GridAI

Using Policy Gradient Reinforcement Learning to Design the Future of the Irish Power Grid

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1 Abstract

As Ireland transitions towards a net-zero energy future, optimizing the power grid presents a complex challenge that requires balancing cost, reliability, emissions, and public opinion. This paper presents GridAI, a custom-built Policy Gradient Reinforcement Learning model designed to explore and identify the most effective, cost-efficient energy strategies for Ireland from 2025 to 2050.

By simulating 100,000+ iterations, the AI autonomously determines an optimal investment timeline, emphasizing early deployment of solar and wind energy, the delayed but eventual adoption of offshore wind and battery storage, and a data-driven approach to carbon offsetting. The model achieves 100% power reliability while driving Ireland into net-negative emissions by 2047—all while balancing economic feasibility and public sentiment.

Beyond the specifics of energy policy, GridAI demonstrates the power of AI-assisted decision-making in national infrastructure planning. This project—built by students with limited resources—proves that governments and policymakers could leverage AI at scale to test, refine, and optimize complex national strategies in days instead of years. AI does not replace human decision-making, but rather acts as a force multiplier, revealing insights and trends that can guide policy with unprecedented precision.

This paper serves as both proof of concept and a call to action. The future of energy is not guesswork—it is data-driven strategy. By embracing AI as a tool for smarter, more adaptive policymaking, Ireland can lead the way in efficient, scalable, and sustainable energy planning.

2 Introduction

Climate change is the defining crisis of our time. As the operator and developer of Ireland's power grid, EirGrid must be at the centre of the solution to this problem. With that in mind, for the CleanerGrid Competition, we propose a simulation and reinforcement-learning based approach to designing the most optimal grid possible.

Everyone has ideas, many are great, but human brains struggle to accurately model complex systems, and there are few systems more intricate than the power grid, which depends on producers, users, transmission, and many other factors. In order to better handle these more complex systems, humankind created statistics, and through the rise of modern computing, this branch of mathematics has evolved into machine learning, commonly known as Artificial Intelligence or AI.

The use of data-driven and simulation-based approaches in decision-making is not novel. In fact, bodies such as the OECD have advocated for the use of data-driven policy approaches as a cornerstone of modern governance, emphasising that data-driven strategies lead to more effective, responsive, and well-optimised policies (Van Ooijen, Ubaldi and Welby, 2019).

In this paper, we emphasise the efficacy of such a strategy, through the development and deployment of our custom simulation and machine-learning software to optimise the search for a cost-effective, net-zero

Ireland. What makes this approach so effective is the simulation's ability to allow us to explore essentially unlimited probability spaces, and the AI's ability to narrow down these spaces to those most likely to hold optimal solutions. By running tens of thousands of simulations, our AI rapidly converges on the most optimal—or near-optimal—solution, provided the model and data are accurate [see Sections 3-5]

Rather than replacing human decision-making, AI serves as a force multiplier—enhancing rational analysis, identifying optimal strategies, and allowing policymakers to make better-informed choices. This is why the team also produced an in-depth analysis, commentary, and critique on the model behaviour [see Section 8].

3 Model Structure

The AI used for this project was written in the Rust programming language from scratch, utilising the team's knowledge of probability, reinforcement learning, and data-interaction. While this implementation is unorthodox, and created additional work for the team, it allowed for smoother connection with the simulation code, also written in Rust.

The specific kind of AI model used for this project is defined as a **Policy Gradient Reinforcement Learning Model** which is defined as follows:

- It has **clearly defined goals**
- It has a set of **predefined actions**
- Actions that bring us **closer to the goal are "*rewarded*"**, while actions that bring us **further away are "*penalized*"**
- Unlike value-based AI models, **policy gradient models adjust probabilities over actions rather than estimating a value function**.

The benefits of this model structure are primarily that **it is human legible**, as opposed to denser neural nets. However, the specific structure of GridAI is slightly more complex.

3.1 Weighting and Temporal Adaptation

Before simulation, each action is provided with a **predetermined weight**. These weights are largely irrelevant after thousands of simulations, however **picking the correct weights initially can save considerable amounts of compute**, by starting the model closer to a presumed optimal path.

<u>The AI considers actions such as:</u>

- **Building new energy generators (e.g., wind, solar, nuclear).**
- **Decommissioning fossil fuel plants.**
- **Implementing carbon offset schemes.**
- **Upgrading grid efficiency.**

These **weights are not static**—they are **year-dependent**. As **technology, economics, and public perception evolve**, the AI adapts, recognizing that the optimal solution in 2025 may not be the same in 2045.

3.2 Contrast Learning and Experience Replay

The code also utilises contrast learning and experience replay.

- Contrast learning is a vital component, as it **helps narrow down on probability spaces** by, when there has been significant time without improvement, positively weighting actions identical to those in the most successful run, and **penalizing differences**, in order to get the **model back on track.**

- Experience replay is similar, in that it tries to **narrow down the positive aspects of the most successful runs**, by **re-running them with some actions changed**, to narrow down what is important.

