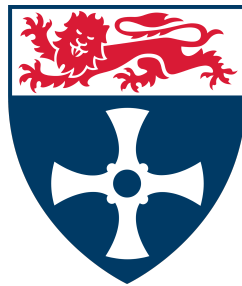


Modelling the transition to a low-carbon energy supply



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This dissertation is submitted for the degree of
Doctor of Philosophy

April 2020

I would like to dedicate this thesis to Sumiré and my loving parents...

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

Alexander John Michael Kell

April 2020

Acknowledgements

And I would like to acknowledge ...

Abstract

This is where you write your abstract ...

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Nomenclature

Roman Symbols

F complex function

Greek Symbols

γ a simply closed curve on a complex plane

ι unit imaginary number $\sqrt{-1}$

$\pi \simeq 3.14\dots$

Superscripts

j superscript index

Subscripts

0 subscript index

crit Critical state

Other Symbols

\oint_{γ} integration around a curve γ

Acronyms / Abbreviations

ALU Arithmetic Logic Unit

BEM Boundary Element Method

CD Contact Dynamics

CFD Computational Fluid Dynamics

CIF Cauchy's Integral Formula

CK Carman - Kozeny

DEM Discrete Element Method

DKT Draft Kiss Tumble

DNS	Direct Numerical Simulation
EFG	Element-Free Galerkin
FEM	Finite Element Method
FLOP	Floating Point Operations
FPU	Floating Point Unit
FVM	Finite Volume Method
GPU	Graphics Processing Unit
LBM	Lattice Boltzmann Method
LES	Large Eddy Simulation
MPM	Material Point Method
MRT	Multi-Relaxation Time
PCI	Peripheral Component Interconnect
PFEM	Particle Finite Element Method
PIC	Particle-in-cell
PPC	Particles per cell
RVE	Representative Elemental Volume
SH	Savage Hutter
SM	Streaming Multiprocessors
USF	Update Stress First
USL	Update Stress Last

Chapter 1

Introduction

1.1 What is lorem ipsum? Title with math σ

Hi Ipsum is simply dummy text of the printing and typesetting industry (see Section 1.3). Lorem Ipsum [?] has been the industry's standard dummy text ever since the 1500s, when an unknown printer took a galley of type and scrambled it to make a type specimen book. It has survived not only five centuries, but also the leap into electronic typesetting, remaining essentially unchanged. It was popularised in the 1960s with the release of Letraset sheets containing Lorem Ipsum passages, and more recently with desktop publishing software like Aldus PageMaker including versions of Lorem Ipsum [? ? ?].

The most famous equation in the world: $E^2 = (m_0c^2)^2 + (pc)^2$, which is known as the **energy-mass-momentum** relation as an in-line equation.

A *LaTeX class file* is a file, which holds style information for a particular \LaTeX .

$$CIF : \quad F_0^j(a) = \frac{1}{2\pi i} \oint_{\gamma} \frac{F_0^j(z)}{z-a} dz \quad (1.1)$$

1.2 Why do we use lorem ipsum?

It is a long established fact that a reader will be distracted by the readable content of a page when looking at its layout. The point of using Lorem Ipsum is that it has a more-or-less normal distribution of letters, as opposed to using 'Content here, content here', making it look like readable English. Many desktop publishing packages and web page editors now use Lorem Ipsum as their default model text, and a search for 'lorem ipsum' will uncover many web sites still in their infancy. Various versions have evolved over the years, sometimes by accident, sometimes on purpose (injected humour and the like).

1.3 Where does it come from?

Contrary to popular belief, Lorem Ipsum is not simply random text. It has roots in a piece of classical Latin literature from 45 BC, making it over 2000 years old. Richard McClintock, a Latin professor at Hampden-Sydney College in Virginia, looked up one of the more obscure Latin words, *consectetur*, from a Lorem Ipsum passage, and going through the cites of the word in classical literature, discovered the undoubtable source. Lorem Ipsum comes from sections 1.10.32 and 1.10.33 of "de Finibus Bonorum et Malorum" (The Extremes of Good and Evil) by Cicero, written in 45 BC. This book is a treatise on the theory of ethics, very popular during the Renaissance. The first line of Lorem Ipsum, "Lorem ipsum dolor sit amet..", comes from a line in section 1.10.32.

The standard chunk of Lorem Ipsum used since the 1500s is reproduced below for those interested. Sections 1.10.32 and 1.10.33 from "de Finibus Bonorum et Malorum" by Cicero are also reproduced in their exact original form, accompanied by English versions from the 1914 translation by H. Rackham

"Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum."

