Carbon Neutral Cardiff by 2030

Cardiff University | CM3203 | 40 Credits

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Abstract

This project focuses on modelling Cardiff's education sector to examine its impact on the environment, through identifying areas that required policy action and creating simulations to run experiments on these problem areas. The simulations were used to test and evaluate policy action and measure how effect these actions were in aiding in Cardiff's journey in reaching their goal of carbon neutrality by 2030.

To achieve this, the System Dynamics methodology was followed, which involves the creation of qualified and quantified models that model factors and their causal relationships in a system to evaluate its impact on the environment. From these models' simulations were created based off trend data to allow for the previously implemented causal relationships in the models prior to be simulated and for the policy action to be tested.

The overall aim of this project was to model the problem space and identify and experiment policy action within identified out of controlled systems in the models created. To prove what areas of the education sector, need policy implementation to tackle the continuing environmental impact the sector has. Additionally, through the experiments I aimed to produce evidential backing for the potential effectiveness of recommended policies and suggestions of areas to consider focusing on for Cardiff Council.

On completion of the project all aims, and objectives were met. Several qualified models were created to guide the creation of several quantified models. Policies were successfully identified, tested, and recommended through experiments ran. Overall, deeming the project a success.

Acknowledgments

I would like to thank my supervisor, Catherine Teehan, for her continued support and guidance throughout this project and my university career as whole. Without her my university experience would not have been half of the experience that it was.

I would also like to thank my technical supervisor, Annelies Gibson, for her continued support during this project through answering all the queries I had and being available whenever I needed reassurance and support in my decisions.

Furthermore, I would like to thank Lee Patterson and Cardiff Council for their support during the early stages of this project through providing me with insight of the current workings of the education sector, providing me with a great footing and direction for the overall project.

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Acronyms

CLD
: Causal Loop Diagram, iv, x, 2, 18, 20, 22, 25, 29, 31, 35, 37, 39, 124

CLDs
: Causal Loop Diagrams, viii, 5, 6, 11, 12, 18, 28, 33, 37, 72, 75

EU
: European Union, 1

IPCC
: Intergovenmental Panel for Climate Change, 1

MPG
: Miles Per Gallon, 50, 83, 85, 94, 111, 117, 121

MPH
: Miles Per Hour, 50, 68, 111

SD
: System Dynamics, vii, 2, 5, 8, 9, 10, 11, 20, 39, 73, 75

UK
: United Kingdom, 1

WHO
: World Health Organisation, 4

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1 Introduction

Our planet is facing a climate emergency which requires action now. Policies are being put in place to ensure global warming is limited to 1.5 degrees Celsius – a threshold the Intergovernmental Panel for Climate Change (IPCC) suggests is safe. These policies are in place to meet the essential target of carbon neutrality by mid-21st century. This target is also laid down in the Paris agreement signed by 195 countries, including the European Union (EU) (European Parliment, 2019). Many countries and large organisations have set themselves an additional goal of a CO2 emissions reduction of at least 50% by 2030, compared to 1990. For the United Kingdom (UK) this goal is 68% (Climate change: UK sets *new 2030 carbon emissions target : CityAM*, no date). Due to the increased pressure from our government to meet this goal many cities have implemented their own strategies to do their part in reducing the UK's contribution to climate change.

Cities are one of the largest contributors to global warming, consuming 78% of the worlds energy and producing more than 60% of greenhouse gas emissions. Despite only covering 2% of the Earth's surface. Making them an ideal place to start when tackling a countries impact on the environment (Nations, 2020). It would come to no surprise to many the impact cities have, but how to address this problem is the true issue we face currently. Cities are complex with multiple moving parts, all of which contribute to their environmental impact. It would be impossible to tackle this issue in one chunk, we need to break down the components of a city and evaluate their contribution to the figures mentioned in above. Even when we evaluate these individual components, there are so many contributing variables to consider. Which is where systems modelling comes into play, to aid in mapping the problem space and finding the trends which will indicate more specific areas that require policy action to achieve our goal of carbon neutrality by 2030.

1.1 The Scope

The scope has been determined by the request of Cardiff's Child Friendly City team, who wanted me to focus on the education sector and its environmental impact for the purpose of potential alignment the results could have with their strategy (see Section 2.2.4 for more details on the strategy. *"The UK schools' estate is responsible for* 10.4MtCO2 (million tonnes of carbon dioxide) from direct and indirect sources per year. These emissions represent less than two per cent of UK carbon emissions, but almost 15 per cent of carbon emissions *attributable to the public sector."* (SDC, 2008). Less than 2% of carbon emissions sounds minimal but there is a greater impact the sector has then just the emissions it emits. What pupils learn through education shapes them and how they live. Which is why I personally see the importance in teaching pupils as early as possible about being eco-conscious, making them aware of their impact and what they can do to reduce it. "Within the next 10 years, the *higher education sector in this country will be recognised as a major contributor to society's* efforts to achieve sustainability – through the skills and knowledge that its graduates learn and put i*nto practice, and through its own strategies and operations."* – this quote sums up nicely my view (Fawcett, 2005). Additionally, although indirect emissions were included in those statistics above there are still many factos that are caused by the education sector that could impact Cardiff's environmental impact that are too complex to measure/ have not been considered. Making this a perfect place to implement system modelling, as it allows full evaluation of a system to find the factors contributing to Cardiff's environmental impact, which is why this will be the scope of the project.

1.2 Intended Audience

Once this project is completed the main beneficiaries would primarily be Cardiff Council and the specific individuals involved with climate related topics. With the best of my ability, I will make the models through Welsh specific data which will allow for further accuracy in the trend data obtained and therefore increase the audience that potentially would be interested in the outcomes of this project. Although, due to the universal aspect of environmental policies being investigated by councils across the country and the education sector being a specifically important area to focus on, I do foresee this project appealing to audiences from all councils, depending on how specific the models are to Cardiff.

1.3 Main Assumptions

It is important to outline all assumptions made during the creation of both causal loop diagrams (CLD) and stock and flow diagrams which are provided in each model section where each model has its own assumptions detailed for further clarification. The assumptions detailed below are at a high level and reflect the assumptions relevant to the project as a whole.

It is assumed that Cardiff Council has the need, infrastructure, and necessary resources to implement further environmental policy action into the education sector, within reasonable constraints.

Furthermore, any data and information provided from either Cardiff Council or partners, is assumed to be correct and true in the terms of the project. Any data obtained will be pre-covid due to the impact of changing circumstances on the usual education activities. This is to ensure that the models reflect the typical situation and associated policy actions remain relevant beyond the pandemic. Finally, any data obtained through research and not Cardiff Council, is provided by a reputable source and backed up by several additional sources.

1.4 The Aim & Objectives

The aim of this project will be to use System Dynamics (SD) to model the problem space with the aid of the One Planet Cardiff and Child Friendly City strategy principles to support the identification and testing of policy action (see Section 2.3.4 for more details). I will be creating both qualitative causality models and quantitative simulation models that identify and test potential policy solutions to the problem raised in the introduction paragraph. This project is highly complex because of the continued developments being made into improving our environmental impact and the numerous factors that are involved. Which is why it was important to outline the main aims and objects that when completed allow me to evaluate the success of my project (see Section 6.2).

Furthermore, I intend to feedback to Cardiff Council and the Child Friendly City team on the policy actions I identify as a result of simulation experimentation and provide them with trend data that shows evidence of the potential success or failure of these policy actions should they be implemented as part of Cardiff's carbon neutrality goal.

1.4.1 Objectives

The following objectives have been identified as necessary to the completion of the project and will be used as evaluation to determine the success/failure of the project. In cases where objectives have not been met, full justification will be provided.

1. Gather research on previous environmental policies that have been implemented within Cardiff and similar locations.
    - Review other city strategies to gain an understanding of common policies.
2. Gather details on the context area through independent and collaborative research with Cardiff Council.
3. Find models around a similar problem space to aid in identifying common areas that policies are required.
4. Use my research to map the system to display all constituent components and their interactions.
    - Ensuring relationships are fully supported and back up by evidence.
5. Identify policies through examination of my qualitative model and the loops in the model.
6. Use my qualitative model to perform a quantitative analysis through the creation of a stock and flow diagram(s).
    - Only partial quantitative analysis due to the time limitations of the project.
    - Analysis will focus on a specific area of the chosen context which will be selected after examination of the qualitative model.
7. Design and run experiments using quantitative model(s) to test the identified and existing policy action to gather evidence of their effect on the carbon neutral goal.
8. Review and discuss the results of the simulation experimentation with Cardiff Council, to evaluate potential future continuation and adaption of identified successful policy action.

2 Background

2.1 Wider Context

"Cardiff today is a three-planet city. If everyone in the world consumed natural resources and generated carbon dioxide at the rate we do in Cardiff, we would need three planets to *support us."* (Council, 2020). Cardiff as a city is not the worst in the world for environmental damage but it does have long way to go before achieving Carbon Neutrality and one planet status. There is a real conscious effort being put in by the government and councils to improve Cardiff's impact, as shown through the One Planet Cardiff strategy and Cardiff's following of the Child Friendly City initiative (see section 2.3.4). Progress is being made in reducing individuals transport, increasing clean energy production, and recycling more waste. In areas such as recycling Cardiff is excelling in, "Latest figures show that 60.03% of all of the waste collected in the city of Cardiff is recycled, compared to 38.5% in Manchester or

33% in London." (How environmentally friendly the city of Cardiff really is right now - Wales Online, 2020).

The progress made has led to the air quality in Cardiff to improve over the years to the point that the levels of air pollution have been recorded to be within World Health Organisation's (WHO) recommended target goal of 10 µg/m³ PM2.5 pollutants. However, during the months of January to June in 2019, pollution levels increased moving Cardiff into the 'Good' category (Cardiff Air Quality Index (AQI) and United Kingdom Air Pollution | AirVisual, 2019). On the surface this may not sound troubling but individuals who live in Cardiff have a 7/8-month lower life expectancy compared to those who live in other parts of Wales. With data from Cardiff and Vale University Health Board showing the number of deaths due to long-term air pollution estimated to be in the range of 178-277 deaths per year (How environmentally friendly the city of Cardiff really is right now - Wales Online, 2020). These figures show the need for more abrupt action to be taken and they also indicate there are areas in the system of Cardiff that are contributing to this air pollutant increase.

2.2 Background Research

2.2.1 Systems Thinking

The nature of systems modelling provides a means of understanding and communicating the complexity of a problem situation by viewing it as a system with multiple areas of influence, causal factors. My interest in Systems Thinking was sparked from my studies on Dr Catherine Teehan's module "Systems Modelling" (Teehan, 2018). Within this module we explored the capabilities of systems thinking to address a problem compared to the more common approach of linear thinking.

Systems Thinking is a non-linear approach to investigate and fully understand a problem situation, it allows one to explore the entirety of the problem space and uncover the cause of the problem instead of focussing on surface-level behaviours, or symptoms, as with linear thinking (Tip, 2018). It attempts to balance holistic and reductionist thinking, which in practice allows you to delve deeper to ask better questions to understand how different systems interact so you can design more impactful solutions (Elle Hempen, 2017).

Climate policies are one of the most complex policy types to design and implement because of the integrated cause and effect variables that must be considered. Therefore, when this challenge arose, a Systems Thinking approach was considered most appropriate because of the ability to understand and communicate complex problem situations. A full investigation into the problem situation using Systems Thinking methodologies provides a fuller picture which in turn enables a deeper understanding of policy actions that may not have been discovered before.

2.2.2 System Dynamics

Selecting the appropriate methodology for the project was critical in ensuring the success of the policy actions created and overall, the evaluation of the problem space. Right from the beginning, with research and guidance from my supervisor, I settled on using System

Dynamics (SD) because of its ability to describe relationships among variables in complex real-world systems (Maryani, Wignjosoebroto and Partiwi, 2015).

"System Dynamics is a computer-aided approach for strategy and policy design. It uses simulation modelling based on feedback systems theory and is an analytical approach that complements systems thinking" (Study of System Dynamics | System Dynamics Society, 2021). From the definition is outlines policy design as a key product obtained from following this modelling style. Further clarifying its suitability for this project. Additionally, SD ignores the fine details of a system producing abstract simulation models, which may sound like a negative. However, these models are ideal for use for long-term, strategic modelling and simulation and this is exactly what this project needs because it is looking at identifying policy action and its long-term effects on Cardiff's carbon neutrality goal (System Dynamics — AnyLogic Simulation Software, no date).

SD modelling is split up into two main parts, the creation of causal loop diagrams (CLDs) and the creation of stock and flow diagrams (simulations). CLDs are used to visualise the relationships that govern complex systems, the cause-and-effect variables that impact the workings of a system and, for this topic specifically, the indication of variables of a system that act as causal factors in producing carbon emissions (Lin, Palopoli and Dadwal, 2020). Stock and flow diagrams quantitatively build upon the qualitative relationships mapped out in CLDs, allowing you to see where appropriate policy action is needed and the impact of the identified policy action (Lin, Palopoli and Dadwal, 2020).

CLDs, as mentioned above, are used for visualising the relationships between the components of a system. Allowing you to understand the different scale and scope of the issue at hand. CLDs do not require extensive quantitative training in engineering or mathematics which is a major advantage of them. They are composed of variables and directional links that represent causal interactions.

The links themselves have two polarities: positive (same direction) and negative (opposite direction). The positive polarity between two variables means when one variable goes up the other variable also goes up too. The negative polarity between two variables has an inverse relationship, as one goes up the other will go down or vice versa. An example of these polarities is shown in figure 1.

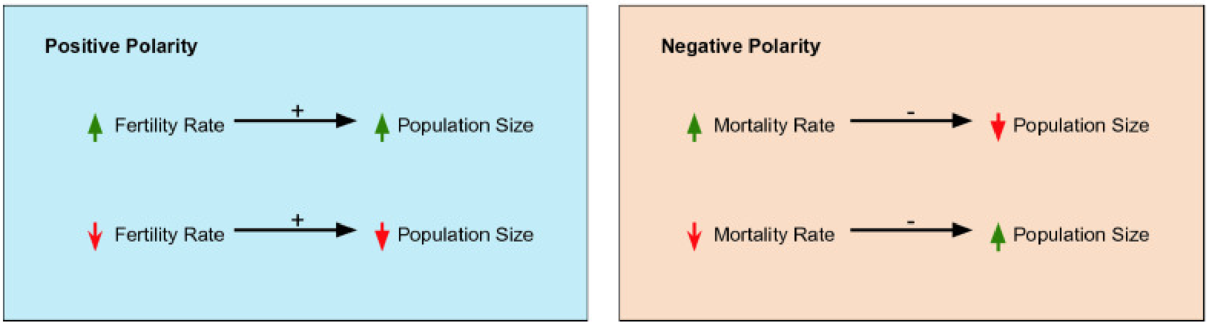

Figure 1 - Positive versus negative polarities

Another important component of CLDs is feedback loops, which have two categories: reinforcing (positive) and balancing (negative). Reinforcing loops, example shown in figure 2, are composed of all positive polarities in the same direction and/ or an even number of negative polarities in the opposite direction (Kim, 1992). Balancing loops, example shown in figure 3, are composed of an odd number of negative polarities. Feedback loops are an extremely important aspect of CLDs, they show the cause and effects of multiple variables in a system and help indicate which part of a system requires policy intervention.

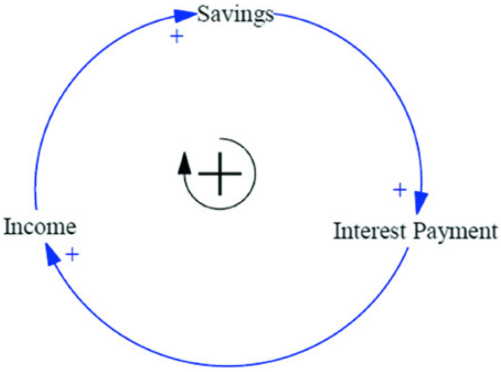

Figure 2 - Example of a reinforcing feedback loop

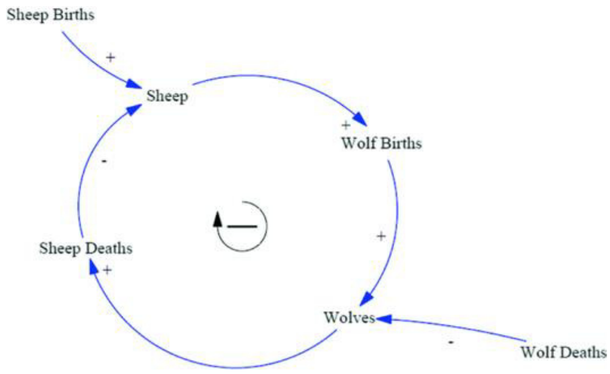

Figure 3 - Example of a balancing feedback loop

Policy action is created when reinforcing loops are discovered, these loops require balancing, which is why policy action is put in place to make the loops negative. Balancing processes attempt to bring things to a desired state and keep them there. This means that the goal of the system is to have a system 'in balance' where it is either moving to an equilibrium or in oscillation.

A map of causal influences and feedback loops for certain projects is the end of the process (Study of System Dynamics | System Dynamics Society, 2021). However, for this project, I want to identify and experiment policy action which requires an additional step, the creation of stock and flow diagrams. Stock and flow diagrams aim to quantify the qualified CLDs using stock and flow variables and allow you to simulate the real-world system you modelled with CLDs. "A stock variable is measured at one specific time and represents a quantity existing at that point in time (say, December 31, 2004), which may have accumulated in the past. A flow variable is measured over an interval of time. Therefore, a flow would be measured per unit of time (say a year)." (What is Stock and Flow Diagram?, 2021). Once these diagrams are made you then you can simulate them. Simulations will show the necessary trends that will guide the understanding of the system and find the required policy action. Simulations can also be used to analyse the impacts policy action will have on a system if implemented. Providing evidential support that is useful in convincing necessary parties to take up the policy action.

2.2.3 Carbon Emissions

Before the modelling began it was important to understand why the focus of this project is on CO2 emissions. CO2 is the biggest contributor to global temperature increase. CO2 sits in our atmosphere absorbing heat radiating off the earth surface. As our CO2 levels increase so does the levels of heat being absorbed and trapped into our atmosphere, leading to a reduction in heat being let into space. This absorption of heat in our atmosphere is what causes global temperatures to increase and in some cases, heat that isn't absorbed is reflected back to the Earth's surface, further increasing temperatures (Bird, 2005). Another important characteristic to note about CO2 is its ability to linger around. CO2 remains in our atmosphere for over 100 years with up to 80% dissolving into the ocean over a period of 20-200 years, causing a further impact on our environment in previously unknown ways. Proving further how important it is to get our CO2 emissions in check now and not later.

Furthermore, another important aspect of CO2 to note, especially when modelling its impact, is the different classification types of CO2 emissions. An understanding of these different types is crucial in ensuring the models created in this project contain factors that cover all the different types, to provide a detailed and accurate representation of the problem space. For the purpose of this project, I will be focusing on three main types of CO2 emissions, shown in figure 4 (SDC, 2008).

Figure 4 - Types of emissions within a school

Direct emission refers to on-site emissions that come from sources that are controlled or owned by the defined entity, in this case school buildings and equipment (Ecochain, 2021). Transport emissions is self-explanatory, it refers to any emission emitting through commuting to school and vehicles associated with a school. Embodied emissions refers to the emission released from the creation and overall supply chain of a product or service (Circularecology.com, 2021). For a school this could include food procurement, materials used for lessons and any item used within the school grounds. During the creation of the causal models, stock and flow diagrams and simulations, I will ensure to include factors that encompass each of these types to ensure all major carbon emitters are taken in consideration. In doing so the models will provide the foundations for accurate policy action to be identified and simulated, with the confidence that all hidden areas that contribute to the sectors carbon emissions have been considered.

2.2.4 One Planet Cardiff & Child Friendly Cities

To manage the scope of this project I decided to look for current strategies that were in place both within Wales and further afield to aid in the decisions made in terms of what parts of

Cardiff were to be modelled. Contacts from Cardiff Council directed me to two strategies/ initiatives, they were: One Planet Cardiff and Child Friendly cities.

The One Planet Cardiff strategy was created in response to the climate emergency we are facing (Council, 2020). The drafted strategy *"proposes a wide range of ambitious actions* that will begin to form the basis of a delivery plan to achieve Carbon Neutrality. It aims to do *this in a way that supports new green economies and greater social wellbeing in the city."* (Council, 2020). Within the strategy there are 7 key themes: energy, waste, built environment, food, green infrastructure & biodiversity, water and transport. This project aims to use these themes to manage its scope through modelling each one in the context of the chosen sector, education. The strategy covers all aspects of a city and for each theme it contains objectives for what Cardiff's government plans on achieving through the strategy and the previous work that has been completed in these areas. A larger part of the strategy revolves around getting individuals on the same page with how to tackle the climate emergency. For this project it makes aligning with this strategy majorly beneficial because the results of this project will follow the principles many individuals also follow. Meaning this strategy does not only provide the project with a direction to go in but also it adds validity to the models.

Policy action is outlined in parts of the strategy, however, here is not a set list of methods of how the plan intends to tackle the key theme areas and ultimately achieve the objective of carbon neutrality. The lack of definitive policy action highlighted the need for modelling to take place and I saw this gap as the perfect opportunity to involve SD. Thankfully, the presence of such a strategy shows there is a desire for change in Cardiff and a determination to reach the 2030 carbon neutrality goal. A determination that demonstrates the need for this project.

The Child Friendly city initiative *"was launched in 1996 by UNICEF and UN-*Habitat to act on the resolution passed during the second United Nations Conference on Human Settlements (Habitat II) to make cities liveable places for all. The UN Conference declared that the wellbeing of children is the ultimate indicator of a healthy habitat, a democratic society and *of good governance."* (UNICEF, 2021). Cardiff is the first city in Wales to participate in the initiative and currently has several projects underway to achieve the goals of the initiative (Child Friendly Cardiff, 2021). The initiatives main focus is on the welfare of children within cities, through ensuring quality social care, future infrastructure and general resources available for children to have a great life. However, the initial attraction to this initiative was its objective in ensuring children *"Live* in a safe secure and clean environment with access to *green spaces"* which is making reference to the surrounding environment of a city (UNICEF, 2021). A city's environment is impacted by the amount of carbon emissions it emits due to the impact carbon emissions have on global warming. This links the initiative with the need to tackle the climate emergency and reach carbon neutrality because without tackling global warming, a child friendly city won't be possible.

Largely, that is the reason for the education sector being chosen as the problem space for this project because there are several different strategies and initiatives already in play trying to achieve carbon neutrality, directly or indirectly for this area. Focusing on the education sector allowed the project to have a refined scope, compared to the entirety of Cardiff, and the project used both the mentioned strategy and initiative to guide the modelling process.

2.2.5 Current Policy Action

Being aware of current policy action implemented in the education sector or within Cardiff that has an impact on the sectors carbon emissions was essential to guide the SD process. Through research I found it tricky to find set blanket policies that were being followed by all schools within Cardiff. Instead, I came across several programmes and initiatives that aimed to promote eco-friendly living to school pupils with aims to teach and educate students on how to reduce their impact on the environment and in turn improve the school's impact overall.

The first programme found was called Eco-schools. The programme *"covers n*ine interlinked topics to help schools develop a more rounded approach to Education for Sustainable *Development and Global Citizenship"* (The Eco-Schools Wales Topics | Keep Wales Tidy, 2021). It has similar topics to the One Planet Cardiff Strategy, they are: Litter, Waste minimisation, Water, Transport, School Grounds, Global Citizenship, Energy, Biodiversity, Healthy Living and Transport. The programme offers plans and learning resources for schools to use and give to their students. On the site there is a tracker that shows all the schools using the programme and the list is extensive. This led to the assumption that these resources were being actively used within the education environment. However, the programme itself does not directly offer policies for schools to follow, but rather aims to educate the youth, so they respect and acknowledge their impact in the hopes that this will reduce the impact the education sector has overall.

Another programme found was called Zero Waste Schools Wales which "was Founded by Circular Economy Wales, Zero Waste Schools is a new organisation and project that allows young people in Wales to design and shape the economy they will inherit. The project, to be piloted in Pembrokeshire and Cardiff, gives school pupils control of school recycling systems, choices over where to sell material and what school activities should be invested in with the profit.*"*(Zero Waste Schools, 2019). This particular programme has similar aims to teach students how to improve their carbon footprint but with an active element of getting students to recycle in their provided containers and get feedback about what their recycling was turned into. This programme reinforces the lessons children and young people are being taught.

Both programmes have an indirect impact on the education sector's environmental impact through the reduction in waste because students are more conscious of their actions. Despite not being a specific policy action it is useful to be aware of when modelling, as these programmes will provide an impacting variable that needs to be considered.

2.2.6 Related Research

When modelling a problem space, it is important and beneficial to be aware of similar research that has been conducted either in the same space or similar areas. For this project there are multiple areas that can relate to previous work out there. Thus, for the final part of my background research and literature review, I will discuss research and models relating to my problem space and topic.

i. **System dynamics modelling for urban energy consumption and CO2 emissions: A case study of Beijing, China** (Feng, Chen and Zhang, 2013)

   "This study explores the intrinsic relationship between energy demand and economic and social environment, which helps forecast municipal energy demand and carbon emissions in a fast-growing urban region." (Feng, Chen and Zhang, 2013). The study hopes "to improve our understanding on the inherent inter-linkages and dynamic evolutionary structures impacting future urban energy system development and identify the significant contributors to urban energy demand and carbon emissions." The study has several aspects that align with this project through its similar problem space of an urban city and its mapping of factors and their causal relationships that contribute to energy consumption and CO2 emissions. The reports objectives outlined are different to those of this project, but the process of getting to the objectives follows similar procedures. Making this report an ideal learning resource for the modelling process in this project. On the other hand, there are several aspects of the project that differ. Their chosen case study covers an area a lot vaster than the one in this project, being the whole of Beijing rather than a sector within the city. Additionally, another clear difference between this report and this project, is the objectives. The modelling completed is for the understanding of Beijing's' energy consumption and CO2 emissions, where this project instead intends to measure causal trends between factors with the objective to identify potential policy action and then test the effectiveness of said policy action.

ii. **Simulation with system dynamics and fuzzy reasoning of a tax policy to reduce CO2 emission in the residential sector** (Kunsch and Springael, 2008)

   The model presented in this paper aimed *"not to develop a new economy*-environment macromodel but to take advantage of the properties of the SD technique to illustrate *the development of a behavioural model taking into account data uncertainties."* (Kunsch and Springael, 2008). What makes this an interesting study to review for this project is the aspect of modelling a policy and simulating its impact on CO2 emissions released by a specific sector. On the surface this relates largely to this project because of the similar scope size and objective of modelling a policies impact. However, this project intends to model the problem space prior to deciding on policy action and use the models created to find where policy action needs to occur. After that is achieved, the policies are simulated and their impacted evaluated, which is the only linking aspect the study and this project has. It was useful reading about their process of calculating carbon emissions and what variables they used in their stock and flow diagrams. Evaluating their complex components was useful during this project when expanding the models, to move away from basic causal relationships, and advance to the truly detailed and potentially previously unconsidered impacting variables.

From reviewing related research, a clearer picture was formulated for what was currently out there in relation to the topic of this project. Useful resources were discovered from these studies but during this research what was also discovered was the gap within the policy creation area of climate action in the education sector. Majority of projects out there that mentioned education, when modelling, all discussed it in terms of its positive impact on teaching students how to be more environmental conscious. There is yet to be a study modelling the running of the education sector and its impact. Which is what this project aims to address.

3 Approach Selection

Once research was completed the next stage of the project was to decide on the software to use for the creation of the CLDs and stock and flow diagrams. There were several potential options available to choose from, which led to the need for the completion of a software analysis on the most viable options to make comparison clearer (see Table 1).

System Dynamics Software	Functions Language	Advantages	Disadvantages
Vensim	C, C++	Supports data import and export, ease of use, pre-added sliders when simulating and overall good visuals.	Bugs apparent on Mac version, not easily shared between different users.
AnyLogic	Java	Brilliant visual features for simulations compared to other software's and supports other types of modelling allowing for further progression of models in the future. The cloud section allows for easy comparisons of multiple experiments at once.	Complex interface making it slower to pick up and work with. Due to the modelling aspect being java based variable names have certain restraints and errors are more prone, overall making it less user friendly out of the software.
Insight Maker	JavaScript	Fully-browser based making online collaboration easy. Simple to pick up and use.	Very steep learning curve required to pick up all the features and visual effects necessary for this project.

Table 1 - SD software comparison analysis

Using the table of analysis alongside advice from my supervisor and technical supervisor it was decided to use a combination of both Vensim and AnyLogic.

For the CLDs (see Section 4) it was decided to use Vensim due to its ease of use and quick pick-up nature. During the “Systems Modelling” module I had a chance to work with

Vensim, giving me a kick start due to my familiarity with some features already. Making the beginning of the project far smoother then if the software used was brand new to me.

After several weeks working with Vensim through creating the CLDs it was evident the software visually didn't offer much variation from its base line. Vensim is a very useful tool in terms of completing CLDs but can be 'clunky' when developing stock and flow diagrams with multiple data visualisations. This led to the decision to move over to AnyLogic for the creation of the stock and flow diagrams. Once the stock and flow diagrams were completed, it was easy to move into simulating due to the handy features on offer with AnyLogic. Each simulation can be ran through the cloud feature, which allowed for easier comparisons amongst multiple experiments (see Section 6.1).

4 Design – Causal Loop Diagrams (CLDs)

The design aspect of this project is the creation of the CLDs. The design of these diagrams then inspires and directs the creation of the stock and flow diagrams and associated simulations. As discussed in Section 2.3.4, it was decided to break down the models into 7 key themes, energy, waste, built environment, food, green infrastructure & biodiversity, water, and transport. However, during the design of the CLDs it became apparent that there was large cross over in several of these themes leading to the combination of several of the themes. In each section I will elaborate further the reasoning for combining certain themes and the benefits it brings to the project and the overall outcome.

4.1 Brainstorming/ First Drafts

Before the models were started in Vensim, a short amount of time was spent making first drafts of the CLDs for each theme. Figures 5-9 show these drafts.