3.3 Multi-Objective Optimisation

GridAI does not optimize for a **single** metric but instead balances **four key incentives**:

1. **Power Reliability** – A grid that doesn't work is useless.
2. **CO_2 Emissions** – The model must achieve net-zero by 2050.
3. **Cost** – The grid must remain financially viable.
4. **Public Opinion** – No one wants a nuclear reactor in their backyard, even if it's the cheapest solution.

4 Simulation Loop

The simulation takes place between 2025 and 2050, breaking everything down into one-year increments, during which the actions are performed, and within which the AI learns. A typical simulation loop follows these steps:

1. **Take Stock**
    - Calculate population and power-requirements
    - Load or compute current carbon emissions, current power generation, and other key metrics
2. **Select Actions**
    - Run a random number generator (RNG)
    - Based off the output of the RNG, select the action (actions with higher weights are more likely, due to the probabilistic nature of RNG)
    - Implement the actions and recalculate the system state (Step 1, but this time after running, Step 2 is skipped)
3. **Handle Power Deficits**
    - There are often power deficits in the grid
    - Rather than running numerous unsuccessful simulations without power balance being achieved, we use a computational function that re-runs power-influencing actions (based off a separate set of temporally-dependent weights), to ensure we always have 100% grid reliability
    - This greatly speeds up model training
4. **Repeat**
    - The simulation repeats for the next year, and so forth, until 2050
5. **(Optional) Multithreading**
    - The code supports multithreading, utilizing multiple CPU cores to parallelize computations.
    - This increases efficiency but requires periodic thread synchronization to keep all processes working from the same data.

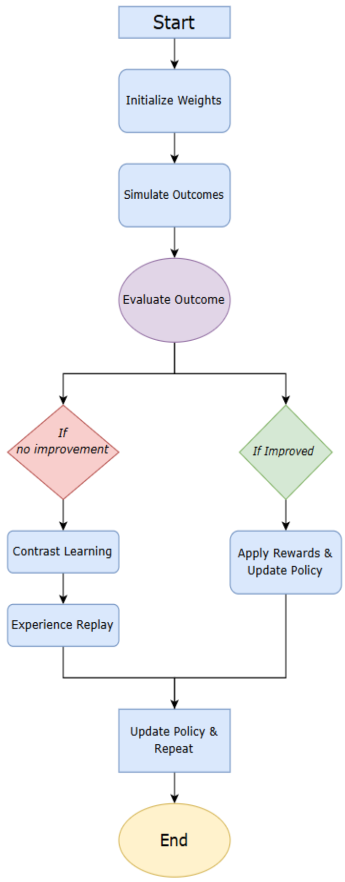

Figure 1: Flowchart of Decision-Making Process

After the year 2050 is reached, the computer checks the actions it performed and the results generated by them, then compares them to prior results, in order to accurately update the weights to bring us closer to optimality.

The simulation is then repeated with the updated weights. This is continued until the user stops the simulation or the requested number of iterations is reached.

The simulation also implements **checkpointing**, enabling restarting after system errors, or simulation batches that were too small to provide accurate results.

5 Sourcing the Data

As the simulator aims to emulate the Irish power grid, and the country at large, to as accurate a degree as possible, significant real-world data is required to create a digital environment in which the AI can optimise our power grid.

There were two kinds of data used for this, defined here as **map data** and **calculation data**.

> **Map Data** – Represents the **current** state of Ireland's infrastructure.
>
> **Calculation Data** – Used to **forecast** future changes and estimate key values such as cost and power output.

The **data collection process** is detailed below.

The processes used to collect these data-sources is detailed below.

5.1 Map Data

Map data consists of **diverse datasets** that collectively construct the digital world in which the AI operates. This data was sourced from:

- **Power plant databases**
- **Census reports**
- **Google Maps API**

The processed data was then converted into **Rust objects**, allowing efficient loading and interaction within the simulator.

5.1.1 Global Power Plant Database

The **Global Power Plant Database** (World Resources Institute, 2024) provides a **.csv file** containing all listed power generators worldwide. However, since much of this data is **irrelevant** (e.g., foreign generators, ownership details, etc.), preprocessing was required.

A series of **Python scripts** were used to:

1. **Filter** the dataset to include only **Irish generators**.
2. **Remove unnecessary fields** (e.g., generator IDs, owners).
3. **Format the output** to retain only **capacity, location, and primary fuel source**.

This produced a **clean, structured dataset** suitable for simulation.

5.1.2 CSO Census 2022 F1011 & Google Maps API

The Central Statistics Office provides census data available to the public on the cso website (Central Statistics Office, 30AD). This provided easy reference to the populations of all settlements in Ireland. This was then adjusted slightly, utilising the ratios found in the original database to provide the entire population of Ireland in 2024.