Section 1.10.32 of "de Finibus Bonorum et Malorum", written by Cicero in 45 BC: "Sed ut perspiciatis unde omnis iste natus error sit voluptatem accusantium doloremque laudantium, totam rem aperiam, eaque ipsa quae ab illo inventore veritatis et quasi architecto beatae vitae dicta sunt explicabo. Nemo enim ipsam voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt. Neque porro quisquam est, qui dolorem ipsum quia dolor sit amet, consectetur, adipisci velit, sed quia non numquam eius modi tempora incidunt ut labore et dolore magnam aliquam quaerat voluptatem. Ut enim ad minima veniam, quis nostrum exercitationem ullam corporis suscipit laboriosam, nisi ut aliquid ex ea commodi consequatur? Quis autem vel eum iure reprehenderit qui in ea voluptate velit esse quam nihil molestiae consequatur, vel illum qui dolorem eum fugiat quo voluptas nulla pariatur?"

1914 translation by H. Rackham: "But I must explain to you how all this mistaken idea of denouncing pleasure and praising pain was born and I will give you a complete account of the system, and expound the actual teachings of the great explorer of the truth, the master-builder of human happiness. No one rejects, dislikes, or avoids pleasure itself, because it is pleasure, but because those who do not know how to pursue pleasure rationally encounter consequences that are extremely painful. Nor again is there anyone who loves or pursues or desires to obtain pain of itself, because it is pain, but because occasionally circumstances occur in which toil and pain can procure him some great pleasure. To take a trivial example, which of us ever undertakes laborious physical exercise, except to obtain some advantage from it? But who has any right to find fault with a man who chooses to enjoy a pleasure that has no annoying consequences, or one who avoids a pain that produces no resultant pleasure?"

Section 1.10.33 of “de Finibus Bonorum et Malorum”, written by Cicero in 45 BC: “At vero eos et accusamus et iusto odio dignissimos ducimus qui blanditiis praesentium voluptatum deleniti atque corrupti quos dolores et quas molestias excepturi sint occaecati cupiditate non provident, similique sunt in culpa qui officia deserunt mollitia animi, id est laborum et dolorum fuga. Et harum quidem rerum facilis est et expedita distinctio. Nam libero tempore, cum soluta nobis est eligendi optio cumque nihil impedit quo minus id quod maxime placeat facere possimus, omnis voluptas assumenda est, omnis dolor repellendus. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.”

1914 translation by H. Rackham: “On the other hand, we denounce with righteous indignation and dislike men who are so beguiled and demoralized by the charms of pleasure of the moment, so blinded by desire, that they cannot foresee the pain and trouble that are bound to ensue; and equal blame belongs to those who fail in their duty through weakness of will, which is the same as saying through shrinking from toil and pain. These cases are perfectly simple and easy to distinguish. In a free hour, when our power of choice is untrammelled and when nothing prevents our being able to do what we like best, every pleasure is to be welcomed and every pain avoided. But in certain circumstances and owing to the claims of duty or the obligations of business it will frequently occur that pleasures have to be repudiated and annoyances accepted. The wise man therefore always holds in these matters to this principle of selection: he rejects pleasures to secure other greater pleasures, or else he endures pains to avoid worse pains.”

Chapter 2

Energy transitions

2.1 Reasonably long section title

I'm going to randomly include a picture Figure 2.1.

If you have trouble viewing this document contact Krishna at: kks32@cam.ac.uk or raise an issue at <https://github.com/kks32/phd-thesis-template/>

