V-KEMS Study Group Report

Recovery from the Pandemic: Transport Logistics
Report Authors and Contributors:

**Challenge 1:** Sophie Abrahams (University of Oxford), Yutong Bai (University of Glasgow), Sabrina Kombrink (University of Birmingham), Adhiraj Mandal (University of Glasgow), Surajit Ray (University of Glasgow), Tony Samuel (University of Birmingham)

**Challenge 2:** Simone Appella (University of Bath), Nicolas Boulle (University of Oxford), Chris Budd (University of Bath), Sam Kamperis (Oxford Brookes University), Ioan Alexandru Puiu (University of Oxford), Babooshka Shavazipour (University of Jyvaskyla), Ann Smith (University of Huddersfield), Yu Tian (University of Oxford), Wenzhong Wang (University of Cambridge), Huining Yang (University of Oxford), Wee Meng Yeo (University of Glasgow), Tina Zhou (University of Bath)

Contributions from Maha Kaouri (Newton Gateway to Mathematics)

Our thanks to the following for their invaluable insights to help develop the Study Group:
Mike Brookbanks (University of Surrey) and Alex Pepper (UK Major Ports Group (UKMPG))

This work was funded in part by UKRI Grant EP/V053507/1: RAMP Continuity Network

WARNING: this report contains preliminary findings that have not been peer reviewed. The findings are intended to provoke further study and policy discussion and should not be treated as definitive scientific advice in response to the COVID-19 pandemic.

Whilst we expect these principles to help others formulate coherent and consistent guidelines, time has prevented any quantitative study of their effectiveness. This could be undertaken, but would require real data and time to build more detailed simulation tools. Thus, we are not able to make specific recommendations from the principles, e.g. we cannot infer that it is safe to do X if you follow principle Y.

Additionally, this report has been assembled in a short time frame, we have made every effort to ensure references and links are present. Where this is not the case, we apologise for the unintentional oversight.
## Contents

1 Executive Summary .......................................................... 4

2 Background ............................................................................ 5
   2.1 Aims & Objectives .............................................................. 6

3 Challenge 1: Trustworthiness at the Border ................................. 8
   3.1 Background ...................................................................... 8
   3.2 Literature review ................................................................. 10
   3.3 Modelling .......................................................................... 13
   3.4 Simple Linear Model ............................................................ 16
   3.5 Structural Equation Model (SEM) ............................................ 19
   3.6 Agent-based models ............................................................. 25
   3.7 Summary & Future Work ....................................................... 26

4 Challenge 2: Delivering Shore Power .......................................... 29
   4.1 Background ...................................................................... 29
   4.2 Summary ........................................................................... 29
   4.3 Background Info about vessels .............................................. 31
   4.4 Vessels types and emissions ............................................... 31
   4.5 Data questions ................................................................... 31
   4.6 Cash flow .......................................................................... 50
   4.7 Modelling questions ........................................................... 60
   4.8 Summary & Future Work ....................................................... 62

5 Conclusions ........................................................................... 65
1 Executive Summary

Increased border restrictions, a reduction in the availability of workers and the increased demand for home delivery over the past 2 years has meant that the freight transport network has had to drastically adapt its operations. The consequent impact on the supply chain has been substantial, and can be observed by simply looking at supermarket shelves. On behalf of the Virtual Forum for Knowledge Exchange in the Mathematical Sciences (V-KEMS), the Newton Gateway to Mathematics convened Recovery from the Pandemic: Transport Logistics, a Virtual Study Group, from 29th – 31st March 2022. This brought those working in mathematical modelling, statistics, operations research, logistics and supply chain management and other disciplines together to solve end user defined challenges in transport logistics.

The following challenges were presented to the study group:

- **Trustworthiness at the Border**, presented by Mike Brookbanks – Independent Consultant and Visiting Fellow at University of Surrey
  
  This subgroup looked at modelling trust at the UK boarders, focusing on the relationship between the importer and the government.

- **Delivering Shore Power**, presented by Alex Pepper– Senior Policy Lead – ESG at UK Major Ports Group (UKMPG)
  
  This subgroup aimed to address the question: Is shorepower good value as an emissions reduction scheme for shipping and as a contributor to the Transport Decarbonisation Plan?

Over the course of the study group, potential solutions were developed and these were presented on the final day. Those stakeholders who presented their challenge were provided with a short tailored report after the event.
2 Background

Increased border restrictions, a reduction in the availability of workers and the increased demand for home delivery over the past two years has meant that the freight transport network has had to drastically adapt its operations. The consequent impact on the supply chain has been substantial, and can be observed by simply looking at supermarket shelves.

Various stages of the shipping and supply chain network have had to deal with the effects of COVID-19, climate change and the change of regulations. These include:

- Transport from producers to importers.
- Importing into the UK, through ships and ports.
- Transport from ports to supermarkets.
- Transport from supermarkets to customers.