Next, we needed to locate each settlement. The way the simulation works, it cannot place generators in locations where settlements exist, there are public opinion impacts of placing it in different places relative to settlements, and finally, there are transmission costs for the distance transmitted.

Unfortunately, the CSO does not provide coordinates for the settlements, and so the Google Maps API was employed to locate them. In order to minimize the cost of API usage, and also avoid needing to compute data for the original 20,000 settlements, the settlements were first compressed by county and population to return a json with just 130 settlements, a more manageable number, but still representing all the population of the constituent settlements.

Then, the settlement names were pre-processed before being passed to the API to return coordinates, resulting in data that could be utilised by the simulator.

5.1.3 Conclusion

With the combination of the publicly available data and our post-processing and cleaning, we were able to create a versatile, high-fidelity dataset, allowing sufficiently accurate emulation of Ireland and her power grid to produce true-to-life results and actionable insights

5.2 Calculation Data

The calculation data was taken from a variety of different sources which make up the bulk of the latter sources in the references section. This data is used to inform the constants file in the final code.

To ensure that GridAI operated within a realistic and data-driven framework, a wide range of economic, technological, geographic, and public opinion factors were incorporated into the simulation. These values were derived from official reports, academic research, market trends, and historical data, ensuring that the AI's decision-making process reflected real-world constraints and opportunities.

The constants used in this simulation were not arbitrarily chosen—they were extracted from historical trends, industry projections, and government policy documents to provide an accurate representation of cost evolution, efficiency improvements, energy demand, and public perception over time.

- Data Sources and Methodology
- Economic and Cost Projections

To simulate real-world investment decisions, cost trends for different energy sources were estimated based on historical market data and projected industry advancements. Key sources included:

- Inflation projections from national economic reports.
- Renewable energy cost curves, showing annual price reductions for wind, solar, and nuclear, derived from global energy market forecasts.
- Fossil fuel cost trajectories, incorporating increasing carbon pricing and decreasing natural gas subsidies.
- Capital and operational expenditures, informed by industry benchmarks for power plant development, maintenance, and decommissioning.
- Technological Advancements & Efficiency Gains

To reflect the progression of energy technology, annual efficiency gains were modeled based on:

- Observed learning rates in renewable energy industries.
- Historical improvements in turbine efficiency, battery storage capacity, and nuclear plant designs.
- Projected performance enhancements for emerging technologies like wave and tidal energy, as these are expected to become viable closer to 2050.
- Public Opinion & Social Acceptance

Public opinion factors were sourced from:

- Surveys and studies on renewable energy acceptance.
- Historical resistance trends to nuclear, coal, and gas infrastructure.
- Evolving attitudes towards climate policy, which influence the feasibility of certain investments over time.

Public sentiment was assigned base values and programmed to shift over time, favoring cleaner technologies while penalizing fossil fuels.

- Geographic and Grid Constraints

To ensure spatial realism, the simulator incorporated:

- Transmission loss calculations, derived from distance-based energy dissipation models.
- Land-use restrictions, ensuring power plants cannot be placed within urban zones or environmentally sensitive areas.
- Coastal and river proximity bonuses, acknowledging the geographic feasibility of hydro, wave, and tidal energy.
- Why This Matters

By integrating economic realities, technological trends, and social factors, the simulation does not just optimize for an abstract "best" solution—it produces viable, policy-ready strategies that align with market conditions and public expectations.

These constants form the mathematical foundation of GridAI, enabling it to balance cost, efficiency, and emissions while adapting to real-world complexities. The result is a data-driven roadmap for Ireland's energy future—one that is grounded in fact, not speculation.

6 Results

After the model was trained and generated its optimal set of actions, and the resultant optimised power grid, the data was exported to multiple csv's, providing an overview, as well as year-by-year overviews of the settlements, generators, and carbon offsets, which was used for direct reference. To complement the data, an animation pipeline was also created, to provide a more visual representation of the changes in the country over the next 25 years.

In the final simulation set:

- **100,000 main-loop iterations** were performed.
- An additional **45,000 fine-tuning iterations** followed, using a **higher-fidelity model** that better accounts for **geographic constraints**.

In the final simulation set, 100,000 main-loop iterations were performed, with a further 45,000 output-centric iterations following, to fine-tune the full-simulation model, which is more expensive to run than the general simulation model, but provides more accurate results, by accounting for geography more completely.

6.1 Actions

The simulator prefers solar farms and wind farms early in the simulation, opting for significant early investment that dips slightly after 2026 and remains reasonably consistent thereafter, with spikes later in the simulation when the renewable energy generation is augmented by large-scale battery storage plants, and, interestingly, a wave generator for 2050. It is worth noting that the construction of these generators would, in reality, need to be scheduled to open by 2050 to reach our goals with sufficient power generation to allow growth in the Irish economy.

A fascinating aspect of the simulation is that its temporal facets can clearly be seen in the output. Generators and plants still in their infancy are postponed until later in the simulation, when they become more cost-effective due to technological advancements.