Enumeration

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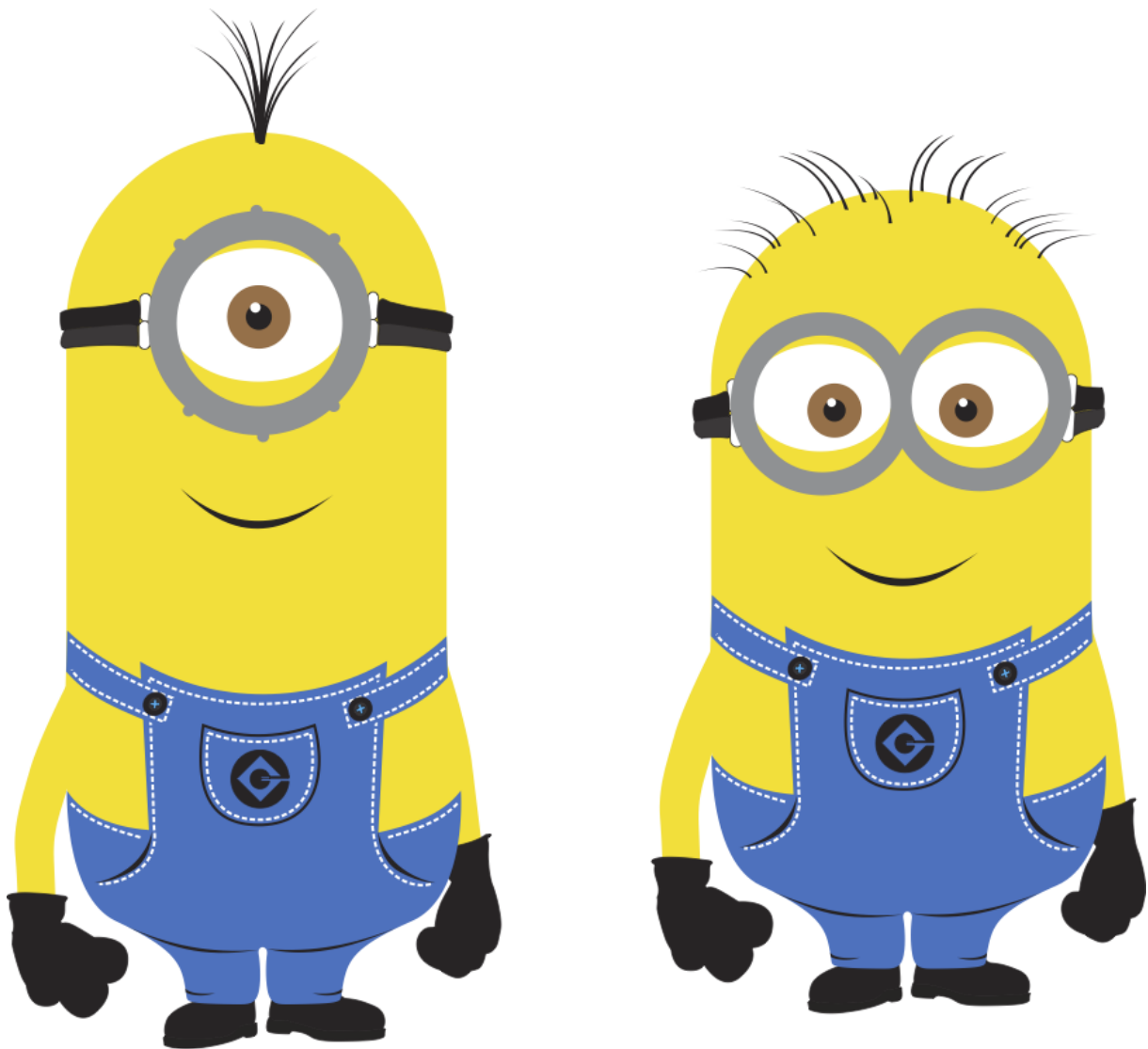


Fig. 2.1 This is just a long figure caption for the minion in Despicable Me from Pixar

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1. The first topic is dull
2. The second topic is duller
 - (a) The first subtopic is silly
 - (b) The second subtopic is stupid
3. The third topic is the dullest

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Itemize

- The first topic is dull
- The second topic is duller
 - The first subtopic is silly
 - The second subtopic is stupid
- The third topic is the dullest

Description

The first topic is dull

The second topic is duller

The first subtopic is silly

The second subtopic is stupid

The third topic is the dullest

2.2 Hidden section

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¹My footnote goes blah blah blah! ...