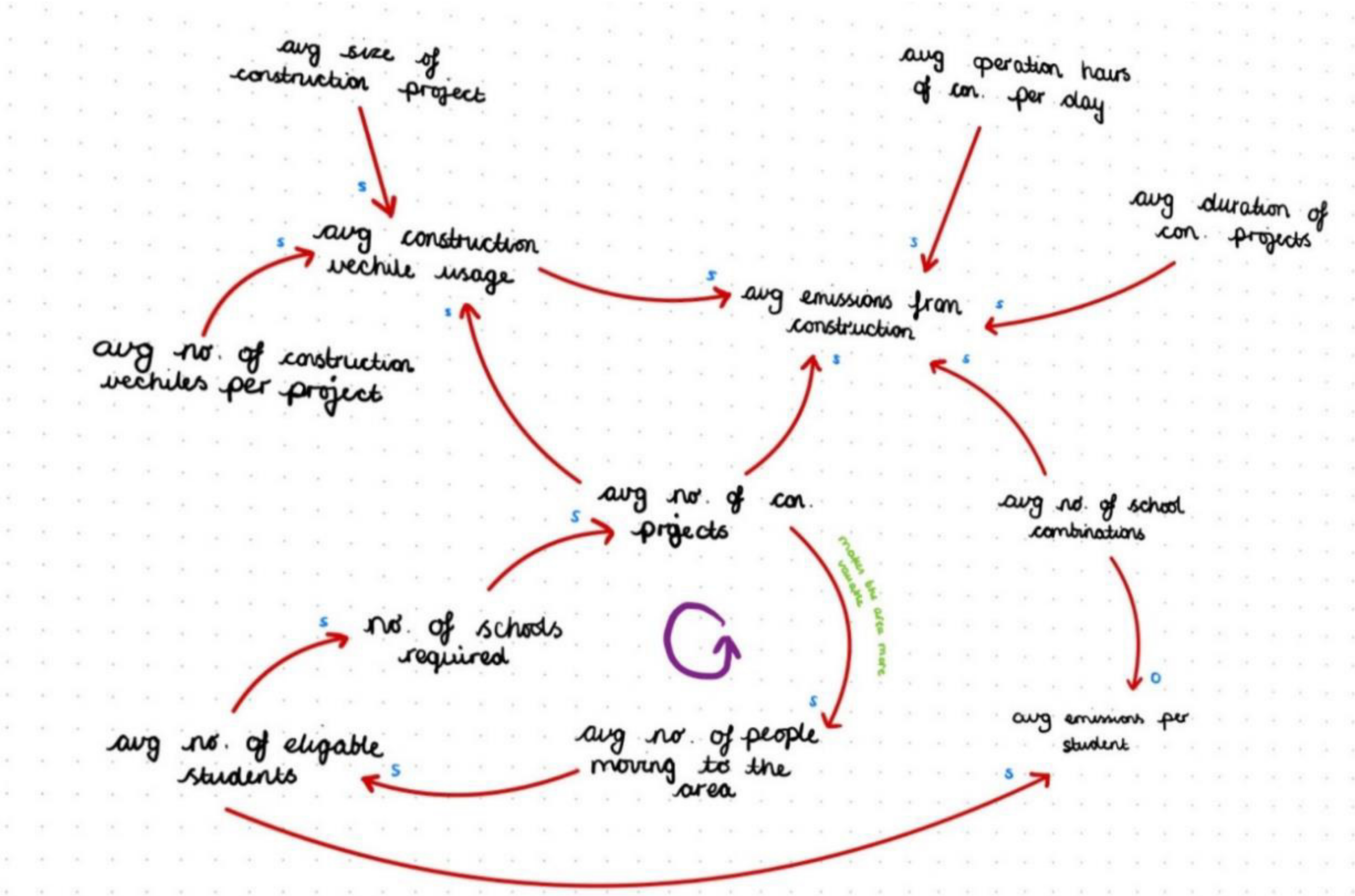

Figure 5 - Built Environment draft model

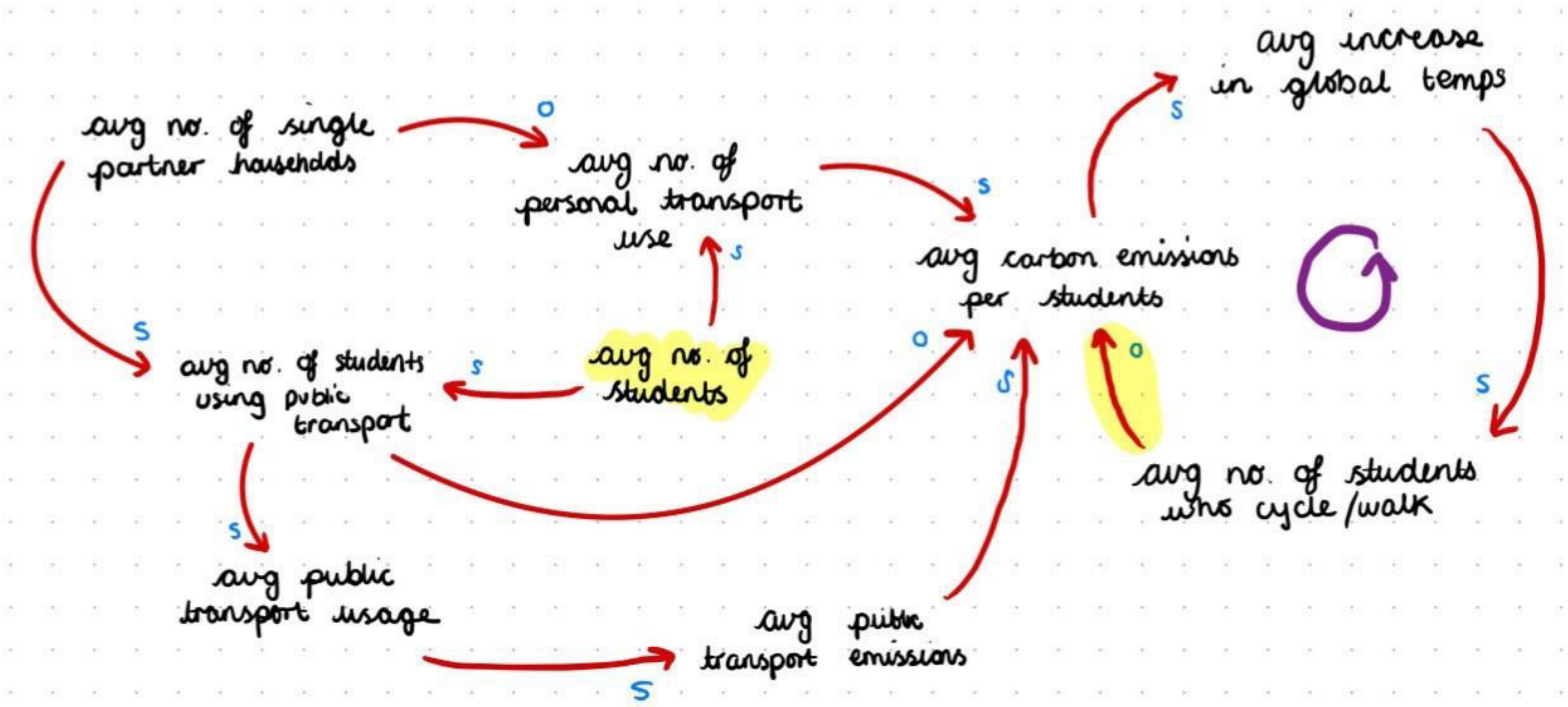

Figure 6 - Transport draft model

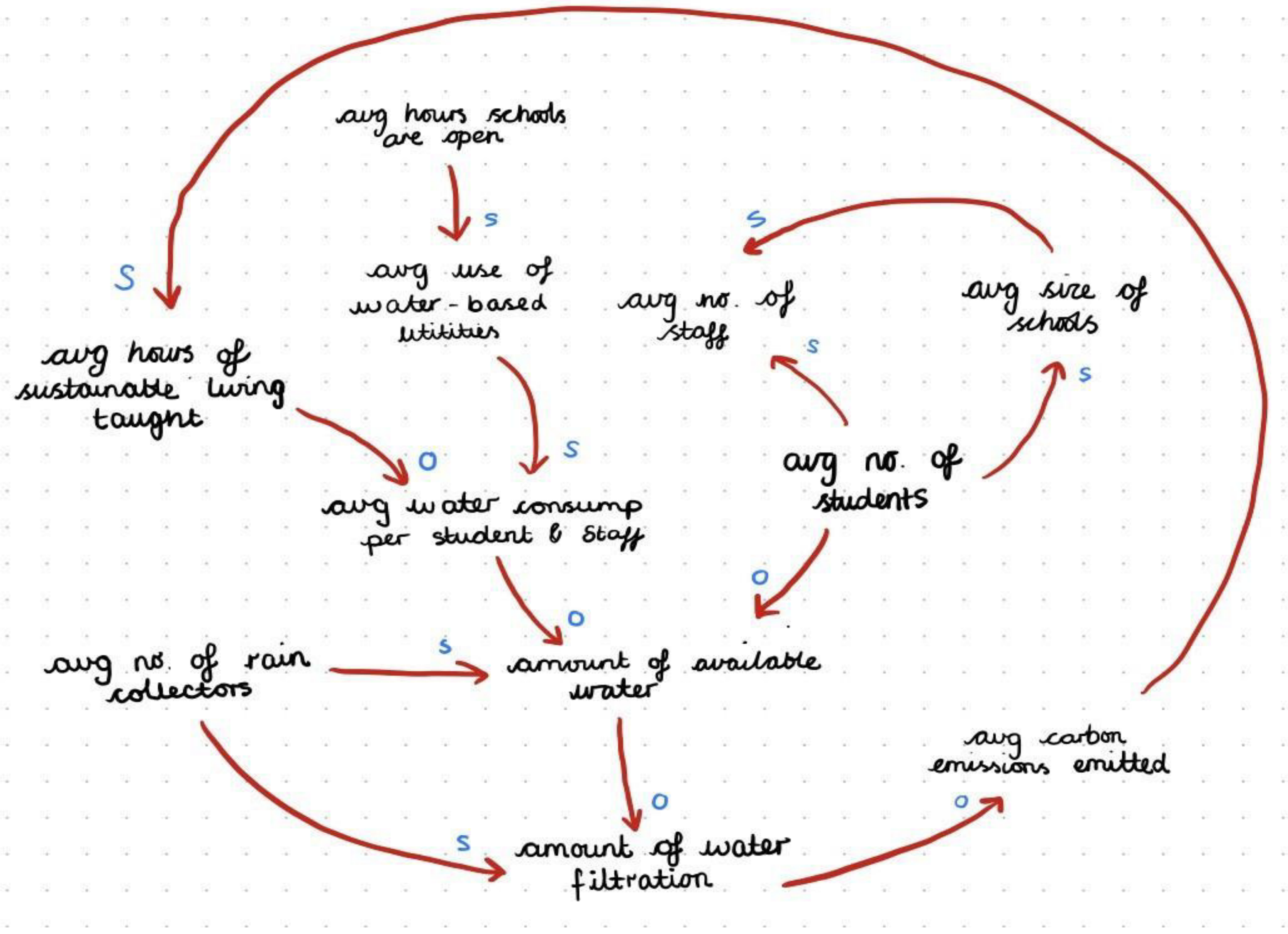

Figure 7 - Water draft model

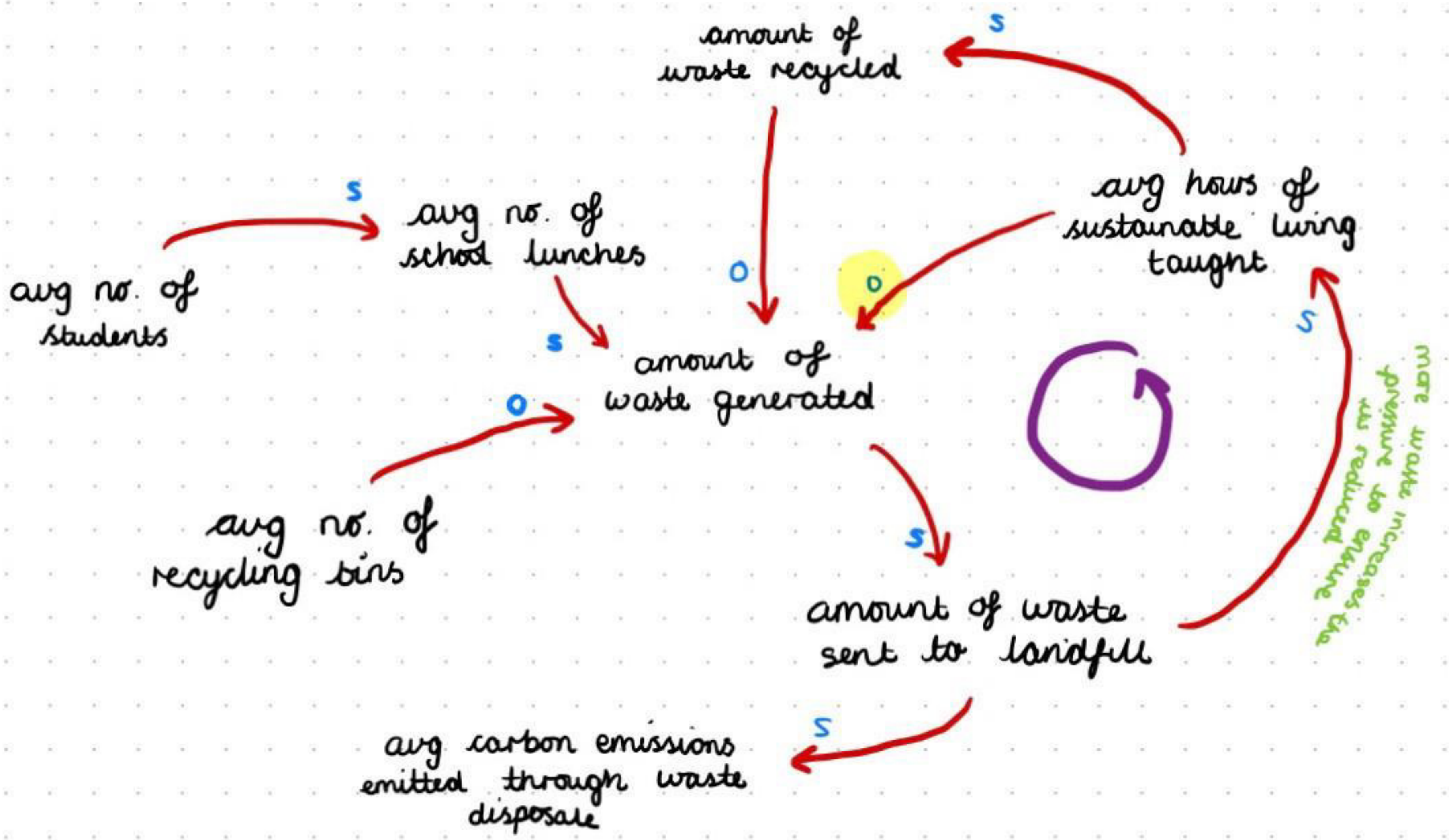

Figure 8 - Food & Waste draft model

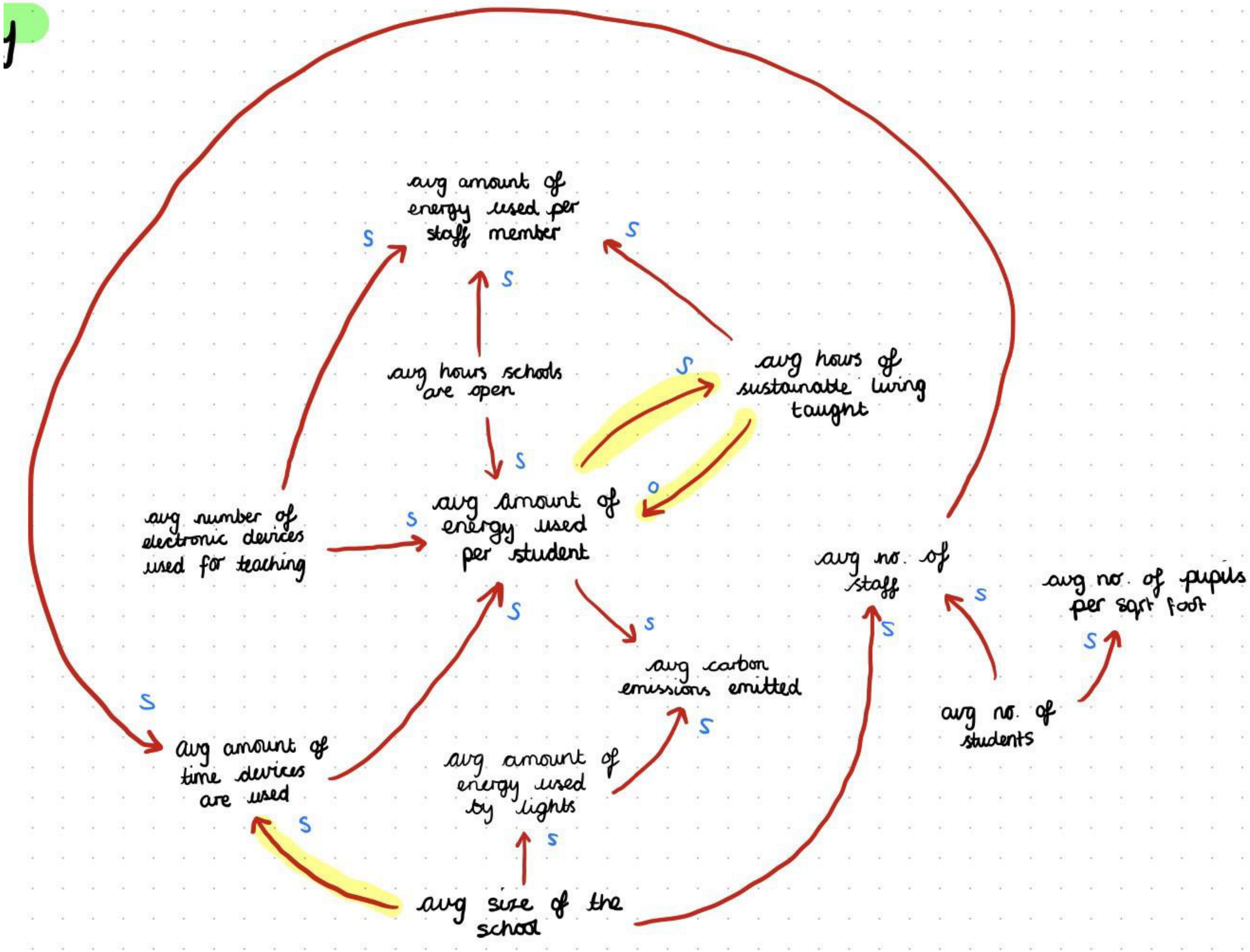

Figure 9 - Energy draft model

This was treated as a training exercise to get used to modelling and understand what makes up a good CLD, through the art of making mistakes. My supervisor worked with me from these models to gage an understanding of how I tackled modelling, because the process of creating models is different for everyone. We used these drafts to highlight areas I needed to improve on and what to do differently for the rest of the project. The main takeaways from this draft were to consider the 5-step rule, which is when you take a factor and go back 5 steps to expand the factors linked with it, and to challenge your own assumptions, why did you do this that way. The last takeaway was the most important because the purpose of your decisions can impact any model significantly, which is why it is important to write down your assumptions to improve the visibility of your model for others.

When creating the drafts, it was evident that similarities and cross overs for several of the themes were presence, leading to combinations of certain themes, as mentioned above. The first combination made was between built environment and green infrastructure & biodiversity. These themes come hand in hand when considering causality factors because of the construction element that is involved throughout. I saw the built environment aspect as the main overarching theme with green infrastructure & biodiversity as a sub section. With the biodiversity part acting as more of a condition to consider during constructions, a topic to keep in mind when designing projects, which is why it is not prominent in figure 5. The final combination made was with food and waste. Both themes linked in several ways but most prominent through food waste, an area of the education section that has one of the biggest environmental impacts (Manager, 2019). This combination allowed the causality between the food waste area and their relationships to be found, which became vital to simulate due to their potential of reducing the education sector's environmental impact.

To avoid repetition, I will not be going over each factor in these drafts as these relationships were less justified by data and more formed from assumptions. However, despite their origins the drafts not only taught me a lot about my modelling process, as mentioned above, but they provided the project with a direction to take when modelling the CLDs.

4.2 Causal Loop Diagrams (CLDs)

After completing the drafts, the CLDs were created in Vensim (see section 3 for more details about the approach). Due to the nature of modelling, where you are never truly done as there will always be more factors to include, each CLD was worked on simultaneously to allow for lessons learnt and research from each theme to influence each other as they are all a part of the same sector. In this section I will be going through my thought process when creating each CLD and showing the final product and loops discovered.

4.2.1 Built Environment

The CLD for built environment encompasses two themes, built environment, and green infrastructure & biodiversity, the reason for this decision is mentioned in Section 4.1.1. Figure 10 shows the completed model with the main reinforcing loop indicated.

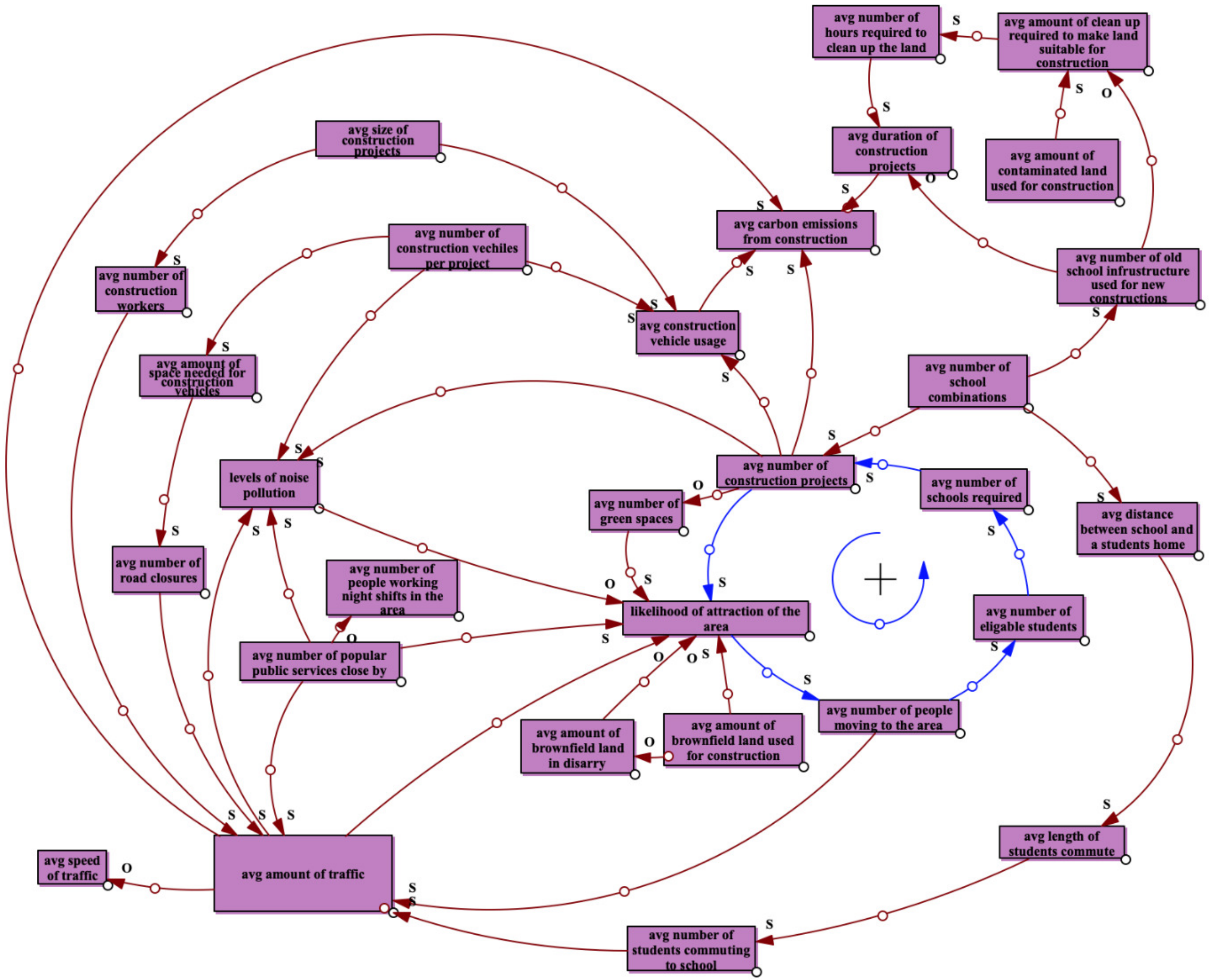

Figure 10 - Built Environment CLD

The first draft of this model was the most helpful out of all the drafts as several factors included in the final model originated from this draft. The first factor that this model started with was “Avg number of construction projects” from these factors were added around it exploring all areas that would be affected by the number of construction projects in the education sector. Which led to the consideration of “Likelihood of attraction of the area” as a factor that can highly impact the population of an area. Expanding on both of these factors I researched different areas that can impact these specific factors which brought in the additional factors of “Avg amount of traffic”, “Avg number of popular public sector services close by”, “Levels of noise pollution” and different land types, along with factors that impact them. Once a large proportion of the model was completed, trends between construction and carbon emissions were researched, leading to the addition of “Avg carbon emissions from construction” and other factors of construction that specifically impact the carbon emissions such as “Avg duration of construction projects”. The process of adding a factor and finding what it impacts and what impacts it followed the advice received from my supervisors and from the lessons learnt through the creation of my drafts. A model truly takes shape as one factor expands into several others that can then link back to previous factors, and through doing this, causal relationships are uncovered that on the surface are not thought of, which is the beauty of SD.

After all that was completed, polarities were added to the relationships in the model. The polarity labelling method chosen for these models was same (S) and opposite (O). The same relationships means as one factor increases the other increase also. The opposite relationship means as one factor increases the other decreases, the opposite effect. With SD it is vital to list your assumptions and justifications for all causal relationships and their polarities to ensure trends shown are backed up by evidence. For this model, assumptions are in Section 4.1.2.1 and all justifications and references to research is contained within a table at Appendix A.

Finally, once most of the factors had been added to the model, examination of the model took place to identify any loops that had formed. The loops are a vital part of the CLD as they show the controlled and uncontrolled aspects of a system which is used to identify where policy action is needed and provide scope to guide the creation of the stock and flow diagram and simulations (see Section 2.3.2 for more details).

Loop Number 1 of length 2
- likelihood of attraction of the area
  - avg number of people moving to the area
  - avg amount of traffic

Loop Number 2 of length 3
- likelihood of attraction of the area
  - avg number of people moving to the area
  - avg amount of traffic
  - levels of noise pollution

Loop Number 3 of length 4
- likelihood of attraction of the area
  - avg number of people moving to the area
  - avg number of eligable students
  - avg number of schools required
  - avg number of construction projects

Loop Number 4 of length 5
- likelihood of attraction of the area
  - avg number of people moving to the area
  - avg number of eligable students
  - avg number of schools required
  - avg number of construction projects
  - levels of noise pollution

Loop Number 5 of length 5
- likelihood of attraction of the area
  - avg number of people moving to the area
  - avg number of eligable students
  - avg number of schools required
  - avg number of construction projects
  - avg number of green spaces

Figure 11 - Loops in the Built Environment CLD

Figure 11 shows a list of all the loops within the model. Loops 1,2,4 & 5 are balancing loops, which means they have a controlled relationship, and they do not cause exponential grow (see Section 2.2.2 for more details). Loop 3 however is reinforcing, meaning it is an area of the model that is out of control because of exponential growth (see Section 2.2.2 for more details). Theis loop is an ideal place to start when creating the stock and flow diagrams and simulations. Loop 3 is marked on figure 12 as an anti-clockwise arrow with a plus in the middle, this loop was identified to be the best place to start when creating the stock and flow diagram (see Section 5.1).

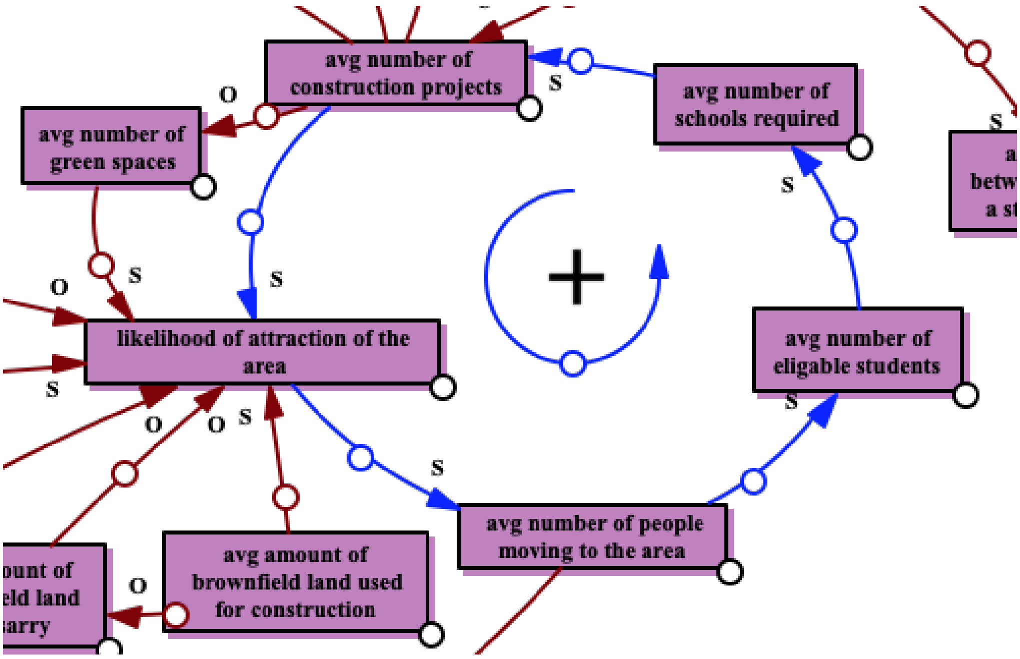

Figure 12 - Snapshot of loop 3 from Built Environment CLD

4.2.1.1 Assumptions

The additional assumptions made beyond those already mentioned in Section 1.3 for this model were:

- All construction involves the formation of a brand-new school and there is enough land to build new schools on.
- Any contaminated land that is needing to be cleaned up can be done in a safe manner.
- Public services either require a vehicle to reach or their main purpose as a service involves the use of a vehicle, such as a bus station.
- All eligible students in the area are required to find a space within their catchment.
- All construction workers live too far away to be able to commute by foot, requiring them to commute by a vehicle.

4.2.2 Transport

The next CLD created was for Transport. Transport was an interesting theme to work with due to its large scope. An issue at the start of the modelling process was knowing what factors were under the education's sector jurisdiction. Through research carried out, I was not able to get a clear answer, so I enlisted the help of Lee Patterson (Cardiff Council contact). Lee directed me to Chris Howe, a member of the director architecture team, from Atkins, who is currently working with Cardiff Council to build new schools. During a meeting Chris was able to guide me through the criteria of what schools are involved with and we went over some ideas I had for the model. He was able to provide me with information that guided my assumptions and research.

Like the built environment model (see Section 4.2.1), the transport model, shown in figure 13 has several different areas all linked through causality relationships. This model started from "Avg amount of traffic on the roads" and from there I researched the different components that impacted this. The main overarching themed centred around types of transport methods to school and the factors that impacted them. It was decided to focus more on this area of transport because from my conversations with Chris, I went with the assumption that schools had greater control over these areas. Meaning if policy action were to be recommended in these areas, schools would be able to implement them. The most interesting development for this model was with the factors that impacted "Avg number of students who cycle/walk". Research uncovered links between an area's attractiveness and the "Avg number of students who cycle/walk", a causal relationship that did not come to mind initially. Unlike the relationship between "Avg number of students who cycle/walk", and the factor "level of safety of commutable area", a factor that has a large impact on the ways students and teachers commute. The other main component of this model involved expanding upon one specific type of commuting transport, that being school/ local buses. Buses are known for not being the most reliable, which is why it was important to model their causality to traffic and carbon emissions so that in the stock and flow diagrams the trends they create could be found.

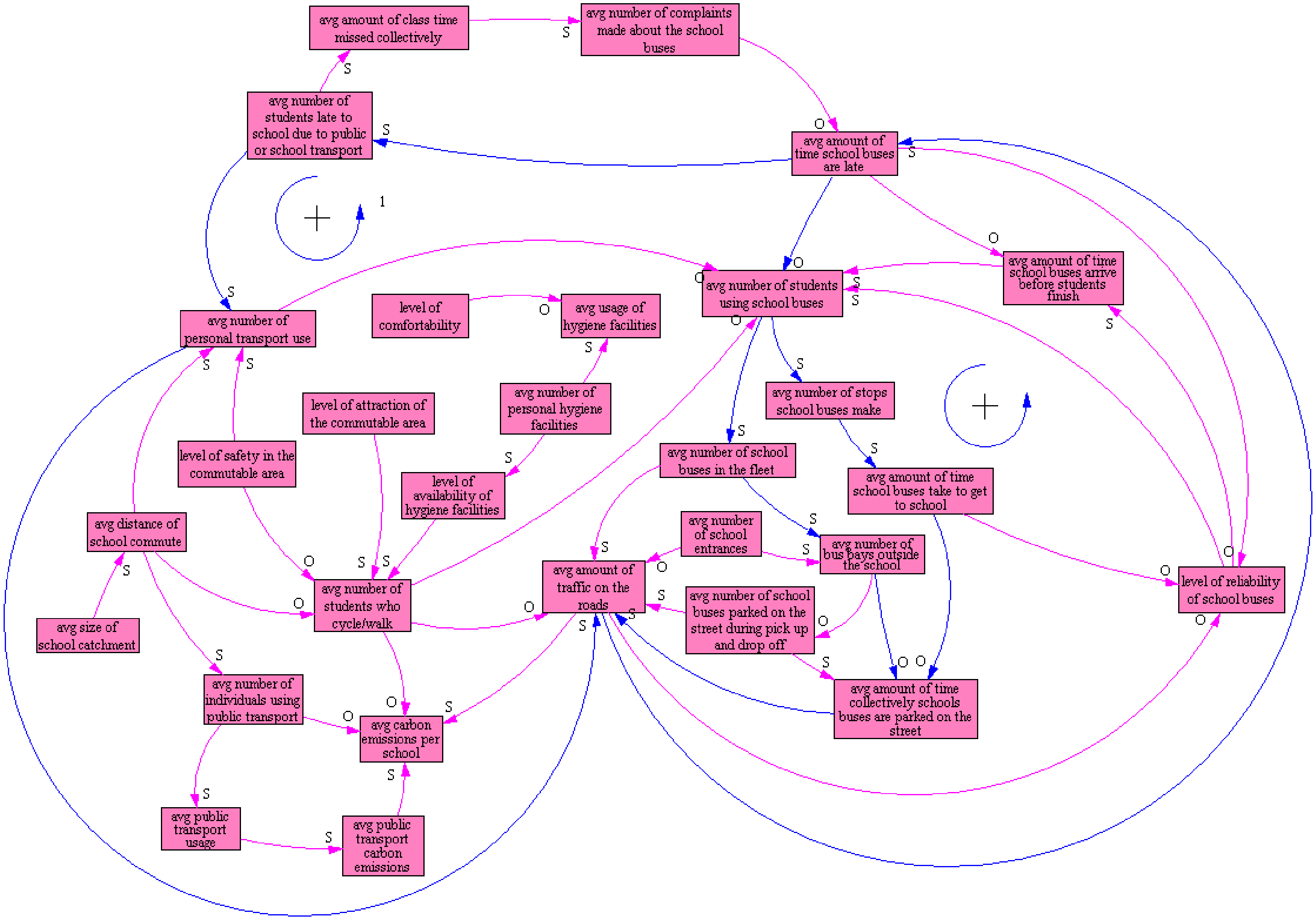

Figure 13 - Transport CLD

During the addition of the factors, their polarities were added at the same time as their relationships after becoming more familiar and comfortable with being able to identify the right polarity, from the experience of working on the built environment model. Adding the polarity as factors were being added made it easier to identify other potential causal relationships and benefitted the modelling process greatly. For full relationships, polarities, justifications, and references see Appendix B.

```
Loop Number 2 of length 3
  avg amount of traffic on the roads
      avg amount of time school buses are late
      avg number of students late to school due to public or school transport
      avg number of personal transport use
Loop Number 3 of length 3
  avg amount of traffic on the roads
      avg amount of time school buses are late
      avg number of students using school buses
      avg number of school buses in the fleet
```

Figure 14 - Loops in the Transport CLD

Once the model was completed, loops that had formed were identified. In Appendix G, all the loops within this model are listed, a lot more then built environment are present. For the purposes of this project, only the reinforcing loops are focused on. These loops are highlighted separately in figure 14. Both these loops focus highly on the factors that impact "Avg amount of traffic on the roads", those factors being school/ local buses and their causal relationship to making students late. Theses loops were particularly interesting because they cause exponential growth on traffic, impacting carbon emissions. But they also show the impact late buses have on student uptake of local transport. Leading to the opposing impact on commuting methods such as person transport, that then also impacts traffic exponentially. These relationships are exactly what I was hoping to uncover, and they ended up becoming a main element of one of the stock and flow diagrams (see Section 5.1).

4.2.2.1 Assumptions

The additional assumptions made beyond those already mention in Section 1.3 for this model were:

- Anyone who commutes by cycling or walking will not impact traffic negatively due to dedicated travel paths.
- Students can only get into schools within their catchment area.
- Areas surrounding schools do not have specific bus lanes for public transport due to generally smaller roads outside of the main city centre.
- All modes of transport are equally accessible for students.
- Schools are able to influence changes in local transport schedules and routes to respond to complaints made by parents due to local transport not running on time.

4.2.3 Food & Waste

For this model it was decided to combine the themes of food and waste, as discussed in Section 4.1. In doing this it allowed for further intricate causality relationships to be discovered and created a detailed CLD, shown by figure 15. The starting point of this model was the factor “Level of demand for school meals” and the initial efforts were focused on finding the factors that impacted this. A large focus that the model ended up having was on the “Avg amount of time students are at school during the day” and the different types of activities within a school that could increase food consumption. However, it was the area around “Level of quality of cooked school meals” and “Likelihood of attraction to cooked school meals” that introduced newer causal relationships, such as how meals are cooked and its impact on “Avg amount of food waste generated” and “Level of demand for school meals”. I did investigate other forms of waste outside of food, but the only other waste I could fully identify was “Avg amount of waste from paper and card” which does not have as much evidential backing compared to food waste. Leading to the decision to focus just on food waste. For full relationships, polarities, justifications, and references see Appendix C.

