers	9 M	1 M	1.5 M	0.6 M	5.2 M	2.5 M	2.2 M
Total Line Length	790,000 km	100,000 km	23,500 km	16,000 km	201,000 km	172,000 km	166,000 km
Size Peak Demand	30,834 MW	4,000 MW	6,502 MW	3,019 MW	4,441 MW	6,960 MW	7,157 MW
Market Structure / Operating Environment	Unregulated Generation and Retail with ISO	Unregulated Generation and Retail with ISO	Vertically Integrated, Municipal Utility	Vertically Integrated, Municipal Utility	Unregulated Generation and Retail with ISO	Unregulated Generation and Retail with ISO	Unregulated Generation and Retail with ISO
Scope of Optimisation							
Utility Scale Resources	✓	✓	✓	✓	✓	✓	✗
Transmission System	✓	✓	✓	✓	✓	✓	✓
Distribution System	✗	✗	✓	✓	✗	✗	✗
Load incl. BTM Resources	✗	✗	✓	✓	✗	✗	✗

Source: Energeia Research. ISO = Independent System Operator, TSO = Transmission System Operator

- The above table shows the ISPs considered within Best Practice research
- Jurisdictions were selected based on the sophistication of the system planning process, scope, and degree of integration

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Key Takeaways and Recommendations

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Key Takeaways and Recommendations

- Key Takeaways
  - Customer behavior regarding equipment and service adoption critical to grid and system planning
  - Existing forecasting, grid, and system planning methodologies are obsolete
  - Implementing agent-based simulation methods can help anticipate emergent behavior and identify a least cost future state
  - A truly integrated, consumer-centric system plan will deliver a least cost future system at the lowest risk of asset stranding
- Key Recommendations
  - Move to truly integrated grid and system planning that is consumer-centric to optimize strategies and minimize asset-stranding risks
  - Review current customer behavior and BTM resource forecasting methods in light of key grid and system planning risks and issues
  - Consider agent-based simulation methods including customer digitization to address needs better
  - Ensure your agent-based simulation approach is optimized in terms of customer characteristics, behavior, and feedback loops

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Q & A

Next Power Session Topic

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Thank You!

Energeia USA
132 E Street, Suite 380
Davis, CA 95616

P +1 (530) 302-3861
energeia@energeia.com.au

energeia-usa.com

Energeia Pty Ltd
L1, 1 Sussex Street
Barangaroo NSW 2000

P +61 (0)2 8097 0070
energeia@energeia.com.au

energeia.au

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Forecasting Methodology Definitions

Modelling Category	Forecasting Method	Definition
Statistical	Linear Regression	A statistical linear relationship is developed to forecast how one (dependent) variable changes in response to changes in other (independent) variables
	Non-Linear Regression	As with linear regression, but the developed equation that defines the statistical relationship will be non-linear.
	Bass Diffusion	A mathematical model used to predict new product adoption patterns by assuming the market is split between innovators and imitators
	Logit/Probit	Regression models that use common mathematical functions to determine a statistical relationship between predictor variables and the probability of an event occurring
	Autoregressive Integrated Moving Average (ARIMA)	A regression model that develops a forecast of a variable based on its own behaviour (hence autoregressive) using historical time series data, accounting for the dependency on past residual errors (differences between past observations and a moving average)
	Extreme Value Theory (EVT)	Focuses on only the extreme values of the data sample and applies a range of limit distribution models to estimate the probability and magnitude of future extreme events
Statistical and Simulation	Monte Carlo	Involves running a high-volume of repeated simulations which generate a random set of independent variables, based on their respective probability distributions, resulting in a distribution of the dependent variable. This is used to predict the dependent variable within a statistical level of confidence
	Machine Learning	Uses a prediction algorithm (which could be based on one of the other described forecasting methods) which is "trained" using actual data. During training the model self-evaluates using an error function and adjusts the model fit accordingly
Simulation	Agent-Based	Simulations technique where a set of individual agents are programmed to make decisions based on the model environment, leading to a simulation of their future behavior
	Linear Programming	Modelling technique based on maximising or minimising a linear objective function constrained by a set of linear inequalities
	Non-Linear Programming	As with Linear Programming, but at least one of the objective function or constraint equations is a non-linear equation

Source: Energeia Research

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Forecasting Criteria Definitions

Category	Criteria	Definitions
Applications	Linear Variables	Can be used to forecast variables with linear drivers (e.g., y = mx +b)
	Non-Linear Variables	Can be used to forecast variables with non-linear drivers (e.g., $y = x^2$)
	Binary Variables	Can be used to forecast variables with binary drivers (i.e., 1 or 0)
	Objective Optimisation	Can be used to solve problems with an objective function (i.e., a function that is to be maximised or minimised)
Ease of Use	Human Effort	The amount of effort required by the user to setup and implement the method (note: good = relatively low human effort)
	Data Requirement	How much data is required for the method to produce reasonable results (note: good = low amounts of data)
	Ease of Interpretation	How easy it is to understand and communicate the outputs
	Computational Efficiency	How much computing power and time is required in the method, with consideration of the relative amount of inputs
Robustness	Resistance to Lack of Independence	How effective is the method at producing valid results if the drivers are correlated
	Resistance to Extraneous Variables	How well does the method deal with drivers that influence the forecast but are not part of the selected independent variables
	Resistance to Outliers	How effective is the method at producing valid forecasts if there are outliers in the input data
	Identifying Emerging Behaviours	How effectively is the method able to identify emerging or evolving patterns/behaviours
	Resistance to Overfitting	How effective is the method at avoiding issues with overfitting (i.e., the model fits too perfectly to the input data, making it unreliable against unseen data)

Source: Energeia

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