Stochastic Agent-Based Modelling to Inform Policy for Long-Term Electricity Planning: ElecSIM a Toolkit

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ABSTRACT

Due to the threat of climate change, a shift from a fossil fuel based system to one based on renewable energy is required. However, this is not as simple as instantaneously closing down all fossil fuel energy generation and replacing them with renewable sources – careful decisions need to be taken. To aid decision makers, we present a new tool, ElecSIM, an agent-based modelling framework used to examine the effect of policy on long term investment decisions. We review different techniques currently used to model long term energy decisions, and motivate why agent-based models will become an important strategic tool for policy makers.

We show how modelling stochasticity improves model reliability. The model runs in yearly time steps, making assumptions based on empirical data on the impact of intermittent renewable energy. We present the dynamics of the system through scenario testing and provide validation. ElecSIM is configured through a scenario file – this allows non-experts to rapidly prototype new ideas, and developed around a modular framework – which allows technical experts to add and remove features at will. We argue in this work why an open-source toolkit is required and demonstrate how ElecSIM meets the requirements of the energy market.

This bit seems to be saying "and our work is not complete yet" – better to say something about the results here (when we have them) and leave the text below for the conclusions.

Future work includes integrating different types of agent based learning for the bidding and investment process, utilising multi-agent reinforcement algorithms that can deal with a non stationary environment. We will use the yearly time-step as a baseline model for integration of a higher temporal and spatial resolution.

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1 INTRODUCTION

The world faces significant challenges from climate change and global warming [CITE]. A rise in carbon emissions increases the risk of severe impacts on the world such as rising sea levels, species extinction, heat waves and tropical cyclones [18]. The scientific literature concurs that the recent change in climate is anthropogenic, with 97% of peer reviewed articles of this view [10].

To achieve carbon neutrality, the energy mix must shift from a largely fossil fuel based system, to one based on renewable energy. In essence, using solar, wind and tidal power to generate electricity and power homes, industry and transport [16]. Electricity is a significant proprtion of our energy consumption – consuming XX% of energy usage per year [CITE]. Although other forms of energy consumption are important we focus here only on the production and consumption of electricity. I'm wondering if some sort of graph / table of different electricity generation techniques, how common they are and how carbon neutral they are would go well in here?

For this to occur, a transition in electricity infrastructure is required. Moving from a centralised and homogenous fossil fuel-based system to a distributed system based on renewable energy and batteries. However, such a transition needs to be performed in a safe and non-disruptive manner – it may be possible to close down all fossil fuel plants in the next year, though if this leads to electricity shortages and power cuts then this is likely to cause significant problems both for companies and homes. Therefore a stepped approach which allows seamless transfer is desirable. This may seem a simple process to achieve – slowly phase out existing fossil fuel generators and replace by renewable sources – however, there are many risks and uncertainties in this process. Existing power plants have an expected lifetime and their owners wish to maximise this and the profits which can be made from them, renewable sources are still developing meaning that their efficiency and reliability will change in years to come, along with the fact that most renewable sources are effected by conditions outside the control of the owners (e.g. time or day or wind speed) thus leading to a need for electricity storage. I'm sure there are better / more.

To better understand the risks and uncertainties surrounding this transition, and to model the potential actions that can be taken by policy makers, this paper presents ElecSIM, an open source agent-based modelling toolkit, written in Python, which allows for the evaluation of alternative scenarios prior to implementation of policy. Through simulation we can evaluate many strategies in order to identify those most likely to achieve our requirements of rapid but non-disruptive migration from fossil to renewable.

This tool can be used by:

- **Policy experts** to test policy outcomes under different scenarios and provide quantitative advice to policy makers. They can provide a simple script defining the policies they wish to use along with the parameters for these polices.
- **Energy market developers** who can use the extensible framework to add such things as new energy sources, policy types, consumer profiles and storage types. Thus allowing ElecSIM to adapt to a changing ecosystem.

International agreements such as the Paris climate agreement [CITE], where nation states agreed on the goal of limiting the rise in global average temperature to well below 2°C above pre-industrial levels, mean that an open-source, reproducible and transparent model that can be taken to account by experts and understood by non-experts is of importance. This allows for the development of policies based on known assumptions, thorough testing and validation.

Not quite clear – Optimisation models calculate an optimal cost pathway of investment in power plants over the long-term. However, many western democracies have purposely moved away from central control in the energy sector, which make the results of optimisation models difficult to implement. Agent-based models provide a solution to this by modelling heterogeneous actors with imperfect knowledge in a regulatory environment. The emergent behaviour of the agents can be observed under different policies such as a carbon tax.

Policy making in energy system comes with inherent risk. Decisions made can have large long term impacts and may be sub-optimal. Power plants have high capital costs, long construction times, and operate over a long period. Therefore, errors made may be compounded, and can have effects well into the future. Think this is quite crucial – though needs drawing out more clearly – there is no overseer in the energy industry and each player can act independently. Hence we can influence the different players but not force them to do something. A diagram showing the different players, who can influence them and how?