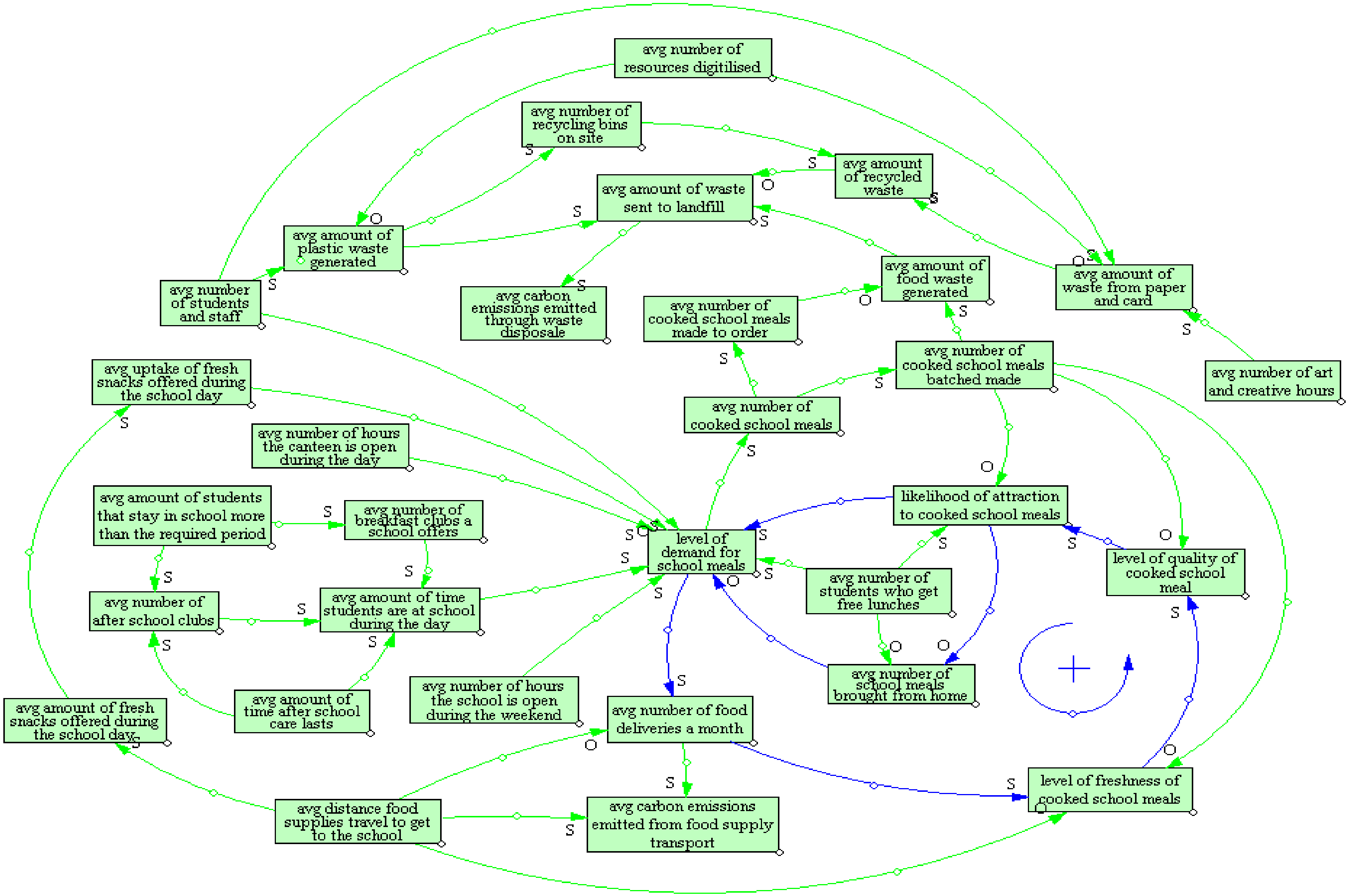

Figure 15 - Food & Waste CLD

Loop Number 1 of length 3
level of demand for school meals
avg number of cooked school meals
avg number of cooked school meals batched made
likelihood of attraction to cooked school meals
Loop Number 2 of length 4
level of demand for school meals
avg number of cooked school meals
avg number of cooked school meals batched made
likelihood of attraction to cooked school meals
avg number of school meals brought from home
Loop Number 3 of length 4
level of demand for school meals
avg number of cooked school meals
avg number of cooked school meals batched made
level of quality of cooked school meal
likelihood of attraction to cooked school meals
Loop Number 4 of length 4
level of demand for school meals
avg amount of food deliveries a month
level of freshness of cooked school meals
level of quality of cooked school meal
likelihood of attraction to cooked school meals
Loop Number 5 of length 5
level of demand for school meals
avg number of cooked school meals
avg number of cooked school meals batched made
level of quality of cooked school meal
likelihood of attraction to cooked school meals
avg number of school meals brought from home
Loop Number 6 of length 5
level of demand for school meals
avg amount of food deliveries a month
level of freshness of cooked school meals
level of quality of cooked school meal
likelihood of attraction to cooked school meals
avg number of school meals brought from home
Loop Number 7 of length 5
level of demand for school meals
avg number of cooked school meals
avg number of cooked school meals batched made
level of freshness of cooked school meals
level of quality of cooked school meal
likelihood of attraction to cooked school meals
Loop Number 8 of length 6
level of demand for school meals
avg number of cooked school meals
avg number of cooked school meals batched made
level of freshness of cooked school meals
level of quality of cooked school meal
likelihood of attraction to cooked school meals
avg number of school meals brought from home

Figure 16 - Loops in the Food & Waste CLD

These relationships, between quality and food waste, became the centre of the reinfocing loop that were later discovered once all my factors were implemented. In figure 16, you can see all the loops with this model but the important one to note is the reinforcing loop, which is loop 6. This loop is made up of 6 factors, which mainly involves overall quality, freshness and attraction of meals. With a causal relationhsip to “Level of demand for school meals” and “Avg number of food delivers a month”; an ideal relatinship that links perfectly to the scope of this project, due to the relationship “Avg nummber of food deliveries a month” has with “Avg carbon emission emitted from food supply transport”. A relationship that causes exponential growth of factors in an area that emits carbon emissions and contributes to a schools overall environemental impact. This later become one of the main loops used to build the stock and flow diagram in section 5.2.

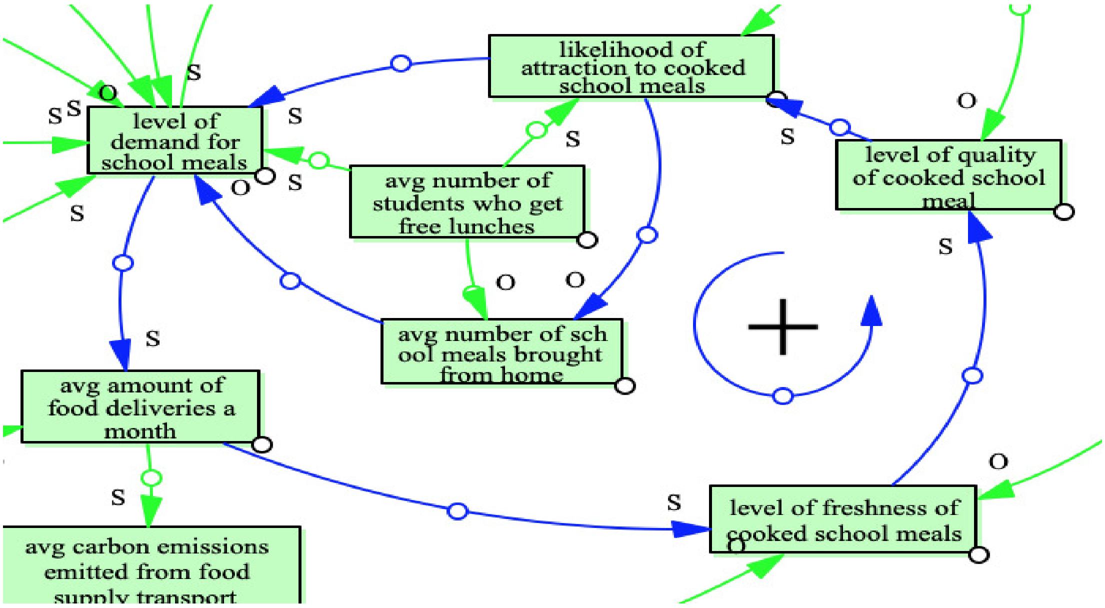

Figure 17 - Snapshot of loops 4 & 6 from the Food & Waste CLD

4.2.3.1 Assumptions

The additional assumptions made beyond those already mention in Section 1.3 for this model were:

- Every student uses the canteen during lunch and break periods.
- All students have equal access to joining clubs before and after school.
- All students eat on school premises.

4.2.4 Energy and Water

Unlike the other combined themes, energy and water started off as two separate models. It was through creating their separate CLDs that the links these two themes shared and the potential benefits that could come from their combination was highlighted.

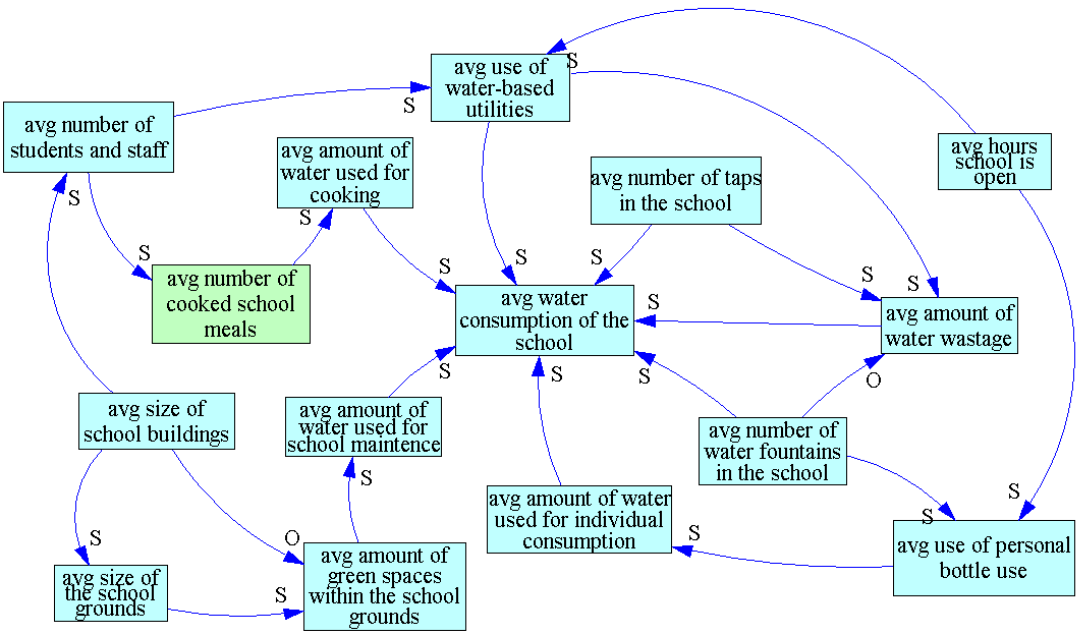

Figure 18 - Water CLD

Figure 18 shows the initial water themed CLD. As you can see it has far less factors compared to the other models above. This is due to the difficulties that there was with identifying causal relationships in this area of schools beyond the basics. The starting point for this model was with the factor “Avg water consumption of the school” and the factors that impacts it. Despite not finding a large range of other factors, a few little aspects of water consumption that initially had not been considered were identified, those being the type of water dispensers, such as water fountains and taps and the differing impact they can have on “Avg water consumption of the school”. However, despite factors like these it became clear that there would not be any additional value added from creating a stock and flow diagram from this CLD. Due to the larger number of policies already out there for this area of schools. Such as rainwater collection and reusing water for not consumption uses (Rainwater harvesting for schools, 2018).

Similar difficulties that were experienced in the creation of the water themed model were had with the energy themed CLD. However, more causal relationships were identified in comparison, model shown by figure 19. This model started with “Avg amount of energy used by the school” and then the causal relationships related to this factor were researched. Through this search, more specific factors were found than compared to the water model. Such as the types of rooms available in the school and their main uses, and the impact that can have on the use of devices that use energy, like heating and lights.

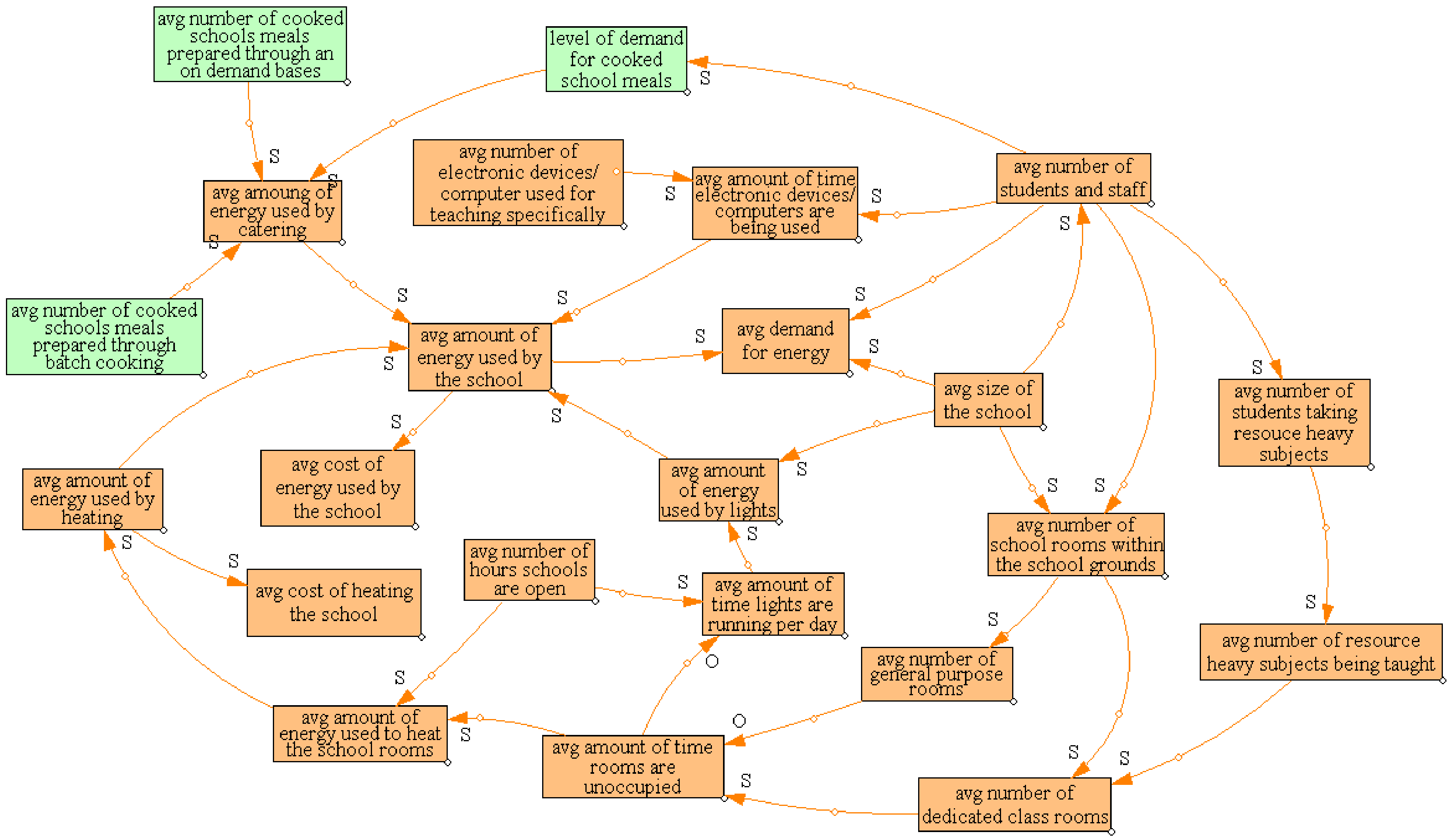

Figure 19 - Energy CLD

Unfortunately, like with the water model, factors that could form a reinforcing loop were not identified. Highlighting that focusing on this theme alone would not be a good use of time due to the little value additional policy in this area would bring. This led to the combination of both the water and energy models in the hopes there would be causal relationships that could be made between them, and these relationships could then form a reinforcing loop. With the exponential growth indicated from this loop potentially highlighting an area that has not already got implemented policy, allowing this CLD to provide value to this area. For full relationships, polarities, justifications, and references see Appendix D.

Figure 20 shows the result of the combination of the energy and water models. To combine these models, a few changes were made, such as removing the relationship of "Avg number of staff and students" directly impacting energy demand and adding the cost of energy, heating, and water consumption. The student and staff relationships were removed because it wasn't fully fleshed out enough and its causality couldn't be backed up. Once these adaptions were made, a reinforcing loop was successfully identified in my model, shown by the anti-clockwise arrow with a plus sign in the middle.

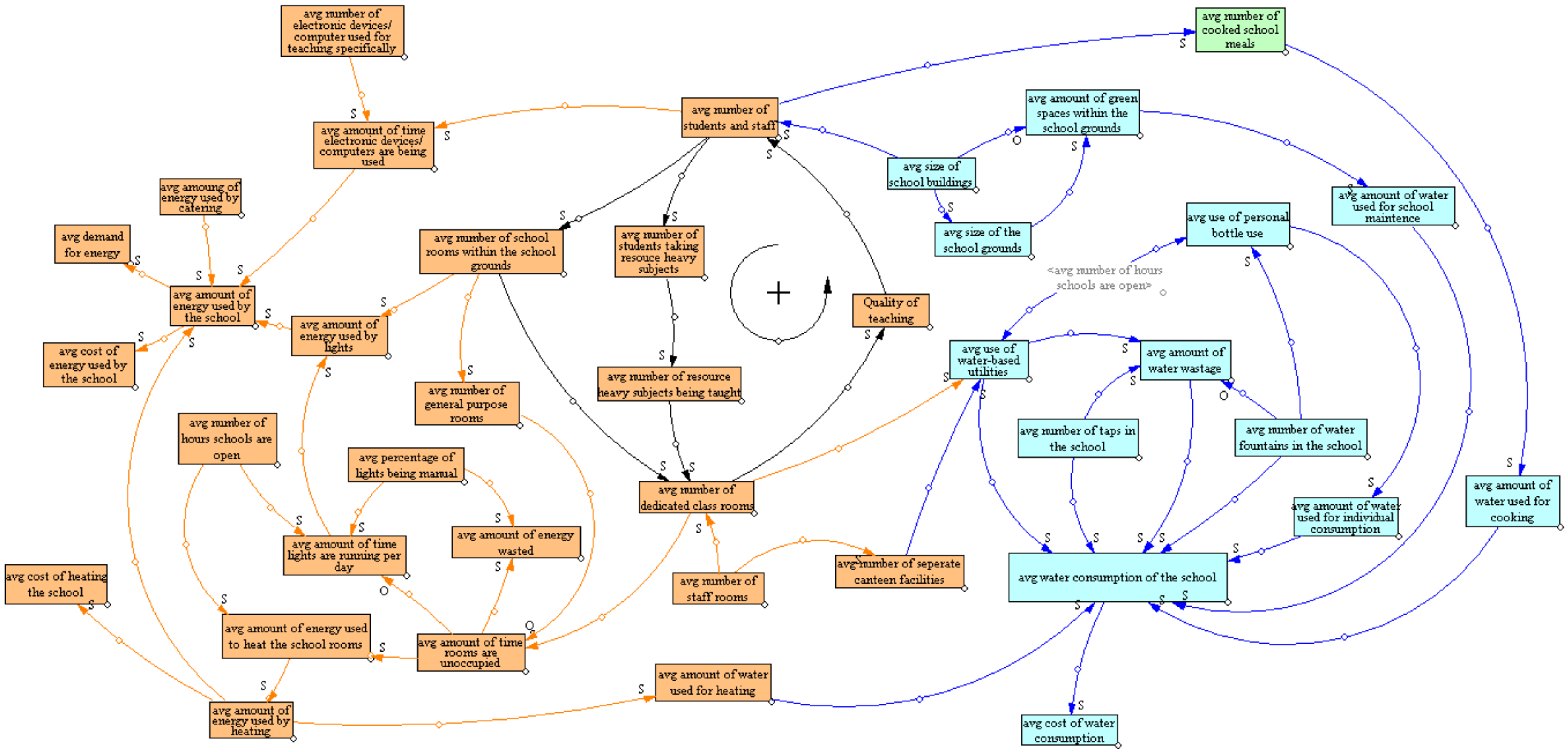

Figure 20 - Energy and Water CLD

Loop Number 1 of length 3
avg number of dedicated class rooms
Quality of teaching
avg number of students and staff
avg number of school rooms within the school grounds
Loop Number 2 of length 4
avg number of dedicated class rooms
Quality of teaching
avg number of students and staff
avg number of students taking resouce heavy subjects
avg number of resource heavy subjects being taught

Figure 21 - Loops in the combined CLD of Energy and Water

Figure 21 shows the two loops within this newly combined model. Both of which are reinforcing. Despite finding reinforcing loops in this model, I decided not to carry them into a stock and flow diagram due to their more simplistic nature, the minimal value that would be added through policy action experiments in this area and timing constraints that the project had. Not making a stock and flow diagram around these loops allowed me time to focus on the more detailed loops identified in the models above, overall benefiting my project and its outcomes.

4.2.4.1 Assumptions

The additional assumptions made beyond those already mention in Section 1.3 for this model were:

- All classrooms have radiators.
- Each school has a differing layout and potentially different specialty in lesson types.
- There is enough energy and water to fulfil the needs of schools.

5 Implementation – Stock and Flow Diagrams

The creation of the CLDs acted as preparation and guidance for the creation of stock and flow diagrams. For these diagrams, as mentioned in Section 3, AnyLogic was chosen due to its industry leading visual features and cloud version, which makes it suitable for experimentation. After completion of the CLDs, I decided to focus on two theme areas, those being the built environment theme (which encompasses built environment and green infrastructure & biodiversity) and food & waste theme. This decision was made to ensure there was time to complete detailed and high standard models and had enough time to fully simulate them and test policy action, the main aim of the project, which I did not think would be possible if all the causal models were to be made into stock and flow diagrams. In this section I will be going over the process I took to make my stock and flow diagrams.

5.1 Built Environment – Stock and Flow Diagram

The first Stock and Flow diagram completed was for built environment. Figure 22 shows the completed model.

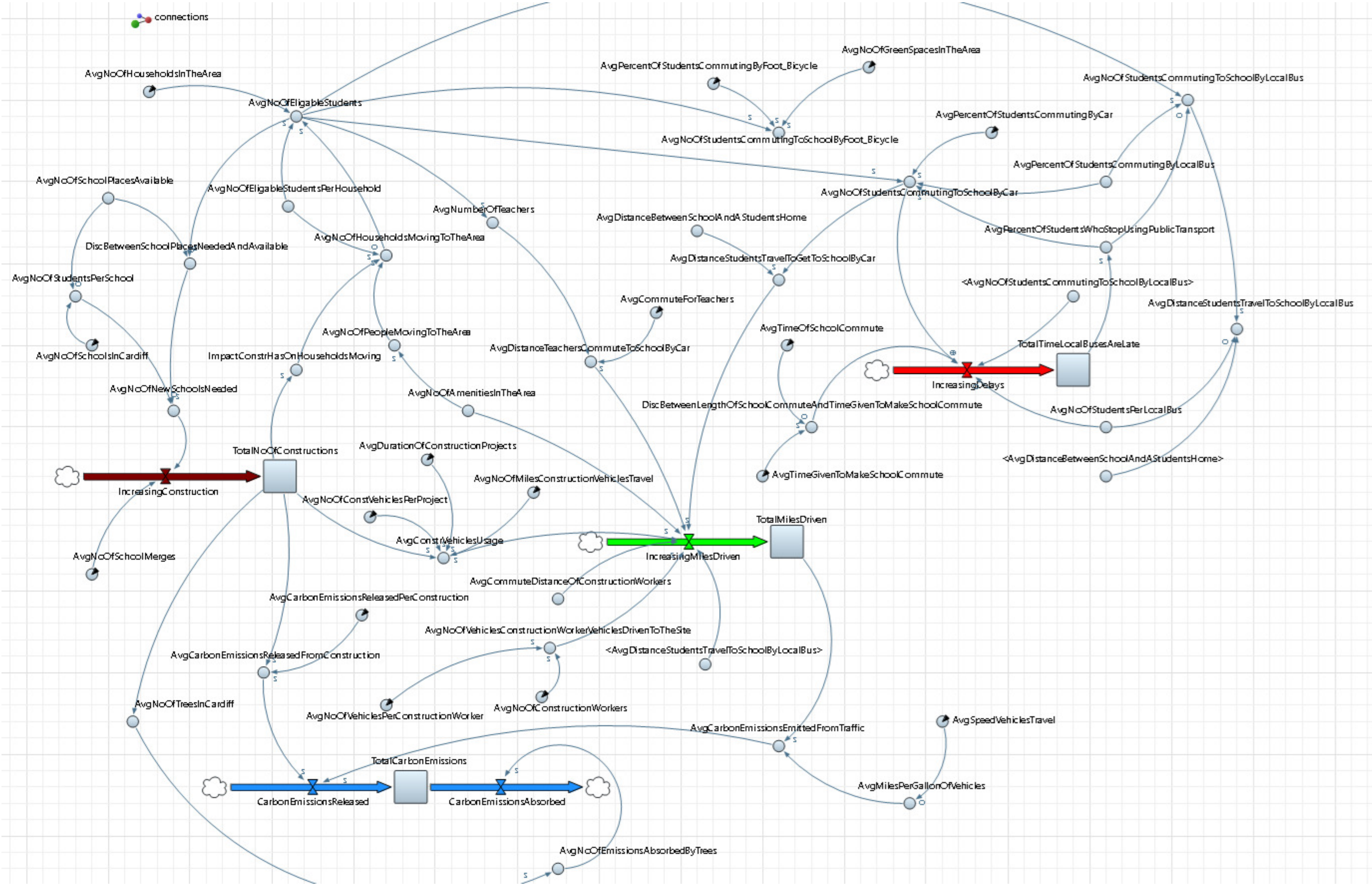

Figure 22 - Built Environment Stock and Flow Diagram

The starting point for this model was implementing the reinforcing loop identified in the CLD creation, in section 4.2.1. Loop 3 was used, shown in figure 12, to form the first loop in this model. The model was started by adding in the stocks and flows, which in this case were “Total number of constructions” and “Total carbon emissions” as stocks and “Increasing construction”, “Carbon emissions released” and “Carbon emissions absorbed” as flows. From here the CLD was used as a guide to fill in the causal relationships, with a few additions and adaptions made to ensure the factors were quantifiable. For example, when adding “Avg number of new schools needed” additional factors of “Avg number of students per school” and “Discrepancy between school places needed and available” needed to be added to ensure quantifiability. For better understanding of the factors in the model I thought it would be beneficial to provide you with a labelled model of the different factor types visible in my model, shown in figure 23.

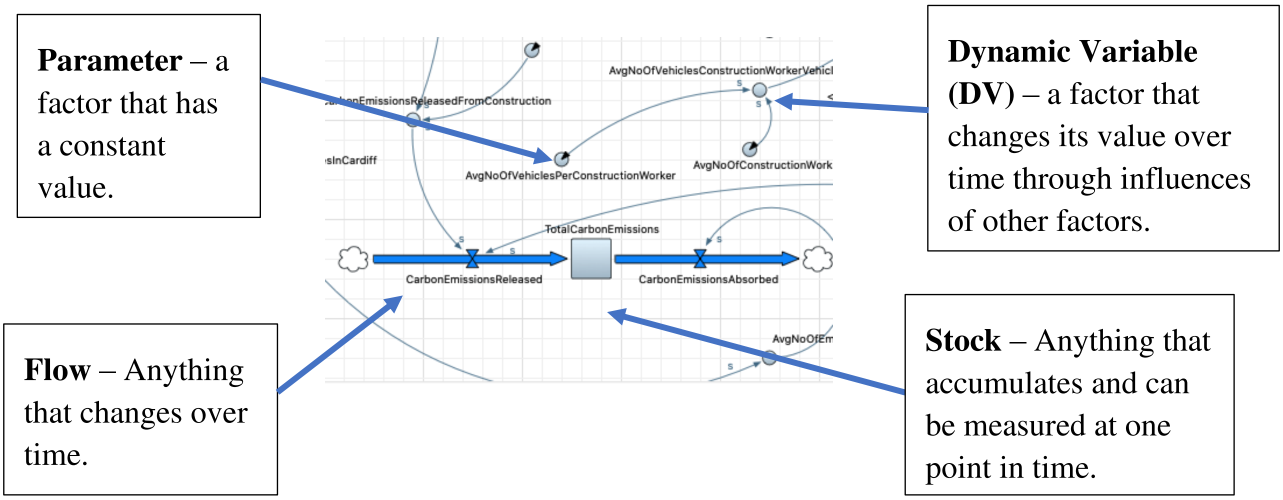

Figure 23 - A labelled section of the Built Environment model

During the formation of the model, cross overs were identified from factors in this model compared to factors in the transport themed CLD, see section 4.2.2. The main factor I am referring to “Avg amount of traffic on the roads”. This factor allowed for the introduction of the reinforcing loop in the transport model to be brought into this simulation, allowing for a broader range of experiments to be carried out later. A combination of both loop 2 and 3, shown in figure 14, were used to guide the addition of a few stocks and flows to this model. Those were “Total time local buses were late” and “Total mile driven” for the stocks and “Increasing delays” and “Increasing miles driven” for the flows. Thanks to the additional stocks and flows this model was able to develop further, through the addition of the teacher commute factors, bringing another dimension into the stock and flow diagram.

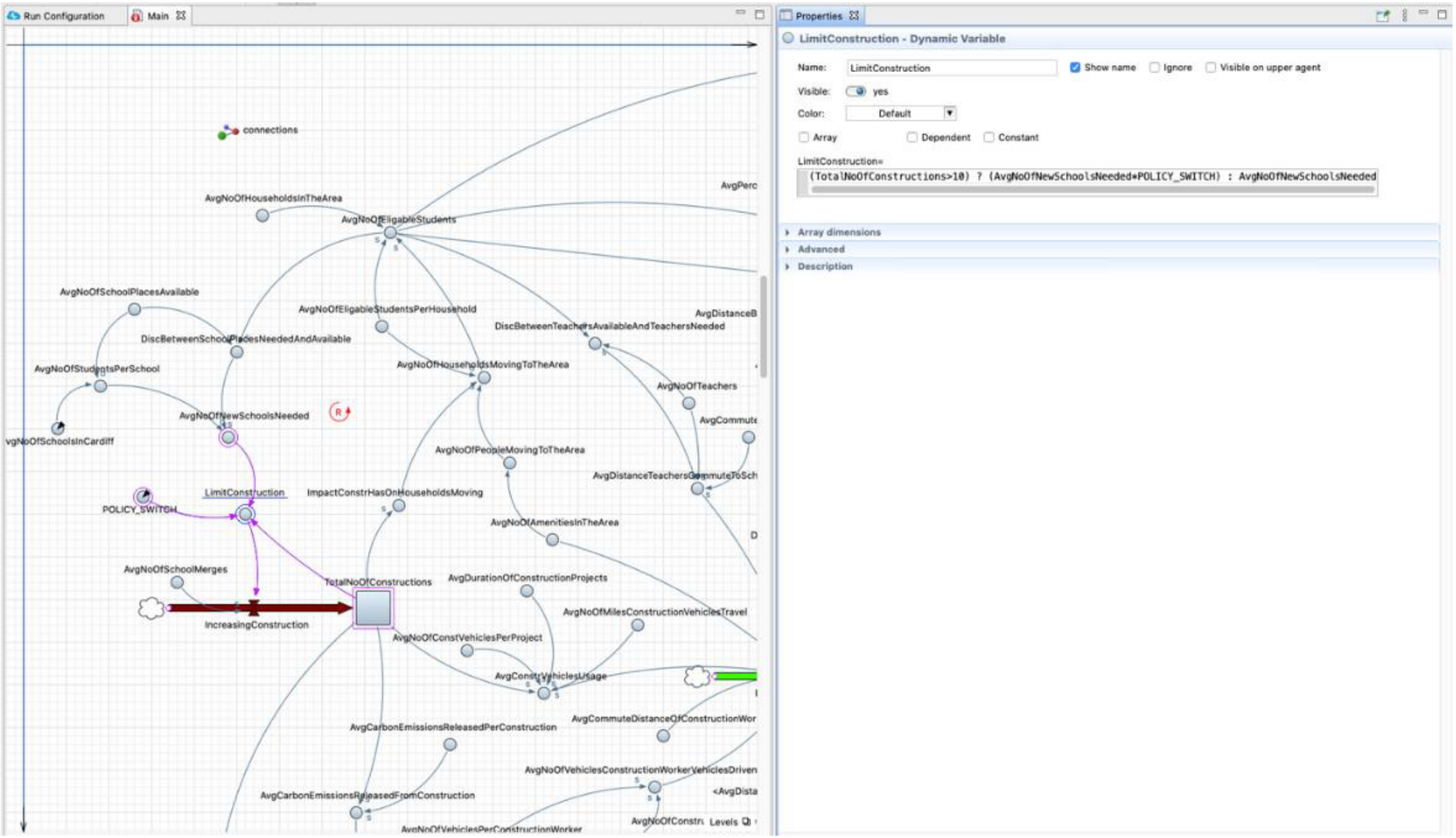

Figure 24 - An example of an equation being added to a factor

After all the factors and their causal relationships were added in, the equations and value inputting was completed. Equations and values are required in the stock and flow diagrams to program trends into the model that then will be shown when you simulate. Adding equations into AnyLogic has a higher complexity than other software's such as Vensim due to it being java based. You are required to follow java conventions, which is not that simple when you are not able to edit the actual code. Figure 24 shows where you input equations for each factor and in this example, an if-then-else statement has been written in, which looks a lot different to the normal if-then-else statement you would write in actual java.

The remaining equations for this model were simpler than the one shown in figure 24, but they all required extensive research to ensure the trends that were programmed into the model were correct and had evidential backing to ensure the trend data received from the experiments are reputable. Like the CLDs, justification is provided through, units of the factors, relationships, equations, and references in a table for this model at Appendix E.

5.1.1 Assumptions

Assumptions are highly important to note for stock and flow diagrams due to the level of interpretations that can be made about certain causal relationships and the equations formulated. The assumptions mentioned in Section 1.3 and Section 4.2.1.1 apply to this model but here are further assumptions made for this model.

- All teachers commute by car because all teachers live to far from school to walk or cycle.
- When I mention schools, I am referring to local-authority schools (excluding special and nursery)
- All current school places are taken up.
- Only one student per car

5.2 Food & Waste – Stock and Flow diagram

The second and final stock and flow diagram completed was for food & waste. Unlike the built environment model this model did not use any additional models for its completion, it only focused on the food & waste CLD. Figure 25 shows the completed food & waste stock and flow diagram.

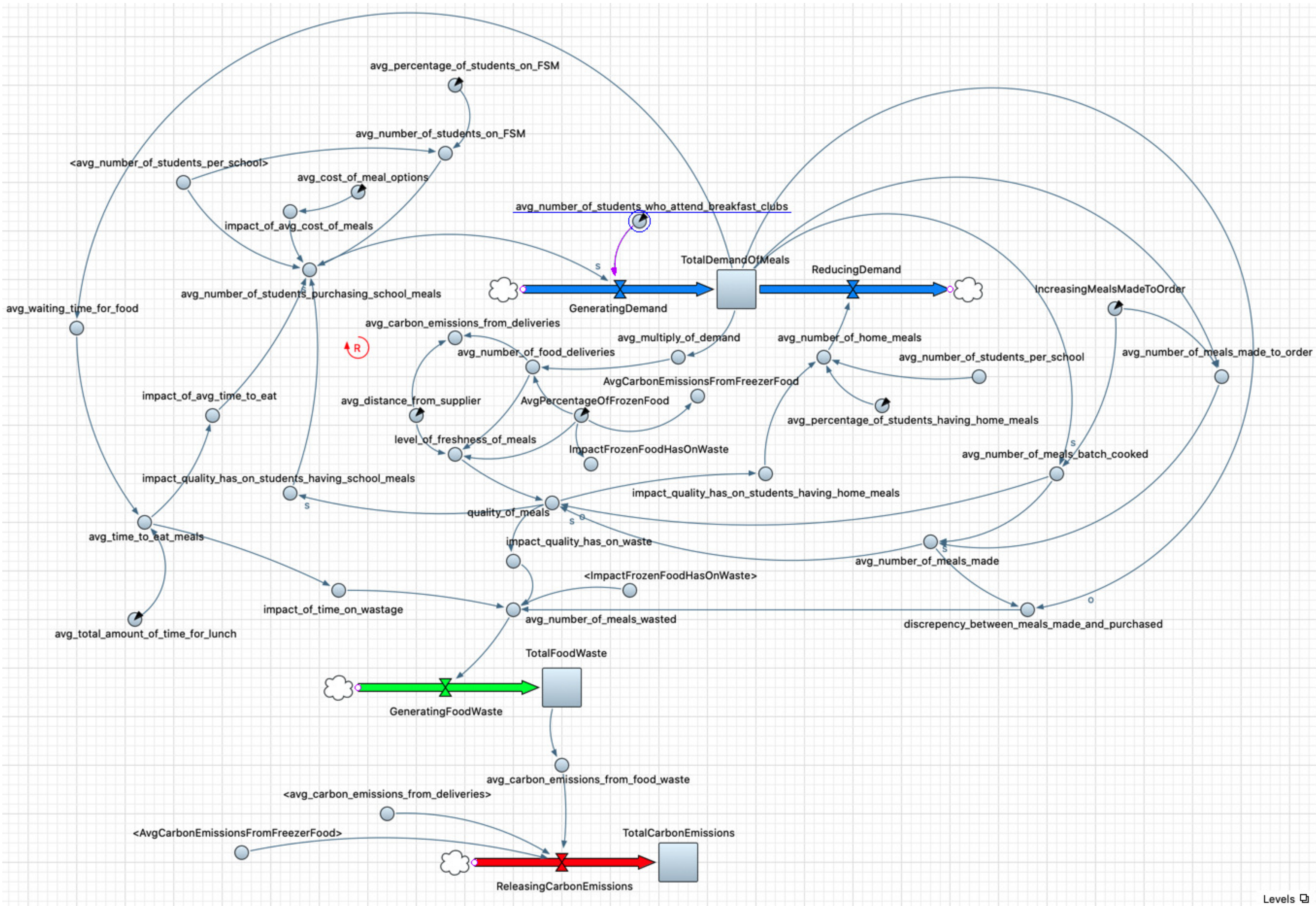

Figure 25 - Food & Waste stock and flow diagram

For this model it started by adding in the stock and flows that were involved in loop 6 (see section 4.2.3), the reinforcing loop identified through the creation of the CLD. The stock and flows added were "Total demand of meals", "Generating demand" and "Reducing Demand" retrospectively. From the stock and flows, the additional factors required to make up the loop were added, with some additions that were not in the CLD, such as "impact quality has on students having school meals" for the purpose of model correctness and quantifiability. On top of the stock and flow from the reinforcing loop two more sets of stocks and flows were also added, the first one being "Total food waste", the stock, and "Generating food waste", the flow. The second being "Total carbon emissions", the stock, and "Releasing carbon emissions" the flow. These additions will allow for further evaluation of the trends impacted by policy action implemented and they link this model to the objective of the project of finding policy to reduce the environmental impact the education sector has.