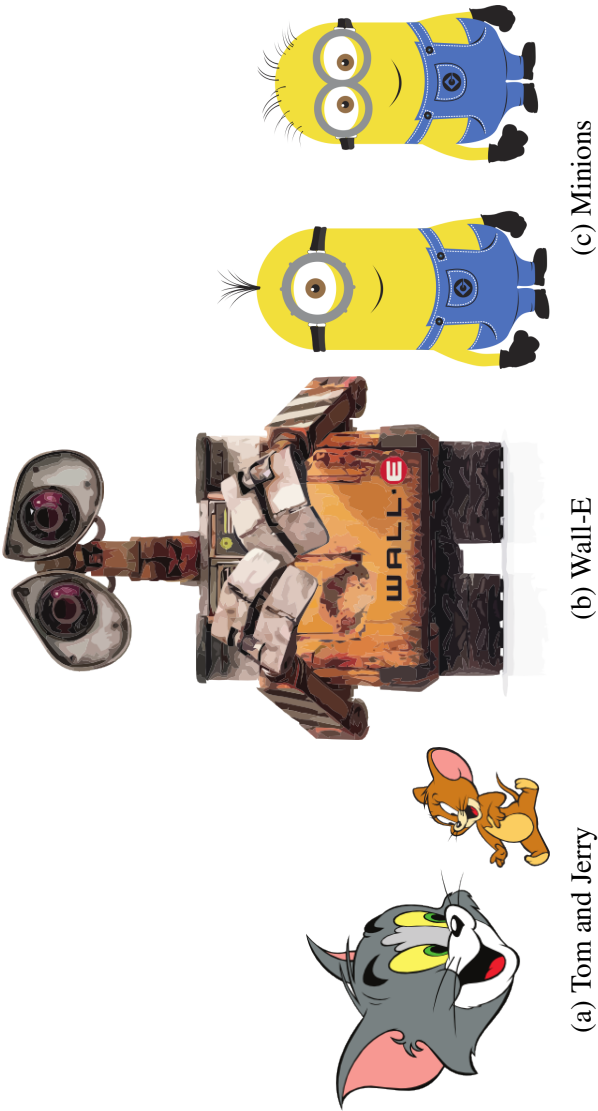


Fig. 2.2 Best Animations

Subplots

I can cite Wall-E (see Fig. 2.2b) and Minions in despicable me (Fig. 2.2c) or I can cite the whole figure as Fig. 2.2

Chapter 3

Literature review

3.1 First section of the third chapter

And now I begin my third chapter here ...

And now to cite some more people ? ?]

3.1.1 First subsection in the first section

...and some more

3.1.2 Second subsection in the first section

...and some more ...

First subsub section in the second subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

3.1.3 Third subsection in the first section

...and some more ...

First subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it and some more and some more and some more and some more and some more and some more and some more ...

Second subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

Table 3.1 A badly formatted table

	Species I		Species II	
Dental measurement	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

3.2 Second section of the third chapter

and here I write more ...

3.3 The layout of formal tables

This section has been modified from “Publication quality tables in L^AT_EX*” by Simon Fear.

The layout of a table has been established over centuries of experience and should only be altered in extraordinary circumstances.

When formatting a table, remember two simple guidelines at all times:

1. Never, ever use vertical rules (lines).
2. Never use double rules.

These guidelines may seem extreme but I have never found a good argument in favour of breaking them. For example, if you feel that the information in the left half of a table is so different from that on the right that it needs to be separated by a vertical line, then you should use two tables instead. Not everyone follows the second guideline:

There are three further guidelines worth mentioning here as they are generally not known outside the circle of professional typesetters and subeditors:

3. Put the units in the column heading (not in the body of the table).
4. Always precede a decimal point by a digit; thus 0.1 *not* just .1.
5. Do not use ‘ditto’ signs or any other such convention to repeat a previous value. In many circumstances a blank will serve just as well. If it won’t, then repeat the value.

A frequently seen mistake is to use ‘\begin{center}’ ... ‘\end{center}’ inside a figure or table environment. This center environment can cause additional vertical space. If you want to avoid that just use ‘\centering’

Table 3.2 A nice looking table

Dental measurement	Species I		Species II	
	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Table 3.3 Even better looking table using booktabs

Dental measurement	Species I		Species II	
	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Chapter 4

ElecSim model

4.1 Introduction

The world faces significant challenges from climate change [16]. A rise in carbon emissions increases the risk of severe impacts on the world such as rising sea levels, heat waves and tropical cyclones [16]. A survey [7] showed that 97% of scientific literature concurs that the recent change in climate is anthropogenic.

High carbon emitting electricity generation sources such as coal and natural gas currently produce 65% of global electricity, whereas low-carbon sources such as wind, solar, hydro and nuclear provide 35% [3]. Hence, to bring about change and reach carbon-neutrality, a transition in the electricity mix is required.

Due to the long construction times, operating periods and high costs of power plants, investment decisions can have long term impacts on future electricity supply [4]. Governments and society, therefore, have a role in ensuring that the negative externalities of emissions are priced into electricity generation. This is most likely to be achieved via carbon tax and regulation to influence electricity market players such as generation companies (GenCos).

Decisions made in an electricity markets may have unintended consequences due to their complexity. A method to test hypothesis before they are implemented would therefore be useful.

Simulation is often used to increase understanding as well as to reduce risk and reduce uncertainty. Simulation allows practitioners to realise a physical system in a virtual model. In this context, a model is defined as an approximation of a system through the use of mathematical formulas and algorithms. Through simulation, it is possible to test a system where real life experimentation would not be practical due to reasons such as prohibitively high costs, time constraints or risk of detrimental impacts. This has the dual benefit of minimising the risk of real decisions in the physical system, as well as allowing practitioners to test less risk-averse strategies.