This paper details our model, ElecSIM. Section 2 is a literature review of the models currently used in practice. Section 3 details the model and assumptions made, and section 4 details how we validated our model, and displays performance metrics. Section 5 details our results, and explores ways in which ElecSIM can be used. We conclude the work in section 6

- We have developed a framework for evaluating alternative scenarios, prior to implementation of policy.
- Used by experts working in collaboration with policy makers.
- Importance of a transition in electricity infrastructure (Paris agreement, UK Climate change act)
- Importance of understanding effect of decisions made today on the future (limit of 1.5C by 2050)
- Introduce ElecSIM as a toolkit to inform long-term domestic policy questions in the electricity market.
- Ability to model the effects of carbon taxation, and the effect of different scenarios
- Talk about the need to model a non-stationary, dynamic system, with multiple interacting agents with imperfect information
- Requirement for an Open-Source, free Toolkit written in python. Low barrier of entry, and integration with existing python data analytics and machine learning techniques. Transparent, reproducible, and data made available. This allows for results to be open to greater criticism and better inform policy decisions.
- Simple model which matches real life behaviour for low complexity and therefore increases transparency.

2 LITERATURE REVIEW

Say something first about what simulation and modelling is.

Energy models can typically be classified as top-down macro-economic models or bottom-up techno-economic models [5]. Top-down models model how demand varies with regards to historical economic data, and analyse aggregate behaviour [14]. They model how energy prices vary with respect to elasticities Give example. Bottom-up models represent the energy sector in detail, and are written as mathematical programming problems [13]. They detail technology explicitly, and can include cost and emissions implications [14].

It is possible to further Is this a sub-category of of the two approaches above or an orthogonal categorisation? categorise energy models into optimisation and simulation models. Optimisation energy models minimise costs or maximise welfare from the perspective of a central planner, for instance a government [19]. A use-case would be a government that wants cheap, reliable and low-carbon electricity supply by a future date. An optimisation model would find the optimal mix of generators to meet this whilst taking into account the constraints. Examples of optimisation models are MARKAL/TIMES [12] and MESSAGE [30]. MARKAL is possibly the most widely used general purpose energy systems model [26].

However, electricity market liberalisation in many Western democracies has changed the framework conditions. Centralised, monopolistic, decision making entities has given way to multiple heterogeneous agents acting in their own best interest [24]. Therefore, certain policy options which encourage changes must be used by a central planner to attain a desired outcome, for example carbon taxes or subsidies. It is therefore proposed that these complex agents are modelled using agent-based modelling.

As a result of this, agent-based simulation has received increasing attention in recent years, and a number of simulation tools have emerged, for example SEPIA [21] EMCAS [9], NEMSIM [4], AMES [32], PowerACE [29], MACSEM [28], GAPEX [8], EMLab [7]. So the obvious question is, so why do we need another one? I'm guessing this comes out in the text below, but can you give a summary answer in this paragraph?

SEPIA is a discrete event agent based model which utilises Q-learning for agent behaviour [15]. However, SEPIA is not primarily a market model, and focuses on transmission of electricity between GenCos (generator companies) and ConCo's (consumer companies). Therefore, they model plants as being always on, and not subject to market forces. As opposed to this, ElecSIM has been designed with a merit-order market in mind, with peaker [sp?] power plants running at times of high demand, and renewable energy supply running intermittently.

EMCAS is a closed source agent-based framework which investigates the interactions between physical infrastructures and economic behaviour of market participants [9]. ElecSIM, however, focuses on purely the dynamics on the market, with the aim to provide a simplified but robust model of market operation. And is also open source.

PowerACE is also a closed source agent-based simulation of electricity markets that integrates short-term perspectives of daily electricity trading and long-term investment decisions [29]. Similarly to ElecSIM, PowerACE initialises agents with all power plants in their respective country. However, unlike ElecSIM, PowerACE does not take into account stochasticity of price risks in electricity markets which is of crucial importance to real markets [24].

EMLab is also an agent-based modelling toolkit for the electricity market [7]. EMLab models an endogenous European emissions trading scheme with a yearly time-step. However, like PowerACE, EMLab differs from ElecSIM by not taking into account stochasticity in the electricity markets, such as outages, differing fuel prices within a year period and randomness in power plant operating costs. open source – could you have added stochasticity to it?

AMES is specific to the US Wholesale Power Market Platform [32], and GAPEX, which utilises the reinforcement technique Roth-Erev, does not model long-term dynamics [8]Something seems missing in this sentence.

We therefore propose ElecSIM to fill a gap of an open source, long-term stochastic investment, agent-based model. Table with ticks and crosses to show desired features and which ones have them?