This can be seen by a shift from onshore to offshore wind, solar farms to efficient domestic solar, battery plants being set up, and wave energy making a late appearance.

6.2 Outcomes

Year	*Pop.*	*Power Usage (MW)*	*Power Generation (MW)*	*Public Opinion*	*Annual Net Cost (€ adj.)*	*Net Emissions (Kilotonne CO_2/day)*
2025	5149136	5252.12	7390.91	0.7732	2.3913E+10	110.7
2026	5200628	5516.83	8776.91	0.7849	314427745	150.3
2027	5252636	5792.73	8786.81	0.7823	562847534	150.8
2028	5305160	6080.27	8786.81	0.7776	831433687	150.8
2029	5358215	6379.89	9133.31	0.7767	965236515	160.7
2030	5411800	6692.07	9702.56	0.7869	1019685284	178.02
2031	5465919	7017.28	9702.56	0.7824	1342987905	178.02
2032	5520574	7356.03	9702.56	0.7778	1687290395	178.02
2033	5575778	7708.84	10108.46	0.7784	1876397699	190.89
2034	5631527	8076.24	10385.66	0.8208	2146201944	-159.14
2035	5687845	8458.81	10771.76	0.8263	2394470311	-170.6
2036	5744726	8857.13	10831.16	0.8255	2814030410	-188.74
2037	5802180	9271.79	10831.16	0.8236	3290058012	-207.85
2038	5860199	9703.41	10831.16	0.8216	3798955716	-225.14
2039	5918800	10152.65	13499.21	0.8303	3174950932	-164.55
2040	5977982	10620.16	13994.21	0.8267	3552944520	-173.76
2041	6037760	11106.66	13994.21	0.8247	4177614415	-186.57
2042	6098141	11612.86	14275.37	0.826	4724226252	-190.04
2043	6159121	12139.5	14275.37	0.824	5442838451	-200.52
2044	6220709	12687.36	15384.17	0.826	5728909389	-178.33
2045	6282917	13257.24	15384.17	0.8241	6558170880	-186.92
2046	6345748	13849.97	15384.17	0.8221	7450056502	-194.68
2047	6409208	14466.42	15384.17	0.82	8410160185	-2241.35
2048	6473298	15107.45	15386.15	0.8191	9443492509	-2271.79
2049	6538030	15774.02	16871.15	0.8129	9950408776	-2284.58
2050	6603409	16467.06	17306.75	0.8066	1.103E+10	-2295.73

Table 1: Simulation Summary Metrics

As can be seen in Table 1 our simulation manages to cater for a very optimistic population growth. This population growth was taken from the current growth rate, which is projected to taper, similar to other developed countries.

It is also interesting to note that the model implements significant carbon offsets relatively early into the simulation and brings us into the net negative. This is likely due to the fixed costs of the offsets used (forests) compared to the ever-changing generator costs.

It is also worthwhile to note that the AI could likely have spaced out the investment more effectively, as while the average annual expenditure is ~€5B, in 2025 the expenditure is €24B. This may be due to a mismatch in the generation capacity calculated to be required and the actual generation provided by the initial grid, an issue that will be fixed in subsequent work. Below, however, can be seen the final metrics for our simulation, which seem quite reasonably despite the mild discrepancy.

Final Metrics

Final Net Emissions (Kilotonne CO_2/day)	**-2295.7329**
Average Public Opinion (%)	80.66
Total Cost (€)	1.27E+11
Avg. Cost (€)	5.08E+09
Power Reliability (%)	100

6.3 Animation

Due to issues with converting the simulation map-coordinates of the generators into animation coordinates, the positioning of generators and carbon offsets is random, but the animation does serve to illustrate the significant differences in the Irish power grid in 2025 and 2050 (the full animation can be found here)