The particular issues faced by the network include:

**COVID-19**

- Staff shortages.
- Restricted use of port facilities.
- Goods contamination.
- Increased online ordering during lockdowns.

**Climate**

- The direct effect of climate on the water ways.
- The impact of sea levels rising.
- Increase of storms and extreme weather events.
- Pollution issues.
- Change in consumer habits, for example, people are less keen to buy things from across the globe leading to an increase on local sourcing.
• Reduction in the use of fossil fuels - less oil consumption, so less oil will be transported.

**Impact of change of regulations on shipping**

• Staff shortages.

• Fuel crisis.

• Change in boarder regulations.

### 2.1 Aims & Objectives

The aim of this event is to bring together those working in mathematical modelling, statistics, operations research, logistics and supply chain management and other disciplines together to solve end user defined challenges in transport logistics.

The following challenges were presented to the study group:

**Trustworthiness at the border**, presented by Mike Brookbanks – Independent Consultant & Visiting Fellow at University of Surrey

This subgroup looked at modelling trust at the UK boarders, focusing on the relationship between the importer and the government.

The reducing friction in International Trade (RFIT) project was initiated in March 2019 as a step towards a more operationally efficient supply chain network, with aims to provide transparency in the data between producers, importers and the UK border.

The aim of the study group was to model the relationship between an importer and the UK border. This model was expected to incorporate attributes such a calculative trust and cognitive trust, as detailed in the paper [1].

**Delivering Shore Power**, presented by Alex Pepper – Senior Policy Lead - ESG at UK Major Ports Group (UKMPG)

The Department of Transport had a call for evidence on shore power and implementing maritime commitments in the Transport Decarbonisation Plan.

The call for evidence looked to see how the government can support the wider implementation of shorepower in the UK. The delivery of shorepower at ports is often quite challenging, with many ports lacking a clear demand or available electrical capacity to deliver such demand.
even if it was to exist. Concerns exist as to whether a mandate on shorepower would be appropriate, when the costs can vary significantly from site to site, and there may be other lower cost options that have a greater emission reduction benefit.

The aim of the study group was to address the question: Is shorepower good value as an emissions reduction scheme for shipping and as a contributor to the Transport Decarbonisation Plan?

References

3 Challenge 1: Trustworthiness at the Border

3.1 Background

This subgroup looked at modelling trust at the UK boarders, focusing on the relationship between an importer and the government.

As explained in the 2025 UK Border Strategy report [9], the reducing friction in International Trade (RFIT) project was initiated in March 2019 to understand how Blockchain Distributed Ledger Technology and associated technologies can be used to seamlessly integrate supply chain data with HM Revenue and Customs (HMRC) and the Food Standards Agency’s systems, guaranteeing the timeliness and provenance of critical data and avoiding the need for discrete declarations. This project was a step towards a more operationally efficient supply chain network, as it aims to provide transparency in the data between producers, importers and the UK border.

There is typically a mature relationship between an importer and a producer. However, this is not necessarily the case for the relationship between an importer and the UK government. Therefore, the study group aimed to model the latter relationship. The model was expected to incorporate attributes such a calculative trust and cognitive trust, as detailed in the paper [5], while also considering uncertainties. Other aspects to do with operational resilience, developments in technology and how the model fits with the complex supply chain (where there is a network of trust) could also be considered.

Together with the HMRC border risk assessment, the model developed during the study group could then be used by relevant parties (e.g., the government) to help determine how trustworthy a given importer is, and thus help manage risk at the borders.

3.1.1 Aims

- Develop a model with scoring mechanism that can model trust.

- Look at trust attributes for modeling the scoring mechanism. Question remains as to how one can measure some these attributes. One proposal might be to use a categorical measurement scheme for these attributes such as (maybe red/amber/green trust)?

- Build a realistic model that demonstrates the type of interactions between all actors. This would help small importers understand how they can build up trust with the UK border?
3.1.2 Considerations for model building

- How do we measure the variables/attributes?
- What type of model do we wish to fit?
- Do we have data for model building at hand?
- Are we supposed to develop a questionnaire or develop a scoring technique for a statistical (possibly Bayesian) model?
- More explanations on the Figure 1 of [5]. Do we have to expand this diagram?
- Find existing models that describe calculative trust, cognitive trust, etc.
- Trustworthiness is improved over time with good experience. How does one build the time component?
- Someone new to border operations has a very low level of trust and gradually builds trust. How do we model this?
- Any "error" (e.g., data entry error or an error in a declaration) results in mistrust at the border. Someone with a high level of movements/deliveries may still not have a mature level of trust. An example would be transporting companies - they do many movements per week, but they do not reach the high level of trust as even with such large volumes, they have discrepancy issues. For example, an importer may present incorrect data (such as an incorrect commodity code) in the declaration. This results in rejection at the border.
- **Calculative trust** is very low level. Cognitive trust has more attributes - trust is built over time.
- Small steps up in trustworthiness, but big step down. For example, an importer can step up X points, but down 2X points if an error is made.
- How should we increase/decrease trust:
  - If an importer decides to import goods themselves, and then struggles with the information required at the border, then they are fundamentally not trusted.
  - If there is an error in the paper work or the operation, then the goods are stuck in the port. Goods stuck in the port is a worst case scenario - if the goods are food, then they can spoil, or there are customer satisfaction issues.
- Small importers may opt to use a third party which is more trusted, as they are doing more imports/successful completions of declarations.
The more successful declarations a company completes, the more trusted they are. Once an importer gets over a certain threshold, then the likelihood of goods getting stopped/rejected at the border falls. If trust is high, goods are not examined when going through customs.