- Agent Based Models - eg. EMCAS, PowerACE, EMLab: Leaves a requirement for an open source toolkit written in python. Many one-off models available, however difficult to apply to different scenarios. (SEPIA [6], EMCAS [7], NEMSIM [8], AMES [9], PowerACE [10], MASCEM [11, 12], and GAPEX [13] [22])
- Bottom-up optimization models to find minimum cost of electricity system. [26]. eg. MARKAL/TIMES, MESSAGE. (These do not provide information on how to achieve a certain goal, particularly in a liberalized energy market. Or scenarios as to why a goal may not be achieved as the goal is assumed to be achieved.)
- Computational general equilibrium (CGE) models - Top-down macroeconomic models partial equilibrium model (energy supply, demand, cross-border trade, emissions)- Can be highly complex and difficult to understand. eg. NEMS, PRIMES.

3 ELECSIM

ElecSIM has been designed for ease of use to enable non-experts to rapidly test different policies and the outcome of various different scenarios such as demand growth. The core to this has been the use of a scenario file. This single file allows exogenous variables such as fuel cost, carbon taxes, power plants, power plant costs, electricity demand and availability factors to be set. This allows for the initialisation of different countries and different scenarios to be tested.

overview.pdf

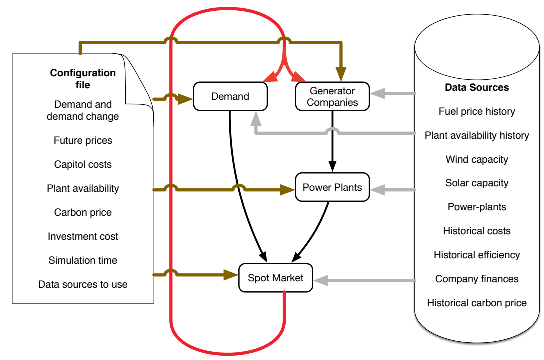

Figure 1: ElecSIM

ElecSIM is made up of 2 different agent types, GenCos (Generation Companies) and a Demand agent. GenCos can be initialised as to the wishes of the user. Either according to real life, or a toy example. Each of the GenCos are initialised with their respective power plants. GenCos are also given a randomized discount rate, which can be set by the user, around a mean of 10% for nuclear power plants [25] and 5.9% for all other generators [20].

ElecSIM's power generation costs is initialised using the UK government Department for Business and Energy power plant generation report [11]. This contains information such as capital costs and operation and maintenance costs, including details such as insurance and connection costs. Where there are power plants of a size that is not included in the costs the parameters are linearly interpolated. Where the capacity of a power plant is larger or smaller than the data points in the report, the parameters are extrapolated by using the last known data point.

For historical power plants, we used historical levels of levelised cost of energy (LCOE). Each parameter was scaled linearly from the modern LCOE, to attain the relevant historical LCOE. This was achieved by using linear optimisation, and therefore can be changed based on an individual user's country and dataset by customising the contraints. As well as historical LCOE, historical plant efficiency was taken into account for Gas and Coal power plants.

When initialised, the variable operation and maintenance costs are selected from a uniform distribution, which can be set by the user. This enables variance in costs between individual power plants for processes such as preventative and corrective maintenance, labour costs and skill, health and safety and chance.

As per [7], we split the electricity demand for one year and split this into 19 load segments. This enabled us to model the varying demand of electricity throughout a year, and at the same time reduce computational complexity. To model the Intermittency of wind and solar power we allow them to contribute only a certain percentage of total capacity for each load segment based on empirical wind and solar capacity factors, relating demand to average capacity

[7, 27, 31]. We do not model curtailment of renewables, or storage capabilities.

Whilst fuel price is controlled by the user, there is inherent volatility in fuel price in a single year. To take into account this variability, an ARIMA model was fit to historical gas and coal price data [1, 2]. The standard deviation of the residuals was taken and then used to model the price of fuel that a generation company will buy fuel at in a given year. This takes into account differences in hedging strategies and chance between generation companies.

Outages are modelled by using availability data of gas, coal, photovoltaic, offshore and onshore power generators [6, 17, 23]. Plants bid a reduced percentage of their nameplate capacity and capacity factor based on their respective availability. Historical availabilities are modelled for older gas, coal and hydro power plants [3].

Operating period, pre-development and construction periods are taken from the UK Government Business, Energy and Industrial Strategy report [11]. Where historical power plants are modelled, and have been refurbished, we initialise their starting year randomly between 15 years prior to initialisation year and the initialisation year.

Power plants are taken out of service if they have been unprofitable for

3.1 Spot Market

The buying and selling of electricity is modelled as a spot market, where each year, electricity is bought and sold in merit order. GenCos place bids for each of their plants at their short run marginal cost. We assume that there is no market power, as from analysis of the electricity prices in the UK, very high or very low electricity price are uncommon.