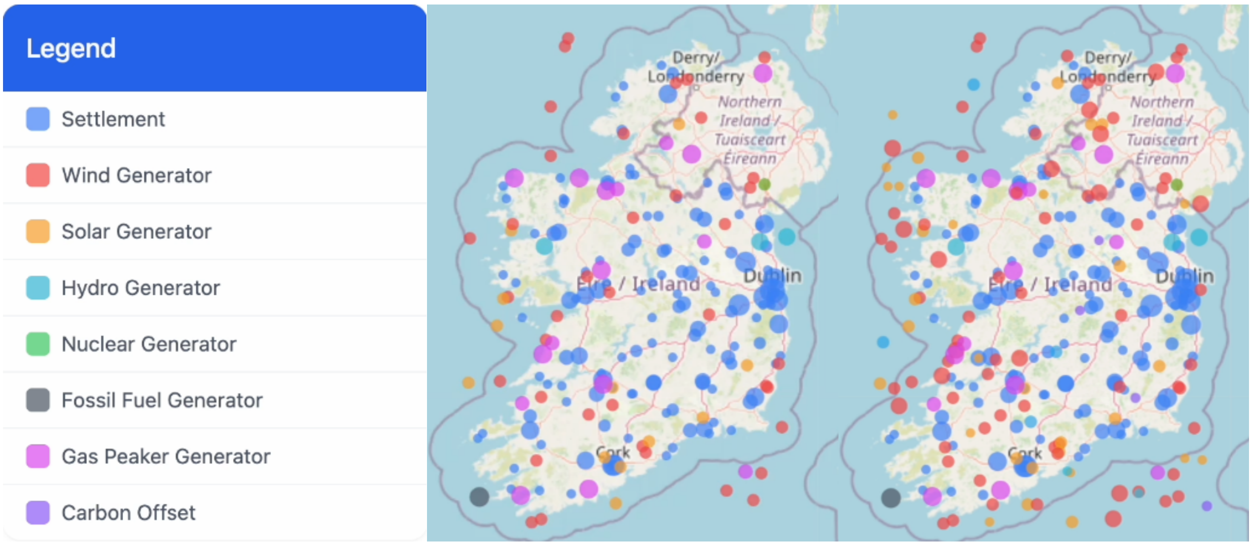

Figure 2: Irish Power Grid Visualisation in 2025 (Centre) and 2050 (Right) with the legend (Left) for reference

The animation here clearly displays the growth of the power grid, and to a lesser extent, shows the growth of populations. The larger the sphere, the higher the population, or the generation capacity.

While, as shown, we don't lose any fossil-fuel capacity, the renewable generation capacity quickly overwhelms the current infrastructure, with the map in the 2050 image being covered in red (wind farms) and yellow (solar farms). This is good, as it allows us to keep traditional power plants to support our main energy sources, even though at this stage their grid contribution is negligible compared to other sources.

Erroneously, the wave generator has been omitted, and the carbon offsets are improperly scaled to represent the generators they offset, but the animation still provides a good overview of the changes experienced by the country over the 25 years, a change which is more obvious in the video animation.

7 Analysis

It is not enough to simply accept the word of the machine god, we must understand *why* our AI is outputting the actions it is. Otherwise, we risk a software bug generating incorrect actions that throws everything off course. In this case, this requires some critical thinking to understand everything. We can see in Table 2, the actions implemented by our AI, giving us a chance to understand why this is the most optimal path for the grid to take.

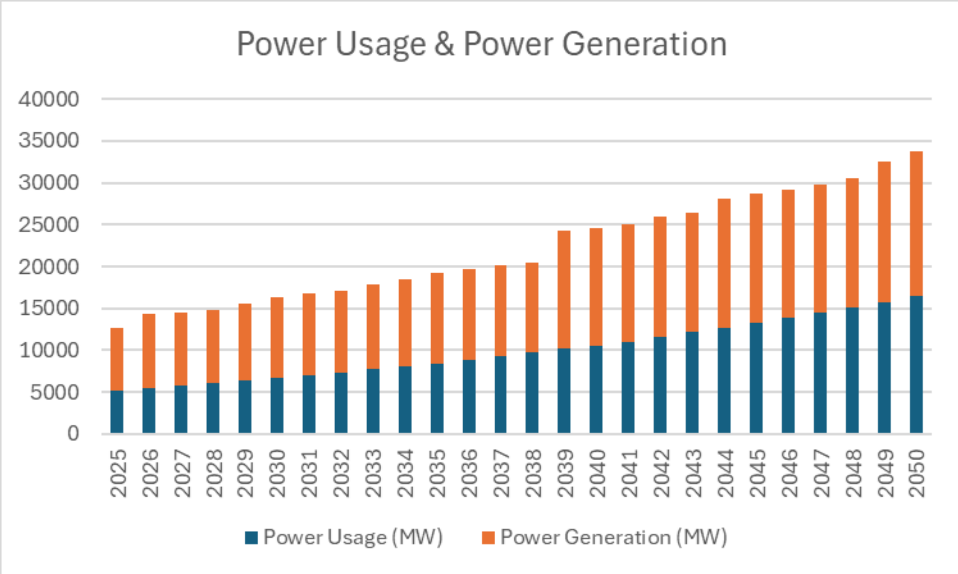

Figure 3: Power Usage vs Generation

While at first it seems that the initial burst of investment in 2025 is due to a deficit left in the power grid, a look at Figure 3 shows that, in fact, we have a significant surplus of energy in 2025.

A more efficacious analysis would require an understanding of the AI model itself:

> The AI model is rewarded based off the 2050 result, and is not constrained to a budget per year (although it attempts to reduce the overall cost). This means that it views a significant investement in one year the same as a more dispersed result over multiple years.

This understanding of the model lets us not view this instantaneous bulk-solar investment not as a mandate, but rather as a suggestion of the direction we should move. Essentially, the AI suggests that investing in solar early is highly conducive to our goal with the power grid. We can also use this logic to understand the bulk investment in wind in 2026.