The UK Government does not give out its trust metrics.

AEO status is a certified standard authorisation issued by customs administrations in the European Union (EU)

- Once an importer has given a certain number of declarations, then they get an AEO 'badge'.

If the study group can build a model that can demonstrate this interaction, then this would be very important for logistics companies.

3.2 Literature review

3.2.1 Types of trust according to Broobanks and Parry [5]:

The literature mentions several types of trust

1. **Calculative trust**: Dominates early in relationships. "Data integrity and information asymmetries characterise transactions where cost, benefit and reputation are core drivers."

2. **Cognitive trust**: Develops as trust builds progressively. "Combines transactional and relational elements, expressed by expectations and predictions that partners will meet obligations."

3. **Affective trust**: Occurs as the relationship matures. "Builds on shared values, creating reciprocal durable personal attachments between buyers and sellers with behavioural trust. Reliance on others and disclosure of confidential information are key trusting behaviours."

3.2.2 Types of trust according to Akrout [1]

1. **Cognitive trust** – generalised expectancy held by an individual that the word of another can be relied on.

2. **Calculative trust** – trust grounded in the rational calculation of the costs and benefits of another individual breaking and maintaining an interdependent relationship. Calculative Trust (CT) is modelled in this paper [11].
3. **Authorised Economic Operator (AEO) certification** – essentially the highest level of trust from HMRC.

### 3.2.3 Properties of trust [1]

**Transitivity:** Due to the lack of previous experience, the central role in establishing trust is given to the brand, reputation of enterprises, references and recommendations by the partner with some history of cooperation with the enterprise, which is referred to as the principle of transitive trust (i.e. if A trusts B, and B trusts C, then A can trust C).

### 3.2.4 Other important points from [5]:

- Trust between importer/logistics company and UK Government agencies remains at calculative level. This is based on risk, compliance and history.

- “The default position is of limited trust, trust is built up over a number of years to partnerships, shared values, based on integrity and personal reputation” (Importer)

- “The UK Government customs and excise regime is based on approving key operators in the supply chain.” (HMRC)

- “There is a higher level of trust in the information when it is a highly regulated product. Where there is a balance between trust, risk and reputation.” (Importer)

- More information on p139 about how trust is built. Trust is built on past interactions.

- Errors in data (common due to data being manually entered) causes distrust.

- Distrust causes friction at borders.

In Figure 1, the attributes circled are not directly measurable, whereas those with a rectangle are.

### 3.2.5 Notes from Chen and Qi [6]

According to the *trade gravity model with trust as additional component* trust significantly influences the trade volume:
A simple linear model for trust can be proposed as

$$\ln \text{trade}_{ijt} = \alpha + \beta \ln \text{trust}_{jt} + \sum_{k=1}^{n} \gamma_k X^k + \epsilon$$

(1)

where,

- $\ln \text{trade}$: dependent variable (trade volume)
- $\ln \text{trust}$: Core explanatory variable (trust level of trading partners)
- $i$ is the exporting country,
- $j$ is the trading partner,
- $t$ is time,
- $X^k$ is the $k$-th dimension control variable (e.g. gross domestic products of trading countries, geographical distance between trading countries),
- $n$ is the number of control variables,
- $\alpha$ is the constant term,
- $\beta$ and $\gamma_k$ are parameters to be estimated, and
- $\epsilon$ is the error term.
3.2.6 Notes from articles for measuring trust attributes

[8] research framework uses path analytic model for modeling trust

![Diagram of trust model](image)

**Figure 2**: Source: [8].

Measuring elements by survey - five-point Likert scale from strongly disagree (1) to strongly agree (5):

3.2.7 Wang and Singh 2010 [12]

Model of trust based on probability distribution of probability of a positive outcome. Begin with uniform probability and update with each interaction.

Trust is affected by 'evidence' and by 'conflict'. Evidence can be positive and negative. Conflict is great when there is an equal amount of negative and positive evidence.