As with the built environment model, the next stage was the addition of the equations to the factors for the purpose of programming the trends into my model to allow these factors to be simulated in the next stage. This model required more experimentation when it came to equation formulation due to the more obscure causal relationships within the model that were based more off personal preference data over pure facts. In cases like these, such as how the relationship of "quality of meals" and "impact quality has on students having school meals" research and data describing the relationship between common impacts of quality and students' uptake of student meals was found and these trends were used to formulate the equation for the mentioned relationship. I have provided justification, units of the factors, relationships, equations and references for this relationship and all relationships in this model in a table at Appendix F.

5.2.1 Assumptions

The assumptions mentioned in Section 1.3 and section 4.2.3.1 apply to this model but here are further assumptions made for this model.

- Every student uses the canteen for lunch time.
- 2 deliveries a month feeds 188 peeps
- Batch cooking damages the quality but made-to order food has no impact on overall quality.

5.3 Implementation – Simulations

Once the stock and flow diagrams were completed, they could now be simulated. A huge perk of the AnyLogic software is its visual features for simulations and how simple the process is to simulate a stock and flow diagram. If all the values and equations of each factor are correct and error free, then running a simulation is as quick as clicking play. But there are other aspects that be added to a stock and flow diagram to enrich the experience for the user, this includes adding graphs, buttons, and sliders. Simulations are the final stage of the SD process and are used to run experiments on the models and track the trend data outputted by the models. In this section I will be showing the additions made to the stock and flow diagrams to form the simulations.

5.3.1 Built Environment – Simulation

Simulations in AnyLogic open in a separate window to the model allowing for adaption of the open page. Below in figure 26 you can see the landing page that was created for the built environment simulation.

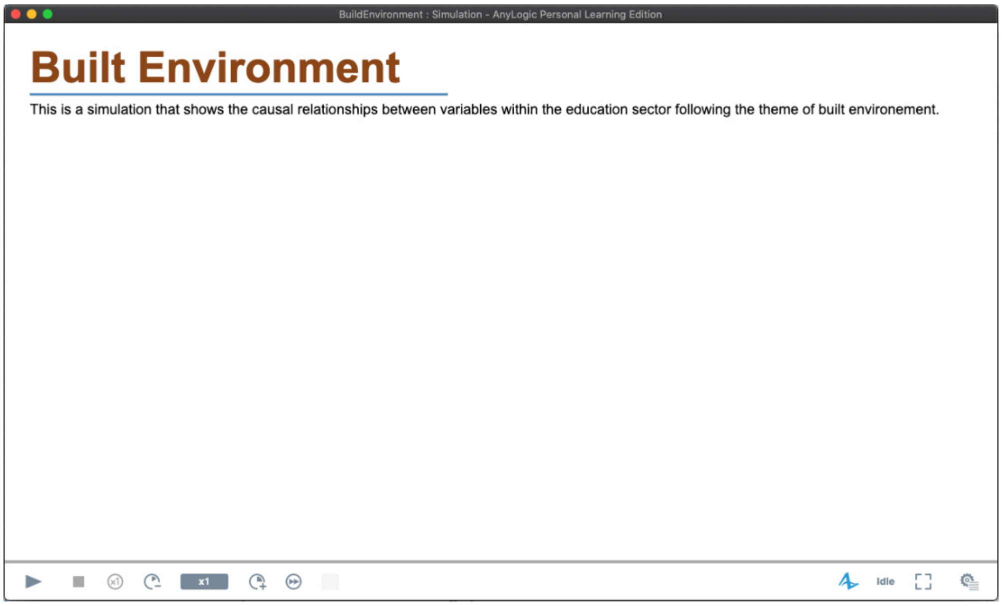

Figure 26 - Landing page for the Built Environment simulation

The page contains text and buttons at the bottom which allow you to begin the simulation, decide on the speed and enlarge it to full screen. Once you press play you are then taken to the simulated model which begins straight away, shown in figure 27. Here you can see the entire model and all its moving parts. Down at the bottom of the screen you can slow down the model, fast forward it or cancel it.

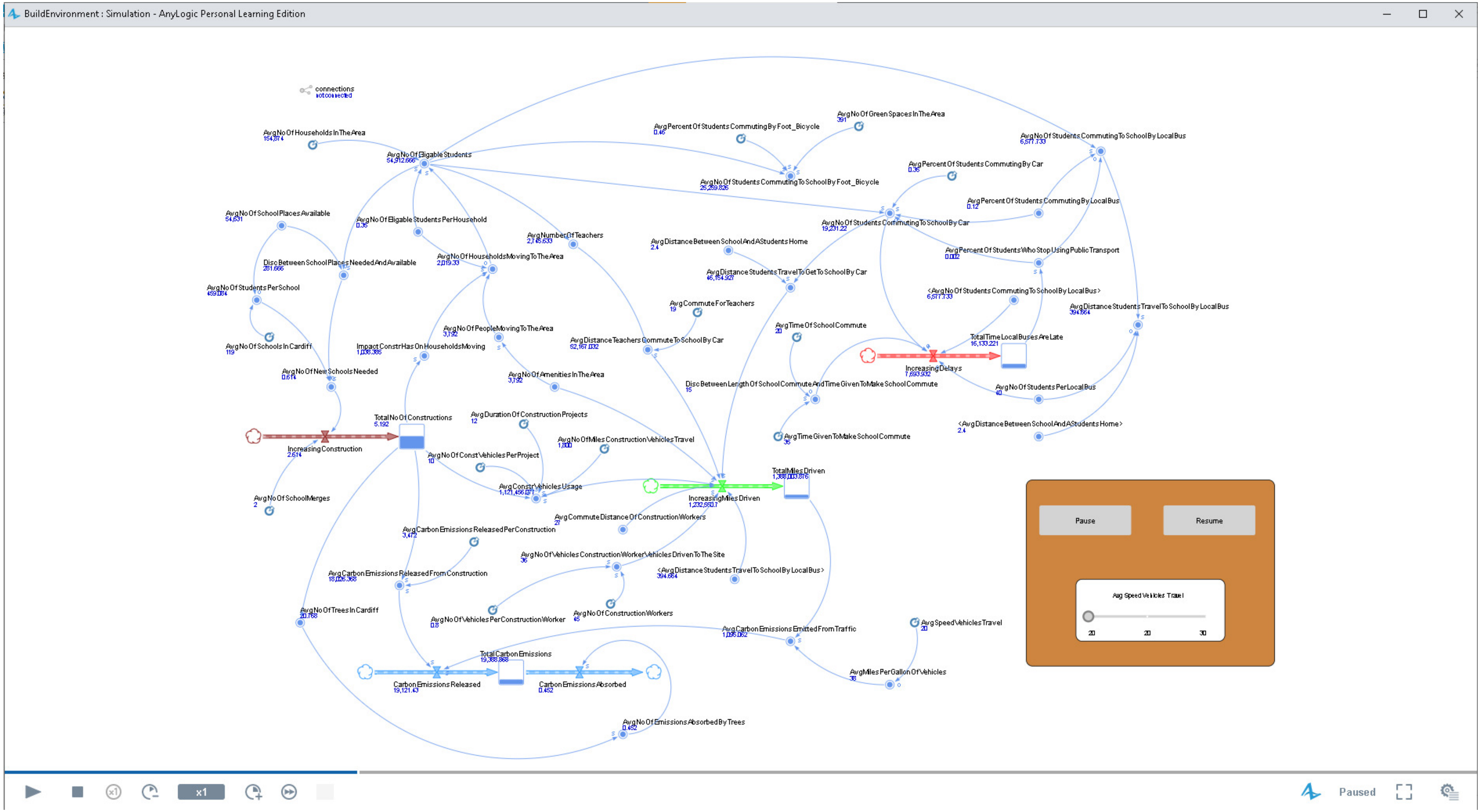

Figure 27 - Built Environment main simulation window

The additions made to this version of the model were the pause and resume buttons in the bottom right-hand corner, and the slider underneath the buttons. This slider is connected to the factor “Avg speed vehicles travel” which were used in the experiments (see Section 6.1.1.1). Later, during the experiments more sliders were added to aid in the policy testing that was being carried out, and they can be seen in figure 28. These elements make the simulation more interactive and allow you to affect the outputs of the simulation whilst it is still running.

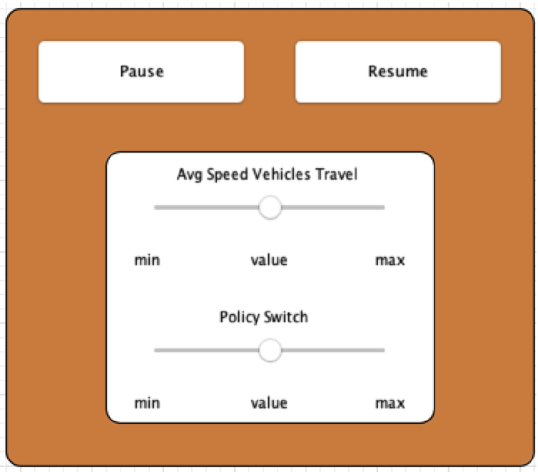

Figure 28 - Additional policy sliders for the Built Environment simulation

To benefit the simulation further and to allow users simulating the model to see the active change in the outputs of the simulation, graphs were added underneath the main screen, shown in figure 29.

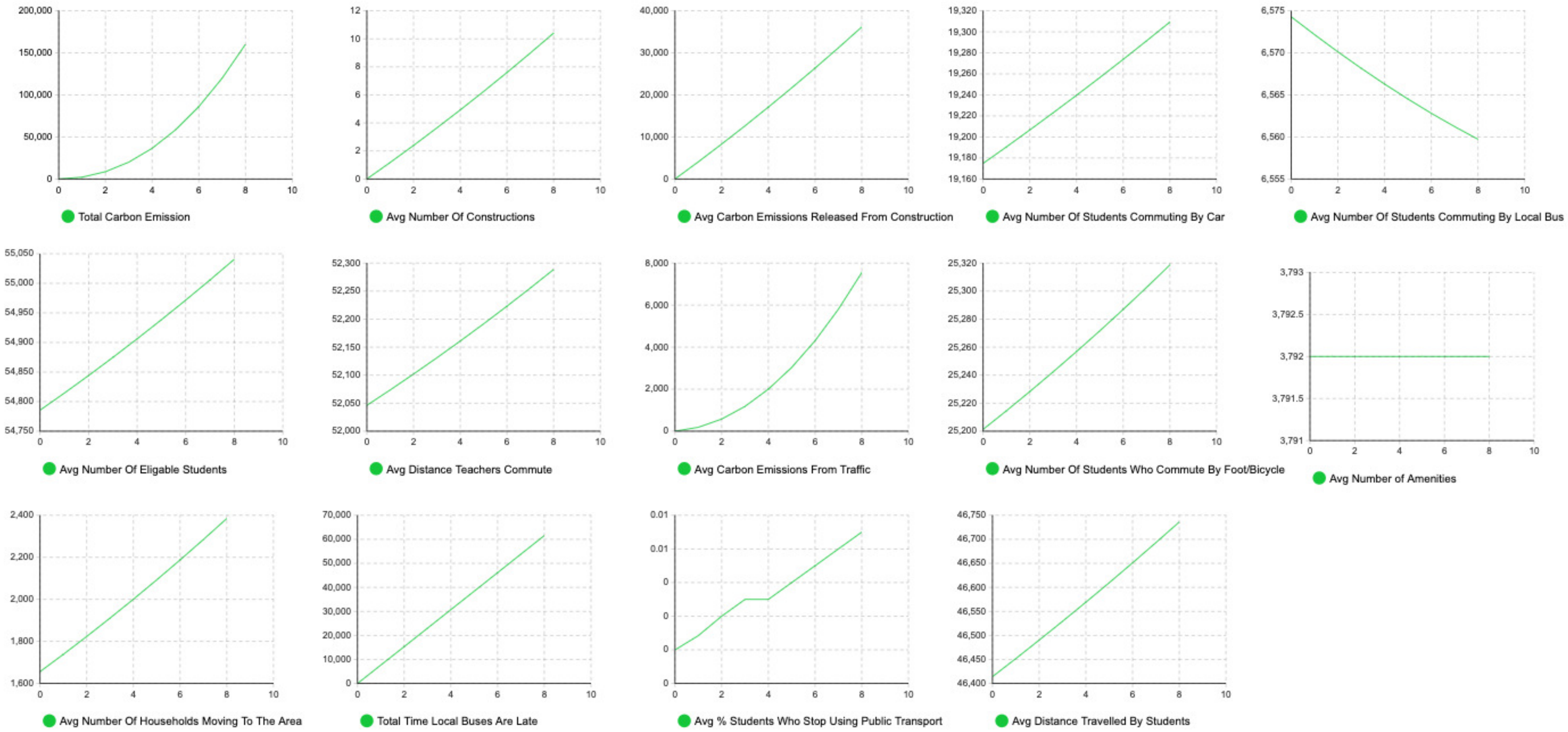

Figure 29 - Graphs in the Built Environment simulation

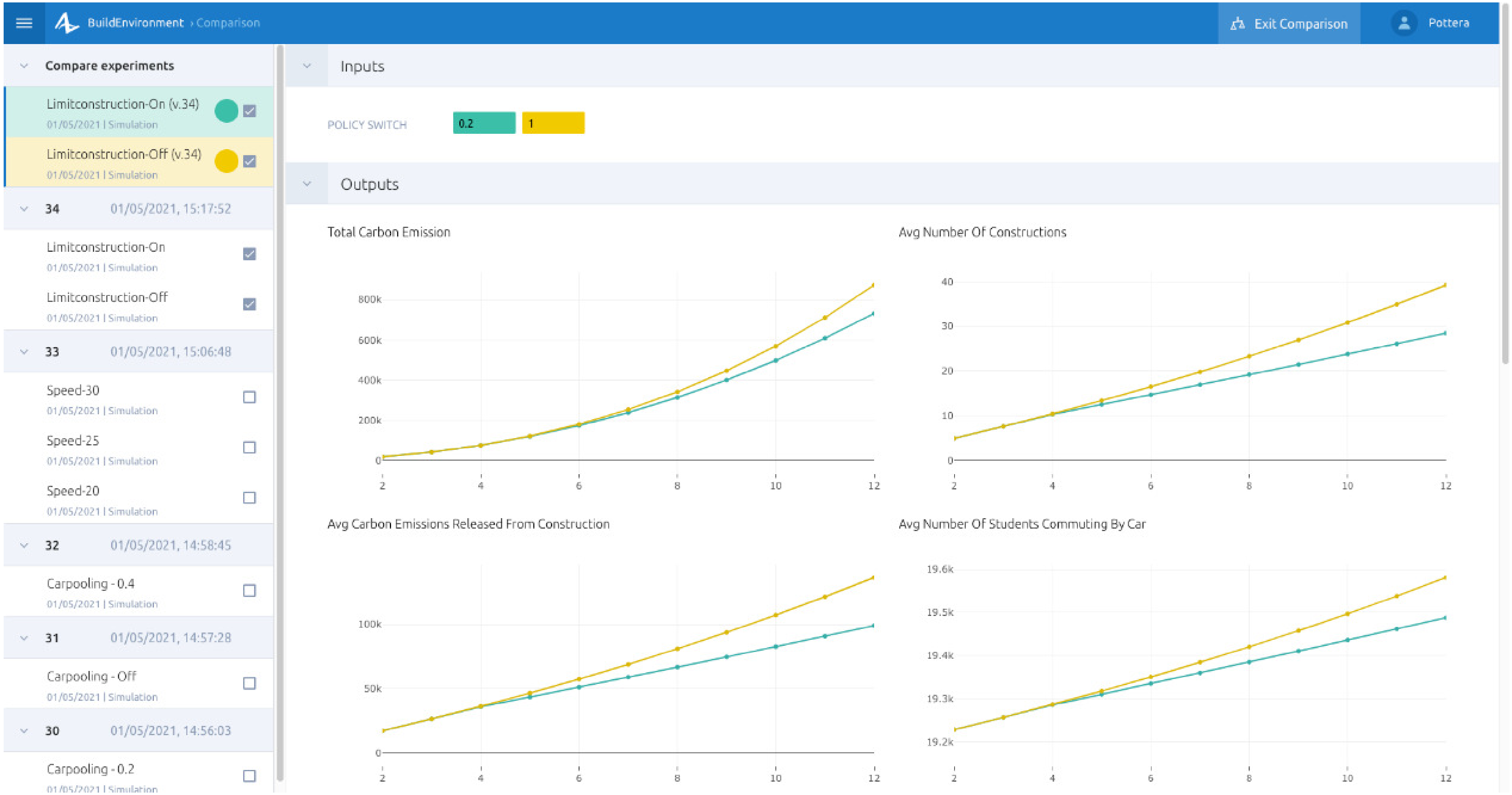

Figure 30 - Example of the cloud feature with the Built Environment simulation

The output graphs chosen were based on what experiments carried out and the most important areas of the model, such as the “Total Carbon Emissions” and “Avg carbon emissions from traffic”. As you move around the sliders you will be able to see an effect in the linking graphs to that variable, a cool feature of the simulated section. Making models more than just a stagnant image.

Another great feature of AnyLogic is its cloud feature, shown in figure 30. This feature allows you to run your simulations on the cloud and compare different variations that act as your experiments. The comparison feature is perfect for a project like this and it is the main reason why AnyLogic was chosen to run and view the simulations for the experiments over Vensim. To set up the cloud simulation all that was required to do was add the parameter factors that were involved in the experiments, and the graph outputs that were going to be compare, the tab to do this in is shown in figure 31.

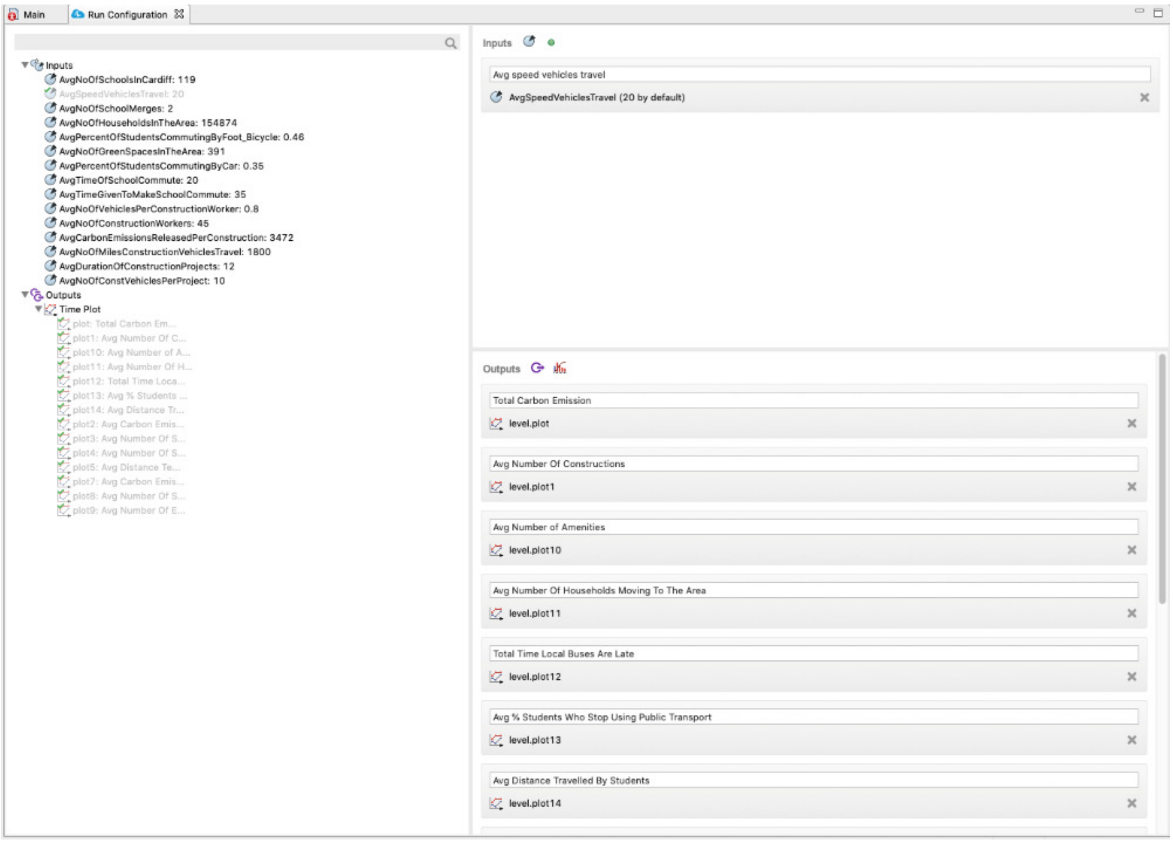

Figure 31 - Cloud feature set up for the Built Environment simulation

5.3.2 Food & Waste – Simulation

To simulate the food & waste stock and flow diagram the same process was followed as the one for the built environment simulation. The landing page was edited in the same design as the built environment simulation and the pause and resume buttons were also added to this model, which is shown by figure 32 & 33.

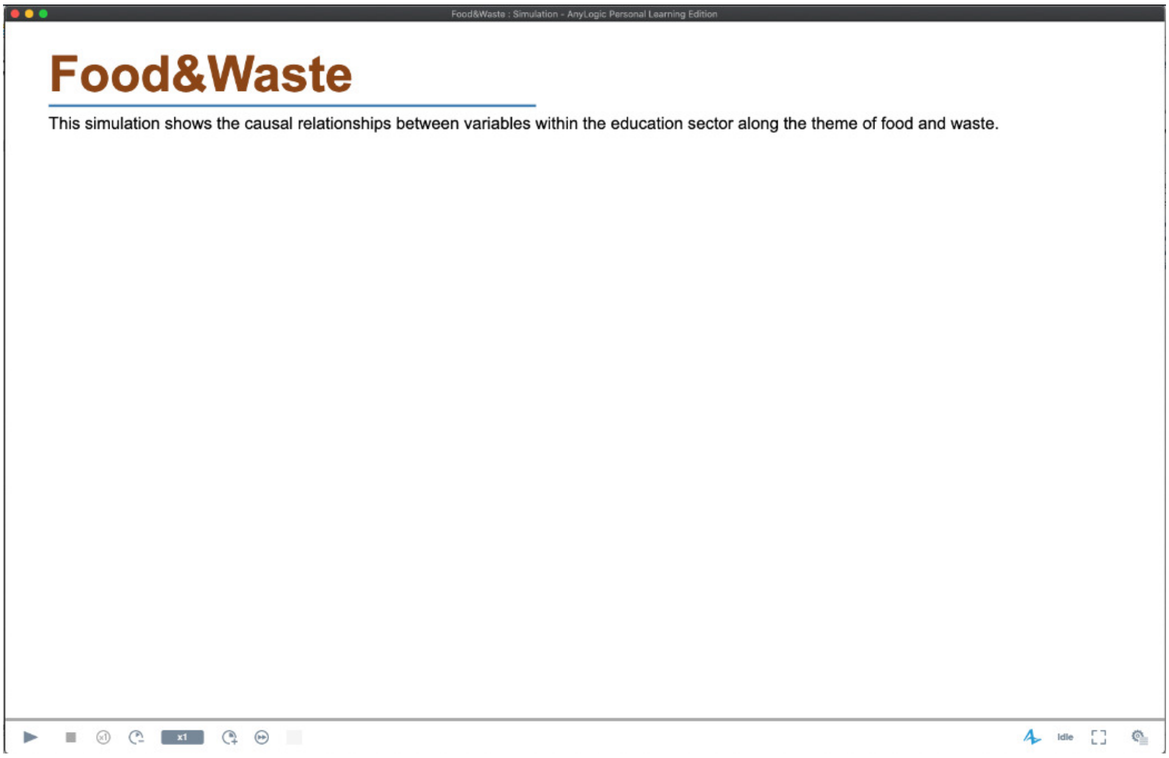

Figure 32 - Landing page for the Food & Waste simulation

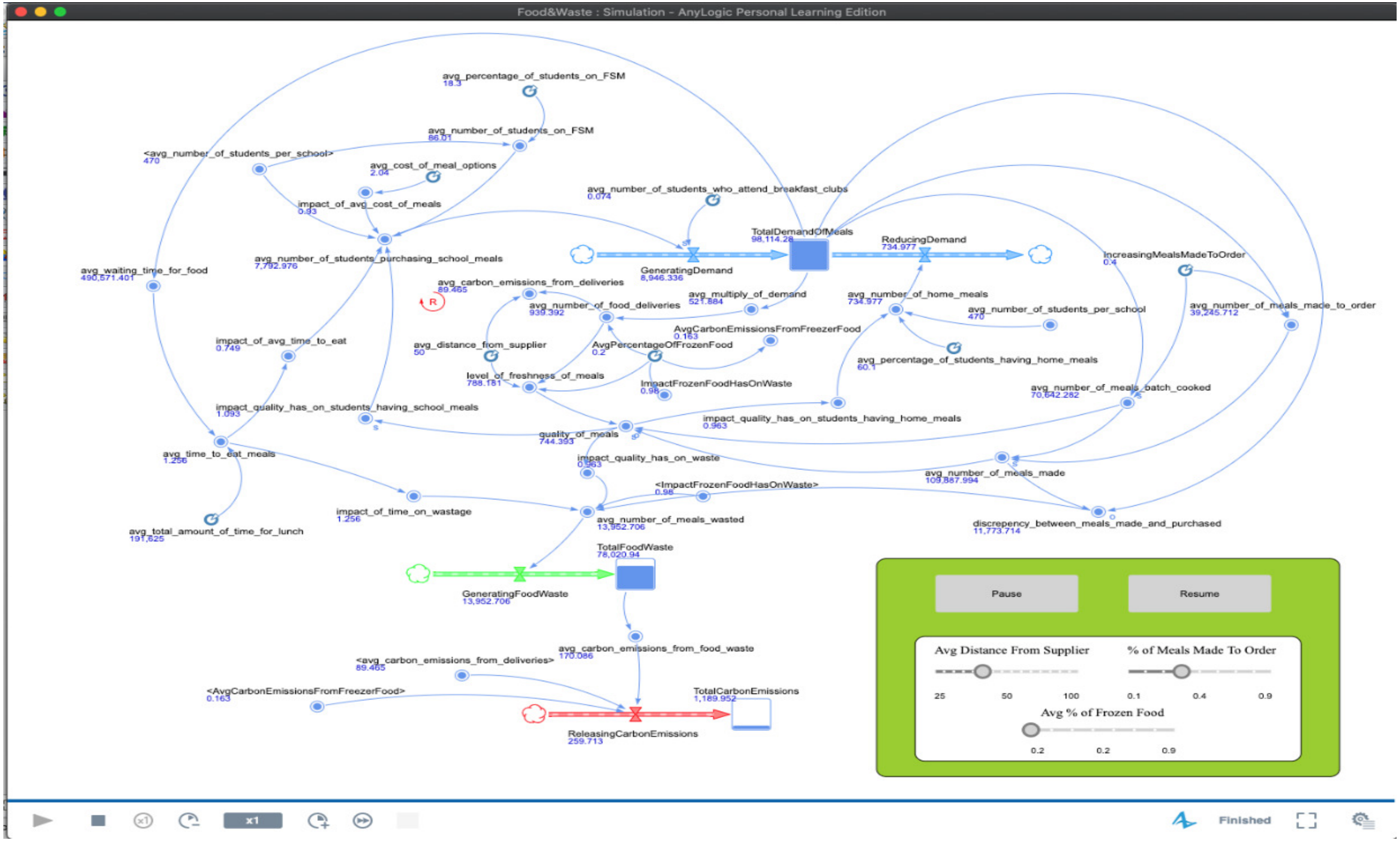

Figure 33 - Food & Waste main simulation window

For this simulation three sliders were added, which were connected to “Avg distance from supplier”, “Increasing meals made-to order” and “Avg percentage of frozen food”. All these sliders relate to the experiments undertaken in Section 6.1.2. Like the built environment simulation, graphs were added just beneath the window view and the graph outputs chosen where for the purpose of covering all the areas of the model and they align with the experiments completed, see figure 34 for the graphs.

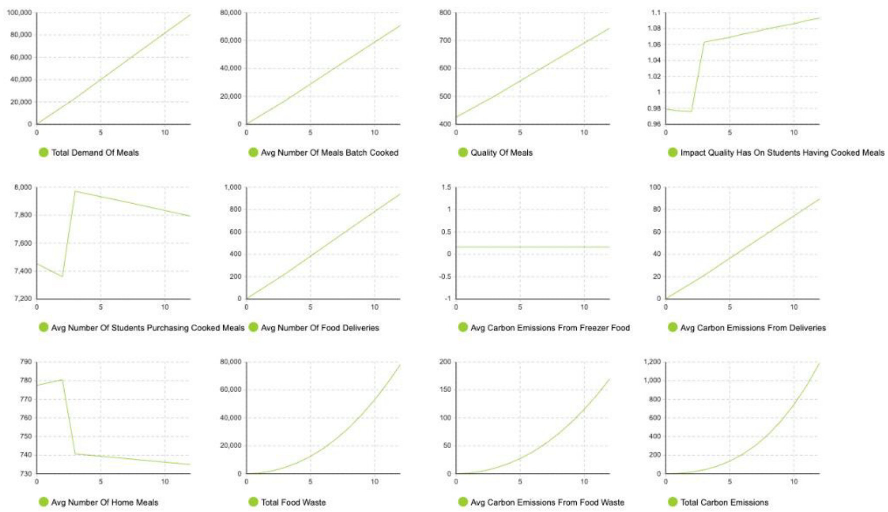

Figure 34 - Graphs in the Food & Waste simulation

Due to the success from running the built environment simulation through cloud feature, the simulation for this model was also ran through the feature, snapchat of this shown in figure 35. The process of setting this up was exactly the same as for the previous simulation, see figure 31.

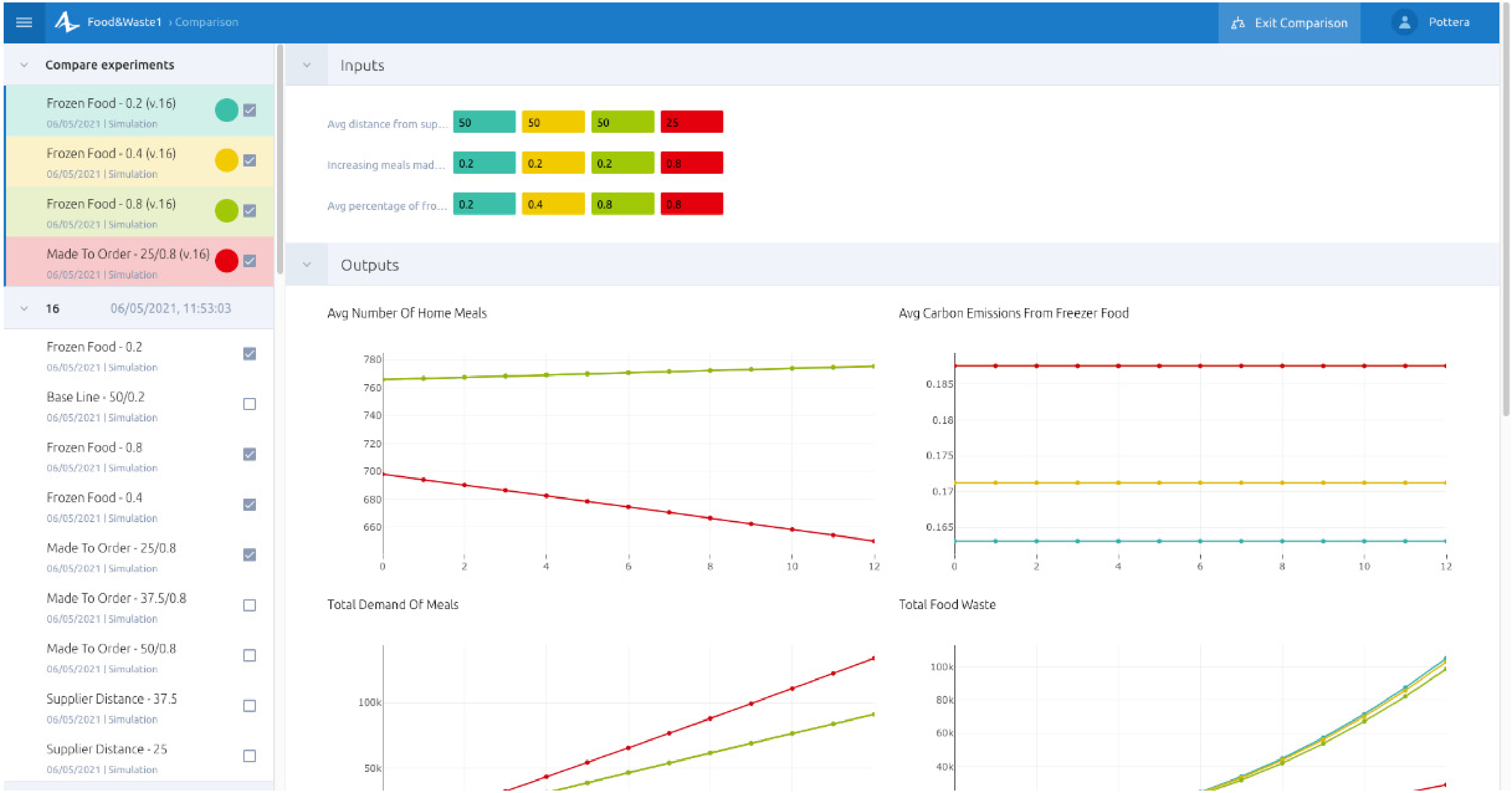

Figure 35 - Example of the cloud feature with the Food & Waste simulation

6 Results & Evaluation

In this section I will be describing the What-if experiments that were completed on the simulated stock and flow diagrams created in Section 5, the outcomes of these experiments and the policy action ultimately discovered through their completion. Additionally, I will be evaluating the success of the experiments in relation to the aims and objectives I intended to complete during the project. As mentioned above in further detail, AnyLogic's cloud feature will be used to run the experiments (See Section 3 Approach Selection for further details).

6.1 Results

6.1.1 Built Environment Simulation

6.1.1.1 Speed Limit Policy

Traffic carbon emissions have a large impact on overall emissions within this simulation, making it an important area to experiment policy action in, it also allows for transport emissions to be experimented, one of the three key areas of emission type described in Section 2.3.3. A major discussion in the space of traffic carbon emissions is in relation to the speed of vehicles. From research it was found that a vehicles mile per gallon (MPG) is negatively impacted when speeds are reduced from 30 miles per hour (MPH) to 20 MPH, which happens to be a common speed limit reduction in many areas with schools ((Department, 2016), and (Sims, 2021)). Due to this causality and link to the project scope an experiment was ran to test these findings and discover if there is an opportunity for policy action to benefit the environment.

There are several elements that can impact a vehicles MPG, but due to the scope of the project it was decided to focus on one of the main causal variables, the speed of the vehicle. Through my research and equation was formulated that simulated the impact speed has on a vehicles MPG (See Appendix E.47 for more details).

For this experiment three different values for "Avg Speed Vehicles Travel" were chosen , which were 20,25 and 30. These values were chosen because above 30 MPH the fuel economy of a vehicle doesn't improve further, making it redundant to go higher then this for the experiment, figure 36 shows these inputs (Sims, 2021).