Agent-based modelling (ABM) is a class of computational simulation models composed of autonomous, interacting agents and model the dynamics of a system. Due to the numerous and diverse actors involved in electricity markets, ABMs have been utilised in this field to address phenomena such as market power [20].

This paper presents ElecSim, an open-source ABM that simulates GenCos in a wholesale electricity market. ElecSim models each GenCo as an independent agent and electricity demand. An electricity market facilitates trades between the two.

GenCos make bids for each of their power plants. Their bids are based on the generator's short run marginal cost (SRMC) [18], which excludes capital and fixed costs. The electricity market accepts bids in cost order, also known as merit-order dispatch. GenCos invest in power plants based on expected profitability.

ElecSim is designed to provide quantitative advice to policy makers, allowing them to test policy outcomes under different scenarios. They are able to modify a script to realise a scenario of their choice. It can also be used by energy market developers who can test new electricity sources or policy types, enabling the modelling of changing market conditions.

The contribution of this paper is a new open-source framework with example scenarios of varying carbon taxes. We provide curated data, and improve realism via Monte-Carlo sampling. Section ?? is a literature review. Section ?? details the model and assumptions made, and Section ?? provides performance metrics and validation. Section ?? details our results. We conclude the work in Section ??.

4.1.1 Literature Review

Live experimentation of physical processes is often not practical. The costs of real life experimentation can be prohibitively high, and can require significant time in order to fully ascertain the long-term trends. There is also a risk that changes can have detrimental impacts and lead to risk-averse behaviour. These factors are true for electricity markets, where decisions can have long term impacts. Simulation, however, can be used for rapidly prototyping ideas. The simulation is parametrised by real world data and phenomena. Through simulation, the user is able to assess the likelihoods of outcomes under certain scenarios and parameters [?].

Energy models can typically be classified as top-down macro-economic models or bottom-up techno-economic models [2]. Top-down models typically focus on behavioural realism with a focus on macro-economic metrics. They are useful for studying economy-wide responses to policies [12], for example MARKAL-MACRO [8] and LEAP [?]. Bottom-up models represent the energy sector in detail, and are written as mathematical programming problems [9].

It is possible to further categorise bottom-up models into optimisation and simulation models. Optimisation energy models minimise costs or maximise welfare, defined as the material and physical well-being of people [14]. Examples of optimisation models are MARKAL/TIMES [8] and MESSAGE [24].

However, electricity market liberalisation in many western democracies has changed the framework conditions. Centralised, monopolistic, decision making entities have given way to multiple heterogeneous agents acting for their own best interest [17]. Policy options must therefore be used to encourage changes to attain a desired outcome. It is proposed that these complex agents are modelled using ABMs due to their non-deterministic nature.

Traditional centralised optimisation models are not designed to describe a system which is out of equilibrium. Optimisation models assume perfect foresight and risk neutral investments

with no regulatory uncertainty. The core dynamics which emerge from equilibrium remain a black-box. For example, the model assumes a target will be reached, and does not provide information for which this is not the case. Reasons for this could be investment cycles which move the model away from equilibrium [4].

A number of ABM tools have emerged over the years to model electricity markets: SEPIA [13], EMCAS [Conzelmann et al.], NEMSIM [1], AMES [25], GAPEX [5], PowerACE [22], EM-Lab [4] and MACSEM [19]. Table ?? shows that these do not suit the needs of an open source, long-term market model. We will demonstrate that Monte-Carlo sampling of parameters is also required to increase realism.

There have been a number of recent studies using ABMs which focus on electricity markets, however they often utilize ad-hoc tools which are designed for a particular application [23, 11, 15]. ElecSim, however, has been built for re-use and reproducibility. The survey [26] cites that many of these tools do not release source code or parameters, which is a problem that ElecSim seeks to address.

Table ?? contains six columns: tool name, whether the tool is open source or not, whether they model long-term investment in electricity infrastructure, and the markets they model. We determine how the stochasticity of real life is modelled, and determine whether the model is generalisable to different countries.

An open source toolkit is important for reproducibility, transparency and lowering barriers to entry. It enables users to expand the model to their requirements and respective country. The modelling of long-term investment enables scenarios to emerge, and enable users to model investment behaviour. We demonstrate that the use of a Monte-Carlo method improves results.

SEPIA [13] is a discrete event ABM which utilises Q-learning to model the bids made by GenCos. SEPIA models plants as being always on, and does not have an independent system operator (ISO), which in an electricity market, is an independent non-profit organization for coordinating and controlling of regular operations of the electric power system and market [27]. SEPIA does not model a spot market, instead focusing on bilateral contracts. As opposed to this, ElecSim has been designed with a merit-order, spot market in mind. As shown in Table ??, SEPIA does not include a long-term investment mechanism.