3.3 Modelling

We first start with a simple set of **Input variables**

- $x_1$: Time required for transaction
- $x_2$: Time required for clearance at the border
- $x_3$: Number of successful transactions in past year
- $x_4$: Number of unsuccessful transactions in past year
### Table 1: Construct operationalization

<table>
<thead>
<tr>
<th>Construct</th>
<th>Types</th>
<th>Relevant literature</th>
<th>Survey items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information sharing</td>
<td>Reflective</td>
<td>Zhou and Benton (2007), Hsu et al. (2008) and Yigitbasioglu (2010)</td>
<td>1. Use of compatible information systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Sharing of information related to various resources deployed for relief activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Existence of a joint information center for effective sharing of information</td>
</tr>
<tr>
<td>reduction</td>
<td></td>
<td></td>
<td>2. Getting along with my work group</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Organize my work</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Seeking help when necessary</td>
</tr>
<tr>
<td>Swift trust</td>
<td>Reflective</td>
<td>Tatham and Kovács (2010), Robert et al. (2009), and Hung et al. (2004)</td>
<td>1. I find my colleagues trustworthy</td>
</tr>
<tr>
<td>Commitment</td>
<td>Reflective</td>
<td>Morgan and Hunt (1994), Kwon and Suh (2004), Kwon and Suh (2005), Wu et al. (2004) and Jin et al. (2013)</td>
<td>1. Impact of relationship termination on the goal of disaster response</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Observed improvement in coordination</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Organizations share values</td>
</tr>
<tr>
<td>Coordination</td>
<td>Reflective</td>
<td>Balci et al. (2010), Akhtar et al. (2012) and Basnet (2013)</td>
<td>1. We consult other members before making decisions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. We understand the pressures and concerns of each other</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. We synchronize our activities with each other</td>
</tr>
</tbody>
</table>

**Figure 3:** Survey Items for modeling trustworthiness extracted from [8].
### Input Variable

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Type</th>
<th>Simulation weight</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for transaction</td>
<td>Numeric in days</td>
<td>-1</td>
<td>Might not be relevant, Poisson</td>
</tr>
<tr>
<td>Time at border (wait time&lt;2 days)</td>
<td>Binary</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Number/Proportion of success</td>
<td>Integer&gt;0, Real between 0 and 1</td>
<td>2</td>
<td>Poisson</td>
</tr>
<tr>
<td>Number of unsuccessful transaction over last year</td>
<td>Real between 0 and 1</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>Type of food</td>
<td>Fixed for now But can be modeled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whether using Technology</td>
<td>Binary</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1**: Table of input variables.

$x_5$: Whether or not using technology

$y$: The output variable (Trustworthiness score)

### Output Variable

Trustworthiness score and threshold for Binary Trust.

#### 3.3.1 Multiple Linear Regression

$$Y_i = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_p x_{pi} + \epsilon_i, \ i = 1, \ldots, n$$  \hspace{1cm} (2)

Restriction: can only model linear relationship between the response and the predictors. In reality relationship might be more complex

#### 3.3.2 Path Analysis

One option is to use path analysis, which is widely used in social sciences. In general path analysis is used to describe directed dependencies among a set of variables. Path analysis includes models equivalent to any form of multiple linear regression (MLR) analysis, factor
analysis, canonical correlation analysis, discriminant analysis, as well as multivariate models with multiple dependent variables, such as different types of trust.

In addition to being thought of as a form of MLR focusing on causality, path analysis can be viewed as a special case of structural equation modeling (SEM). Other terms used to refer to path analysis include causal modeling, analysis of covariance structures, and latent variable models.

Typically, path models consist of several independent and dependent variables depicted graphically by "boxes" or "rectangles". Variables that are independent variables, are called 'exogenous' variables. Graphically, these exogenous variable boxes lie at one end of the model and have only "single-headed" arrows exiting from them. No single-headed arrows point at "exogenous" variables. On the other hand variables that are solely "dependent variables", or are both independent and dependent variables, are termed 'endogenous'. Graphically, endogenous variables have at least one single-headed arrow pointing at them.

### 3.4 Simple Linear Model

We assign some weights to the variables under consideration based on our perceptions of their importance. The simulated result gives us an idea of the trust scores. In the absence of data this gives a head start for including further complexities in other models.

We make the following distributional assumptions on the variables.

- $x_1$ Poisson with mean $= 3$
Figure 5: Possible relationships between variables in a path diagram

- $x_2$ Binomial with probability 0.8
- $x_3$ Poisson with mean = 40
- $x_4$ Poisson with mean = 5
- $x_5$ Binomial with probability 0.7

Thus, we get a simple linear model

$$y = 50 - x_1 + 2x_2 + 2x_3 - 10x_4 + x_5 + \text{error}$$

(3)

Where, ‘error’ follows $N(0, 7)$ distribution.

The results for running the simulation using the simple linear model outlined above are given in Figure 6.