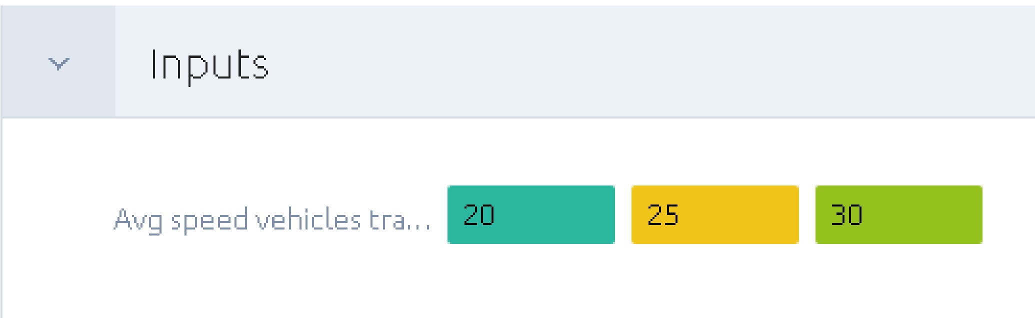

Figure 36 - Input for Speed Limit Policy

Examining the output graph “Avg Carbon Emissions from Traffic”, shown in figure 37, you can clearly see a decrease in emissions over time indicated by the green, yellow, and blue lines on the graph. The simulation output specifically shows a 7% decrease in emissions totally 867 T CO_2 emissions. Looking at the “Total carbon emission”, shown in figure 38, there is not as much of an impact, but that is to be expected due to the number of other factors contribute to this value. Despite the minimal change in “Total carbon emissions” overall the outputs show the trend predicted above and further backs the research I discovered.

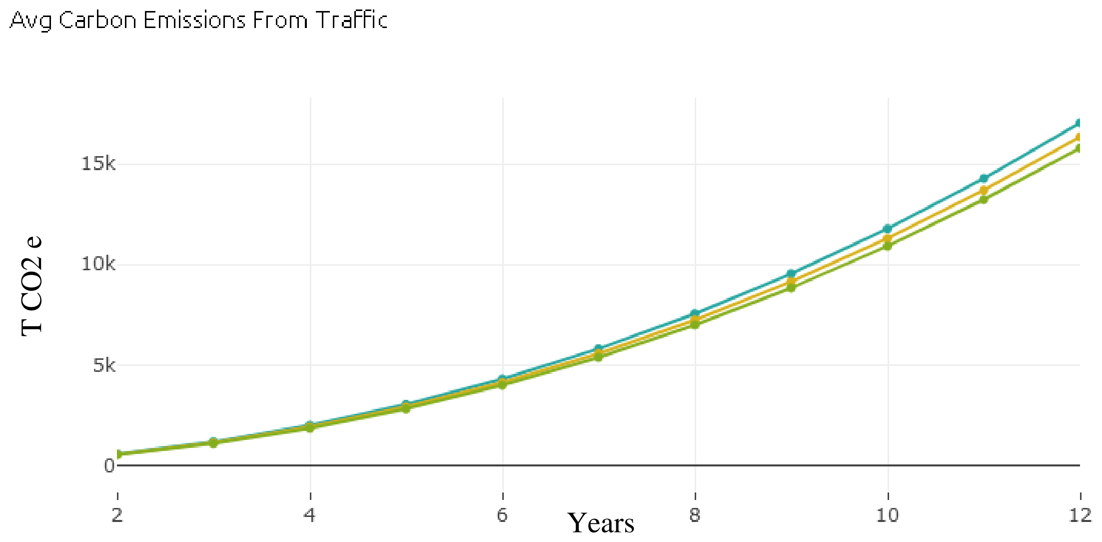

Figure 37 - Speed Limit policy "Avg carbon emissions from traffic" graph output

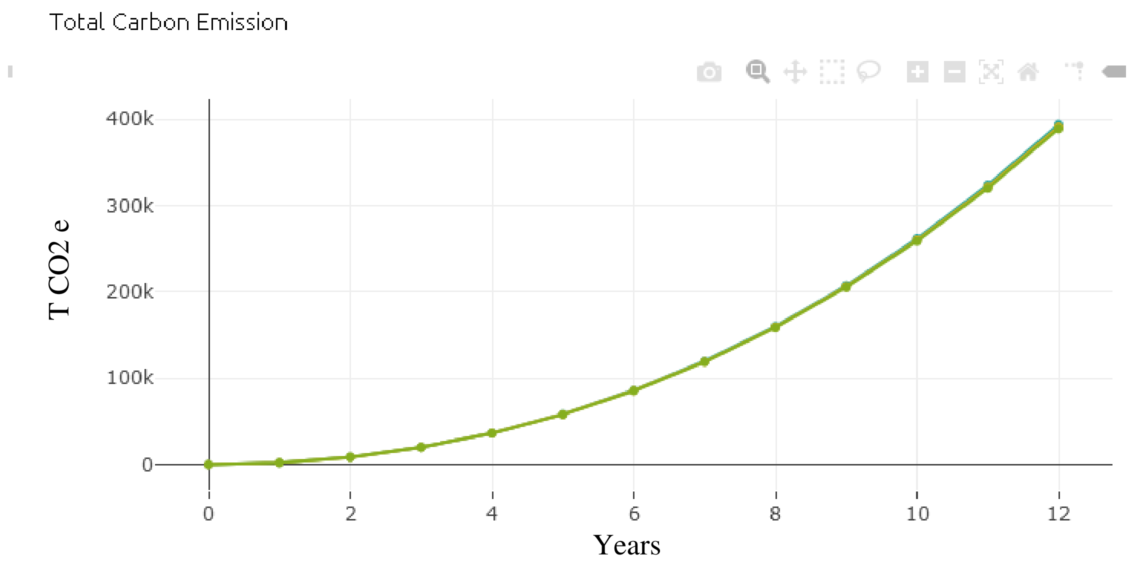

Figure 38 - Speed Limit policy "Total carbon emission" graph output

From this experiment I would recommend to Cardiff Council to increase speed limits in areas that are safe to do so. The trend shown proves that this policy would aid in reducing Cardiff’s transport carbon emissions and achieve the goal set in place of carbon neutrality by 2030.

6.1.1.2 Reducing School Construction Policy

Above the experiment was completed through solely what-if analysis of a parameter in the model. But for this experiment an additional dynamic variable was added to one of the reinforcing loops in the model (shown in figure 12) with the hopes of slowing the growth of constructions, which should reduce overall released carbon emissions.

The dynamic variable added is called “Limit Construction” (see Appendix E.57 for the calculation). “Limit Construction” represents a policy which limits the number of constructions in the education sector across 10 years. Between a certain threshold any new construction can only include extending a previous school building and not a whole new construction. Alongside this a parameter was added called “POLICY_SWITCH” to provide the simulation with the ability to switch the policy on and off to allow the experiment to be carried out fully on the Any Logic cloud feature (addition shown in Figure 39). I hypothesised that when switched on, the policy variable will cause the trend of decreasing construction and direct emissions to be apparent.

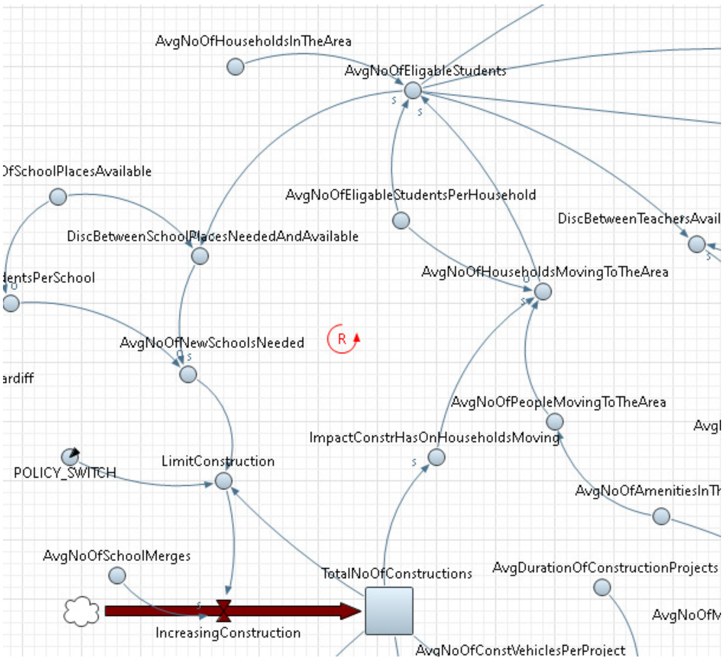

Figure 39 - Limit Construction policy addition to Built Environment stock and flow diagram

Figures 40 & 41 show the outputs of this experiment, the blue line indicates the policy variable being off and the yellow indicates it is switched on. There is a noticeable difference in “Avg Number of Constructions”, shown by figure 40, when comparing the two lines on the graph, which I hypothesised. More importantly the output of the “Avg Carbon Emissions Released from Construction” graph, shown in figure 41, shows a 23% decrease in carbon emissions. Understandably this is the result expected due to the trends the model showed prior to this policy but nonetheless this proves that such a policy would benefit and contribute to the carbon neutrality goal. There is further room for experimentation with this policy, for example, the limit on number of school constructions can be changed increasing or decreasing the emission levels but with the current model follow trends rather than exact data I did not see it fit to test anymore factors because the outcome would have been the same, in terms of trend data.

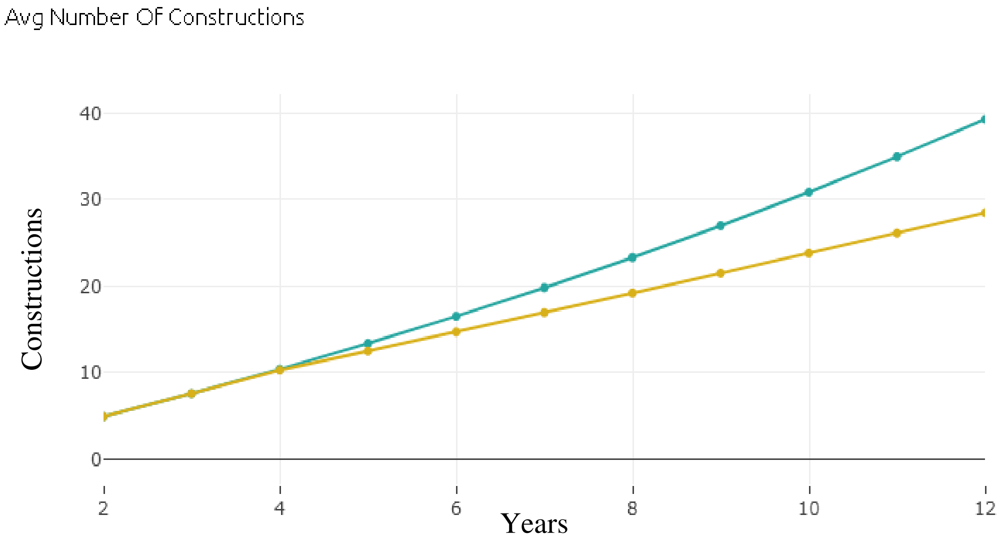

Figure 40 - Limit Construction policy "Avg number of constructions" graph output

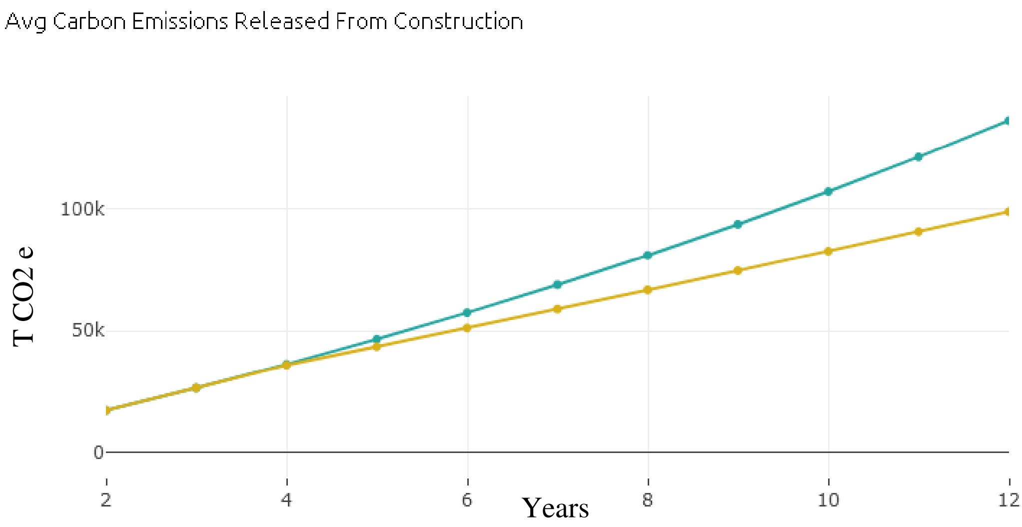

Figure 41 - Limit Construction policy "Avg carbon emissions released from construction" graph output

From this experiment I can concluded that a policy that limits the number of full school constructions and suggests school enlargements instead would provide noticeable impacts in slowing the exponential growth of number of school constructions shown by the model, which in turn will decrease the direct carbon emission from the education sector. The importance of such policy is vital due to its ability to reduce the reinforcing effects of the loop I identified and mentioned above. Without intervention constructions level will continue to grow and direct emission levels will reach dangerous levels, as shown by the model.

6.1.1.3 Carpool Policy

For this experiment, like the one above, it was decided to add an additional dynamic variable, but this time to the second reinforcing loop in the model (see Figure 42). With the aim to slow the increase in delays over time and reduce the rate that students switch from local buses to personal cars.

The dynamic variable added is called "Carpool" (see Appendix E.59 for the calculation). "Carpool" represents a policy which promotes carpooling to school over pupils going in their own cars every day. For this it was assumed that students live close enough to each other to make this possible and that all privacy and security concerns could be addressed by the school. I decided on implementing this policy because the reinforcing loop in this model indicated exponential growth between the link of "Total Time Local Buses Are Late" and the "Avg number of students who commute to school by car". Growth, which if not dealt with, could hinder the achievement of carbon neutrality due to the decrease in students using public transport and increase in personal transport instead. With this policy I hypothesised that there will be a reduced number of cars on the road, due to students pairing up on their commutes, which will reduce overall delays and slow down the decreasing numbers of students taking the local bus. Overall reducing carbon emissions from traffic and the transport carbon emission released by the education sector.

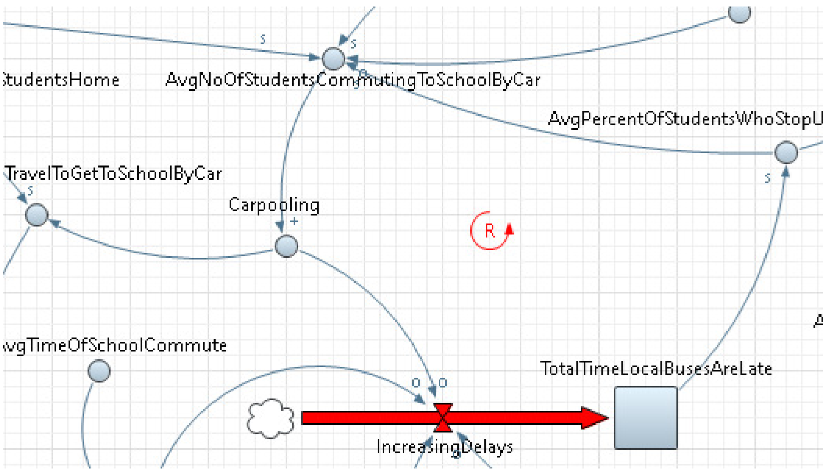

Figure 42 - Carpool policy addition to the Built Environment stock and flow diagram

Figures 43-48, shows the results of this experiment. Unlike the experiment above, two different variations of this policy were chosen for the experiment, the first being 20% of students who go by car share with another student (represented by the green line) and the second being 40% of students who go by car share with another student (represented by the blue line). The yellow line shows the policy is off/ not implemented. Several graphs were chosen to view the results of this experiments due the differing impact this policy can have on multiple factors. Looking at the "% Students who stop using public transport", shown by figure 43, when the policy is set to 20%, there is a 11.1% decrease in students who stop using local transport, which increases further to 22.2% when the percentage of students who carpool is set to 40%.

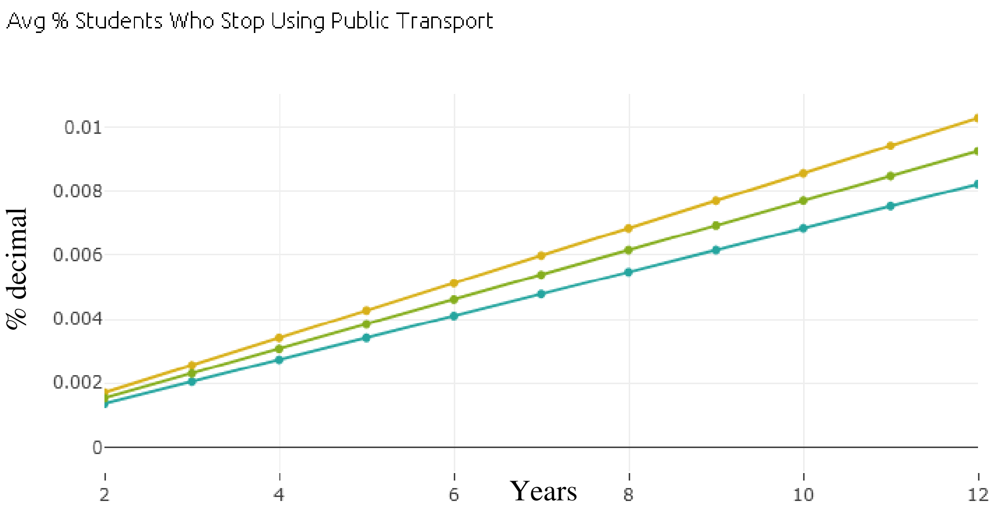

Figure 43 - Carpool policy "Avg % students who stop using public transport" graph output

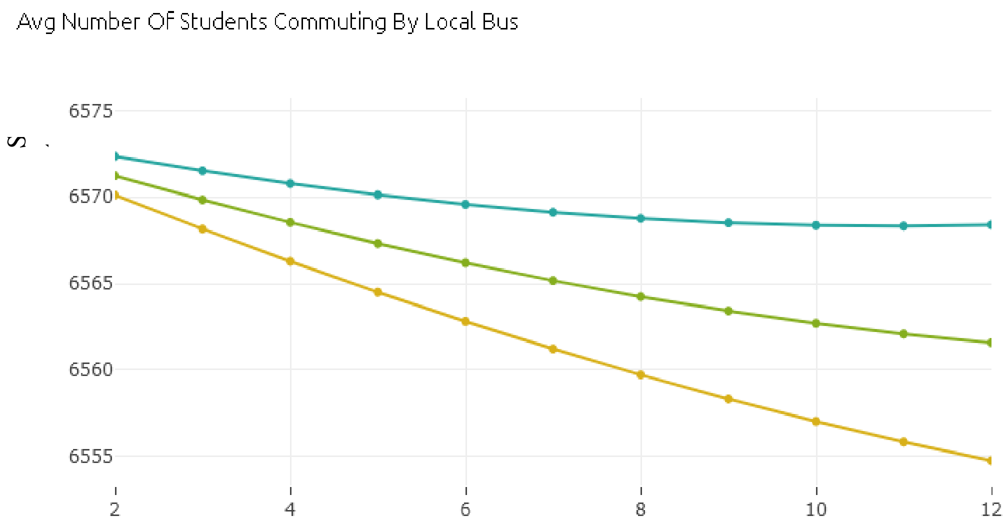

Figure 44 - Carpool policy "Avg number of students commuting by local bus" graph output

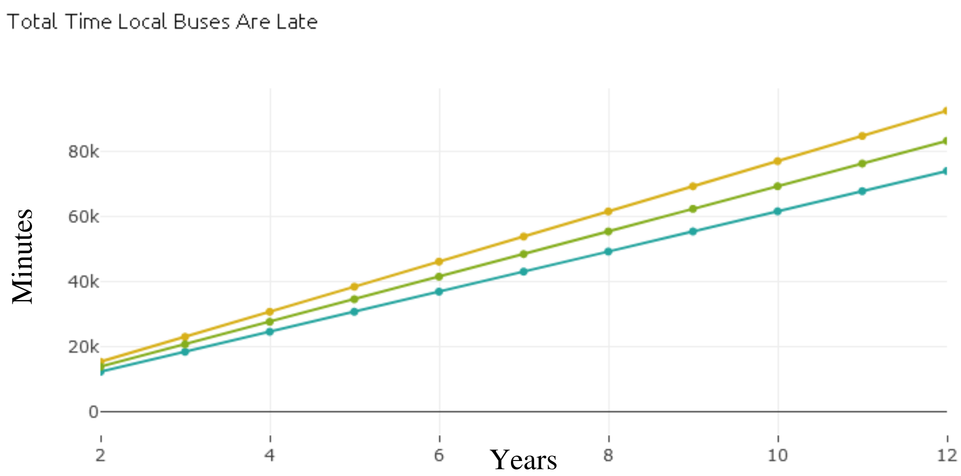

Figure 45 - Carpool policy "Total time local buses are late" graph output

A similar trend can be seen in “Total Time Local Buses Are Late”, shown by figure 45, which shows a 10% decrease in total time buses are late when the policy is set to 20% and a 20% decrease when the policy is set to 40%. Showing the exact trend, I hypothesised. Undoubtedly this trend is then reflected on the “Avg number of students who commute to school by local bus”, shown by figure 44, which is also expected because of its direct link to the “% Students who stop using public transport”.

More importantly however, we can see there is an impact on the “Avg distance travelled by students”, “Avg carbon emissions from traffic”, and “Avg number of students commuting by car”, shown by figure 46, 47 & 48. The impact here shows a slight reduction of students going my car but a larger reduction in the “Avg distance travelled by students” which reduces “Avg carbon emissions from traffic”, a trend I hypothesised.

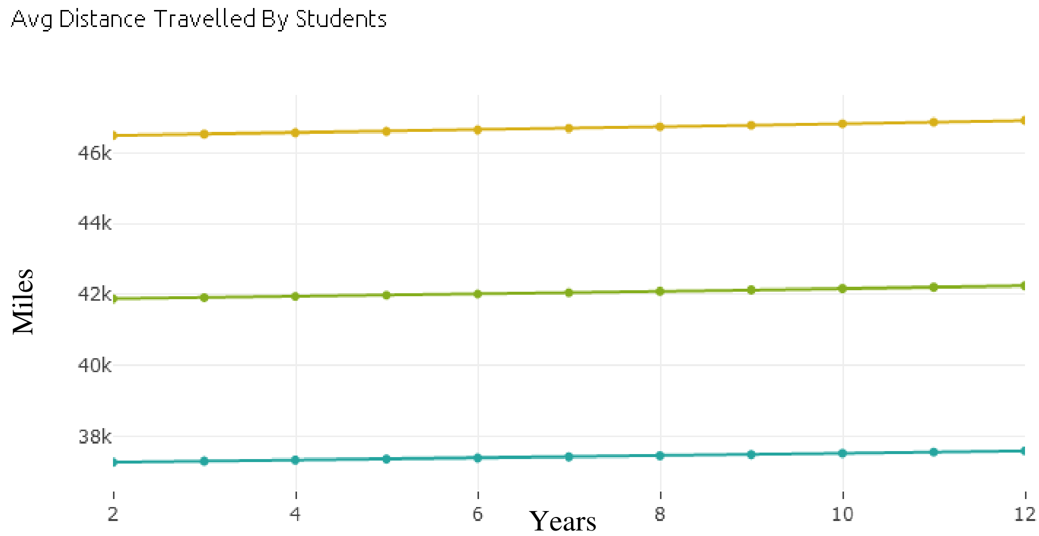

Figure 46 - Carpool policy "Avg distance travelled by students" graph output

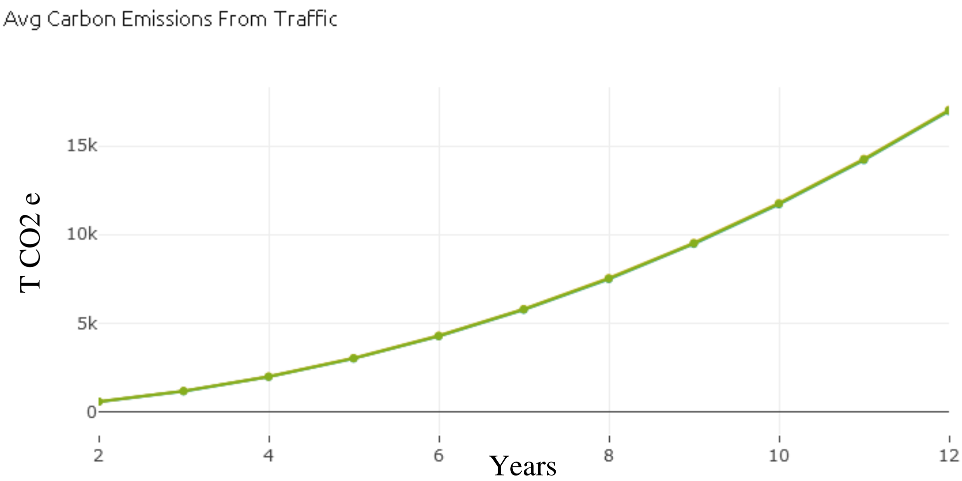

Figure 47 - Carpool policy " Avg carbon emissions from traffic" graph output

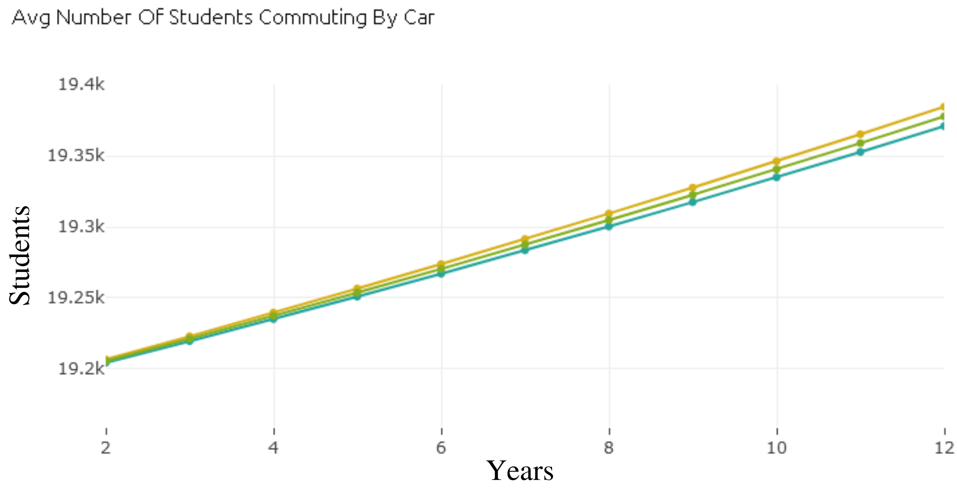

Figure 48 - Carpool policy "Avg number of students commuting by car" graph output

From this experiment I concluded that the policy of recommending carpooling to school to students, has not only a positive impact in increasing public transport usage, which will aid in the reduction of traffic and delays, but it has also impacted the overall distance travelled per student by reducing it and reducing the transport carbon emissions released from traffic. These trends obtained from the experiment shows the important effect this policy could have on the carbon neutrality goal, if implemented in schools.

6.1.2 Food & Waste Simulation

Due to the size of this model and the higher interconnectivity of the factors within the model compared to the previous one, there will not be as many experiments. However, the interconnectivity of the factors does allow for more complex experiments to take place, which involves changing multiple factors at once, rather than just one.

6.1.2.1 Local Food Suppliers & Made-to Order Policies

Within this simulation there is one main reinforcing loop (see Figure 49). This loop shows the reinforcing impacts of increased demand on deliveries needed and overall quality of meals, causing a further increase in demand. Normally, policy would be inserted to slow down the exponential growth loops like this cause. However, in this case it is not a bad thing that more students are purchasing more food, the problem lies with the impact this exponential growth has on direct carbon emissions and wastage.

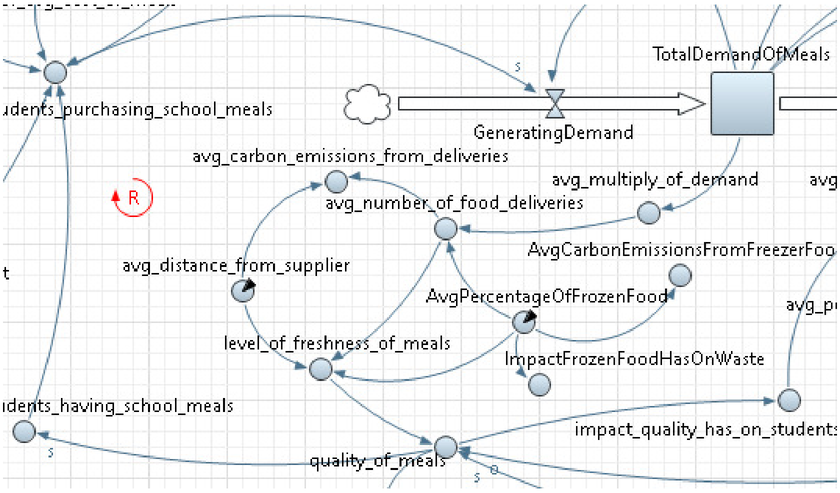

Figure 49 - Food & Waste reinforcing loop

For these experiments two factors were chosen, to represent several potential policies. The factors names were “Avg distance from supplier” and “Avg % of meals made to order”. The experiment on “Avg distance from supplier” represents a policy that recommends schools purchasing from local suppliers over more distant ones, to reduce carbon emissions from deliveries and the experiment including “Avg % of meals made to order” will represent a policy that persuades schools to make pre-ordering possible when purchasing school meals to reduce food waste from leftover meals.

I hypothesised that a combination of these factors will decrease overall direct and embodied carbon emissions released from the food and waste sector of education. Through the reduction of waste and embodied carbon emissions in the supply chain by the reduction of miles driven to get the food required to schools.

6.1.2.1.1 Local Food Supplier Policy

For the first experiment only the value of “Avg distance from supplier” was changed to get results of the impacts changing the value of this factor has on certain areas of the model. Providing a baseline to evaluate against after completion of the other experiments. The value of “Avg % of meals made to order” is set at 0.2 (accounting for any special food items that are only pre-order) and “Avg percentage of frozen food” currently isn’t implemented so the factor is not involved in the experiment. The values chosen for “Avg distance from supplier” were 25, 37.5 & 50. These were chosen due to data indicating the average distance that food suppliers are from schools (50 miles) and what constitutes as ‘local’ for a school in terms of deliveries (25 miles), with 37.5 miles being in the middle of the two (Life, 2021).

Figures 51-55 show the outputs of the experiment, where the blue line represents 25 miles, the yellow line represents 37.5 miles, and the green line represents 50 miles. The trends shown in the results align exactly as I hypothesised. As “Avg distance from supplier” was decreased, shown by figure 50, the “Avg carbon emissions from deliveries” decreased by 48.2%, and “Total carbon emissions” decreased by 22.1%, a highly successful result.