Year	Action Type	Generator Type	Count	Estimated Cost (€)
2025	Add Generator	Utility Solar	x12	12000000.0
2026	Add Generator	Onshore Wind	x8	7920000.0
2027	Add Generator	Commercial Solar	x1	94090.0
2029	Add Generator	Onshore Wind	x2	1921192.0
2030	Add Generator	Commercial Solar	x5	429367.0
	Add Generator	Onshore Wind	x3	2852970.2
2033	Add Generator	Utility Solar	x1	783743.4
	Add Generator	Onshore Wind	x2	1845489.4
2034	Add Generator	Offshore Wind	x1	1827034.5

	Add Carbon Offset	Forest	x1	1000000.0
2035	Add Generator	Commercial Solar	x4	294969.6
	Add Generator	Onshore Wind	x2	1808764.2
2036	Add Generator	Utility Solar	x1	715301.4
2039	Add Generator	Offshore Wind	x8	13799933.0
	Add Generator	Onshore Wind	x1	868745.8
2040	Add Generator	Battery Storage	x1	500000000.0
2042	Add Generator	Domestic Solar	x2	11916.5
	Add Generator	Offshore Wind	x1	1685886.4
2044	Add Generator	Offshore Wind	x4	6609349.0
2047	Add Carbon Offset	Forest	x3	3000000.0
2048	Add Generator	Domestic Solar	x1	4963.1
2049	Add Generator	Battery Storage	x3	1500000000.0
2050	Add Generator	Wave Energy	x2	2000000000.0
	Add Generator	Utility Solar	x4	1867898.8

After 2026, the generation slows down somewhat, to the point that no generators at all being produced in 2028. However, in 2030, investment picks up again, somewhat, though not with the same intensity as 2025.

In 2034 we see our first carbon offset. This suggests that around this time, the combination of clean energy and pricing changes make a beginning to carbon offsetting a wise financial decision. However, it is worth noting that the bulk of our carbon offset comes in 2047.

Another interesting thing to note is the seemingly spontaneous investment in offshore wind in the late 2030s and early 2040s. However, this is not spontaneous. The model's trends likely indicate that this is the best time to invest in offshore wind, which has a better public opinion score, as at this stage, the technology is much more mature and feasible.

Finaly, between 2049 and 2050, we get into the true new-age technology. Here, we see huge swathes of battery storage being constructed to augment our less reliable generators. Taking advantage of the new infrastructure comes new solar farms, which require the batteries to be effective.

We also see two wave generators being constructed, suggesting the technology has finally become cost-effective towards the end of the simulation. This suggests that beyond 2050 wave generation could become a central aspect of power generation, which could be a very powerful source of offshore power generation, and could also be used to combat sea pollution, in a fashion similar to SHIELD (Carter, 2022).

Policy Implications:

This analysis translates AI recommendations into actionable insights:

- Early solar & wind investment is critical, but should be staggered for budget feasibility.
- Carbon offsets are cost-efficient post-2034, with aggressive scaling from 2047.
- Offshore wind becomes a prime option in the 2040s once public & tech factors align.
- Battery storage is essential for renewable expansion and should be prioritized by 2050.
- Wave energy is promising post-2050 and should be explored beyond the simulation's timeline.

This analysis makes clear the meaning of the AI insights and showcases exactly how this simulation and others similar to it can be used to inform policy decision-making when the policymakers have a proper understanding of the underlying technology, and the creativity to make sense of the generated metrics. As Jim Rohn said, "If the Why is Powerful, the How is Easy".

8 The Vision

This project is more than just a theoretical exercise, it is a proof of concept. It shows a new way of making policy decisions that augments our current methods, and could shape the future. It represents a blueprint, one we don't have, but are making, of how Ireland can lead the world, leveraging AI to build a more resilient, more forward-thought power grid, starting today.

At its core, this work proves a fundamental thesis: AI is not just for writing SEO articles for businesses; when harnessed correctly, it can be a powerful decision-making engine that can transform how we plan, optimize, and execute national energy strategies.

8.1 An Enabler, Not a Replacement

This project demonstrates how AI can augment human expertise, rather than replace it. The AI does not dictate policy—it reveals insights, trends, and optimal strategies that would be exceptionally challenging for traditional analysis to uncover. With a more powerful and resource-backed implementation, linked directly to real-time data, the potential is unbounded:

- Near-instant policy testing – Governments can simulate different investment strategies and immediately see their long-term impacts.
- Better risk management – Instead of reacting to crises, we can anticipate and mitigate grid failures decades in advance.
- Dynamic, adaptive strategies – Rather than committing to rigid energy plans, AI-driven models can evolve with technological advancements.