We will next focus on structural equations model
Figure 6: Simulation using Simple Linear Model.
3.5 Structural Equation Model (SEM)

Some similarity with structural equation model Paper [14, 2] SEM involves the construction of a model, an informative representation of some observable or theoretical phenomenon, such as subject matter information on trustworthiness. Different relationships of a phenomenon are theorized to be related to one another using a structure. This structure is represented by a system equations, but can also be represented graphically using a path diagram. The structure implies

- statistical and often causal relationships between variables
- Error terms at several levels

The equation (or equations) in SEM are mathematical and statistical properties that are implied by the model and its structural features, and then estimated with statistical algorithms (usually based on matrix algebra and generalized linear models) using experimental or observational data, by equating the implied population variance with sample variance. Often a model selection [3, 4] step is used to choose the right relationship among the variables.

![Figure 2. Final structural equation modeling with squared multiple correlations (R-square) and error terms](image)

**Figure 7:** Relationship diagram from [14].
Appendix: Sample Questionnaire

<table>
<thead>
<tr>
<th>Part 1 Personal Information</th>
</tr>
</thead>
</table>
| **Q1.1** Do you have experience to take part in partnering project(s)?  
  a) Yes  
  b) No |  
| **Q1.2** Your role in this partnering project  
  a) Developer  
  b) Contractor  
  c) Consultant |  
| **Q1.3** Working experience  
  a) < 5 years  
  b) 5-10 years  
  c) 11-15 years  
  d) 16-20 years  
  e) >20 years |  

**PART 2 The trust factors in partnering projects**

According to the answers you provided in Part 2(a), please circle the no. that best reflects the degree of importance of the following 14 attributes in developing trust:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Very low</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2.1 The competence of work of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.2 Problem solving ability of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.3 The frequency and the effectiveness of communication of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.4 The openness and integrity of communication of my partners</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.5 Alignment of effort and rewards among partners</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.6 Effective and sufficient information sharing with my partner.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.7 The sense of unity of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.8 Partners’ respect, believe and rely on the project management system</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.9 The compatibility of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.10 A long-term relationships with my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.11 The financial stability of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.12 Adoption of ADR techniques by my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.13 The reputation of my partner</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q2.14 My partners’ satisfaction on the contract terms and agreement</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>

**PART 3 Achievement of project goals**

According to the answers you provided in Part 3, in considering the successfulness of the partnering project, please indicate the degree of importance of achieving following project goals:-

<table>
<thead>
<tr>
<th>Goal</th>
<th>Not important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q3.1</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q3.2</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q3.3</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>Q3.4</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>

\[\text{Figure 8: Sample Questionnaire for collecting data to model trustworthiness}\]
3.5.1 Existing problem in model selection of SEM

Exploratory and confirmatory model selection tools are often used to choose the right model:

1. Relationship
2. Variable selection
3. Model goodness of fit (AIC-BIC)
4. Preparing appropriate questions to answer objectively

Reference: [7]

In the absence of real data we demonstrate the workings of SEM using a simulated data.

3.5.2 Initial model and result

We build the model using a linear regression and fit a SEM to the simulated data.

The SEM model we fit is described as follows:

\[ i : \text{"Experience-based trust" from } x_1, x_2, x_4 \]  \hspace{1cm} (4)

\[ s : \text{Trust from all variables/indicators } x_1, x_2, x_3, x_4, x_5 \]  \hspace{1cm} (5)
and the resulting path diagram is given in Figure 10.

Model:

![SEM model diagram]

**Figure 10:** SEM model following (4) for fitting simulated data

Model with fitted weights of SEM model from the simulated data is given Figure 11.
Figure 11: Fitted model based on Figure 10
More extensive SEM based on theoretical model in the original paper

\[
\begin{align*}
&x_1 = \text{Time for transaction Poisson with mean 3} \\
&x_2 = \text{Time at border (wait time < 2 days)} \\
&x_3 = \text{Number of success over last 3 years. → Poisson with mean 40} \\
&x_4 = \text{Number of unsuccessful transaction over last year → Poisson with mean 5} \\
&x_5 = \text{technology use} \\
&x_6 = \text{trustworthy AEO importer} \\
&x_7 = \text{Proper documentation} \\
\end{align*}
\]

Cognitive trust (CoT) indicator: \(x_2\)
Calculative trust (CaT) indicators: \(x_5, x_6, x_7\)
Affective trust (AfT) indicators: \(x_1, x_3, x_4\)

Unfortunately, no data was available to fit this model, but one could design a survey to collect these variables.

---

**Figure 12:** Path Diagram for model.

We next consider Agent-based models.
3.6 Agent-based models

"An agent-based model (ABM) is a computational model for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) in order to understand the behavior of a system and what governs its outcomes. It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming. Monte Carlo methods are used to understand the stochasticity of these models." [13]

Agent-based models are used for a diverse range of applications such as: the spread of disease in a country; the development of friendships in a society; and the movement of cars at a junction. The simulations show the evolution of the systems over time.