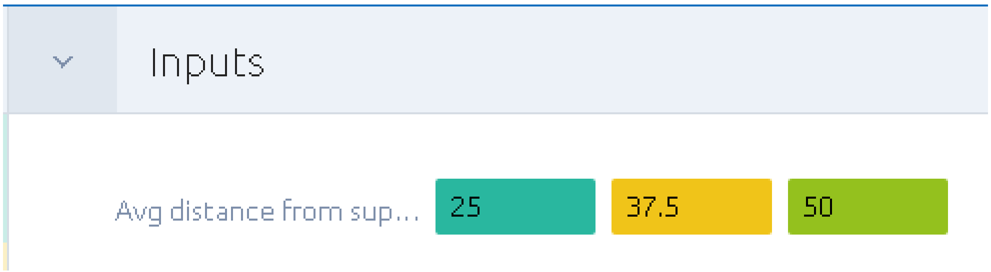

Figure 50 - Local Food supplier policy input

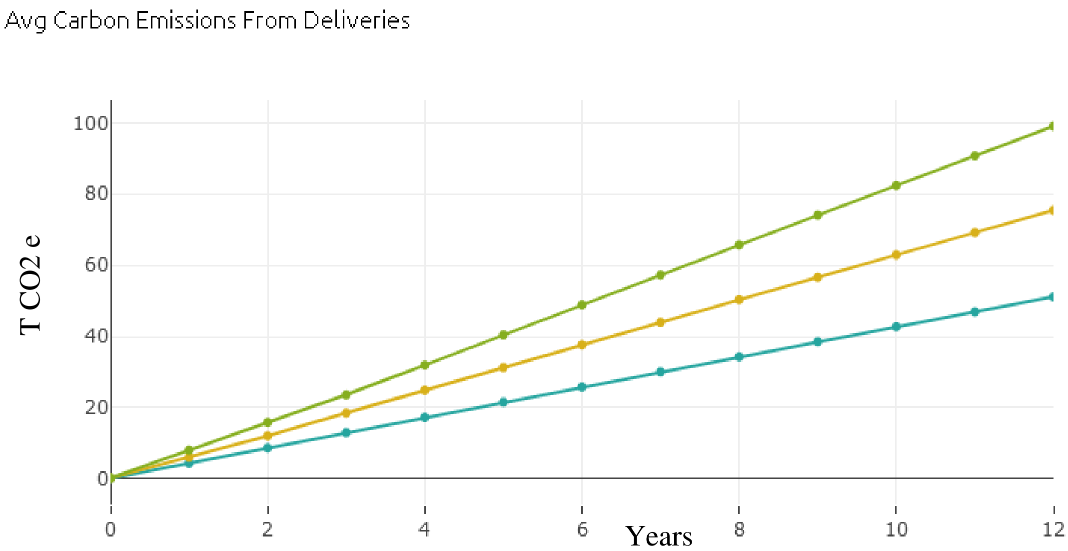

Figure 51 - Local food supplier policy "Avg carbon emissions from deliveries" graph output

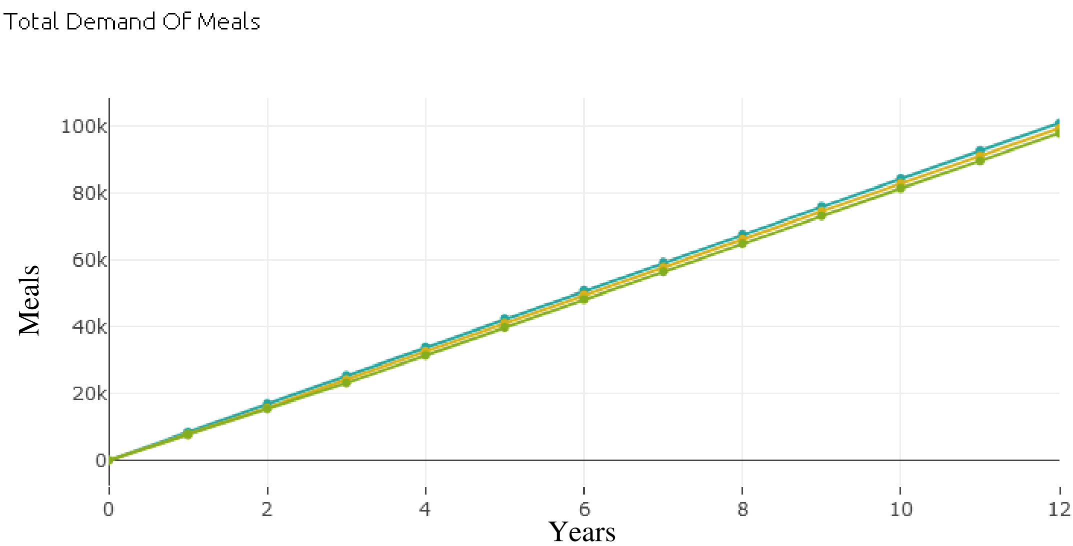

Figure 52 - Local food supplier policy "Total demand of meals" graph output

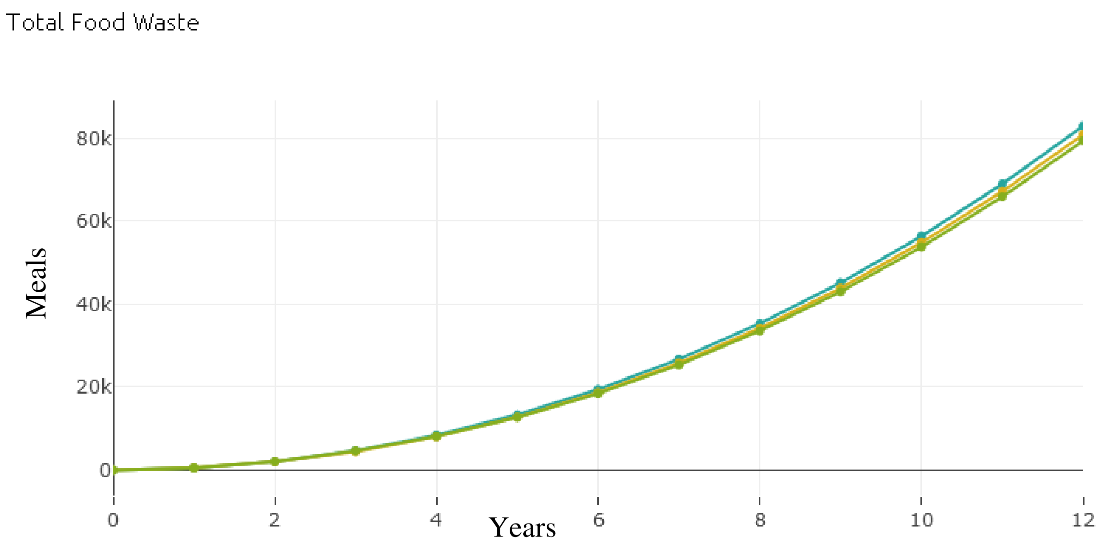

Figure 53 - *Local food supplier policy "Total food waste" graph output*

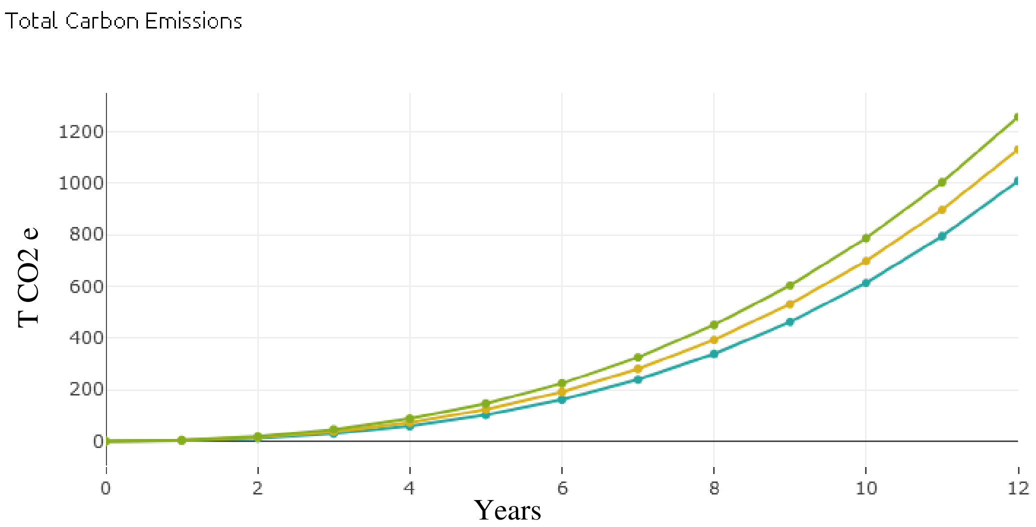

Figure 54 - *Local food supplier policy "Total carbon emission" graph output*

Figure 55 - Local food supplier policy "Avg carbon emissions from food waste" graph output

Another trend shown by the results that I also hypothesised was the impact the distance between school and supplier would have on food waste. The graph “Total demand of meals”, shown by figure 52, showed a slight increase when distance was decreased which is then reflected by an increase in “Total food waste” and subsequently “Avg carbon emissions from food waste”. However, “Total carbon emissions” showed an overall decrease despite the additional food waste, meaning the adoption of purchasing from local suppliers will have an overall positive impact on Cardiff reducing its 2030 goal, without the need to change any other variable.

6.1.2.1.2 Made-to Order Policy

Despite the experiment above providing evidence that the local food supplier policy would reduce “Total carbon emissions” by itself, it was still important to run an experiment that involved the implementation of the made-to order policy due to its undoubtable benefits it would bring in terms of food waste and carbon emissions reduction. For this experiment the value of 0.8 for “Avg % of meals made to order” was chosen and the values used for “Avg distance from supplier” in the above experiment were the same values used for this experiment.

Figures 56-60, show the results of the experiment, each graph also shows the results from the previous experiment for easier comparison. The blue, yellow and green lines still represent the results from the experiment above to avoid confusion. The new lines, red, brown and salmon, show the values of 25, 37.5 and 50 for “Avg distance from supplier” with a value of 0.8 for “Avg % of meals made to order” retrospectively. On initial inspection the trends shown by the outputs seem to be as expected. For “Total food waste” and “Avg carbon emission from food waste”, shown by figure 56 & 57, you can see the lines for this experiment are below those from the previous experiment showing the implementation of the made-to order policy has reduced food waste and carbon emissions from food waste.

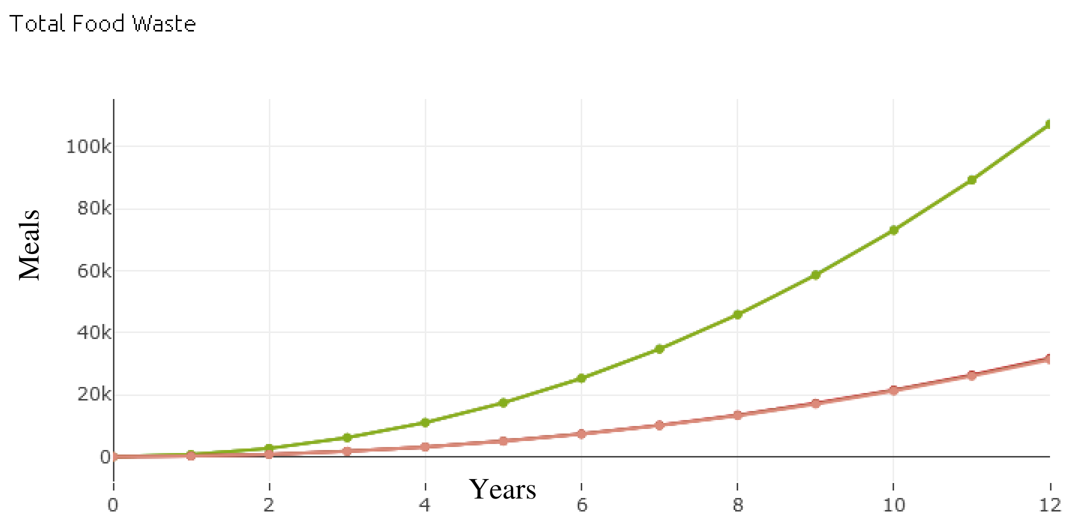

Figure 56 - Made-to order policy "Total food waste " graph output

Figure 57 - Made-to order policy "Avg carbon emissions from food waste " graph output

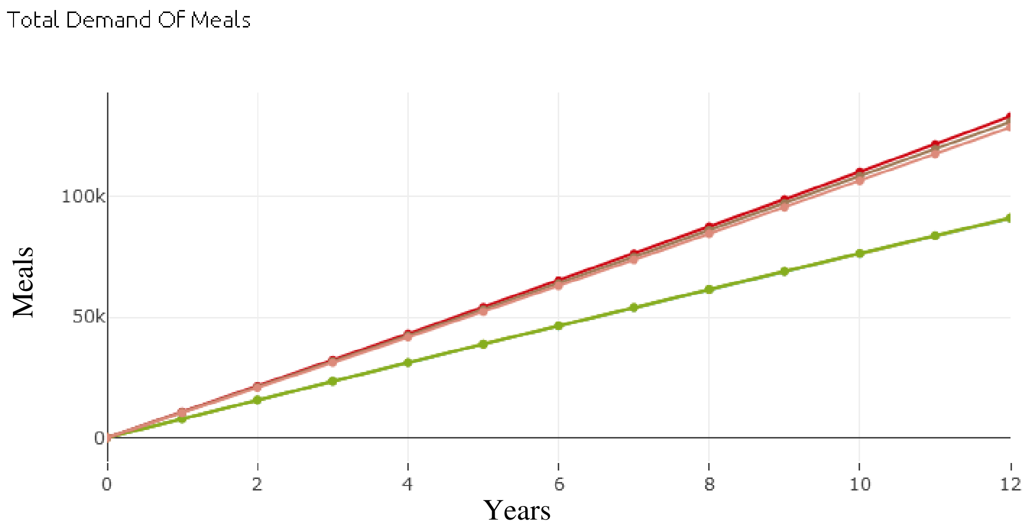

Figure 58 - Made-to order policy "Total demand of meals " graph output

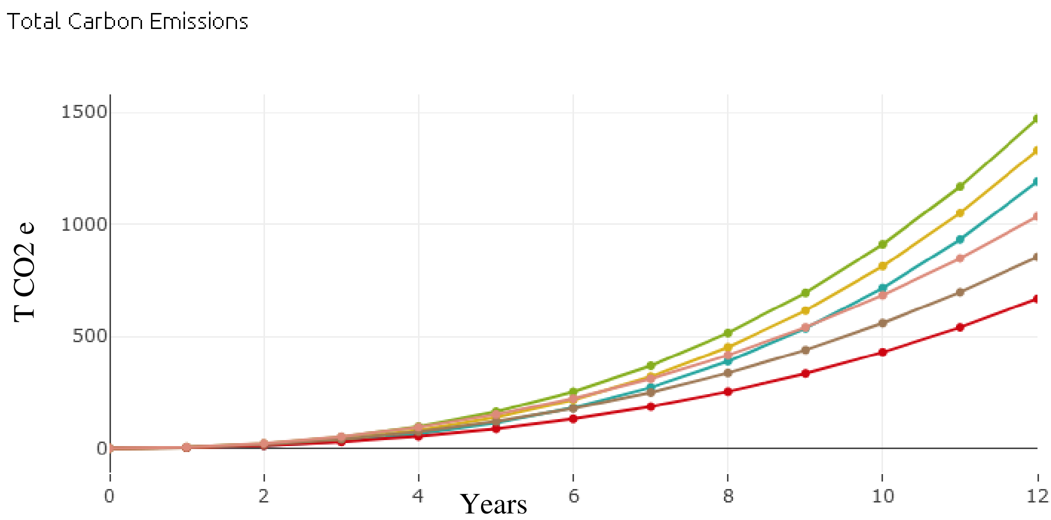

Figure 59 - Made-*to order policy "Total carbon emissions" graph output*

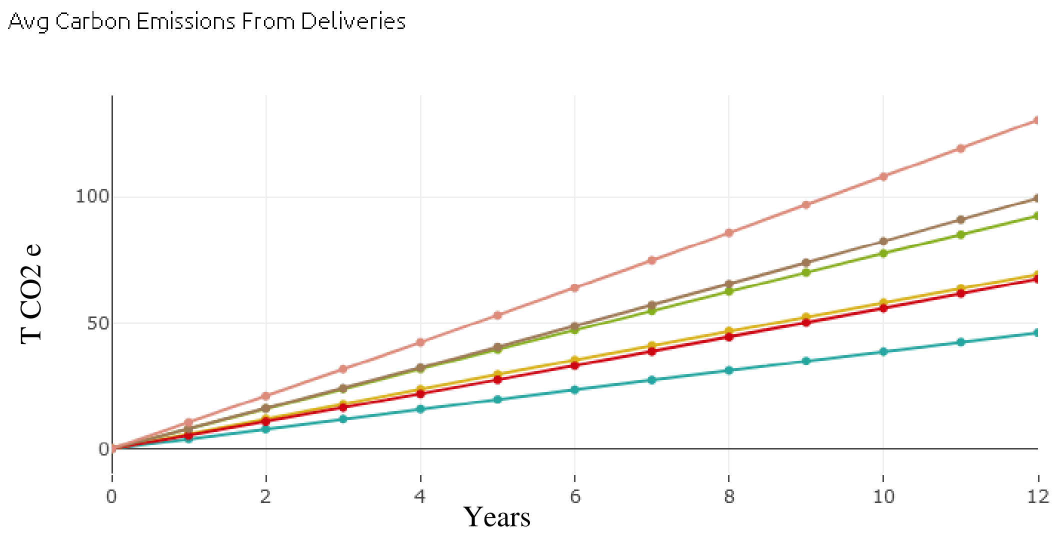

Figure 60 - Made-to order policy "Avg carbon emissions from deliveries" graph output

However, looking at “Total demand of meals”, shown by figure 58, the results show an increase effect caused by this new policy. Which is understandable, as made-to order meals are fresher then batched cooked meals but I wasn’t expecting such a large impact of 23% (based off the top lines of each experiment). This effect has carried over to “Avg carbon emissions from deliveries”, shown by figure 60, where you can see a crossover of the two experiment groups. This cross over shows despite the implementation of the new policy reducing “Avg carbon emissions from food waste” greater than any value variations in the previous experiment, it is the blue line, which is from the previous experiment, that measures the lowest for “Avg carbon emissions from deliveries”. Indicating, in terms of “Avg carbon emissions from deliveries”, that the most carbon efficient value pair for “Avg distance from supplier” and “Avg % of made-to order meals” is 25 and 0.2 and not 25 and 0.8, retrospectively. Emphasising the importance of balance when deciding on how multiple policies are implemented at once. Careful considering is required to deciding the best value pair, to ensure the best results. Further evidence of this balance needed to be considered is shown by “Total carbon emissions”, shown by figure 59, which also has an experiment group cross over. Unlike the results of “Avg carbon emissions from deliveries”, the lowest “Total carbon emissions” value is from the expected experiment group, this current experiment, but it is important to note a cross over at the 8-year mark between the value pairs of 50/0.8 (salmon line) and 25/0.2 (blue line). By the 10 year mark this experiment group does produce lower carbon emissions in all value pairs but if the policies were to be removed before a 10-year period was completed, then they no longer are the best performing. Highlighting the importance of knowing the exact amount of time the policies chosen are going to be enforced for to ensure optimised performance.

6.1.2.2 Frozen Food Policy

After the successful results from the previous experiment, other areas of the model were examined to identify any areas that would benefit from further policy action. There wasn’t a clear area chose, so an additional policy around deliveries and avg carbon emissions from deliveries was added, with the aim to tackle one of the main causes of delivery carbon emissions from the sector, the number of deliveries being made.

For this experiment an addition factor was added called “Avg % of frozen food” to represent a policy that recommends schools to move away from fresh produce and focus on frozen ingredients to reduce deliveries required and potentially decrease food waste. I hypothesised that the experiment would show that exact trend, decreased deliveries and food waste when the percentage of frozen food increased, which subsequently will reduce “Avg carbon emissions from deliveries” and “Total carbon emissions”.

Three values were chosen for the experiment which were 0.2, 0.4 and 0.8, ensuring a range of variations of uptake of the policy were measured. For three of the iterations of this experiment “Avg distance from supplier” and “Increasing meals made to-order” were kept as their base line values of 50 and 0.2 retrospectively. For the fourth and final iteration of this experiment the “Avg distance from supplier” and “Increasing meals made to-order” value pair was changed to 25/0.8, which represents the most effective combination of these two policies indicated from the previous experiment (see Section 6.1.2.1), based on the assumption a school will keep them implemented for a 10-year period (inputs shown by figure 61).

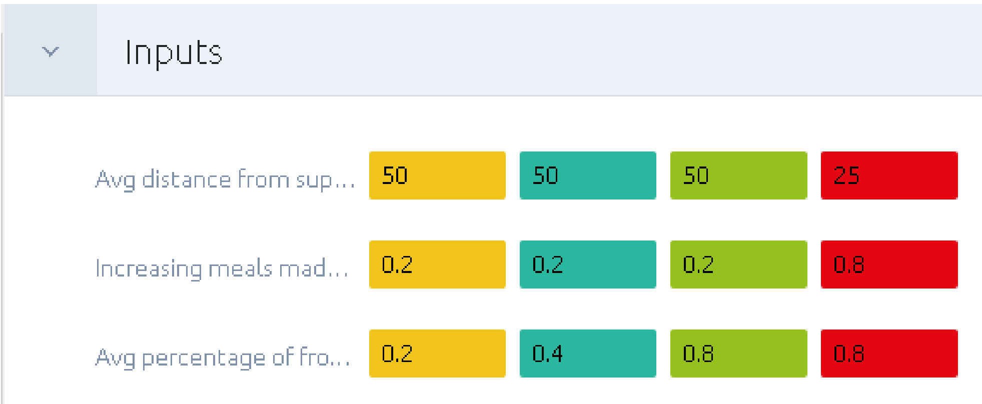

Figure 61 - Frozen Food policy input

Figures 62-65 show the results of the experiment. The yellow, blue and green lines show the outputs for the values of 0.2, 0.4 and 0.8 with base line values for the other factors, retrospectively. The red line shows the output of the iteration that had 0.8 as the value for “Avg % of frozen food” and the value pair of 50/0.8 for “Avg distance from supplier” and “Increasing meals made to-order”. Looking at the “Avg carbon emissions from deliveries” graph output, shown by figure 62, the trends are as expected and the impact of the policy is shown to successfully reduced carbon emission; as the percentage of frozen food increases, avg carbon emissions decreases. The red line shows the result of combining all three policies together, and the output is lower than all the iterations above, which was expected.

Figure 62 - Frozen food policy "Avg carbon emissions from deliveries" graph output

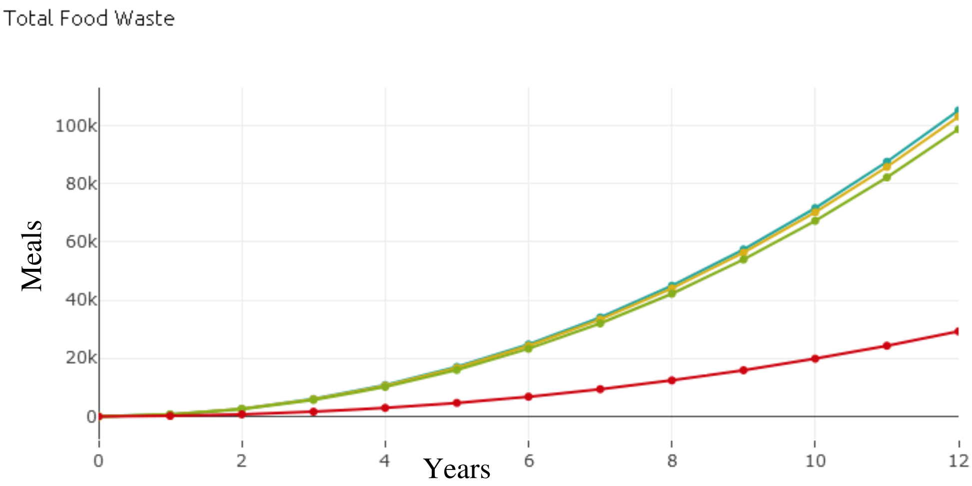

Figure 63 - Frozen food policy "Total food waste" graph output

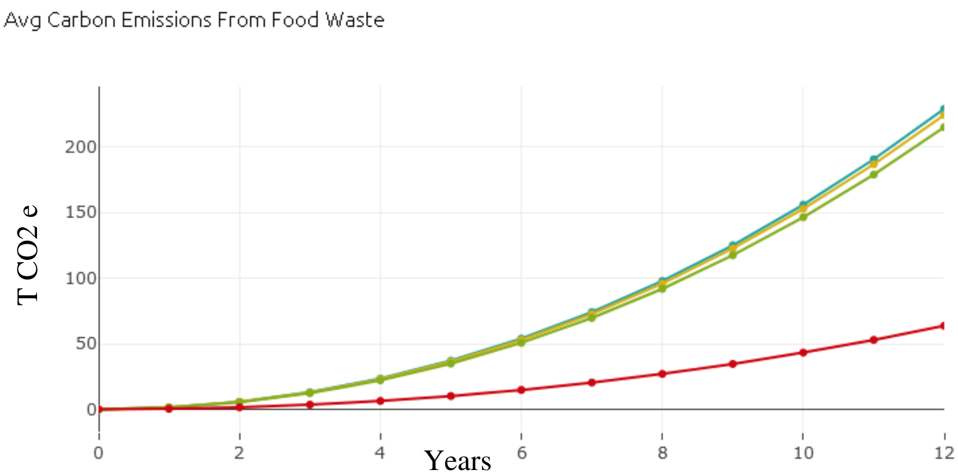

Figure 64 - Frozen food policy "Avg carbon emissions from food waste" graph output

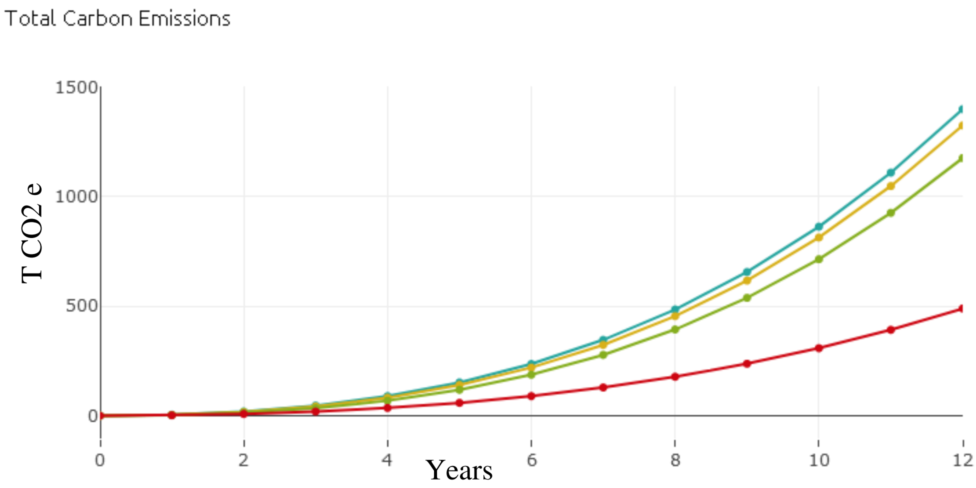

Figure 65 - Frozen food policy "Total carbon emissions" graph output

For “Avg carbon emissions from food waste” and “Total food waste” graphs, shown by figures 62 & 63, the impact of varying the percentage of food waste is not as high compared to the results illustrated on the “Avg carbon emissions from deliveries” but that was to be expected due to there being more factors impacting food waste compared with the number of deliveries. However, when combined with the other two policies there is a huge impact on “Avg carbon emissions form deliveries” and “Total food waste”. Providing further evidence of the benefits of policy combination in terms of this area of the education sector. The same result is similarly reflected on “Total carbon emissions”, shown in figure 62, but there is a larger impact between the varying values of the frozen food policy. However, overall, across all outputs, the combination of all the policies produces better results.

6.1.2.3 Summary

From all the experiments completed with the food and waste simulation I can recommend that a combination of all three policies tested will positively impact Cardiff progress in reducing carbon neutrality by 2030. They shall aid in the reduction of not only the direct carbon emissions released from the education sector but also some of the embodied emissions through reducing the use of the food supply chain. However, it is important to note that schools who implemented these policies need to understand that for the policies to be their most effective they need to be continued for a long period of time and not sporadically.

6.1.3 SMART Policies

For clearer recommendations and justification of the polices experimented above policies were aligned with the SMART principle to clarify how they can be achieved. The SMART principles are:

Specific - which identifies the specific policy,

Measurable – which identifies how the progress of the policy can be measured and when is the policy marked a success,

Achievable – which indicates how achievable a policy is and how do you go about achieving it,

Relevant – which identifies the need and assesses the relevancy of the policy in the given context (for us in terms of reducing Cardiff's environmental impact" and,

Time-bound – which identifies the time in which it will take to see the results of the policy.

For ease of comparison between all the polices I have implemented the SMART principles to my polices in a table below (Table 2).

Specific	Measurable	Achievable	Relevant	Time-bound
Speed limit policy – Speed limits should be increased, where safe, to 30 MPH to improve vehicle efficiency and reduce carbon emissions from transport.	This policy can be measured through the careful examination of the direct carbon emissions from transport. Any decline in emissions will mark this policy as a success due to the larger impact transport has on the environment. The measuring itself will need to be completed by Cardiff Council rather than the schools themselves due to the available data and resources to do this is limited for schools.	This policy is fully achievable based on the assumption that health and safety in the areas that will have their speed limits increased has been fully evaluated. I only foresee this policy having troubles with roads that are closer to school grounds where the increased risk to pedestrians would be harder to manage due to the concentrated footfall traffic.	For all the policies their relevancy has been proven through the experiments and results obtained from the experiments ran in Section 5. Each policy being suggested has already been shown to improve the environmental impact the education sector has and overall aid Cardiff in reaching its carbon neutral goal by 2030.	Depending on time it takes for approval of speed limit changes will depend on how quickly this policy can be implemented. Once in place, positive impacts will be measurable within the first year.
Limit Construction – School constructions should be limited to a certain threshold each year and only school additions should be allowed once the threshold has been met to reduce carbon emissions from construction.	This policy can be measured through the examination of direct carbon emissions from constructions within Cardiff and the decrease in full school constructions in a 10-year period. If the policies construction limit is agreed upon across the city, then the policy will ultimately be a success as there will be a reduction in direct carbon emissions due to the reduction in number of constructions.	For this policy, if it allows for school places to be increased when needed, then I don't see any concerns with its achievability. The only concerns I can see would be the additional strain schools could incur from adding rooms onto their school grounds. But if these schools are fully supported in their upgrades and given enough funds to complete these then the policy is achievable.		For a policy such as this, the full 10 years would be required to fully evaluate the impact it has had, due to its reliance on a threshold to be met before technically the policy is implemented officially.
Carpool policy – Students should be encouraged to carpool with other	This policy can be measured through surveys and examination of direct carbon emissions from transport. Surveys will indicate the student percentages of who	This policy specifically could rise concerns around safety of students in terms of who carpools with who. But if you were to assume		For this policy it is down to the parents and how they uptake the policy which defines when it is

students if they intend on commuting to school via personal transport such as cars, to reduced transport carbon emissions and delays on the road.	takes what type of transport to school. A decrease in the number of cars driven to school and the increasing number of students moving from personal transport to public or walking/cycling will indicate successful implementation of this policy.	students carpooled with friends and they were able to choose with whom they pair up with, then I see this policy being achievable. Corporation with parents would be vital but the benefits it could bring them personally too, what ensure their support and overall increase the success of this policy.		implemented and when any results are shown. Once parents are on board with the policy, the implementation would be fairly instant.
Local Supplier policy – Schools should purchase their food from suppliers closer to the school grounds to reduce the direct and embodied emissions from the supply chain of school meals.	This policy can be measured easily and enforced by schools carrying out simple calculations of how far their suppliers are from the school grounds to assess how local their suppliers are. Any improvements made will be measurable through examining the direct carbon emissions and embodied carbon emissions from the food supply chain.	This policy would be achievable if there are local suppliers for schools to use. Increased costs from buying local could occur but these costs would be offset by the reduction of food waste which is why I do not think cost would impact its achievability.		This policy would require some time for impacts to be shown due to the time required to find suppliers that are within 'local' range of school grounds. These suppliers would also need to be able to supply all the necessary ingredients and meet all the rules and regulations linked to being a school food supplier. Once a supplier has been identified, then the policy can be implemented, and I expect the impacts to be noticeable within a school year and more prominent over multiple years.
Made-to Order policy – Schools	This policy can be measured by examining the reduction in food waste	For this policy I think it is highly achievable due to the		For this policy, depending on the way it is implemented,

should be encouraged to implement a made-to order option for school meals for students to pre-order their meals to reduce food waste processed by schools.	schools send to landfill each month. This data can be collected by the schools. Any reduction in food waste would indicate the success of this policy, due to the evident impacts food waste has on carbon emissions.	infrastructure already in place. Schools have online pay systems which could be easily adapted to make this policy happen. The undoubtable benefits to the school and to the parents, through increased control parents could have over what their children eat, will make this policy not only achievable but a success.		will impact when it can be implemented. For example, if the adaption of the online pay system were to be the method chosen, this would require around 6 months to complete. I recommend this type of implementation over paper for example, due to the counteractive impacts on the environment this could introduce. Impacts would be measurable far sooner than other policies as within a week there would be noticeably less food wastage.
Frozen Food policy – Schools should consider purchasing more frozen food to benefit from its longer self-life and impact it will have on reducing food waste.	This policy can be measured by the school like the made-to order policy. Through accessing of their own food waste numbers. Any reduction in food waste will show the success of this policy.	This policy is achievable if schools have access to frozen food suppliers which all schools currently do as they will be currently purchasing at least some ingredients frozen. The increase self-life will allow schools to potential expand their menus giving students more options and improving their experience. Adding an additional benefit layer that would make this policy work even better.		For this policy, how quickly it can be implemented and how soon impacts can be measured will be the same as the local supplier policy.

Table 2 - SMART Policies

6.2 Evaluation

To critically evaluate my final year project and I will be comparing the outcomes of the project to the aims and objectives set out in Section 1.4. These are the best indicators of the success of the project and allow me to cover the strengths and weaknesses of my overall project.

Firstly, I will evaluate my objectives:

1. **Gather research on previous environmental policies that have been implemented within Cardiff and similar locations.**

During my background research stage, I tackled this objective and completed it, see Section 2.3.4. This was one of the first objectives I completed due to its importance in providing the project with a direction for potential policy action that could be implement. Through this research I was able to find leads for factors I should consider in my models and overall, it benefitted the project greater.

2. **Gather details on the context area through independent and collaborative research with Cardiff Council.**

Similar to objective 1, this objective was completed at the beginning of the project through the completion of the background research. Without this completed I would have struggled immensely in knowing what direction to go in. Additionally, this research came in handy in ensuring I did not produce a piece of work that has already been completed before. One aspect of this objective, however, did not go fully to plan. The collaborative research with Cardiff Council started off well, through meetings with my Cardiff Council contact, Ian Patterson, but after week 4/5 we ran into the barrier of no other individual within Cardiff Council wanting to contribute to the project. Despite this unfortunate turn of events, the individuals who did offer help in my research, provided useful material and I am greatly appreciative for their support.

3. **Find models around a similar problem space to aid in identifying common areas that policies are required**.

This objective was completed within my background research, see Section 2.3.6. Several projects were found that had at least one linking aspect to this project. However, on creation of this objective I assumed this type of research would have benefited me more than it did. Due to the lack of models created in the problem space of this project, I was not able to identify 'common areas' that policies were implemented. But instead, I was able to identify the large need for this project because of the lack of projects out there. All in all, making the completion of this objective a success, even if that success was different from what was expected originally.

4. **Use my research to map the system to display all constituent components and their interactions.**
    - Ensuring relationships are fully supported and back up by evidence.

The outcomes of this objective can be seen in Section 4. I was able to successfully complete this objective through the creation of draft models, showing my initial thoughts for each model, and final CLDs, which combined my initial thoughts and an accumulation of all the research carried out to provide models with several factors, with backed relationships shown in Appendix A-D. With this objective being linked to the first stage of the System Dynamic process it was vital it was completed to the best standard. I definitely feel I achieved this, but it was no easy feat. A few extra weeks were spent than originally planned on the CLDs due to adaptions that were made to the modelling process I took. Changes that ensured I was challenging each relationship I added and expanded the factors to encompass all their causal relationships, so they were represented in the model accurately. This was a large learning curve for me (more details about that in Section 9).However, despite the delay I did complete the objective in time for the other objectives to be completed and the additional time taken did benefit the project as it allowed for more detailed models to be created me.

5. **Identify policies through examination of my qualitative model and the loops in the model.**

Now for this objective I did complete it but not exactly as it is written, due to an inaccuracy in the objective itself, which I discovered during the project. The CLDs (qualitative models) are there for the identification of loops, but not exactly the identification of policies, more the identification of areas that policies could be implemented. It is not until the creation of the stock and flow diagrams (quantitative models) and simulations, that precise policy action can be identified. So, changing the wording of this objective to "Identify areas for policy action through examination of qualitative models and the loops in the model' then yes, I did complete this objective. Through the models shown in Section 4, I was able to identify several reinforcing loops that indicated a need for policy action. These areas were later used to form the stock and flow diagrams and simulations and then the experiments testing the policy action identified.

6. **Use my qualitative model to perform a quantitative analysis through the creation of a stock and flow diagram(s).**

For this objective I did successfully use the CLDs to perform quantitative analysis through the creation of stock and flow diagrams, shown in section 5. Initially at the beginning of the project it was intended to make all the CLDs into stock and flow diagrams, however, due to time constraints and lack of reinforcing loops in some of the models I decided to focus on the creation of only two models. In the end this allowed for more time to be spent on ensuring these models were high quality and it provided more time to experiment several policy actions on each. Overall benefiting the project far more than if I had more than two stock and flow diagrams of little detail and only one policy action each, which would have been the case due to timing constraints.

7. **Design and run experiments using quantitative model(s) to test the identified and existing policy action to gather evidence of their effect on the carbon neutral goal.**

This objective covers a large aspect of the project. To properly evaluate its completion, I will break it down into the design process and testing process (experiments).

In a nutshell I did complete the design process, shown by section 5. However, a part of this process required the gathering of data for the formulation of equations to provide the models with the relationships between the factors and allow for these relationships to be simulate. And this part there was a problem. Gathering this data was initially meant to be in collaboration with Cardiff Council and they were meant to provide me with most of the data I required so I could design simulations that aligned with their specific education sector. But unfortunately, due to covid, and the increased pressure members of Cardiff Council had, not only did guidance in obtaining this data not get given but it was clear the data I required either was not there or wasn't accessible beyond what was on government approved sites. At first this was a setback for the project as I thought this would mean my models could not be aligned with Cardiff's current environmental impact. However, SD is not intended for the application of predicting precise values. Instead, it is about evaluating the trends between factors and the impacts implemented policies have on those trends. Meaning as long as the data found was representative of the trends that were designed into the models, high quality experiments could still be produced. Which would the provide evidential backing of the impact the implemented policy actions could have on a sector. Additionally, if the exact data for Cardiff was obtained then in the future the models could be adapted to produce further precise results. Although, no matter what, the models still showed the trends the implemented policy action would have, but instead of only showing this for Cardiff it can now represent all cities. Meaning, not only do the results of the project align with Cardiff but they also could apply to other cities across the country.

After this issue was mitigated, the project was able to continue stronger than ever because the models were now more universal than they initially were going to be, making their potential uses even greater (see Section 7 for further discussion on this). An important thing to note about the data is that it was ensured, where possible, to gather data that was Cardiff specific, so that the trend relationships were as close as possible to representing Cardiff as a city because that was the main aim of the project. Which was achieved.

Once the issues with the design process were cleared up, all policy actions that were identified were able to be tested, with at least one policy action per reinforcing loop (experiments can be seen at Section 6.1). During the policy testing I was extremely pleased with the number of policies that were experimented within the time constraints of this project. I am proud of the policies identified and the with the trend data that was obtained from the testing of these policies.

Overall, I completed this objective, arguably the most important objective, to an extremely high standard despite the problems that arose. I do feel the issues I did come across strengthened the project, rather than weakening it. Leaving me extremely happy with how my final project turned out.