3.2 Investment

Investments are made on a yearly basis. Investment decisions are made purely on net present value calculations. The order in which GenCos invest in each simulated year is randomised as to not give agents an advantage.

Agents have imperfect information, and therefore fuel and carbon prices are predicted using linear regression, with a training period selected uniformly between the 3 and 7 years, to model heterogeneity of GenCos. Demand is modelled through the use of an exponential function, due to compounded growth, however if a reasonable fit is not found linear regression is used instead.

GenCos only bid if they have 25% of the upfront capital costs, with the rest of the capital provided through equity and debt. This is modelled as a weighted average cost of capital (WACC) of 5.9% for non-nuclear power plants, and 10% for nuclear power plants [20, 25]. The WACC is used as the discount rate for net present value calculations. Each GenCo is initialised with a slightly different WACC and discount rate based on a uniform distribution, with a ±3% standard deviation. This allows us to model the variability in discount rates/WACC that GenCos may have, based on differing reputations.

The sale price of electricity in the future reference year is predicted by each generation company simulating the same merit-order market algorithm that is used for the spot market. They simulate the behaviour of power plants that will be in operation by the reference year.

- Model can be modified through a single python scenario file which includes exogenous variables such as number of generation companies, power plants, power plant costs, tax and fuel prices, and demand.
- Architectural framework:
  - Agents are generation companies.
  - Generation companies initialized from government data. And randomized discount rate around a mean of 10% for nuclear power plants and 5.9% for other types of generators.
  - Costs of power plants taken from empirical data.
  - Historical LCOE costs taken from data, with individual costs such as fixed operation and maintenance, construction and pre-development costs scaled linearly to match LCOE value. (This can be changed by user by specifying linear optimisation constraints).
  - Historical Gas turbine and Coal plant efficiency taken from epa data.
  - Variable operation and maintenance costs are stochastic to take into account differences in design types, preventative and corrective maintenance, labour costs and skill, asset and site management, health and safety and chance.
  - Electricity demand taken from historical data and split up into 19 load segments.
  - CO2 prices, fuel Prices, demand growth are exogenous
  - Fuel is bought by power producers each year at different prices, related to the standard deviation from historical data. This simulates different hedging strategies, luck and timing of fuel purchasing.
  - Outages are modelled by assuming a 93% outage rate for fuel plants [23] and 97% outage for renewables. [6]
  - Generation companies bid their short run marginal costs.
  - Investments made on highest Net Present Value results. CO2 price, fuel price and demand are predicted 7 years ahead using linear regression.
  - Estimated sale of electricity price calculated by simulating a market 7 years into the future with expected power plants that are running and have been taken out of service.
  - Investors will only invest if they have 25% of the total upfront costs. (the rest taken on by debt and equity as assumed by WACC value.)
  - Intermittent power generators can only submit a certain percentage of their total capacity for each load segment. This percentage is matched with empirical data.
  - Bids accepted by a centralised power exchange based on merit order. Generation companies bid their short run marginal cost.
- Assumptions:
  - Yearly time step
  - Renewables contribute to load curve of each demand segment matched with empirical data of typical wind and solar availability at each demand segment
  - Different discount rates per user (randomized)

  - Country initialized with full amount of power plants and generation companies in country and total demand data considered
  - No curtailment of renewables
  - Imperfect foresight - Prediction required for demand, co2 price, fuel cost, other investments.
  - Power plant construction and pre-development periods and costs modelled from UK Government BEIS data
  - Investments based on highest NPV using a single year 7 (can be changed in scenario file) time steps into the future to predict all years of power plant.
  - Agents predict next year's fuel, carbon and demand using linear regression and randomized look back period (between 3 and 6.)
  - Plants are dismantled after their lifetime, and only enter operation after pre-development/construction.
  - Legacy power plants are reinitialized to random starting year to account for refurbishment.

4 VALIDATION AND PERFORMANCE

- Validation of model
  - Compare price duration curve
  - Compare power plant costs and NPV calculations
  - Look number of steps ahead to compare electricity mix and compare to actual (cross-validation)
- Performance metrics - Comparison with EMLab, PowerACE (15 minute run time)
  - Memory, disk size, runtime
  - Increase in time complexity with additional data.

5 SCENARIO TESTING

- Effect of different carbon tax on investments made.
- Effects of different demand scenarios. (High peaks, high growth, high reduction in demand)
- Effects of high fuel prices.
- Different costs of capital (eg. Borrowing for Nuclear of interest rate to equal 2% at government bonds rate, as opposed to 10% for private companies.)
- Different learning rates for renewable costs.
- The effect of long term carbon tax policy (eg. Carbon price known for next 25 years) vs short term changes in carbon tax.