Application to modelling trust

As agent-based modelling is time-dependent, it is a useful tool for modelling the development of trust over time. We begin with aspects of a structural equation type model to model how ‘inputs’ (in this case called ‘attributes’) can be used to determine a trust score for an importer. To this framework, we introduce elements of randomness to observe how the trust score of an importer can change over time. The agent-based model gives a visual output, marking an importer as red, orange or green based on their trust score.

To model trust, we use the framework of a dynamic network. In our initial example the network consists of two importers, each marked with a node on the network. Each importer has three attributes: number of previous successful imports; number of previous unsuccessful imports; and delay on their most recent import. Each of these three attributes is represented by a node on the network. The weight of an edge on the network between an attribute and an importer is the value of that attribute for that importer. Number of previous unsuccessful and successful imports are positive integers. Delay on most recent import is given the value 1 for no delay, 0 for a moderate delay and -1 for a severe delay.

Our model is time-dependent and the trust value changes with every attempted import. At each time step, one importer attempts an import:

- the processing time at the border depends on the current trust score of the importer
  - if the current trust score is high, then with high probability there are no delays, or moderate delays
  - if the current trust score is low, then with high probability there is a delay, or a moderate delay
• a delay decreases the trust score by 1
• a moderate delay leaves the trust score unchanged
• no delays increases the trust score by 1
• similarly, the success of the import depends on the current trust score of the importer
  – if the current trust score is high, then with high probability the import is successful
  – if the current trust score is low, then with high probability the import is unsuccessful
• if the import is successful, the trust score increases by 2
• if the import is unsuccessful, the trust decreases by 10

This network can easily be extended to include more importers and more attributes. Interactions between importers could be taken into account, for example, modelling the case where a small importer attempts to import via a large importer. The benefit of this model is that mutual dependencies can be implemented (e.g. the trust score influences the processing time at the border, which in turn influences the trust).

Our model is implemented in NetLogo, where the time-dependent simulation can be run.

Alternatively, an implementation in R is possible. R Packages that can be used:

• lavaan
• semTools
• semPlot

**Outlook:** Consider the scenario where there's AEO certificates, where data from other countries is used (transitivity), where interactions between small and large importers are modeled more realistically.

### 3.7 Summary & Future Work

During the study group, three possible modelling techniques were considered to model trustworthiness at the border:
Recovery from the Pandemic: Transport Logistics - Study Group Report

- A Simple Linear Model: We assign some weights to the variables under consideration based on our perceptions of their importance. The simulated result gives us an idea of the trust scores. In the absence of data this gives a head start for including further complexities in other models.

- A Structural Equations Model: Widely used in Social Sciences and Psychology, this involves the construction of a model, an informative representation of some observable or theoretical phenomenon.

- A Dynamic Network Model (Agent Based Model)

In future work, we can use subject matter knowledge and data in order to build more complex models, the models can be retrained and we can possibly prepare a web interface.

References


4 Challenge 2: Delivering Shore Power

4.1 Background

This subgroup took a fresh look at a range of reports on shore power in order to address the question: Is shorepower good value as an emissions reduction scheme for shipping and as a contributor to the Transport Decarbonisation Plan?

The Department of Transport had a call for evidence on shore power and implementing maritime commitments in the Transport Decarbonisation Plan that looked to see how the government can support the wider implementation of shorepower in the UK. The details gathered from this consultation were sought to inform future policy development.

The delivery of shorepower at ports is often quite challenging, with many ports lacking a clear demand or available electrical capacity to deliver such demand even if it was to exist. Concerns exist as to whether a mandate on shorepower would be appropriate, when the costs can vary significantly from site to site, and there may be other lower cost options that have a greater emission reduction benefit.

4.2 Summary

Ships arrive at a port and use shore power whilst in port e.g. for heating, refrigeration, living support.

Figure 13 shows the UK port ship arrivals.

Years from 2009 to 2017: Figures are derived from data supplied by Lloyds List Intelligence, combined with data on passenger vessel arrivals collected by the Department for Transport (DfT) from ferry companies, as well as counts of cargo vessel voyages collected from ports and shipping agents as part of port freight statistics.

2018: From 2018 onward, the data sources used to estimate vessel arrivals have changed. The primary source of data is now the Maritime and Coastguard Agency CERS system, though data from ferry companies, ports and shipping agents collected by DfT is also still used.

Users should note that as a result the 2018 figures are not directly comparable with those for earlier years.

For further details please refer to the technical documentation.
Figure 13: UK Vessels where 2009-2017 is the old basis and 2017-2020 is the new basis.

2020: Due to insufficient data, Manchester and Liverpool use a different estimation method based on CERS and experimental AIS data.