8. **Review and discuss the results of the simulation experimentation with Cardiff Council, to evaluate potential future continuation and adaption of identified successful policy action.**

The above objectives cover the evaluation of my main aims of the project but an aspect of the project that has not been covered is the final objective to feedback to Cardiff Council about the results of the project and recommend the policy action I had discovered and tested. This objective has not been met at this point in time. This is mainly down to time constraints and lack of uptake of this project from Cardiff Council. Leaving no specific individuals to feedback to, who could make use of this project. I contribute this issue to the rapidly developing covid situation which has made a major impact on the education section. However, despite not being to feedback to Cardiff Council at this point, I do hope the completed project and the results obtained will come in use to Cardiff Council when they have the time and individuals to evaluate it.

7 Future Work

Every project has areas in which, with more time, additions could be made, and areas could be improved from what has been created and this project is no exception. Many factors can impact a project, for this project COVID-19, unexpected additions needed for the models and generally areas of the project taking longer than expected led to some desired aspects I wanted to complete not plausible to do.

The first area being the further expansion of the models. System Dynamics is an extremely power model tool but that comes with the downside that you are never truly finished modelling. There is always more that could potentially be added to the models created, more factors and relationship to be considered. However, the models are complete, to the level possible within the time constraints of this project. What has been produced is of high quality and has led to great results. However, if more time was available to allocate to adding to the models, that would only benefit the overall project and is something that should be considered if someone were to carry on with the project.

During the project I learnt more about the software's available, and I came across a 3D modelling feature within AnyLogic, a feature I did not know existed until after the initial plan was submitted and the project was well underway. Due to the late awareness of this feature, despite wanting to try making a 3D model, time was not on my side, and it was not sensible to take a large chunk of the project figuring out how to use the feature and then recreate one of my models with it. However, the simulations were created in AnyLogic for the purpose of potential future work. Having the simulations already in the software will allow for ease of transfer over to the 3D feature if there was more time allocated to this project. I see several benefits of this feature, with the main being making the model more accessible to a wider audience who may not understand the rawer form of the simulations that have been created.

Finally, all the policies I have recommended are all based around the theme of reducing carbon emissions released from identified out of control systems. An important aspect of getting Cardiff to carbon neutrality. However, what these policies have also highlighted is the difference between neutrality and being carbon free. Despite the successful results of the policies tested, even they do not show a decrease of carbon emissions all the way to zero because that's not possible. This project was about showing how to reduce carbon emissions, which is one half of achieving carbon neutrality. The other half is absorbing carbon emissions. This aspect of achieving carbon neutrality is an area, if there was more time, this project would have considered exploring policy action in as it would add immense value to project as a whole. Ways this could be added is through carbon absorbing policies. This was not possible to be completed within this iteration of the project as I did not want to dilute the other policies I was testing with even more policies. But with greater time and resources I see this being a great place to carry on with this project.

8 Conclusions & Discussion

Summarising this project, 5 CLDs based off themes from the One Planet strategy, backed by research obtained by me were created. These CLDs were used to create 2 highly detailed stock and flow diagrams which were simulated using data to formulate detailed equations to model trend relationships between factors within these models. All resulting in 6 policies being experimented across the two simulations and finally being recommended with evidential and SMART principle backing to prove the positive trends that they will have on improving the educations environmental impact.

The additional work outlined in the future work section I see as opportunities to enhance the results of this project and not as an indicator of missing elements. The possible application of the results of this project is beyond what could have been imagined before starting. The once negative issue of not having Cardiff specific data turned into a benefit for the project, as it has made the policy recommendations applicable to potentially all UK cities. Increasing the value of the work produced from this project.

In conclusion, the project was overall a success. All the main objectives were met, despite issues arising and the singular objective that was not met at this time does not take away from the successfully nature of the project. Despite not being able to feedback to Cardiff Council I still successfully used SD to model the education sector and identify, experiment and evaluated policy action that I foresee being fully plausible policies that can be implemented can positively impact Cardiff's goal of being carbon neutral by 2030.

9 Reflection on Learning

With this final year projected completed I want to reflect on all that I have learnt about myself, what skills I have improved, things that surprised me and how I tackled the difficult aspects of the project.

The first and arguably the most important part of the project to reflect on is the re-learning of the System Dynamics process. Originally, I chose this final year project due to my initial experience with System Dynamics through the "Systems Thinking" module in second year. However, I was truly not prepared for the learning curve required to take what I learnt 2 years ago and apply it to a project on this scale. I fully underestimated the scope of System Dynamics that I didn't have experience with, and even the areas I did have practice with, my skills in them were rusty. This meant an intense learning process was required right at the start, one in which I tackled head on because I knew it was a barrier I had to overcome if the project was to go anywhere. In the end I produced a successful project, which speaks volumes on how I tackled the learning curve challenge. Teaching me I can over barriers that in the moment seem unachievable.

Although, the learning process at the beginning of the project was unexpected, I felt as if it set me up to be more resilient during the other trials and tribulations I faced throughout the project. Not only did I have to pick up System Dynamics skills quickly, but I also had to learn new tools, software, and lingo. All of this improved my other resilience and perseverance, as it taught me how to focus and taught me how to tackle similar issues in the future. I learnt that I should not avoid the hard parts of any situation because those are the sweetest aspects to conquer. Once you complete them you feel like you can do anything. That was a feeling I got halfway through the project when I started to see it come together, and it provided me with the push to get to the end and create the project you have just finished reading. I noticed that avoiding difficult aspects of situation was a common trait in my studies in the pandemic due to the more "self-teaching" style of learning we moved to this year. During this project I could notice that seeping in. So, I took a step back and reviewed how I was tackling these difficult issues, and I fully revaluated the system of how I faced challenges to figure out why I had this trait. Through this evaluation of my challenge tackling process, I was able to uncover the origin of this trait and create mechanisms to dismantle it to avoid it happening in the future and impacting the project.

Now moving onto more of the project content itself. During the model creation, I ensured my scope wasn't too large to avoid creating models with little focus. But desperate my seemingly small scope, I came to realise that there are so many factors that come into play in any problem space no matter how minimal you keep the scope. Leading me to moments where I had to make big decisions earlier on into the project that would define the remaining scope of my models because I had to decided what I should expand on and want I should leave as is. From this I learnt to trust the new skills I had only recently acquired to provide myself with the needed confidence to commit to the decisions I made. In the end these decisions worked out for the best and has taught me that I am capable of understanding new content quickly and I am able to put it into action swiftly with successful results.

For me, this final year project had me experiencing all the feelings I have felt during my degree and allowed me to put to the test the soft skills I have built up through my time here at Cardiff University. It became a perfect balance of teaching myself new skills and allowing me to use my existing skill base to flourish through a project entirely dependent on my work. Overall, I have learnt a lot about how I tackle challenges, I have proven to myself I can achieve and overcome the toughest of barriers in the moment and produce a piece of work such as this final year project, that I am proud of.

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11 Appendix

11.1 Appendix A - Justification Table for Built Environment model

Factor 1	Polarity	Factor 2	Justification	Evidence
Avg size of construction projects	Same (S)	**Avg number of construction workers**	Each construction project has different requirements depending on its size and duration. Larger and longer lasting projects will undoubtedly need more construction workers, and this will increase vehicle usage on the project. Increased vehicle usage also impacts traffic due to the need of getting the vehicles to the site and the transporting of materials and resources for the project. More vehicles and individuals on the construction site will contribute to noise pollution due to each element producing noise.	196,000 results on google scholar for 'positive correlation between the size of construction projects and the number of construction vehicles', (Gray, 2015), (Western, 2007)
Avg size of construction projects	Same (S)	**Avg construction vehicle usage**		
Avg number of construction vehicles per project	Same (S)	**Level of noise pollution**		
Avg number of construction vehicles per project	Same (S)	**Avg amount of space needed for construction vehicles**		
Avg number of construction vehicles per project	Same (S)	**Avg construction vehicle usage**		
Avg number of construction workers	Same (S)	**Avg amount of traffic**		
Avg duration of construction projects	Same (S)	**Avg carbon emissions from construction**		
Avg amount of traffic	Opposite (O)	**Avg speed of traffic**	Traffic on the road will reduce speeds that vehicles can travel, which in turn increases pollution due to the impact on vehicles MPG because they are travelling at slower speeds. Increasing traffic impacts noise pollution because cars are still for longer in lower gears which are louder than non-station higher gears. Increased noise pollution and disruption caused by traffic also impacts how attractive an area is	(Vehicle noise, no date), (Environment Law, 2017), (Bitesize, 2021)
Avg amount of traffic	Same (S)	**Level of noise pollution**		
Avg amount of traffic	Opposite (O)	**Likelihood of attraction of the area**		
Avg amount of traffic	Same (S)	**Avg carbon emissions from construction**		

Factor 1	Polarity	Factor 2	Justification	Evidence
Level of noise pollution	Opposite (O)	**Likelihood of attraction of the area**	because no one wants to live in an area plagued with traffic and any form of pollution.	
Avg amount of space needed for construction vehicles	Same (S)	**Avg number of road closures**	Construction vehicle usage, as briefly mentioned above, impacts traffic through the transportation of materials and resources that happens often several times a week. Some resources are too large to transport safely with other vehicles around requiring road closures. These closures can cause bottlenecks in other areas of the city increasing traffic and carbon emission due to the same reason mentioned above.	(Gray, 2015), (Western, 2007)
Avg number of road closures	Same (S)	**Avg amount of traffic**		
Avg construction vehicle usage	Same (S)	**Avg carbon emissions from construction**		
Avg amount of contaminated land used for construction	Same (S)	**Avg amount of clean up required to make land suitable for construction**	Depending on land type, some construction projects may require cleaning up the land they are using. The length of this is dependent of how much is there, how long it will take to remove and how dangerous the waste on the land is. Using old school infrastructure can reduce construction time because main components of a building are already present, meaning less work is needed to be done, reducing overall time.	(Land contamination—issues in construction projects, 2021)
Avg amount of clean up required to make land suitable for construction	Same (S)	**Avg number of hours required to clean up the land**		
Avg number of old school infrastructure used for new constructions	Opposite (O)	**Avg amount of clean up required to make land suitable for construction**		
Avg number of old school infrastructure used for new constructions	Opposite (O)	**Avg duration of construction projects**		
Avg number of school combinations	Same (S)	**Avg number of old school infrastructure used for new constructions**	School combinations contribute to school constructions as construction is normally required to provide enough room for two schools to come together. The combination of schools does increase commutes for some students as normally the two schools are close but still have different catchments. When schools combine these catchments are combined and	(The ultimate guide to how school catchment areas work, no date), 25,000 results on google scholar for 'positive correlation between school combinations and commuting distance for students'
Avg number of school combinations	Same (S)	**Avg number of construction projects**		

Factor 1	Polarity	Factor 2	Justification	Evidence
Avg number of school combinations	Same (S)	**Avg distance between school and a student's home**	students who went to school grounds that is no longer in use will have to increase their commute to get to the new school grounds where the combined school is. This causes an increase in traffic as more students are likely to take personal transport as it is easier then walking or cycling the extra distance.	
Avg distance between school and a student's home	Same (S)	**Avg length of student's commute**		
Avg length of student's commute	Same (S)	**Avg number of students commuting to school**		
Avg number of students commuting to school	Same (S)	**Avg amount of traffic**		
Avg number of construction projects	Same (S)	**Likelihood of attraction of the area**	The number of construction projects occurring is complicated as is does benefit the attraction of an area because it shows money is being invested into an area. However, the decrease in the number of green spaces because of these projects can reduce the attraction. Additionally, the number of construction projects also contributes to noise pollution which also impacts attractiveness because no one wants to live somewhere nosey.	(Gray, 2015), (Western, 2007), (Noise nuisance - Designing Buildings Wiki, 2020), (Arch2O.com, 2017)
Avg number of construction projects	Opposite (O)	**Avg number of green spaces**		
Avg number of construction projects	Same (S)	**Level of noise pollution**		
Avg number of green spaces	Same (S)	**Likelihood of attraction of the area**		
Likelihood of attraction of the area	Same (S)	**Avg number of people moving to the area**	The more attractive an area, the more people are likely to move there as people want to like where they live. The more households moving in means the potential of more eligible students, increasing the number of school places needed which increases the number of schools needed and in turn the number of constructions, to build the schools necessary.	36,000 results on google scholar for 'positive correlation between households moving to an area and the number of constructions'
Avg number of people moving to the area	Same (S)	**Avg number of eligible students**		
Avg number of eligible students	Same (S)	**Avg number of schools required**		
Avg number of schools required	Same (S)	**Avg number of construction projects**		
Avg amount of brownfield land used for construction	Same (S)	**Likelihood of attraction of the area**	Brownfield sites bring down the attraction of an area due to their unsightly visuals but if these are used for construction	(What are the pros and cons of brownfield sites for se..., no date)

Factor 1	Polarity	Factor 2	Justification	Evidence
Avg amount of brownfield land used for construction	Opposite (O)	**Avg amount of brownfield land in disarray**	then they are being made into something more pleasing to the eye, which increases attraction because people like to live in a good-looking area.	
Avg amount of brownfield land in disarray	Opposite (O)	**Likelihood of attraction of the area**		
Avg number of popular public services close by	Same (S)	**Avg amount of traffic**	Public services are normally used by a lot of people, so the more in a single area will increase traffic due to people travelling to get to them. The traffic increases noise pollution as mentioned above. Public services normally run 24/7 so more people who work late shifts will be living in an area with lots of public services.	417,000 results on google scholar for 'positive correlation between the number of public services and traffic', 130,000 results on google scholar for 'positive correlation between the number of public services and noise pollution'
Avg number of popular public services close by	Same (S)	**Level of noise pollution**		
Avg number of popular public services close by	Same (S)	**Likelihood of attraction of the area**		
Avg number of popular public services close by	Opposite (O)	**Avg number of people working night shifts in the area**		

11.2 Appendix B – Justification Table for Transport Model

Factor 1	Polarity	Factor 2	Justification	Evidence
Avg number of students late to school due to public transport or school transport	Same (S)	**Avg amount of class time missed collectively**	These relationships are based off data that suggests when public transport does not run-on schedule it causes individuals to stop using it. Late transport, if late enough, correlates to missing class time because lessons don't have to wait for all students to arrive, they start at the time scheduled. In turn this causes complaints due to the importance of being on time to school, complaints normally made by parents.	(Scottish Government, 2010), (Stein and Grigg, 2019)
Avg number of students late to school due to public transport or school transport	Opposite (O)	**Avg number of personal transport use**		
Avg amount of class time missed collectively	Same (S)	**Avg number of complaints made about the school buses**		
Avg amount of time school buses are late	Opposite (O)	**Avg number of students using school buses**		
Avg number of complaints made about the school buses	Opposite (O)	**Avg amount of time school buses are late**	Complaints, if enough are made, lead to action being taken by transport company to reduce individuals dropping their transport service. Leading to a reduction in buses being late because measures are put in place to minimise lateness.	(White, 2018)
Avg amount of time school buses are late	Opposite (O)	**Avg amount of time school buses arrive before students finish**	The amount of time students are late, directly relates to the time students have between being dropped off and start of class. This impacts the reliability of buses, and with a low reliability, students are less likely to use this mode of transport.	25,000 results on google scholar for 'negative correlation between school bus delays and students using school buses'
Avg amount of time school buses are late	Opposite (O)	**Level of reliability of school buses**		
Avg amount of time school buses are late	Same (S)	**Avg number of students late to school due to public transport or school transport**		

Avg amount of time school buses arrive before students finish	Same (S)	**Avg number of students using school buses**		
Level of reliability of school buses	Same (S)	**Avg number of students using school buses**		
Level of reliability of school buses	Same (S)	**Avg amount of time school buses arrive before students finish**	If buses have a high reliability this would be based off a good track record of arriving to school on time. Meaning they would arrive in plenty of time before students start class.	57,000 results on google scholar for 'positive correlation between reliability of buses and buses being on time'
Avg number of students using school buses	Same (S)	**Avg number of stops school buses make**	The usage of school buses determines the number of stops made because the more students on the route the need for more stops to ensure no student has to travel a long distance to make it to the bus stop. More students using buses also leads to an increase in the fleet size, to accommodate the increased demand. However, an increase in the number of stops will affect the journey time because extra time is taken to stop and start again.	76,000 results on google scholar for 'positive correlation between students using buses and number of buses available'
Avg number of students using school buses	Same (S)	**Avg number of school buses in the fleet**		
Avg number of stops school buses make	Same (S)	**Avg amount of time school buses make to get to school**		
Avg amount of time school buses take to get to school	Opposite (O)	**Level of reliability of school buses**	The reliability of buses can be based off a lot of factors but as mentioned above, a major factor is if a bus can get to school in an efficient manner. If a bus can, then that increases its reliability.	57,000 results on google scholar for 'positive correlation between reliability of buses and buses being on time'
Avg amount of time school buses take to get to school	Opposite (O)	**Avg amount of time collectively schools' buses are parked on the street**	All these relationships are around school buses and the facilities needed for these buses. Some schools have bus bays to avoid buses sitting on the road, and the number of bays a school has increases if the numbers of buses in the fleet increases. Even with buse bays, the more buses in the fleet will contribute to traffic on the roads as they are a large vehicle, taking up quite a bit of room. Some	(Schemes to reduce school run traffic congestion, 2021), 20,000 results on google scholar for 'positive correlation between number of buses available and number of bus bays outside schools'
Avg number of school buses in the fleet	Same (S)	**Avg number of bus bays outside the school**		
Avg number of school buses in the fleet	Same (S)	**Avg amount of traffic on the roads**		

Avg number of bus bays outside the school	Opposite (O)	**Avg amount of time collectively schools' buses are parked on the street**	schools don't have bus bays resulting in buses having to be parked on the road to drop off and pick up students, impacting traffic further.	
Avg number of bus bays outside the school	Opposite (O)	**Avg number of school buses parked on the street during pick up and drop off**		
Avg number of school buses parked on the street during pick up and drop off	Same (S)	**Avg amount of time collectively schools' buses are parked on the street**		
Avg number of school buses parked on the street during pick up and drop off	Same (S)	**Avg amount of traffic on the roads**		
Avg amount of time collectively schools' buses are parked on the street	Same (S)	**Avg amount of traffic on the roads**		
Avg number of school entrances	Same (S)	**Avg number of bus bays outside the school**	School entrances allow for more road space to place bus bays and they help reduce traffic, through offering more ways to enter and exit the school grounds.	(Schemes to reduce school run traffic congestion, 2021)
Avg number of school entrances	Opposite (O)	**Avg amount of traffic on the roads**		
Avg amount of traffic on the roads	Same (S)	**Avg amount of time school buses are late**	Traffic on the roads increases commuting time for each vehicle on the road, including those commuting to school. The added commute time means vehicles are burning more fuel, leading to an increase in carbon emissions. Due to the extended commute time, traffic impacts the reliability of school transport by making them late.	(Stein and Grigg, 2019), (Rashid, no date)
Avg amount of traffic on the roads	Same (S)	**Avg carbon emissions per school**		
Avg amount of traffic on the roads	Opposite (O)	**Level of reliability of school buses**		
Avg number of students who cycle/walk	Opposite (O)	**Avg amount of traffic on the roads**	Cycling and walking to school, directly reduces traffic and emissions through removing vehicles off the road	

Avg number of students who cycle/walk	Opposite (O)	**Avg carbon emissions per school**	by not using them to commute to school. This reduction in traffic then improves the school transports chances of staying on schedule and making them a more attractive transport, so more students use it.	(School Streets provide solution to inactivity, congestion and air pollution - Sustrans.org.uk, 2020)
Avg number of students who cycle/walk	Opposite (O)	**Avg number of students using school buses**		
Avg number of individuals using public transport	Opposite (O)	**Avg carbon emissions per school**	Using public transport, despite still being a vehicle, can reduce overall carbon emissions as its less impactful compared to each student commuting by car.	(Commons, 2006)
Avg number of individuals using public transport	Same (S)	**Avg public transport usage**		
Avg public transport usage	Same (S)	**Avg public transport carbon emissions**		
Avg public transport carbon emissions	Same (S)	**Avg carbon emissions per school**		
Avg size of school catchment	Same (S)	**Avg distance of school commute**	The larger the catchment area, the further students potentially will be commuting to get to school. Increasing the amount of vehicle modes of transport taken due to long commutes via foot and cycling not being the most efficient.	(Easton and Ferrari, 2015)
Avg distance of school commute	Same (S)	**Avg number of personal transport use**		
Avg distance of school commute	Same (S)	**Avg number of individuals using public transport**		
Avg distance of school commute	Opposite (O)	**Avg number of students who cycle/walk**		
Avg number of personal transport use	Opposite (O)	**Avg number of students using school buses**	The more students using personal transport ultimately reduces the number of students using public transport. Depending on how safe an area is, will depend on how comfortable parents are with their children using public transport or commuting by foot/ cycle. Personal transport is the most guaranteed transport for students safety, leading to an increase of this mode of transport if an area isn't safe.	(Scottish Government, 2010)
Avg number of personal transport use	Same (S)	**Avg amount of traffic on the roads**		
Level of safety in the commutable area	Same (S)	**Avg number of personal transport use**		
Level of safety in the commutable area	Opposite (O)	**Avg number of students who cycle/walk**		
Level of attraction of the commutable area	Same (S)	**Avg number of students who cycle/walk**		

Level of comfortability	Opposite (O)	**Avg usage of hygiene facilities**	Commuting on foot or by bicycle can be labour intensive and cause you to get dirty, leading to you feeling less comfortable. Facilities being available to students to use, would make students feel more comfortable as they offer the chance to get clean and change if required.	20,000 results on google scholar for 'positive correlation between the number of shower facilities and the number of students walking and cycling to school'
Avg number of personal hygiene facilities	Same (S)	**Avg usage of hygiene facilities**		
Avg number of personal hygiene facilities	Same (S)	**Level of availability of hygiene facilities**		

11.3 Appendix C – Justification Table for Food & Waste model

Factor 1	Polarity	Factor 2	Justification	Evidence
Avg number of fresh snacks offered during the school day	Same (S)	**Avg uptake of fresh snacks offered during the school day**	These relationships are based off the data that shows a greater variety of food increases the amount of food students consume and purchase. More food purchased means a greater demand for meals.	(British Nutrition Foundation, 2011)
Avg uptake of fresh snacks offered during the school day	Opposite (O)	**Level of demand for school meals**		
Avg distance food supplies travel to get to the school	Opposite (O)	**Avg amount of food deliveries a month**	The distance that needs to be travelled to get food to schools impacts number of deliveries because it is more cost efficient for schools to have fewer deliveries if supplier is further away. Additionally, more miles driven for deliveries will ultimately increase carbon emissions released from food deliveries.	(Department, 2016), (Sims, 2021), (What fuel economy (MPG) does a lorry get?, 2020)
Avg distance food supplies travel to get to the school	Same (S)	**Avg carbon emissions emitted from food supply transport**		
Avg amount of food deliveries a month	Same (S)	**Avg carbon emissions emitted from food supply transport**		
Avg amount of food deliveries a month	Same (S)	**Level of freshness of cooked school meals**	This is based off data that suggests food purchased from local suppliers will produce fresher meals due to the less travel required to get food to the plates of students.	(Using locally produced foods | Catering Blog, 2021)
Avg number of hours the canteen is open during the day	Opposite (O)	**Level of demand for school meals**	All these relationships are covering the same assumption that the longer students are in school the more food they will consume, and the more services required by schools to ensure students can purchase or obtain food.	111,000 results on google scholar for 'positive correlation between the amount of time students spend at school and food consumption', (Healthy Eating After School & Brakfast Club | Care Love Learn, 2021)
Avg number of students that stay in school more than the required period	Same (S)	**Avg number of breakfast clubs a school offers**		
Avg number of students that stay in school more than the required period	Same (S)	**Avg number of after school clubs**		

Avg number of after school clubs	Same (S)	**Avg amount of time students are at school during the day**		
Avg number of breakfast clubs a school offers	Same (S)	**Avg amount of time students are at school during the day**		
Avg amount of time after school care lasts	Same (S)	**Avg number of after school clubs**		
Avg amount of time after school care lasts	Same (S)	**Avg amount of time students are at school during the day**		
Avg number of hours the school is open during the weekend	Same (S)	**Level of demand for school meals**		
Level of demand for school meals	Same (S)	**Avg amount of food deliveries a month**	More meals demanded by students will cause more deliveries to obtain the food required to meet this demand. Ultimately more demand results in more meals being cooked to ensure the demand is met.	50,000 results on google scholar for 'positive correlation between food deliveries and food consumption'
Level of demand for school meals	Same (S)	**Avg number of cooked school meals**		
Avg number of students who get free lunches	Same (S)	**Level of demand for school meals**	Free lunches provided to students are often used because those students are in need of food being provided because they can't afford to make their own lunch, ultimately increasing demand. This results in school meals becoming a more attractive options to students who can't afford another option.	(Butler, 2020)
Avg number of students who get free lunches	Same (S)	**Likelihood of attraction to cooked school meals**		
Avg number of students who get free lunches	Opposite (O)	**Avg number of school meals brought from home**		
Likelihood of attraction to cooked school meals	Same (S)	**Level of demand for school meals**	For many families making lunches isn't plausible and often, even if it is, the meals are not that nutritious. The increased quality of school meals makes them very attractive to those who cannot make their own high-quality meals. Leading to an increase in demand for these meals and pressure on schools to ensure their meals are fresh and to standard.	(Healthy school meals win over secondary pupils | Education | The Guardian, 2010)
Likelihood of attraction to cooked school meals	Opposite (O)	**Avg number of school meals brought from home**		
Avg number of school meals brought from home	Opposite (O)	**Level of demand for school meals**		

Level of freshness of cooked school meals	Same (S)	**Level of quality of cooked school meals**		
Level of quality of cooked school meals	Same (S)	**Likelihood of attraction to cooked school meals**		
Avg number of cooked school meals	Same (S)	**Avg number of cooked school meals made to order**	These are basic relationship to cover that the increase in meals means there will be an increase in meals made and in turn the number of meals produced in certain ways.	
Avg number of cooked school meals	Same (S)	**Avg number of cooked school meals batched made**		
Avg number of cooked school meals batched made	Opposite (O)	**Likelihood of attraction to cooked school meals**	Batch cooking can be a quick way to prepare meals when there are lots of people to serve. However, this comes at the cost of reducing the quality and freshness of the meals you are producing, impacting the overall attractiveness of the meals made. Another downside to batch cooking is the leftovers due to over estimation of the amount of food required. This leads to an increase in food waste.	35,000 results on google scholar for 'Negative impacts batch cooking has on food quality'
Avg number of cooked school meals batched made	Opposite (O)	**Level of quality of cooked school meals**		
Avg number of cooked school meals batched made	Opposite (O)	**Level of freshness of cooked school meals**		
Avg number of cooked school meals batched made	Same (S)	**Avg amount of food waste generated**		
Avg number of cooked school meals made to order	Opposite (O)	**Avg amount of food waste generated**	Unlike batch cooking, made-to order cooking is a perfect way to reduce food waste because the whole premise of it is to only cook what is needed.	(Stop Food Waste Day, 2020)
Avg amount of food waste generated	Same (S)	**Avg amount of waste sent to landfill**	Majority of schools send most of their food waste to landfills. Landfills then dispose of this waste in carbon emitting processes.	(Post, 2021)
Avg amount of waste sent to landfill	Same (S)	**Avg carbon emissions emitted through waste disposal**		
Avg amount of plastic waste generated	Same (S)	**Avg amount of waste sent to landfill**	Plastic waste, if not recycled, must be sent to landfills. Currently there is minimal recycling facilities at schools leaving landfills to be the main option for this type of waste. However, the more waste sent to landfills, is making schools introduce more recycling bins because of the benefits they provide to the school's carbon footprint and the educating benefits for students.	(How much does your school waste? | Recycle Now, 2021)
Avg amount of plastic waste generated	Same (S)	**Avg number of recycling bins on site**		
Avg number of recycling bins on site	Same (S)	**Avg amount of recycled waste**		

Avg amount of recycled waste	Opposite (O)	**Avg amount of waste sent to landfill**		
Avg number of students and staff	Same (S)	**Avg amount of plastic waste generated**	More students and staff at a school results in more resources being used causing an increase in waste in all areas and a further increase in demand on school meals.	(Recycling in Schools ǀ Guidance on Reducing Waste, 2020)
Avg number of students and staff	Same (S)	**Avg amount of waste from paper and card**		
Avg number of students and staff	Same (S)	**Level of demand for school meals**		
Avg number of resources digitised	Opposite (O)	**Avg amount of plastic waste generated**	The more schools that move over to digital resources the less resources wasted because less resources are required by schools in the first place.	(The Paperless School: 9 Ways to Reduce Waste and Increase Efficiency, 2020)
Avg number of resources digitised	Opposite (O)	**Avg amount of waste from paper and card**		
Avg amount of waste from paper and card	Same (S)	**Avg amount of recycled waste**	Resources such as paper and card are easy to recycle meaning they directly contribute to recycled waste produced by schools. Courses that use these resources increase the need for these resources, leading to further recycled waste to be produced.	(Recycling Guide, 2016)
Avg number of art and creative hours	Same (S)	**Avg amount of waste from paper and card**		

11.4 Appendix D - Justification Table for Energy and Water combined model

Factor 1	Polarity	Factor 2	Justification	Evidence
Avg amount of energy used by catering	Same (S)	**Avg amount of energy used by the school**	The energy used by a facility within a school will increase the energy used overall by the school due to the assumption that facilities inside a school contributes to the same energy consumption total.	41,400 results on google scholar for ‘positive correlation between catering and energy consumption’, (Max, 2021), 2,070,000 results on google scholar for ‘positive correlation between cost of energy and energy consumption’
Avg amount of energy used by the school	Same (S)	**Avg demand for energy**		
Avg amount of energy used by the school	Same (S)	**Avg cost of energy used by the school**		
Avg amount of energy used by lights	Same (S)	**Avg amount of energy used by the school**		
Avg amount of energy used by heating	Same (S)	**Avg cost of heating the school**		
Avg number of hours schools are open	Same (S)	**Avg amount of energy used to heat the school rooms**	The longer a school is open for will impact how long the heating and lights are on for, increasing the energy used by these areas and overall increasing the cost of energy required to run the school. Increased school opening hours also means water facilities are used more, increasing water consumption.	316,000 results on google scholar for ‘positive correlation between school hours and energy consumption’, 379,000 ‘positive correlation between school hours and water consumption’
Avg number of hours schools are open	Same (S)	**Avg amount of time lights are running per day**		
Avg number of hours schools are open	Same (S)	**Avg use of water-based utilities**		
Avg number of hours schools are open	Same (S)	**Avg use of personal bottle use**		
Avg amount of time lights are running per day	Same (S)	**Avg amount of energy used by lights**		
Avg amount of energy used to heat the school rooms	Same (S)	**Avg amount of energy used by heating**		
Avg percentage of lights being manual	Same (S)	**Avg amount of time lights are running per day**	For these relationships the energy usage and wastage through having manual light systems is represented. Lights that are manual are more likely to be on longer than those that are automatic.	(Penny, 2012), 222,000 results on google scholar for ‘positive correlation between manual light systems and energy consumption’
Avg percentage of lights being manual	Same (S)	**Avg amount of energy wasted**		

Avg amount of time rooms are unoccupied	Same (S)	**Avg amount of energy wasted**	These relationships are based off the assumption that all rooms are heated no matter if they are occupied or not. If a room is not being used, then that energy is going to be wasted because no one if benefiting from it. The lighting relationship is a negative correlation due to the assumption that lights aren't on when individuals aren't present.	20,000 results on google scholar for 'positive correlation between vacant rooms and energy wastage', (Stockley, 2015)
Avg amount of time rooms are unoccupied	Same (S)	**Avg amount of energy used to heat the school rooms**		
Avg amount of time rooms are unoccupied	Opposite (O)	**Avg amount of time lights are running per day**		
Avg number of school rooms within the school grounds	Same (S)	**Avg amount of energy used by lights**		
Avg number of school rooms within the school grounds	Same (S)	**Avg number of general-purpose rooms**	These relationships are based off the size of the school positively correlating to the number of classrooms as there is more space for rooms to be, increasing both general classrooms and dedicated rooms.	97,500 results on google scholar for 'positive correlation between size of school grounds and number of classrooms in a school',
Avg number of school rooms within the school grounds	Same (S)	**Avg number of dedicated classrooms**		
Avg number of general-purpose rooms	Opposite (O)	**Avg amount of time rooms are unoccupied**	The negative correlation is based of data indicating that the more general-purpose rooms, the increased usage of said rooms because it is not made for anything specific so can be used by a variety of individuals.	(Rohrer and Samson, 2014)
Avg number of electronic devices/ computers used for teaching specifically	Same (S)	**Avg amount of time electronic devices/ computers are being used**	This relationship represents the known link between the number of devices and the collective amount of time devices are used. The more devices, the more time overall devices are used. This increased time then impacts the amount of energy used because the longer you use an electric device the more energy used.	200,000 results on google scholar for 'positive correlation between number of electronic devices and amount of time spent on electronic devices', (Mayclin, 2016)
Avg amount of time electronic devices/ computers are being used	Same (S)	**Avg amount of energy used by the school**		
Avg number of students and staff	Same (S)	**Avg amount of time electronic devices/ computers are being used**	The increased number of student and staff impacts several factors because the greater number of individuals, increases device usage, the number of required school	(Whitehurst and Chingos, 2011), 77,000 results on google scholar for 'positive

Avg number of students and staff	Same (S)	**Avg number of school rooms within the school grounds**	rooms, the number of students on certain courses and the number of meals required. These links exist due to greater student and staff numbers equalling greater demand.	correlation between number of students and number of school lunches'
Avg number of students and staff	Same (S)	**Avg number of students taking resource heavy subjects**		
Avg number of students and staff	Same (S)	**Avg number of cooked school meals**		
Avg number of students taking resource heavy subjects	Same (S)	**Avg number of resource heavy subjects being taught**	The more students taking resource heavy subjects increases demand for these courses, which then impacts the need for dedicated classrooms to be able to facilitate the increased student numbers. All contributing the positive correlation relationship.	(Garrison, Anderson and Archer, 2001)
Avg number of resource heavy subjects being taught	Same (S)	**Avg number of dedicated classrooms**		
Avg number of dedicated classrooms	Same (S)	**Avg amount of time rooms are unoccupied**	Dedicated classrooms normally have specific facilities, facilities in which use more water. These classrooms also relate to special courses which require specific teaching, forcing quality of teaching to improve. As mentioned previously, these classrooms are not as versatile as general-purpose rooms. Leading to these rooms being left vacant and causing wastage of heating energy.	(Gomendio, no date)
Avg number of dedicated classrooms	Same (S)	**Quality of teaching**		
Avg number of dedicated classrooms	Same (S)	**Avg use of water-based utilities**		
Quality of teaching	Same (S)	**Avg number of students and staff**	This relationship is based off data that the quality of teaching improves a school's appeal through showing their students make great achievements, which brings in more students and teachers due to the want to work and be taught in a successful environment.	(Tucker and Stronge, 2005)
Avg number of staff rooms	Same (S)	**Avg number of dedicated classrooms**	Staff rooms aren't versatile, they only can be used for staff, meaning they aren't optimised for use like general classrooms. Leaving them to be placed under the dedicated classroom category. Many staff rooms also have	(Staff Amenities and Rest Room Advice Guide for Employers | Peninsula UK, 2021)
Avg number of staff rooms	Same (S)	**Avg number of separate canteen facilities**		

			special facilities like kitchens for staff meals, increasing the number canteen facilities within a school.	
Avg number of separate canteen facilities	Same (S)	**Avg use of water-based utilities**	Canteen facilities are a huge consumer of water, for the purpose of cooking and cleaning, a vital function of this type of facility.	(Usepa and WaterSense, 2012)
Avg amount of water used for heating	Same (S)	**Avg water consumption of the school**	Many heating systems use water as a base resource to produce heat, meaning the usage of heating in a school will impact the water consumption.	(Smarter House, 2017)
Avg size of school buildings	Same (S)	**Avg number of students and staff**	Several aspects of schools are positively correlated to the size of school buildings due to their dependency on the buildings themselves. For factors such as the number of students and staffs, it is more that the larger a building is, the more opportunity to have more students and staffs, ultimately causing an increase in this area.	(Department for education, 2014), 148,000 results on google scholar for 'positive correlation between size of school buildings and size of school grounds'
Avg size of school buildings	Same (S)	**Avg size of school's grounds**		
Avg size of school buildings	Opposite (O)	**Avg number of green spaces within the school grounds**		
Avg size of school's grounds	Same (S)	**Avg number of green spaces within the school grounds**		
Avg number of green spaces within the school grounds	Same (S)	**Avg amount of water used for school maintenance**	Green spaces are known to be resource intensive. If they are kept to a high standard for visual benefits, then water consumption of a school is impacted.	(EL-Nwsany, Maarouf and Abd el-Aal, 2019)
Avg amount of water used for school maintenance	Same (S)	**Avg water consumption of the school**		
Avg number of cooked schools' meals	Same (S)	**Avg amount of water used for cooking**	Any factor around canteen will impact the water consumption due to the dependency canteen facilities have on this resource.	(EL-Nwsany, Maarouf and Abd el-Aal, 2019), (Richter and Stamminger, 2012)
Avg amount of water used for cooking	Same (S)	**Avg water consumption of the school**		
Avg use of water-based utilities	Same (S)	**Avg amount of water wastage**	Simple relationships here. As water-based utilities are used their main resource consumption is water, which	(EL-Nwsany, Maarouf and Abd el-Aal, 2019)