6 CONCLUSIONS

- Requirement for agent based models based on imperfect information, liberalised energy markets
- Requirement for low barriers to entry open source model.
- Discuss results
- Future work:
  - Embedding multi-agent intelligence such as Genetic Algorithms, Q-learning and dynamic reinforcement learning
  - Raise spatial and temporal resolution.

7 INTRODUCTION

ACM's consolidated article template, introduced in 2017, provides a consistent LaTeX style for use across ACM publications, and incorporates accessibility and metadata-extraction functionality necessary for future Digital Library endeavours. Numerous ACM and SIG-specific LaTeX templates have been examined, and their unique features incorporated into this single new template.

If you are new to publishing with ACM, this document is a valuable guide to the process of preparing your work for publication. If you have published with ACM before, this document provides insight and instruction into more recent changes to the article template.

The "`acmart`" document class can be used to prepare articles for any ACM publication — conference or journal, and for any stage of publication, from review to final "camera-ready" copy, to the author's own version, with *very* few changes to the source.

8 TEMPLATE OVERVIEW

As noted in the introduction, the "`acmart`" document class can be used to prepare many different kinds of documentation — a double-blind initial submission of a full-length technical paper, a two-page SIGGRAPH Emerging Technologies abstract, a "camera-ready" journal article, a SIGCHI Extended Abstract, and more — all by selecting the appropriate *template style* and *template parameters*.

This document will explain the major features of the document class. For further information, the *LaTeX User's Guide* is available from https://www.acm.org/publications/proceedings-template.

8.1 Template Styles

The primary parameter given to the "`acmart`" document class is the *template style* which corresponds to the kind of publication or SIG publishing the work. This parameter is enclosed in square brackets and is a part of the `documentclass` command:

```
\documentclass[STYLE]{acmart}
```

Journals use one of three template styles. All but three ACM journals use the `acmsmall` template style:

- `acmsmall`: The default journal template style.
- `acmlarge`: Used by JOCCH and TAP.
- `acmtog`: Used by TOG.

The majority of conference proceedings documentation will use the `acmconf` template style.

- `acmconf`: The default proceedings template style.
- `sigchi`: Used for SIGCHI conference articles.
- `sigchi-a`: Used for SIGCHI "Extended Abstract" articles.
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8.2 Template Parameters

In addition to specifying the *template style* to be used in formatting your work, there are a number of *template parameters* which modify some part of the applied template style. A complete list of these parameters can be found in the *LaTeX User's Guide*.

Frequently-used parameters, or combinations of parameters, include:

- `anonymous,review`: Suitable for a "double-blind" conference submission. Anonymizes the work and includes line numbers. Use with the `\acmSubmissionID` command to print the submission's unique ID on each page of the work.
- `authorversion`: Produces a version of the work suitable for posting by the author.
- `screen`: Produces colored hyperlinks.

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9 MODIFICATIONS

Modifying the template — including but not limited to: adjusting margins, typeface sizes, line spacing, paragraph and list definitions, and the use of the `\vspace` command to manually adjust the vertical spacing between elements of your work — is not allowed.

Your document will be returned to you for revision if modifications are discovered.

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```
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```

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Each author must be defined separately for accurate metadata identification. Multiple authors may share one affiliation. Authors' names should not be abbreviated; use full first names wherever possible. Include authors' e-mail addresses whenever possible.

Grouping authors' names or e-mail addresses, or providing an "e-mail alias," as shown below, is not acceptable:

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```

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If your author list is lengthy, you must define a shortened version of the list of authors to be used in the page headers, to prevent overlapping text. The following command should be placed just after the last `\author{}` definition:

```
\renewcommand{\shortauthors}{McCartney, et al.}
```

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14 CCS CONCEPTS AND USER-DEFINED KEYWORDS

Two elements of the "acmart" document class provide powerful taxonomic tools for you to help readers find your work in an online search.

The ACM Computing Classification System — https://www.acm.org/publications/class-2012 — is a set of classifiers and concepts that describe the computing discipline. Authors can select entries from this classification system, via https://dl.acm.org/ccs/ccs.cfm, and generate the commands to be included in the LATEX source.

User-defined keywords are a comma-separated list of words and phrases of the authors' choosing, providing a more flexible way of describing the research being presented.

CCS concepts and user-defined keywords are required for all short- and full-length articles, and optional for two-page abstracts.

15 SECTIONING COMMANDS

Your work should use standard LATEX sectioning commands: `section`, `subsection`, `subsubsection`, and `paragraph`. They should be numbered; do not remove the numbering from the commands.

Simulating a sectioning command by setting the first word or words of a paragraph in boldface or italicized text is **not allowed.**

16 TABLES

The "`acmart`" document class includes the "`booktabs`" package — https://ctan.org/pkg/booktabs — for preparing high-quality tables.

Table captions are placed *above* the table.

Because tables cannot be split across pages, the best placement for them is typically the top of the page nearest their initial cite.