Will construct two models

**Model 1: Statistical/Monte-Carlo model of demand and supply**

- Number of ships arriving at a port (95 600 per year in the UK ?? Poisson process)
- Length of stay (?? Poisson process)
- Type of ship (size, cruise/cargo/ferry)
- Power demand of each type of ship (1MW-10MW)
- Aggregate over the UK

**Model 2: Costs/income**

- Cost of infrastructure
- Costs to ship owners (eg. $1M per ship)
- Costs to ship operators
- Running costs eg. electricity
Recovery from the Pandemic: Transport Logistics - Study Group Report

- Income to port operator
- Taxation (e.g., Carbon tax)
- Legislation
- Environmental costs/benefits e.g., CO2, pollution reduction (possible 80% reduction)

**Inform both models by careful data gathering**

**Use Model 1 to inform Model 2 and optimise**

**Do we have future capacity in the national grid?**

### 4.3 Background Info about vessels

Shore power or “cold ironing” is the use of electricity from the shore to power a ship’s systems when it is in port. When it is cruising, a ship’s main engines drive an auxiliary power generator. As the ship begins maneuvering to enter a port, the main engines slow down and no longer drive the generator. An auxiliary generator is then switched on to supply electricity. Once the ship docks, the main engines are switched off, and the auxiliary generator continues to power it.1 The electricity needed by a vessel in port, called the hoteling load, can range from a few hundred kilowatts to several megawatts, depending on the vessel’s size and purpose.

### 4.4 Vessels types and emissions

Update on emissions and environmental impacts from the international fleet of ships. The contribution from major ship types and ports [3].

### 4.5 Data questions

1. Average power required in each port as a statistic (mean and sd) for different days in the year

2. Projected estimate of this as it changes year on year.
### Table 2. Specific fuel consumption and emission factors. For vessels at sea.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Fuel g/kWh</th>
<th>Exhaust gas emissions in kg/tonne fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO₂</td>
<td>SO₂⁺</td>
</tr>
<tr>
<td>B</td>
<td>196</td>
<td>92</td>
</tr>
<tr>
<td>C</td>
<td>199</td>
<td>89</td>
</tr>
<tr>
<td>CT</td>
<td>203</td>
<td>83</td>
</tr>
<tr>
<td>GC</td>
<td>203</td>
<td>81</td>
</tr>
<tr>
<td>LGT</td>
<td>258</td>
<td>41</td>
</tr>
<tr>
<td>OA</td>
<td>222</td>
<td>59</td>
</tr>
<tr>
<td>OL</td>
<td>202</td>
<td>83</td>
</tr>
<tr>
<td>OT</td>
<td>217</td>
<td>75</td>
</tr>
<tr>
<td>P</td>
<td>219</td>
<td>62</td>
</tr>
<tr>
<td>R</td>
<td>198</td>
<td>88</td>
</tr>
<tr>
<td>RO</td>
<td>207</td>
<td>76</td>
</tr>
<tr>
<td>OOA</td>
<td>215</td>
<td>63</td>
</tr>
<tr>
<td>OSV</td>
<td>212</td>
<td>66</td>
</tr>
<tr>
<td>TUG</td>
<td>212</td>
<td>65</td>
</tr>
<tr>
<td>FV</td>
<td>215</td>
<td>65</td>
</tr>
</tbody>
</table>

NMVOC (Non Methane Volatile Organic Compounds) can be considered as HC minus CH₄, or VOC minus CH₄ (Cooper, 2002).

* 10 kg/tonne fuel applies for vessels <1000 GT.

B: Bulk Ship; C: Container Ship; CT: Chemical Tanker; FV: Fishing vessels; GC: General Cargo; LGT: Liquefied Gas Tanker; OA: Other activities; OL: Other Liquids; OOA: Offshore Other Activities; OSV: Offshore Supply Vessel; OT: Oil Tanker; P: Passenger Vessel; R: Reefers; RO: Ro-Ro Cargo; TUG: tugs.

**Figure 14:** Emission at sea.
Table 3. Specific fuel consumption and emission factors. For vessels in-port.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Fuel g/kWh</th>
<th>NOₓ</th>
<th>SO₂⁺</th>
<th>CO₂</th>
<th>CO</th>
<th>PM</th>
<th>NMVOC</th>
<th>CH₄</th>
<th>N₂O</th>
<th>CO</th>
<th>BC</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>222</td>
<td>62</td>
<td>54</td>
<td>3179</td>
<td>6.8</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>223</td>
<td>62</td>
<td>54</td>
<td>3179</td>
<td>6.7</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>223</td>
<td>60</td>
<td>54</td>
<td>3179</td>
<td>9.7</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>GC</td>
<td>225</td>
<td>59</td>
<td>54</td>
<td>3179</td>
<td>6.5</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>LGT</td>
<td>278</td>
<td>33</td>
<td>49</td>
<td>3179</td>
<td>7.8</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>238</td>
<td>48</td>
<td>10</td>
<td>3179</td>
<td>7.2</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>OL</td>
<td>222</td>
<td>60</td>
<td>54</td>
<td>3179</td>
<td>10.0</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>OT</td>
<td>237</td>
<td>55</td>
<td>54</td>
<td>3179</td>
<td>9.6</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>236</td>
<td>50</td>
<td>54</td>
<td>3179</td>
<td>7.7</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>225</td>
<td>60</td>
<td>54</td>
<td>3179</td>
<td>5.5</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>RO</td>
<td>227</td>
<td>58</td>
<td>54</td>
<td>3179</td>
<td>6.3</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>OOA</td>
<td>232</td>
<td>52</td>
<td>10</td>
<td>3179</td>
<td>6.9</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>OSV</td>
<td>231</td>
<td>52</td>
<td>10</td>
<td>3179</td>
<td>7.5</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>TUG</td>
<td>231</td>
<td>51</td>
<td>10</td>
<td>3179</td>
<td>7.7</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>FV</td>
<td>227</td>
<td>59</td>
<td>10</td>
<td>3179</td>
<td>3.6</td>
<td>2.4</td>
<td>0.05</td>
<td>0.08</td>
<td>7.4</td>
<td>0.18</td>
<td>0.29</td>
<td></td>
</tr>
</tbody>
</table>