EMCAS [Conzelmann et al.] is a closed source ABM. EMCAS investigates the interactions between physical infrastructures and economic behaviour of agents. However, ElecSim focuses on the dynamics of the market, and provides a simplified, transparent model of market operation, whilst maintaining robustness of results.

NEMSIM [10] is an ABM that represents Australia's National Electricity Market (NEM). Participants are able to grow and change over time using learning algorithms. NEMSIM is non-generalisable to other electricity markets, unlike ElecSim.

AMES [25] is an ABM specific to the US Wholesale Power Market Platform and therefore not generalizable for other countries. GAPEX [5] is an ABM framework for modelling and simulating power exchanges. GAPEX utilises an enhanced version of the reinforcement technique Roth-Erev [21] to consider the presence of affine total cost functions. However, neither of these model the long-term dynamics for which ElecSim is designed.

PowerACE [22] is a closed source ABM of electricity markets that integrates short-term daily electricity trading and long-term investment decisions. PowerACE models the spot market, forward market and a carbon market. Similarly to ElecSim, PowerACE initialises GenCos with each of their power plants. However, as can be seen in Table ??, unlike ElecSim, PowerACE does not take into account stochasticity of price risks in electricity markets [17].

EMLab [4] is an open-source ABM toolkit for the electricity market. Like PowerACE, EMLab models an endogenous carbon market, however, they both differ from ElecSim by not taking into account stochasticity in the electricity markets, such as in outages, fuel prices and operating costs. After correspondence with the authors, however, we were unable to run the current version.

MACSEM [19] has been used to probe the effects of market rules and conditions by testing different bidding strategies. MACSEM does not model long term investments or stochastic inputs.

As can be seen from Table ??, none of the tools fill each of the characteristics we have defined. We therefore propose ElecSim to contribute an open source, long-term, stochastic investment model.

4.1.2 Second subsection in the first section

...and some more ...

First subsub section in the second subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

4.1.3 Third subsection in the first section

...and some more ...

First subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it and some more and some more and some more and some more and some more and some more ...

Second subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

4.2 Second section of the third chapter

and here I write more ...

Table 4.1 A badly formatted table

	Species I		Species II	
Dental measurement	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

4.3 The layout of formal tables

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Table 4.2 A nice looking table

Dental measurement	Species I		Species II	
	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
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CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Table 4.3 Even better looking table using booktabs

Dental measurement	Species I		Species II	
	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
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I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Chapter 5

Electricity demand prediction

5.1 First section of the third chapter

And now I begin my third chapter here ...

And now to cite some more people ? ?]

5.1.1 First subsection in the first section

...and some more

5.1.2 Second subsection in the first section

...and some more ...

First subsub section in the second subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

5.1.3 Third subsection in the first section

...and some more ...

First subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it and some more and some more and some more and some more and some more and some more and some more ...

Second subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

Table 5.1 A badly formatted table

	Species I		Species II	
Dental measurement	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

5.2 Second section of the third chapter

and here I write more ...

5.3 The layout of formal tables

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Dental measurement	Species I		Species II	
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CBL	11.88	0.05	13.11	0.04

Table 5.3 Even better looking table using booktabs

Dental measurement	Species I		Species II	
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CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Chapter 6

Carbon optimization

6.1 First section of the third chapter

And now I begin third chapter here ...

And now to cite some more people ? ?]

6.1.1 First subsection in the first section

...and some more

6.1.2 Second subsection in the first section

...and some more ...

First subsub section in the second subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

6.1.3 Third subsection in the first section

...and some more ...

First subsub section in the third subsection

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Second subsub section in the third subsection

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Table 6.1 A badly formatted table

	Species I		Species II	
Dental measurement	mean	SD	mean	SD
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CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

6.2 Second section of the third chapter

and here I write more ...

6.3 The layout of formal tables

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Dental measurement	Species I		Species II	
	mean	SD	mean	SD
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CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Chapter 7

Differential logistic equation models

7.1 First section of the third chapter

And now I begin my third chapter here ...

And now to cite some more people ? ?]

7.1.1 First subsection in the first section

...and some more

7.1.2 Second subsection in the first section

...and some more ...

First subsub section in the second subsection

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7.1.3 Third subsection in the first section

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Second subsub section in the third subsection

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Table 7.1 A badly formatted table

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Dental measurement	mean	SD	mean	SD
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and here I write more ...

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Chapter 8

Conclusion

8.1 First section of the third chapter

And now I begin my third chapter here ...