Table 1: Frequency of Special Characters

Non-English or Math	Frequency	Comments
Ø	1 in 1,000	For Swedish names
π	1 in 5	Common in math
$	4 in 5	Used in business
Ψ_1^2	1 in 40,000	Unexplained usage

To ensure this proper "floating" placement of tables, use the environment **table** to enclose the table's contents and the table caption. The contents of the table itself must go in the **tabular** environment, to be aligned properly in rows and columns, with the desired horizontal and vertical rules. Again, detailed instructions on **tabular** material are found in the *LaTeX User's Guide*.

Immediately following this sentence is the point at which Table 1 is included in the input file; compare the placement of the table here with the table in the printed output of this document.

To set a wider table, which takes up the whole width of the page's live area, use the environment **table*** to enclose the table's contents and the table caption. As with a single-column table, this wide table will "float" to a location deemed more desirable. Immediately following this sentence is the point at which Table 2 is included in the input file; again, it is instructive to compare the placement of the table here with the table in the printed output of this document.

17 MATH EQUATIONS

You may want to display math equations in three distinct styles: inline, numbered or non-numbered display. Each of the three are discussed in the next sections.

17.1 Inline (In-text) Equations

A formula that appears in the running text is called an inline or in-text formula. It is produced by the **math** environment, which can be invoked with the usual `\begin . . . \end` construction or with the short form `$ . . . $`. You can use any of the symbols and structures, from α to ω, available in LaTeX [?]; this section will simply show a few examples of in-text equations in context. Notice how this equation: $\lim_{n\rightarrow \infty}x=0$, set here in in-line math style, looks slightly different when set in display style. (See next section).

17.2 Display Equations

A numbered display equation—one set off by vertical space from the text and centered horizontally—is produced by the **equation** environment. An unnumbered display equation is produced by the **displaymath** environment.

Again, in either environment, you can use any of the symbols and structures available in LaTeX; this section will just give a couple of examples of display equations in context. First, consider the equation, shown as an inline equation above:

$$\lim_{n\rightarrow \infty}x=0 \tag{1}$$

Notice how it is formatted somewhat differently in the **displaymath** environment. Now, we'll enter an unnumbered equation:

$$\sum_{i=0}^{\infty} x + 1$$

and follow it with another numbered equation:

$$\sum_{i=0}^{\infty}x_i=\int_{0}^{\pi+2} f \tag{2}$$

just to demonstrate LaTeX's able handling of numbering.

18 FIGURES

The "`figure`" environment should be used for figures. One or more images can be placed within a figure. If your figure contains third-party material, you must clearly identify it as such, as shown in the example below.

Figure 2: 1907 Franklin Model D roadster. Photograph by Harris & Ewing, Inc. [Public domain], via Wikimedia Commons. (https://goo.gl/VLCRBB).

Your figures should contain a caption which describes the figure to the reader. Figure captions go below the figure. Your figures should **also** include a description suitable for screen readers, to assist the visually-challenged to better understand your work.

Figure captions are placed *below* the figure.

18.1 The "Teaser Figure"

A "teaser figure" is an image, or set of images in one figure, that are placed after all author and affiliation information, and before the body of the article, spanning the page. If you wish to have such a figure in your article, place the command immediately before the `\maketitle` command:

```
\begin{teaserfigure}
  \includegraphics[width=\textwidth]{sampleteaser}
  \caption{figure caption}
  \Description{figure description}
\end{teaserfigure}
```

Table 2: Some Typical Commands

Command	A Number	Comments
`\author`	100	Author
`\table`	300	For tables
`\table*`	400	For wider tables

19 CITATIONS AND BIBLIOGRAPHIES

The use of BibTeX for the preparation and formatting of one's references is strongly recommended. Authors' names should be complete — use full first names ("Donald E. Knuth") not initials ("D. E. Knuth") — and the salient identifying features of a reference should be included: title, year, volume, number, pages, article DOI, etc.

The bibliography is included in your source document with these two commands, placed just before the `\end{document}` command:

```
\bibliographystyle{ACM-Reference-Format}
\bibliography{bibfile,custom-bibtex}
```

where "`bibfile`" is the name, without the "`.bib`" suffix, of the BibTeX file.