8.2 Key Insights: The Roadmap for Action

This simulation delivers clear data-backed strategies that should be immediately actionable:

1. Early and sustained investment in renewables is essential. Solar and wind must be scaled as early as possible, ensuring grid stability with batteries and complementary tech.
2. Public opinion cannot be ignored. Offshore wind and wave energy become far more viable in the 2040s, and are some of the most highly-rated in public opinion from our datasets [see Section 5.2].
3. Carbon offsets should be phased in post-2034, with aggressive scaling by 2047. This suggests an immediate need for policy and infrastructure planning.
4. Battery storage will be the linchpin of the energy transition. No renewable-heavy grid can function without it. They will become more cost-effective in the future, however from a realistic standpoint,

investment should start sooner, to prepare the grid for the setup, and to enable a smoother transition.

5. Wave energy is an untapped goldmine for post-2050 energy security. The data suggests it could become a core pillar of Ireland's energy mix if developed properly. This makes sense, as Ireland is a prime candidate for wind power, thanks to our geography.

8.3 Beyond This Project: The Future of AI-Driven Infrastructure

This simulator was built by a single team of students, in a matter of months, using publicly available data and limited computational resources. Imagine what could be achieved if a national initiative leveraged this approach with:

- Greater computing power for deeper simulations
- Higher-fidelity datasets for more precise results
- Expanded models covering more economic, social, and environmental factors
- AI forecasting models providing the predictive data found in Section 5.2, ensuring even higher fidelity

This is not just an energy tool. The same AI-driven simulation approach can be applied to transport, urban planning, climate adaptation, and beyond.

Ireland has the opportunity to be a global leader in AI-assisted policy, proving that technology can empower governments to make smarter, faster, and more sustainable decisions, when augmented by intelligent analysis and understanding, as detailed in Section 7.

9 Conclusion

This project set out to answer a simple but profound question: Can AI be used to design a better power grid? The results speak for themselves—not only can it be done, but it should be done.

Through 100,000+ simulated iterations, this model identified a cost-effective, net-zero pathway for Ireland's energy future, while providing clear insights into how investment, public opinion, and emerging technologies should be managed. It highlighted key strategies—early renewables investment, the importance of battery storage, and the phased adoption of carbon offsets and offshore wind—all while ensuring 100% power reliability and balancing economic constraints.

But beyond the specifics of the Irish grid, this work demonstrates a larger truth: AI-assisted decision-making is not just a tool—it is a necessity.

By integrating AI into national energy planning, policymakers have the opportunity to:

- Identify optimal strategies in days, not years.
- Anticipate and prevent crises before they happen.
- Adapt dynamically to economic and technological shifts.

However, AI alone is not a solution—it is a force multiplier for human expertise. The technology provides the insights, but it is people who must understand and act on them. The future of energy is not just about better power generation—it's about better decision-making.

This simulation is just the beginning. What comes next is up to us

10 External Resources

The code for the project can be found here: https://github.com/ETM-Code/eirgrid

The video for the project can be found here: https://youtu.be/E03waZZOr6M

11 References

Van Ooijen, C., Ubaldi, B. and Welby, B. (2019). A data-driven public sector: Enabling the strategic use of data for productive, inclusive and trustworthy governance. OECD Working Papers on Public Governance, [online] 33. doi:https://doi.org/10.1787/09ab162c-en.

World Resources Institute (2024). Global Power Plant Database. *Global Power Plant Database*. [online] Available at: https://datasets.wri.org/datasets/global-power-plant-database?map=eyJ2aWV3U3RhdGUiOnsibG9uZ2l0dWRlIjotNy4wNjQwNjU1MDg1OTk1ODMsImxhdGl0dWRlIjo1Mi4zOTY4MjkzMzYwNDcxMiwiem9vbSI6Ni4xMzUwODI3NzQ1ODAwNDI1LCJwaXRjaCI6MCwiYmVhcmluZyI6MCwicGFkZGluZyI6eyJ0b3AiOjAsImJvdHRvbSI6MCwibGVmdCI6MCwicmlnaHQiOjB9fSwiYmFzZW1hcCI6ImxpZ2h0IiwiYm91bmRhcmllcyI6ZmFsc2UsImxhYmVscyI6ImRhcmsiLCJhY3RpdmVMYXllckdyb3VwcyI6W3siZGF0YXNldElkIjoiNTM2MjNkZmQtM2RmNi00ZjE1LWEwOTEtNjc0NTdjZGI1NzFmIiwibGF5ZXJzIjpbIjJhNjk0Mjg5LWZlYzktNGJmZS1hNmQyLTU2YzM4NjRlYzM0OSJdfV0sImJvdW5kcyI6eyJiYm94IjpudWxsLCJvcHRpb25zIjp7fX0sImxheWVyc1BhcmFtcyI6W1siMmE2OTQyODktZmVjOS00YmZlLWE2ZDItNTZjMzg2NGVjMzQ5Iix7InZpc2liaWxpdHkiOnRydWUsImFjdGl2ZSI6dHJ1ZSwib3BhY2l0eSI6MSwiekluZGV4IjoxMX1dXX0%3D [Accessed 10 Jan. 2025].