And now to cite some more people ? ?]

8.1.1 First subsection in the first section

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8.1.2 Second subsection in the first section

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First subsub section in the second subsection

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	Species I		Species II	
Dental measurement	mean	SD	mean	SD
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References

- [1] Batten, D. and Grozev, G. (2006). NEMSIM: Finding Ways to Reduce Greenhouse Gas Emissions Using Multi-Agent Electricity Modelling. *Complex Science for a Complex World*, pages 227–252.
- [2] Böhringer, C. (1998). The synthesis of bottom-up and top-down in energy policy modeling. *Energy Economics*, 20(3):233–248.
- [3] BP (2018). BP Statistical Review of World Energy. pages 1–56.
- [4] Chappin, E. J., de Vries, L. J., Richstein, J. C., Bhagwat, P., Iychettira, K., and Khan, S. (2017). Simulating climate and energy policy with agent-based modelling: The Energy Modelling Laboratory (EMLab). *Environmental Modelling and Software*, 96:421–431.
- [5] Cincotti, S., Gallo, G., and Berkeley, L. (2013). The Genoa Artificial Power-Exchange The Genoa artificial power-exchange. (January).
- [Conzelmann et al.] Conzelmann, G., Boyd, G., Koritarov, V., and Veselka, T. Multi-agent power market simulation using EMCAS. *IEEE Power Engineering Society General Meeting, 2005*, pages 917–922.
- [7] Cook, J., Nuccitelli, D., Green, S. A., Richardson, M., Winkler, B., Painting, R., Way, R., Jacobs, P., and Skuce, A. (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ. Res. Lett*, 8:24024–7.
- [8] Fishbone, L. G. and Abilock, H. (1981). Markal, a linear programming model for energy systems analysis: Technical description of the bnl version. *International Journal of Energy Research*, 5(4):353–375.
- [9] Gargiulo, M. and Brian, O. (2013). Long-term energy models : Principles , characteristics , focus ,. *WIREs Energy and Environment*, 2(April).
- [10] Grozev, G., Batten, D., Anderson, M., Lewis, G., Mo, J., and Katzfey, J. (2005). NEMSIM: agent-based simulator for Australia’s national electricity market. *SimTecT 2005 Conference Proceedings, Sydney, Australia*.
- [11] Hadar, A. and Hartmann, B. (2019). Simulation of cross-border capacity allocation. *1st IEEE Student Conference on Electric Machines and Systems, SCEMS 2018*, pages 1–6.
- [12] Hall, L. M. H. and Buckley, A. R. (2016). A review of energy systems models in the UK : Prevalent usage and categorisation. *Applied Energy*, 169:607–628.
- [13] Harp, B. S. A., Wollenberg, B. F., and Samad, T. (2000). SEPIA: A Simulator for Electric Power Industry Agents. (August):53–69.
- [14] Keles, D., Jochem, P., Mckenna, R., Ruppert, M., and Fichtner, W. (2017). Meeting the Modeling Needs of Future Energy Systems. *Energy Technology*, pages 1007–1025.
- [15] Künzel, T., Gmbh, F., Kg, C., Klumpp, F., Gmbh, F., and Kg, C. (2018). Bidding Strategies for Flexible and Inflexible Generation in a Power Market Simulation Model. pages 532–537.

- [16] Masson-Delmotte, V., Zhai, P., Pörtner, H., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., and Waterfield, T. (2018). *IPCC Special Report 1.5 - Summary for Policymakers*. IPCC.
- [17] Möst, D. and Keles, D. (2010). A survey of stochastic modelling approaches for liberalised electricity markets. *European Journal of Operational Research*, 207(2):543–556.
- [18] Perloff, J. M. (2012). *Microeconomics Sixth Edition*.
- [19] Praça, I., Ramos, C., Vale, Z., and Ascem, M. (2003). MASCEM : A Multiagent Markets.
- [20] Ringler, P., Keles, D., and Fichtner, W. (2016). Agent-based modelling and simulation of smart electricity grids and markets - A literature review. *Renewable and Sustainable Energy Reviews*, 57(September):205–215.
- [21] Roth AE and Erev I (1995). Learning in extensive-form games: Experimental data and simple dynamic models in the intermediate term. *Games and economic behavior*, 8(1):164–212.
- [22] Rothengatter, W. (2007). Assessment of the impact of renewable electricity generation on the German electricity sector An agent-based simulation approach.
- [23] Saxena, K. and Abhyankar, A. R. (2019). Agent based bilateral transactive market for emerging distribution system considering imbalances. *Sustainable Energy, Grids and Networks*, 18:100203.
- [24] Schrattenholzer, L. (1981). The energy supply model MESSAGE. *European Journal of Operational Research*, (December).
- [25] Sun, J. and Tesfatsion, L. (2007). Dynamic Testing of Wholesale Power Market Designs : An Open-Source Agent-Based Framework. *Computational Economics*, 30(3):291–327.
- [26] Weidlich, A. and Veit, D. (2008). A critical survey of agent-based wholesale electricity market models. *Energy Economics*, 30(4):1728–1759.
- [27] Zhou, Z., Chan, W. K., and Chow, J. H. (2007). Agent-based simulation of electricity markets: A survey of tools. *Artificial Intelligence Review*, 28(4):305–342.