Citations and references are numbered by default. A small number of ACM publications have citations and references formatted in the "author year" style; for these exceptions, please include this command in the **preamble** (before "`\begin{document}`") of your LaTeX source:

```
\citestyle{acmauthoryear}
```

Some examples. A paginated journal article [?], an enumerated journal article [?], a reference to an entire issue [?], a monograph (whole book) [?], a monograph/whole book in a series (see 2a in spec. document) [?], a divisible-book such as an anthology or compilation [?] followed by the same example, however we only output the series if the volume number is given [?] (so Editor00a's series should NOT be present since it has no vol. no.), a chapter in a divisible book [?], a chapter in a divisible book in a series [?], a multi-volume work as book [?], an article in a proceedings (of a conference, symposium, workshop for example) (paginated proceedings article) [?], a proceedings article with all possible elements [?], an example of an enumerated proceedings article [?], an informally published work [?], a doctoral dissertation [?], a master's thesis: [?], an online document / world wide web resource [? ? ?], a video game (Case 1) [?] and (Case 2) [?] and [?] and (Case 3) a patent [?], work accepted for publication [?], 'YYYYb'-test for prolific author [?] and [?]. Other cites might contain 'duplicate' DOI and URLs (some SIAM articles) [?]. Boris / Barbara Beeton: multi-volume works as books [?] and [?]. A couple of citations with DOIs: [? ?]. Online citations: [? ? ?].

20 ACKNOWLEDGMENTS

Identification of funding sources and other support, and thanks to individuals and groups that assisted in the research and the preparation of the work should be included in an acknowledgment section, which is placed just before the reference section in your document.

This section has a special environment:

```
\begin{acks}
...
\end{acks}
```

so that the information contained therein can be more easily collected during the article metadata extraction phase, and to ensure consistency in the spelling of the section heading.

Authors should not prepare this section as a numbered or unnumbered `\section`; please use the "`acks`" environment.

21 APPENDICES

If your work needs an appendix, add it before the "`\end{document}`" command at the conclusion of your source document.

Start the appendix with the "`appendix`" command:

```
\appendix
```

and note that in the appendix, sections are lettered, not numbered. This document has two appendices, demonstrating the section and subsection identification method.

22 SIGCHI EXTENDED ABSTRACTS

The "`sigchi-a`" template style (available only in LaTeX and not in Word) produces a landscape-orientation formatted article, with a wide left margin. Three environments are available for use with the "`sigchi-a`" template style, and produce formatted output in the margin:

- `sidebar`: Place formatted text in the margin.
- `marginfigure`: Place a figure in the margin.
- `margintable`: Place a table in the margin.

ACKNOWLEDGMENTS

To Robert, for the bagels and explaining CMYK and color spaces.

REFERENCES

[1] [n. d.]. Coal Futures Historical Prices. *investing.com* ([n. d.]). https://www.investing.com/commodities/coal-cme-futures-historical-data

[2] [n. d.]. Gas Futures Historical Prices. *investing.com* ([n. d.]). https://www.investing.com/commodities/coal-cme-futures-historical-data

[3] Alberta System Electric Operator. 2016. AESO 2015 Annual Market Statistics. March (2016), 28. https://www.aeso.ca/market/market-and-system-reporting/annual-market-statistic-reports/

[4] David Batten and George Grozev. 2006. NEMSIM: Finding Ways to Reduce Greenhouse Gas Emissions Using Multi-Agent Electricity Modelling. *Complex Science for a Complex World* (2006), 227–252.

[5] Christoph Böhringer. 1998. The synthesis of bottom-up and top-down in energy policy modeling. *Energy Economics* 20, 3 (1998), 233–248. https://doi.org/10.1016/S0140-9883(97)00015-7

[6] James Carroll, Allan May, Alasdair McDonald, and David McMillan. [n. d.]. Availability Improvements from Condition Monitoring Systems and Performance Based Maintenance Contracts. 45 ([n. d.]), 39.

[7] Emile J.L. Chappin, Laurens J. de Vries, Joern C. Richstein, Pradyumna Bhagwat, Kaveri Iychettira, and Salman Khan. 2017. Simulating climate and energy policy with agent-based modelling: The Energy Modelling Laboratory (EMLab). *Environmental Modelling and Software* 96 (2017), 421–431. https://doi.org/10.1016/j.envsoft.2017.07.009