Central Statistics Office (30AD). F1011 - Population. *Census 2022 Profile 1 - Population Distribution and Movement*. [online] Available at: https://data.cso.ie/table/F1011 [Accessed 14 Jan. 2025].

Carter, C. (2022). *Wave-assisted coastal rubbish collector*. [online] superinnovators.com. Available at: https://superinnovators.com/2022/11/wave-assisted-coastal-rubbish-collector/.

Barbose, G., Darghouth, N., O'Shaughnessy, E., & Forrester, S. (2024). *Tracking the Sun*.

Bombora Wave Power. (2022). Independent Review of Cost of Energy Study for mWave Farm.

Brennan, J. (2023a, October 31). 5 MW Solar Power Plant Cost in Ireland. *Going Solar*.

Brennan, J. (2023b, December 4). 1 MW Solar Panel Cost in Ireland. *Going Solar*.

Bullis, K. (2013). Safer Nuclear Power, at Half the Price. *MIT Technology Review*.

Central Statistics Office. (2019). Urban and Rural Life in Ireland, 2019.

Central Statistics Office. (2024a). *Consumer Price Index August 2024*.

Central Statistics Office. (2024b). *Metered Electricity Consumption 2023*.

Central Statistics Office. (2024c). Population and Labour Force Projections 2023-2057.

Energy Policy & Modelling Group. (2024). Data centres in the context of Ireland's carbon budgets.

ESB. (2024, November 15). ESB officially opens its latest battery storage project in Co Cork as part of €300m investment.

EURELECTRIC "Preservation of Resources" Working Group's "Upstream" Sub-Group in collaboration with VGB. (2003). Efficiency in Electricity Generation. In *Eurelectric*.

European Commission. (2024). *European Economic Forecast*.

Funk, C., & Kennedy, B. (2016). Public opinion on renewables and other energy sources.

GlobalData. (2025). Wind Turbines Market Size, Share and Trends Analysis by Technology, Installed Capacity, Generation, Key Players and Forecast to 2028.

Government of Ireland. (2024). *Budget 2025 Expenditure Report*.

International Energy Agency. (2024). *Energy Efficiency 2024*.

Jenkinson, O. (2024, June 3). Nordex sells 1.6GW of wind turbines as pricing holds steady in Q2. *Windpower Monthly*.

Kazulis, V., Vigants, H., Veidenbergs, I., & Blumberga, D. (2018). Biomass and natural gas co-firing – evaluation of GHG emissions. *Energy Procedia*.

Mongird, K., Viswanathan, V., Alam, J., Vartanian, C., Sprenkle, V., Pacific Northwest National Laboratory, Baxter, R., & Mustang Prairie Energy. (2020). *2020 Grid Energy Storage Technology Cost and Performance Assessment*.

Nuclear Energy Institute. (2018). *Nuclear Costs in Context*.

Ratanakuakangwan, S., & Morita, H. (2021). Energy efficiency of power plants meeting multiple requirements and comparative study of different carbon tax scenarios in Thailand. *Cleaner Engineering and Technology*, *2*.

Rezaeimozafar, M., Eskandari, M., Amini, M., Moradi, M., & Siano, P. (2020). A Bi-Layer Multi-Objective Techno-Economical Optimization Model for Optimal Integration of Distributed Energy Resources into Smart/Micro Grids. *Energies*.

Statista Research Department. (2024). Average installation cost for hydropower worldwide from 2010 to 2022.

Subramanian, N., & Madejski, P. (2023). Analysis of CO2 capture process from flue-gases in combined cycle gas turbine power plant using post-combustion capture technology. *Energy*.

Sustainable Energy Authority of Ireland. (2011). *SMARTGRID Roadmap*. https://www.seai.ie/sites/default/files/publications/Smartgrid-Roadmap.pdf

Sustainable Energy Authority of Ireland. (2023). *Energy In Ireland: 2023 Report*.

Sustainable Energy Authority of Ireland. (2024). *Energy in Ireland: 2024 Report*.

Trading Economics. (2025a, February 17). *Coal - Price Data*.

Trading Economics. (2025b, February 17). *Gasoline - Price Data*.

Trading Economics. (2025c, February 24). *Ireland - Urban Population Growth*.

Unwin, J. (2019, March 21). Potential vs. expense: is tidal energy worth the cost? *Power Technology*.

U.S. Energy Information Administration. (2022). Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2022.

West, R. (2022, June 16). *Power cables: carrying capacity and loss rates?* Thunder Said Energy. https://thundersaidenergy.com/downloads/power-cables-how-much-copper-and-aluminium/

Windustry. (2024, August 9). What is the Cost of Offshore Wind Energy? *Windustry*.

World Nuclear Association. (2023, September 29). *Economics of Nuclear Power*.

Xiong, Y., Zou, W., & Wang, Y. (2023). Estimate the City Size Threshold of Industrial Agglomeration Model: Evidence From Chinese Prefecture Level Cities. *International Regional Science Review*.