Avg use of water-based utilities	Same (S)	**Avg water consumption of the school**	means more water will be used up, increasing water consumption of a school.	
Avg use of personal bottle use	Same (S)	**Avg amount of water used for individual consumption**	Personal bottles can persuade students to use more water, and if filled at school, that impacts water consumption of the school. The main way to fill water bottles is through water fountains which leads to increased water consumptions through the use of water fountains.	(EL-Nwsany, Maarouf and Abd el-Aal, 2019), (Bottle, 2020)
Avg amount of water used for individual consumption	Same (S)	**Avg water consumption of the school**		
Avg number of water fountains in the school	Same (S)	**Avg use of personal bottle use**		
Avg number of water fountains in the school	Same (S)	**Avg water consumption of the school**	Fountains are more water efficient as they don't let out water as quick as taps leading to a reduction in water wastage is their usage is increased compared to water usage through taps. However, the more of them in schools means more students are likely to want water, increasing water consumption overall.	(EL-Nwsany, Maarouf and Abd el-Aal, 2019), (Action, 2017)
Avg number of water fountains in the school	Opposite (O)	**Avg amount of water wastage**		
Avg amount of water wastage	Same (S)	**Avg water consumption of the water**		
Avg number of taps in the school	Same (S)	**Avg amount of water wastage**	Taps have the similar impact as manual lights as in they can be left on easily, wasting water and increasing water consumption.	(EL-Nwsany, Maarouf and Abd el-Aal, 2019), 24,000 results on google scholar for 'positive correlation between water consumptions and number of taps in a school'
Avg number of taps in the school	Same (S)	**Avg water consumption of the school**		

11.5 Appendix E - Justification Table for Built Environment Simulation

Factor	Model Type	Units	Initial Value	Justification	Evidence	Equation
1. Avg percentage of students commuting by local bus	DV	% of students	0.12	Based off data obtained indicating the percentage of students commuting by local bus.	(Travel to school figures, 2019)	N/A
2. Increasing delays	Flow	Minutes	N/A	Based off data outlining the impact an increase in vehicle numbers on the road has on commute time. Using this data in the calculation to display the trends that increased commute time can have on local bus travel.	(Department, 2019)	((0.1*(AvgNoOfStudentsCommutingToSchoolByLocalBus/AvgNoOfStudentsPerLocalBus))+(0.4*AvgNoOfStudentsCommutingToSchoolByCar))-DiscBetweenLengthOfSchoolCommuteAndTimeGivenToMakeSchoolCommute
3. Total time local buses are late	Stock	Minutes	N/A	Calculated from increasing delays.	" "	Increasing Delays
4. Avg time of school commute	DV	Minutes	20	Based off data outlining the average length of a school commute for students who cannot walk to schools. Using this distance and the average speeds in Cardiff the average time was calculated.	(Department, 2014)	N/A
5. Avg time given to make school commute	DV	Minutes	35	Based off data outlining the schedule local buses intend to stick to. The time between buses expected arrival compared to the start of school gave me this value.	(Department, 2014), (GOV, 2020)	N/A

6. Discrepancy between length of school commute and time given to make school commute	DV	Minutes	N/A	Calculated from the length of the commute and the time allocated to local buses to make the commute to give the buffer window available.	“ ”	(avg time given to make school commute - avg length of school commute)
7. Avg percentage of students who stop using public transport	DV	% of students	N/A	Calculated from the amount of time buses are late and the average dropout rate of public transport use.	(Department, 2014)	(Total Time Local Buses Are Late-30)/1e+11
8. Avg number of students commuting to school by local bus	DV	Students	N/A	Calculated from the percentage of students commuting by local bus and the eligible student population. Also taking into consideration the impact delays have on local bus uptake.	(Number of pupils in Cardiff, 2021), (Households by Local Authority and Year, 2019), (Travel to school figures, 2019)	(avg number of eligible students*avg percentage of students commuting by local bus) - ((avg number of eligible students*avg percentage of students commuting by local bus)*avg percentage of students who stop using public transport)
9. Avg percentage of students commuting to school by car	DV	% Decimal of students	0.35	Based off data obtained indicating the percentage of students commuting by car.	(Travel to school figures, 2019)	N/A
10. Avg number of students commuting to school by car	DV	Students	N/A	Based off data obtained indicating the percentage of students commuting by car and the eligible student population. Also taking into consideration the local bus data because students who stop taking the bus are more likely to use cars due to their improved reliability, having an effect of the number of students commuting by car.	“ ”	(avg number of eligible students*(avg percentage of students commuting by car)) + ((avg number of eligible students*avg percentage of students commuting by local bus) * avg percentage of students who stop using public transport)

11. Avg percentage of students commuting by foot or bicycle	DV	% of students	0.46	Based off data obtained indicating the percentage of students commuting by foot or bicycle.	(Travel to school figures, 2019)	N/A
12. Avg number of green spaces in the area	DV	Green spaces	391	Based off data obtained from a reliable source outlining the different types of green spaces in Cardiff.	(Hughes, 2017)	N/A
13. Avg number of students commuting to school by foot/bicycle	DV	Students	N/A	Calculated from the average number of eligible students, the percentage of students who go by foot/bicycle and the number of green spaces. Green spaces have been added to measure their impact on students commuting type, as the more attractive an area is the more likely students will commute by foot or bicycle.	(Hughes, 2017), (Travel to school figures, 2019)	(((avg number of green spaces in the area-391)/20) + (avg percentage of students commuting by foot or bicycle))*avg number of eligible students
14. Avg number of households in the area	DV	Households	154874	Based off data obtained from reliable source which provided a breakdown of households in wales.	(Households by Local Authority and Year, 2019)	N/A
15. Avg number of eligible students per household	DV	Students	0.35	Based off data for number of students in the area and avg number of households in the area. Backed up by data from the projection of school places in Cardiff.	(Number of pupils in Cardiff, 2021), (Households by Local Authority and Year, 2019), (Projected availability of and demand for school places, no date)	Number of students in the area (54631) / Avg number of households in the area (154874)

16. Avg number of school places available	DV	Places	54631	Based off data for number of current pupils enrolled at primary and secondary schools following the assumption all current places are taken.	(Number of pupils in Cardiff, 2021)	N/A
17. Impact construction has on households moving to the area	DV	Students	N/A	Calculated from the number of constructions. I have assumed that there will be 200 extra students attracted to the area per school due to the increase in spaces available. The assumption is based off the trend that more school constructions will increase the number of households moving to the area.	(Number of pupils in Cardiff, 2021), (Households by Local Authority and Year, 2019), (School Census, 2019)	(Total number of constructions) *200
18. Avg number of households moving to the area	DV	Households	N/A	Calculated from the impact construction has on households moving to the area divided by the number of students per household, and the number of people moving to the area divided by the average number of people per household to ensure all values are in the right units to give a total number of households.	(Households by Local Authority and Year, 2019)	(impact construction has on households moving to the area/avg number of eligible students per household) + (avg number of people moving to the area/2.29)
19. Avg number of eligible students	DV	Students	N/A	Calculated from the collective number of households either in the area or moving into the area multiplied by the number of students per household to give the	(Number of pupils in Cardiff, 2021), (Households by Local Authority and Year, 2019)	(avg number of eligible students per household*(avg number of households moving to the area + avg number of households in the area))

				number of students that are eligible for a school place in the city.		
20. Discrepancy between school places needed and available	DV	Places	N/A	Calculated from the figures of current school places and the number of school places available.	" "	avg number of eligible students - avg number of school places available
21. Avg number of school merges	DV	School merges	2	Based off data obtained from a reliable source which provided the number of school merges in wales. Uses that figure and the number of schools across wales I calculated the avg number of school merges in Cardiff.	(School Census, 2019)	(Number of merges in Wales (27)/ number of LA schools) * number of schools in Cardiff
22. Avg number of schools in Cardiff	DV	Schools	116	Based off data obtain from a reliable source for number of schools in Cardiff.	" "	
23. Avg number of students per school	DV	Students/School	N/A	Calculated from data obtained from a reliable source for avg number of schools in Cardiff and avg number of school places available to get the number of students per school currently.	(School Census, 2019), (Number of pupils in Cardiff, 2021)	avg number of school places available/avg number of schools in Cardiff
24. Avg number of new schools needed	DV	Schools	N/A	Calculated from the discrepancy between school places needed and available and avg number of students per school, to provide the number of schools needed to make up extra places.	(Number of pupils in Cardiff, 2021), (Households by Local Authority and Year, 2019), (School Census, 2019)	(DiscBetweenSchoolPlacesNeededAndAvailable/ AvgNoOfStudentsPerSchool)
25. Increasing construction	Flow	Constructions	N/A	Calculated from the number of new schools needed and the	" "	avg number of new schools needed + avg number of school merges

				number of new school merges needed.		
26. Total Construction	Stock	Constructions	N/A	Calculated from the increasing construction flow.	" "	The value of "increasing construction"
27. Avg number of amenities in the area	DV	Amenities	3792	Based off data obtained outlining the impact amenities has on the population of cities. Using this data I calculated the initial value so that it aligned with my models format.	(How does the amenity offer differ across cities? | Centre for Cities, 2019)	N/A
28. Avg number of people moving to the area	DV	People	N/A	Calculated from the current population of Cardiff multiplied by the percentage increase caused by the number of new public services. The percentage increase was calculated by using data of other cities of similar build (Edinburgh) and the impact increasing services has on their population.	(Cardiff, UK Metro Area Population 1950-2021 | MacroTrends, 2021), (Edinburgh, UK Metro Area Population 1950-2021 | MacroTrends, 2021), (How does the amenity offer differ across cities? | Centre for Cities, 2019)	(474000*((avg number of amenities in the area-3791)*0.008))
29. Avg number of construction vehicles per project	DV	Construction Vehicles	10	Based off data outlining the safety features required on construction projects around vehicles. Using this I made an estimation of the number of vehicles allowed during a school build.	(Books, 2009)	N/A
30. Avg duration of construction projects	DV	Months	12	Based off data from a reliable source providing details on	(Education buildings - SteelConstruction.info, 2019)	N/A

				lengths of different types of construction projects.		
31. Avg number of miles construction vehicles travel	DV	Miles	1800	Based off data outlining the safety features required on construction projects for vehicles. Using this data, I estimate the miles driven by vehicles yearly.	(Books, 2009)	N/A
32. Avg construction vehicles usage in miles	DV	Miles	N/A	Calculated from the total number of constructions, the number of vehicles used per project, the duration of the projects and miles driven by construction vehicles to give the overall usage in miles.	(Education buildings - SteelConstruction.info, 2019)	Total number of constructions*((avg number of construction vehicles per project*(avg number of miles construction vehicles travel per month))*avg duration of construction projects)
33. Avg number of teachers	DV	Teachers	N/A	Based off the number of teachers per student (0.05), calculated from the number of current teachers and students to provide an average that can be used for the model when student numbers increase.	(School Census, 2019)	(avg number of eligible students*0.05)
34. Avg commute for teachers	DV	Miles	19	Based off data outlining the average commutes in miles of adults in wales.	(Average commute time, 2019)	N/A
35. Avg distance teachers commute to school by car	DV	Miles	N/A	Calculated from the number of teachers, including any more teachers from the discrepancy, multiplied by the average commute distance for teachers.	(School Census, 2019), (Average commute time, 2019)	((avg number of teachers) *avg commute for teachers)
36. Avg commute distance of construction workers	DV	Miles	27	Based off data outlining the average commutes construction workers have to make.	(Belger, 2015)	N/A

37. Avg number of construction workers	DV	People	45	Based off data outlining the safety features of a construction site. Using this data, I made an estimation on the number of construction workers that would be involved in a school build.	(Books, 2009)	N/A
38. Avg number of vehicles per construction worker	DV	Vehicles	0.8	Based off data of the number of cars per household, taking into consideration the number of adults in a household and the average number of workers who car share to work.	(Households by Local Authority and Year, 2019), (NimbleFins, 2020)	N/A
39. Avg number of personal construction worker vehicles driven to the site	DV	Vehicles	N/A	Calculated from the number of vehicles per construction worker and the number of construction workers on a project to get the average number of vehicles driven to a construction site.	" "	avg number of vehicles per construction worker*avg number of construction workers
40. Avg distance between school and a student's home	DV	Miles	2.4	Based off data from a reliable source outlining the commuting patterns of students	(Travel to school figures, 2019)	N/A
41. Avg number of students per local bus	DV	Students/Bus	40	Based off data from a reliable source outlining the capacity of average school buses	(Vehicles et al., no date)	N/A
42. Avg distance students travel to get to school by car	DV	Miles	N/A	Calculated from data for average distance students commute and the number of students who commute by car to provide the overall distance travelled.	(Travel to school figures, 2019)	avg distance between school and a student's home*avg number of students commuting to school by car

43. Avg distance students travel to school by local bus	DV	Miles	N/A	Calculated from data for average distance students commute, the number of students who commute by local bus and the number of students who can fit on a bus to provide the overall distance travelled by students.	“ ”	(avg number of students commuting to school by local bus/avg number of students per local bus) *avg distance between school and a student’s home
44. Increasing miles driven	Flow	Miles	N/A	Calculated from multiple variables, all of which can be seen in the equation, variables in which provide miles driven by vehicles of cars, local buses and construction vehicles. The equation also takes into consideration the impact amenities have on miles driven by residents of Cardiff. For this model I have assumed its average impact, but I have ensured it follows the trend data shows, in which more amenities mean more miles travelled by cars.	(Education buildings - SteelConstruction.info, 2019), (School Census, 2019), (Average commute time, 2019), (Belger, 2015), (Households by Local Authority and Year, 2019), (NimbleFins, 2020), (Travel to school figures, 2019), (Vehicles et al., no date)	(avg distance teachers commute to school by car) + (avg distance students travel to school by local bus) + (avg distance students travel to get to school by car) + (avg construction vehicles usage in miles) + ((((avg number of amenities in the area /10) + 1) *30)) +(avg number of personal construction worker vehicles driven to the site*avg commute distance of construction workers)
45. Total miles driven	Stock	Miles	N/A	Calculated from increasing miles driven.	“ ”	Increasing miles driven
46. Avg speed vehicles travel	DV	MPH	20, 25, 30	Based off data obtained outlining the average speeds in cities and their correlation to MPG of vehicles.	(Department, 2016), (Sims, 2021)	Changed by the slider that impacts the speed of vehicles.
47. Avg miles per gallon of vehicles	DV	MPG	38, 43, 48	Based off data obtained outlining the average MPG of vehicles	(Sims, 2021)	(AvgSpeedVehiclesTravel+18)

				depending on average speed. This data was used to formulate the value 18 which works as constant to convert a vehicles speed to a vehicles MPG.		
48. Avg carbon emissions emitted from traffic	DV	CO2 e	N/A	Based off data obtained from a reliable source outlining the complete carbon emissions of a vehicle, from manufacturing emissions to fuel combustion emissions.	(Sims, 2021), (Wilson, 2017)	((0.00051 + (0.0106/avg miles per gallon of vehicles))*avg number of miles driven)
49. Avg carbon emissions released per construction	DV	CO2 e	3472	Based off data from the carbon emissions emitted from a construction of a home. Using this data the average size home and school were compared and their differences used to calculate, from the carbon emissions of an average home, the carbon emissions for a school construction.	(Berners-Lee, 2010), (dwh.co.uk, 2018), (EFA, 2014)	N/A
50. Avg carbon emissions released from construction	DV	CO2 e	N/A	Calculated from the total number of constructions multiplied by the emissions released per construction resulting in the overall emissions released from constructions.	" "	Total number of constructions*avg carbon emissions released per construction
51. Carbon emissions released into the atmosphere	Flow	CO2 e	N/A	Calculated from the emissions of traffic and emissions released from construction, to provide the	" " , (Sims, 2021), (Wilson, 2017)	avg carbon emissions emitted from traffic + avg carbon emissions released from construction

				emissions released into the atmosphere.		
52. Avg number of trees in Cardiff	DV	Trees	N/A	Based off data obtained outlining the number of trees that the average school has on its grounds.	(*Valuing Cardiff's* Urban Forest: A Summary Report, 2017), (Trees in school grounds / RHS Campaign for School Gardening, 2015)	Total number of constructions *4
53. Avg number of emissions absorbed by trees	DV	CO2 e		Calculated from the number of trees in Cardiff by the yearly amount of carbon emissions absorbed.	(All About Trees - Keystone 10 Million Trees Partnership, 2018)	(avg number of trees in Cardiff*0.0217724)
54. Carbon emissions being absorbed from the atmosphere	Flow	CO2 e	N/A	Based off data obtained of natural elements that absorb carbon emissions without the need for policy action.	(*Valuing Cardiff's* Urban Forest: A Summary Report, 2017), (All About Trees - Keystone 10 Million Trees Partnership, 2018)	Avg number of emissions absorbed by trees
55. Total Carbon Emissions	Stock	CO2 e	N/A	Calculated from the emissions emitted and emissions absorbed	" "	Carbon emissions released into the atmosphere-Carbon emissions being absorbed from the atmosphere
56. Limit Construction	DV	Constructions	N/A	Calculated using an if-then-else statement which states if more then 10 constructions have occurred then only allow partial constructions to take place. Which in this case are equivalent to 20% of a fully constructed school.	(Berners-Lee, 2010), (dwh.co.uk, 2018), (EFA, 2014)	(TotalNoOfConstructions>10) ? (AvgNoOfNewSchools Needed*POLICY_SWITCH) : AvgNoOfNewSchoolsNeeded

57. Policy Switch	P	N/A	0.2,1	Used as a switch to turn on and off the limit construction policy. 0.2 is on and 1 is off.	N/A	N/A
58. Carpool	DV	Cars	N/A	Calculated by taking the percentage of students who are carpooling and dividing by 2 to calculate the number of cars used and then adding the remaining number of students who go by car. It is assumed that there is one student per car without this policy.	N/A	20% - (((AvgNoOfStudentsCommutingToSchoolByCar*0.40)/2) + (AvgNoOfStudentsCommutingToSchoolByCar*0.60)) 40% - (((AvgNoOfStudentsCommutingToSchoolByCar*0.20)/2) + (AvgNoOfStudentsCommutingToSchoolByCar*0.80))

11.6 Appendix F - Justification Table for Food & Waste simulation

Factor	Model Type	Units	Initial Value	Justification	Evidence	Equation
1. Avg number of students who	DV	% decimal of Students	0.074	Based off data outlining the number of students who attend breakfast	(BREAKFAST CLUBS A How to...Guide AND,	N/A

attend breakfast clubs				clubs across the UK based off surveys.	2020), (Kelloggs, 2014)	
2. Avg total amount of time for lunch	DV	Minutes	191625	Based off data outlining the average amount of lunch breaks across schools in the UK in minutes.	(Baines and Blatchford, 2019)	191625 (Average lunch break being 52.2 over 10 years)
3. Avg percentage of students on FSM	DV	% students	18.3	Based off data obtained outlining the percentage of students who have FSM	(School Census, 2019)	N/A
4. Avg number of students on FSM	DV	Students	N/A	Calculated from the percentage of students on FSM and the average number of students per school who would receive FSM.	(School Census, 2019)	avg_number_of_students_per_school* (avg_percentage_of_ students_on_FSM/100)
5. Avg cost of meal options	DV	Pounds (£)	2.04	Based off data outlining the average cost of school meals in the UK.	(School lunch take-up survey, 2015)	N/A
6. Impact of avg cost of meals	DV	% decimal of students	N/A	Calculated from the cost of the meal options. From the data sourced in the following column I calculated a 7% increase in uptake when prices decreased by 50p. This figure has been implemented into the equation.	(Apse, 2017)	If (avg_cost_of_meal_options < 2.04) avg_cost_impact_on_uptake = 0.93 else if (avg_cost_of_meal_options = = 2.04) avg_cost_impact_on_uptake = 1 else avg_cost_impact_on_uptake = 1.07
7. Avg number of students per school	DV	Students /School	470	Appendix A.19	Appendix A.19	Appendix A.19
8. Avg percentage of students having home meals	DV	%	60.1	Based off data outlining the number of students who do not purchase cooked school meals.	(School lunch take-up survey, 2015)	N/A
9. Avg number of home meals	DV	Meals	N/A	Calculated from the number of students at the school, the percentage of students who bring	(School lunch take-up survey, 2015), Appendix E.19	(avg_number_of_students_per_school *((avg_percentage_of_students_having_ home_meals/100)+impact_quality_has

				home meals into school and the impact the quality of school meals has on students bringing in their meals.		_on_students_having_home_meals))
10. Impact quality has on students having home meals	DV	% decimal of students	N/A	Calculated through using an if-then-else statement indicating if the quality is lower than a certain level, students who have home meals will increase and if it is above that level it'll decrease.	" "	(quality_of_meals < 500) ? (1+(quality_of_meals/8000)) : (1-(quality_of_meals/20000))
11. Avg multiplier of demand	DV	N/A	N/A	Calculated from the base level of demand of meals, which is calculated from the number of students at the school – the number of students who eat food from home. Required to calculate deliveries.	N/A	(TotalDemandOfMeals/188)
12. Avg distance from supplier	Parameter	Miles	25, 37.5 & 50	Based off data outlining the distance between schools and supplier, indicating what is counted as local in terms of distance.	(Life, 2021)	Slider
13. Avg number of food deliveries	DV	Deliveries	N/A	Based off data obtained indicating the average number of food deliveries schools make normally. Then I multiplied by demand to show that for anymore meals required, above the normal, the more deliveries that are needed to be made.	" ", (Simple, 2020)	(avg_multiply_of_demand*2) **Policy Added** - (avg_multiply_of_demand*(1+(1*(1-AvgPercentageOfFrozenFood))))

				Policy Added – Additional variable added called avg percentage of frozen food which has an impact on deliveries because frozen food can store for longer so doesn't require as many deliveries.		
14. Avg carbon emissions from delivery	DV	T CO2e	N/A	Calculated similarly to Appendix E.47. Expected MPG of a vehicle has been changed to 7.6 due to the average vehicle that completes food deliveries to schools being a truck and that is their average MPG.	(What fuel economy (MPG) does a lorry get?, 2020)	((0.00051+(0.0106/7.6))*(avg_distance_from_supplier *avg_number_of_food_deliveries))
15. Level of freshness of meals	DV	Rating	N/A	Calculated using data obtained that provides information on the impact deliveries make on the freshness of food. The equation created represents this trend to the best of its ability with the data available. **Policy Added** – Additional variable added to ensure policy doesn't impact freshness as I assume between frozen and fresh the fresh at the same level in terms of when food is used compared to frozen.	" "	((1+((avg_number_of_food_deliveries /1000)+(1(avg_distance_from_supplier /100))))*300 Policy Added - ((1+((avg_number_of_food_deliveries *(1+AvgPercentageOfFrozenFood))/1000) +(1(avg_distance_from_supplier /100))))*300
16. Avg waiting time for food	DV	Minutes	N/A	Based off data outlining the average time students need to eat lunch to give me the average time students should be waiting, and the number of meals purchased to give you	(Kids, 2019)	(TotalDemandOfMeals*5)

				overall time spent waiting to get food when put into a equation.		
17. Impact of avg time to eat	DV	% decimal of meals	N/A	Based off data outlining the impact less time to eat lunch has on students buying habits within a canteen.	(Time For Lunch Policy, 2014), (Kids, 2019)	1-(avg_time_to_eat_meals/5)
18. Avg number of students purchasing school meals	DV	Students	N/A	Based off all the factors shown in the equation which have referenced evidence of their impact on the purchasing nature of students in school.	(Time For Lunch Policy, 2014), (Partnership, 2010), (School lunch take-up survey, 2015), (School Census, 2019)	(((((avg_number_of_students_on_FSM) +(avg_number_of_students_per_school *21.6))*impact_of_avg_cost_of_meals) *impact_quality_has_on_students_ having_cooked_meals)* impact_of_avg_time_to_eat)
19. Avg time to eat meals	DV	Minutes	N/A	Calculated based on data outlining the impact increased waiting time can have on students buying habits. The more time they wait the less they buy.	" "	(1 + ((avg_waiting_time_for_food /avg_total_amount_of_ time_for_lunch)/10))
20. Impact of time on wastage	DV	% decimal of meals	N/A	" "	(Time For Lunch Policy, 2014), (Kids, 2019)	avg_time_to_eat_meals
21. Avg number of meals batch cooked	DV	Meals	N/A	Based off the split I wanted for my model between batch cooked meals and meals made-to order. Batch cooked meals on average produces too much food, hence the 1.2 multiple to increase the number of meals made by 20%, based off data obtained.	(Time For Lunch Policy, 2014), (Partnership, 2010), (School lunch take-up survey, 2015), (School Census, 2019), (Manager, 2019), (Oregon.gov, 2021)	(TotalDemandOfMeals*0.6)*1.2

22. Avg number of meals made to order	DV	Meals	N/A	Based off the split I wanted for my model between batch cooked meals and meals made-to order. Made-to order I assume doesn't cook any excess meals because it only makes meals that have been ordered.	" "	TotalDemandOfMeals*0.4
23. Avg number of meals made	DV	Meals	N/A	Calculated from the number of meals made from batch cooking and made-to order which makes up all meals made.	" "	avg_number_of_meals_batch_cooked+avg_number_of_meals_made_to_order
24. Discrepancy between meals made and purchased	DV	Meals	N/A	Calculated from meals made and total demand of meals as the demands indicates the number of meals actually consumed.	" "	avg_number_of_meals_made-TotalDemandOfMeals
25. Quality of meals	DV	Rating	N/A	Based off several factors supported by data showing trends of the impacts that affect the quality of food.	(Life, 2021), (Time For Lunch Policy, 2014), (Partnership, 2010), (School lunch take-up survey, 2015), (School Census, 2019), (Manager, 2019), (Oregon.gov, 2021)	((level_of_freshness_of_meals)*((avg_number_of_meals_made/(avg_number_of_meals_batch_cooked*0.8))-1))
26. Impact quality has on students who have school meals	DV	% decimal of students	N/A	Calculated from quality of meals and its rating. If the quality is below a threshold, then there will ultimately be an impact on students buying habits, causing less students to buy meals. If it has a high enough score	" "	(quality_of_meals < 500) ? (1-(quality_of_meals/20000)) : (1+(quality_of_meals/8000))

				there will be an increase in students buying meals.		
27. Impact quality has on waste	DV	% decimal of meals	N/A	Calculated from the quality of meals and its rating. If the quality is below a threshold, then there will be an increase in food waste. If it has a high enough score there will be a reduction in wastage.	" "	(quality_of_meals < 500) ? (1+(quality_of_meals/8000)) : (1-(quality_of_meals/20000))
28. Avg number of meals wasted	DV	Meals	N/A	Calculated from the discrepancy of meals made and meals purchased multiplied by the factors that impact overall meal wastage, shown in the equation section. **Policy Added -** Additional factor added to take into consideration the impact of the policy, justified at 39.	" ", (16 Ways To Reduce Food Waste At Home, School, and More, 2019)	((discrepency_between_meals_made_and_purchased)*impact_of_time_on_wastage)*impact_quality_has_on_waste **Policy Added -** (((discrepency_between_meals_made_and_purchased)*impact_of_time_on_wastage)*impact_quality_has_on_waste)*ImpactFrozenFoodHasOnWaste
29. Avg carbon emissions from food waste	DV	T CO2e	N/A	Calculated from data obtained outlining the amount of food waste produced in the UK last year and the amount of carbon emissions released from that waste. Using this I calculated the average amount of carbon emissions released per meal, which was 0.00218 T CO2e.	(Feeding America, 2016), (Manager, 2019)	(TotalFoodWaste*0.00218)
30. Generating demand	Flow	Meals	N/A	Calculated from students who are purchasing food and those who attend breakfast clubs. I have	(Time For Lunch Policy, 2014), (Partnership, 2010),	(avg_number_of_students_purchasing_school_meals)+((avg_number_of_students_purchasing_school_meals

				multiplied the number of students who go to breakfast clubs to represent them having two meals a day rather than just the one at dinner time.	(School lunch take-up survey, 2015), (School Census, 2019), (BREAKFAST CLUBS A How to...Guide AND, 2020), (Kelloggs, 2014)	*avg_number_of_students_who _attend_breakfast_clubs)*2)
31. Total demand of meals	Stock	Meals	188	" "	" "	GeneratingDemand-ReducingDemand
32. Reducing demand	Flow	Meals	N/A	Appendix F.9	(School lunch take-up survey, 2015), Appendix E.15	avg_number_of_home_meals
33. Generating food waste	Flow	Meals	N/A	Calculated from the number of meals wasted, as that value increases so does the amount of food waste generated.	(Life, 2021), (Time For Lunch Policy, 2014), (Partnership, 2010), (School lunch take-up survey, 2015), (School Census, 2019), (Manager, 2019), (Oregon.gov, 2021)	avg_number_of_meals_wasted
34. Total food waste	Stock	Meals	N/A	" "	" "	GeneratingFoodWaste
35. Releasing Carbon Emission	Flow	T CO2e	N/A	Calculated from the carbon emissions produced from food waste and the carbon emissions released from food delivers.	(Feeding America, 2016), (Manager, 2019), (What fuel economy (MPG)	(avg_carbon_emissions_from_food _waste)+(avg_carbon_emissions _from_deliveries) **Policy Added** -

				Policy Added – Additional factor added when frozen food policy added as the carbon emissions released from the extra energy needed to store the frozen food needs to be accounted for.	does a lorry get?, 2020)	(avg_carbon_emissions_from_food_waste) +(avg_carbon_emissions_from_deliveries) +(AvgCarbonEmissionsFromFreezerFood)
36. Total Carbon Emissions	Stock	T CO2e	N/A	" "	" "	ReleasingCarbonEmissions
37. Increasing Meals-to order	Parameter	% decimal of students	0.1-0.9	The lowest value is based off the assumption that at least some meals must be made-to order to aid in ensuring allergy policies are followed, which is the reason for the minimal value of 0.1. The highest value is based off the assumption that not all meals can be made-to order due to a chance some students won't make an order in time, but they still require food, giving a maximum value of 0.9.	(School Food Allergy Policy | With Free Allergy Poster, 2019)	N/A
38. Avg percentage of frozen food	Parameter	Meals	0.2-1	Based off assumptions due to lack of data on the average amount of frozen food used by schools. I assume that every school already uses some frozen food but will never use 100% frozen food.	N/A	N/A
39. Impact frozen food has on waste	DV	% decimal of waste	N/A	Based off research showing a trend in frozen food reducing waste, which is why I created this equation to show this trend in the model.	(16 Ways To Reduce Food Waste At Home, School, and More, 2019)	(1-(AvgPercentageOfFrozenFood/10))

40. Avg Carbon Emissions From Freezer Food	DV	T CO2e	N/A	Firstly, I assume that schools already have a walk-in freezer. The power currently used to store food I chose not to include in this equation as its energy is already accounted for. However, the increase in frozen food would increase the energy required to run the freezer, so I calculated the difference between the normal running power amount and the new power amount to get the power needed to store the additional frozen food. Average energy needed to run a walk-in freezer is 700 kwh, per kwh produces 0.000233 tonnes of carbon emissions. Using these figures, the equation multiplies every extra kwh required by 0.000233 to give the amount of carbon emissions emitted due to the additional storage needed to implement this policy.	(Are walk-in freezers eco-friendly?, 2015), (Bulb Energy, 2020)	(700*(0.95+(AvgPercentage OfFrozenFood/4)))*0.000233

11.7 Appendix G – Loops within the Transport CLD

Loop Number 1 of length 3
avg amount of traffic on the roads
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 2 of length 3
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students late to school due to public or school transport
avg number of personal transport use
Loop Number 3 of length 3
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 4 of length 4
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 5 of length 4
avg amount of traffic on the roads
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 6 of length 4
avg amount of traffic on the roads
avg amount of time school buses are late
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 7 of length 5
avg amount of traffic on the roads
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
Loop Number 8 of length 5
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students late to school due to public or school transport
avg number of personal transport use
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 9 of length 5
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 10 of length 5
avg amount of traffic on the roads
level of reliability of school buses
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 11 of length 5
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 12 of length 5
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
Loop Number 13 of length 5
avg amount of traffic on the roads
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg amount of time collectively schools buses are parked on the street
Loop Number 14 of length 5
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg amount of time collectively schools buses are parked on the street
Loop Number 15 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
avg amount of time school buses arrive before students finish
avg number of students using school buses
Loop Number 16 of length 6
avg amount of traffic on the roads
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
Loop Number 17 of length 6
avg amount of traffic on the roads
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
avg amount of time collectively schools buses are parked on the street
Loop Number 18 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg amount of time collectively schools buses are parked on the street
Loop Number 19 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
avg amount of time collectively schools buses are parked on the street
Loop Number 20 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 21 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school

Loop Number 22 of length 6
avg amount of traffic on the roads
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg amount of time collectively schools buses are parked on the street
Loop Number 23 of length 6
avg amount of traffic on the roads
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 24 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
Loop Number 25 of length 6
avg amount of traffic on the roads
avg amount of time school buses are late
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 26 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg amount of time collectively schools buses are parked on the street
Loop Number 27 of length 7
avg amount of traffic on the roads
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
Loop Number 28 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students late to school due to public or school transport
avg number of personal transport use
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
Loop Number 29 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 30 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students late to school due to public or school transport
avg number of personal transport use
avg number of students using school buses
avg number of stops school buses make
avg amount of time school buses take to get to school
avg amount of time collectively schools buses are parked on the street
Loop Number 31 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
avg amount of time collectively schools buses are parked on the street
Loop Number 32 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
avg amount of time collectively schools buses are parked on the street
Loop Number 33 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students late to school due to public or school transport
avg number of personal transport use
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg amount of time collectively schools buses are parked on the street
Loop Number 34 of length 7
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
Loop Number 35 of length 8
avg amount of traffic on the roads
avg amount of time school buses are late
avg number of students late to school due to public or school transport
avg number of personal transport use
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
avg amount of time collectively schools buses are parked on the street
Loop Number 36 of length 8
avg amount of traffic on the roads
avg amount of time school buses are late
level of reliability of school buses
avg amount of time school buses arrive before students finish
avg number of students using school buses
avg number of school buses in the fleet
avg number of bus bays outside the school
avg number of school buses parked on the street during pick up and drop off
avg amount of time collectively schools buses are parked on the street