Appendix A

Number 1

Windows OS

TeXLive package - full version

1. Download the TeXLive ISO (2.2GB) from
<https://www.tug.org/texlive/>
2. Download WinCDEmu (if you don't have a virtual drive) from
<http://wincdemu.sysprogs.org/download/>
3. To install Windows CD Emulator follow the instructions at
<http://wincdemu.sysprogs.org/tutorials/install/>
4. Right click the iso and mount it using the WinCDEmu as shown in
<http://wincdemu.sysprogs.org/tutorials/mount/>
5. Open your virtual drive and run setup.pl

or

Basic MikTeX - T_EX distribution

1. Download Basic-MiK_TE_X(32bit or 64bit) from
<http://miktex.org/download>
2. Run the installer
3. To add a new package go to Start » All Programs » MikTeX » Maintenance (Admin) and choose Package Manager
4. Select or search for packages to install

TexStudio - T_EX editor

1. Download TexStudio from
<http://texstudio.sourceforge.net/#downloads>
2. Run the installer

Mac OS X

MacTeX - T_EX distribution

1. Download the file from
<https://www.tug.org/mactex/>
2. Extract and double click to run the installer. It does the entire configuration, sit back and relax.

TexStudio - T_EX editor

1. Download TexStudio from
<http://texstudio.sourceforge.net/#downloads>
2. Extract and Start

Unix/Linux

TeXLive - T_EX distribution

Getting the distribution:

1. TeXLive can be downloaded from
<http://www.tug.org/texlive/acquire-netinstall.html>.
2. TeXLive is provided by most operating system you can use (rpm, apt-get or yum) to get TeXLive distributions

Installation

1. Mount the ISO file in the mnt directory

```
mount -t iso9660 -o ro,loop,noauto /your/texlive####.iso /mnt
```

2. Install wget on your OS (use rpm, apt-get or yum install)
3. Run the installer script install-tl.

```
cd /your/download/directory
./install-tl
```

4. Enter command ‘i’ for installation

5. Post-Installation configuration:

<http://www.tug.org/texlive/doc/texlive-en/texlive-en.html#x1-320003.4.1>

6. Set the path for the directory of TexLive binaries in your .bashrc file

For 32bit OS

For Bourne-compatible shells such as bash, and using Intel x86 GNU/Linux and a default directory setup as an example, the file to edit might be

```
edit ~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/i386-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

For 64bit OS

```
edit ~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/x86_64-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

Fedora/RedHat/CentOS:

```
sudo yum install texlive
sudo yum install psutils
```

SUSE:

```
sudo zypper install texlive
```

Debian/Ubuntu:

```
sudo apt-get install texlive texlive-latex-extra
sudo apt-get install psutils
```


Appendix B

Number 2

\LaTeX .cls files can be accessed system-wide when they are placed in the $\langle\text{texmf}\rangle/\text{tex}/\text{latex}$ directory, where $\langle\text{texmf}\rangle$ is the root directory of the user's \TeX installation. On systems that have a local texmf tree ($\langle\text{texmflocal}\rangle$), which may be named “ texmf-local ” or “ localtexmf ”, it may be advisable to install packages in $\langle\text{texmflocal}\rangle$, rather than $\langle\text{texmf}\rangle$ as the contents of the former, unlike that of the latter, are preserved after the \LaTeX system is reinstalled and/or upgraded.

It is recommended that the user create a subdirectory $\langle\text{texmf}\rangle/\text{tex}/\text{latex}/\text{CUED}$ for all CUED related \LaTeX class and package files. On some \LaTeX systems, the directory look-up tables will need to be refreshed after making additions or deletions to the system files. For \TeX Live systems this is accomplished via executing “ texhash ” as root. $\text{MIK}\text{\TeX}$ users can run “ initexmf -u ” to accomplish the same thing.

Users not willing or able to install the files system-wide can install them in their personal directories, but will then have to provide the path (full or relative) in addition to the filename when referring to them in \LaTeX .

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