[8] Silvano Cincotti, Giulia Gallo, and Lawrence Berkeley. 2013. The Genoa Artificial Power-Exchange The Genoa artificial power-exchange. January (2013). https://doi.org/10.1007/978-3-642-36907-0
[9] G. Conzelmann, G. Boyd, V. Koritarov, and T. Veselka. [n. d.]. Multi-agent power market simulation using EMCAS. *IEEE Power Engineering Society General Meeting, 2005* ([n. d.]), 917–922. https://doi.org/10.1109/PES.2005.1489271
[10] John Cook, Dana Nuccitelli, Sarah A Green, Mark Richardson, Bärbel Winkler, Rob Painting, Robert Way, Peter Jacobs, and Andrew Skuce. 2013. Environmental Research Letters Quantifying the consensus on anthropogenic global warming in the scientific literature Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ. Res. Lett* 8 (2013), 24024–7. https://doi.org/10.1088/1748-9326/8/2/024024
[11] Department for Business Energy & Industrial Strategy. 2016. Electricity Generation Costs. *Department for Business, Energy and Industrial Strategy* November (2016).
[12] Leslie G. Fishbone and Harold Abilock. 1981. Markal, a linearâĂŘprogramming model for energy systems analysis: Technical description of the bnl version. *International Journal of Energy Research* 5, 4 (1981), 353–375. https://doi.org/10.1002/er.4440050406
[13] Maurizio Gargiulo and O Brian. 2013. Long-term energy models : Principles , characteristics , focus ,. *WIREs Energy and Environment* 2, April (2013). https://doi.org/10.1002/wene.62
[14] Lisa M H Hall and Alastair R Buckley. 2016. A review of energy systems models in the UK : Prevalent usage and categorisation. *Applied Energy* 169 (2016), 607–628. https://doi.org/10.1016/j.apenergy.2016.02.044
[15] By Steven A Harp, Bruce F Wollenberg, and Tariq Samad. 2000. SEPIA: A Simulator for Electric Power Industry Agents. August (2000), 53–69.
[16] Martin I Hoffert, Martin I Hoffert, Ken Caldeira, Gregory Benford, David R Criswell, Christopher Green, Howard Herzog, Atul K Jain, Haroon S Kheshgi, Klaus S Lackner, John S Lewis, H Douglas Lightfoot, Wallace Manheimer, and John C Mankins. 2002. Advanced Technology Paths to Global Climate Stability : Energy for a Greenhouse Planet. *Science* 298, 2002 (2002), 981–988. https://doi.org/10.1126/science.1072357
[17] Kirby Hunt, Anthony Blekicki, and Robert Callery. 2015. Availability of utility-scale photovoltaic power plants. *2015 IEEE 42nd Photovoltaic Specialist Conference, PVSC 2015* (2015), 0–2. https://doi.org/10.1109/PVSC.2015.7355976
[18] IPCC. 2014. Foreword, Preface, Dedication and In Memoriam. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (2014), 1454. https://doi.org/10.1017/CBO9781107415416 arXiv:arXiv:1011.1669v3
[19] Dogan Keles, Patrick Jochem, Russell Mckenna, Manuel Ruppert, and Wolf Fichtner. 2017. Meeting the Modeling Needs of Future Energy Systems. *Energy Technology* (2017), 1007–1025. https://doi.org/10.1002/ente.201600607
[20] KPMG. 2017. Cost of Capital Study 2017. *KPMG* (2017).
[21] O. Kraan, G. J. Kramer, and I. Nikolic. 2018. Investment in the future electricity system - An agent-based modelling approach. *Energy* 151 (2018), 569–580. https://doi.org/10.1016/j.energy.2018.03.092
[22] Fernando Lopes. 2018. MATREM : An Agent-Based Simulation Tool for Electricity Markets. *Electricity Markets with Increasing Levels of Renewable Generation: Structure, Operation, Agent-based Simulation, and Emerging Designs* (2018), 189–225.
[23] LeighFisher Ltd. 2016. Final Report: Electricity Generation Costs and Hurdle Rates.
[24] Dominik Möst and Dogan Keles. 2010. A survey of stochastic modelling approaches for liberalised electricity markets. *European Journal of Operational Research* 207, 2 (2010), 543–556. https://doi.org/10.1016/j.ejor.2009.11.007
[25] Icept Working Paper and Phil Heptonstall. 2012. Cost estimates for nuclear power in the UK. *ICEPT Working Paper* August (2012).
[26] Stefan Pfenninger, Adam Hawkes, and James Keirstead. 2014. Energy systems modeling for twenty- fi rst century energy challenges. *Renewable and Sustainable Energy Reviews* 33 (2014), 74–86. https://doi.org/10.1016/j.rser.2014.02.003
[27] Stefan Pfenninger and Iain Staffell. 2016. Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. *Energy* 114 (2016), 1251–1265. https://doi.org/10.1016/j.energy.2016.08.060
[28] Isabel Praça, Carlos Ramos, Zita Vale, and M Ascem. 2003. MASCEM : A Multiagent Markets. (2003).
[29] Werner Rothengatter. 2007. Assessment of the impact of renewable electricity generation on the German electricity sector An agent-based simulation approach. *Thesis* (2007).
[30] Leo Schrattenholzer. 1981. The energy supply model MESSAGE. *European Journal of Operational Research* December (1981). https://doi.org/10.1016/0377-2217(83)90165-0
[31] Iain Staffell and Stefan Pfenninger. 2016. Using bias-corrected reanalysis to simulate current and future wind power output. *Energy* 114 (2016), 1224–1239. https://doi.org/10.1016/j.energy.2016.08.068
[32] Junjie Sun and Leigh Tesfatsion. 2007. Dynamic Testing of Wholesale Power Market Designs : An Open-Source Agent-Based Framework. *Computational Economics* 30, 3 (2007), 291–327. https://doi.org/10.1007/s10614-007-9095-1

A RESEARCH METHODS

A.1 Part One

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A.2 Part Two

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B ONLINE RESOURCES

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