* 10 kg/tonne fuel applies for vessels <1000 GT.

Table 1. Utilization of installed engine power for ships operating in different modes (% of Maximum Continuous Rating).

<table>
<thead>
<tr>
<th>Main Ship type</th>
<th>Ship type</th>
<th>Load at sea a</th>
<th>Load in port</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Main engines</td>
<td>AUX</td>
</tr>
<tr>
<td>Cargo and Passenger ships</td>
<td>Bulk Vessels (B)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Container Vessels (C)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>General Cargo (GC)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Liquefied Gas Tankers (LGT)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Other Service Vessels (OA)</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Other Liquids (OL)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Oil Tankers (OT)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Passenger Vessels (P)</td>
<td>50%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Reefers (R)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Ro Ro Cargo Vessels (RO)</td>
<td>70%</td>
<td>15%</td>
</tr>
<tr>
<td>Non-Cargo Ships</td>
<td>Offshore Other Vessels (OOA)b</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Offshore Supply Vessels (OSV )b</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>TUG</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Fishing Vessels (FV)</td>
<td>50%</td>
<td>10%</td>
</tr>
</tbody>
</table>

a Includes manoeuvring mode.
b Includes the dynamic position mode.

Figure 15: Emission in port.

Figure 16: Engine power.
Table 7. Estimated time in port and number of calls per continent (%) (LMIU, 2004).

<table>
<thead>
<tr>
<th>Continent</th>
<th>Time in port (%)</th>
<th>Port calls (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>9.5</td>
<td>6.7</td>
</tr>
<tr>
<td>America</td>
<td>15.1</td>
<td>15.0</td>
</tr>
<tr>
<td>Asia</td>
<td>42.2</td>
<td>37.1</td>
</tr>
<tr>
<td>Europe</td>
<td>30.5</td>
<td>38.7</td>
</tr>
<tr>
<td>Australia</td>
<td>2.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Figure 17: In port time on average.

Table 4. Modelled fuel consumption (Kt) for different ship types and modes, 2004.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>No. of vessels</th>
<th>Total fuel consumption</th>
<th>Fuel consumption per mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>Kt</td>
</tr>
<tr>
<td>Cargo and Passenger ships</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6684</td>
<td>13.9</td>
<td>30186</td>
</tr>
<tr>
<td>C</td>
<td>3237</td>
<td>21.7</td>
<td>47083</td>
</tr>
<tr>
<td>CT</td>
<td>3121</td>
<td>4.0</td>
<td>8670</td>
</tr>
<tr>
<td>GC</td>
<td>16729</td>
<td>8.9</td>
<td>19319</td>
</tr>
<tr>
<td>LGT</td>
<td>1190</td>
<td>4.5</td>
<td>9701</td>
</tr>
<tr>
<td>OA</td>
<td>4356</td>
<td>2.8</td>
<td>5982</td>
</tr>
<tr>
<td>OL</td>
<td>246</td>
<td>0.1</td>
<td>201</td>
</tr>
<tr>
<td>OT</td>
<td>6873</td>
<td>13.7</td>
<td>29603</td>
</tr>
<tr>
<td>P</td>
<td>7609</td>
<td>8.9</td>
<td>19250</td>
</tr>
<tr>
<td>R</td>
<td>1239</td>
<td>2.1</td>
<td>4583</td>
</tr>
<tr>
<td>RO</td>
<td>1504</td>
<td>4.7</td>
<td>10214</td>
</tr>
<tr>
<td>Non-Cargo Ships</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OOA</td>
<td>1371</td>
<td>1.1</td>
<td>2305</td>
</tr>
<tr>
<td>OSV</td>
<td>3564</td>
<td>2.7</td>
<td>5889</td>
</tr>
<tr>
<td>TUG</td>
<td>10202</td>
<td>4.8</td>
<td>10358</td>
</tr>
<tr>
<td>FV</td>
<td>23194</td>
<td>6.1</td>
<td>13215</td>
</tr>
<tr>
<td>TOTAL</td>
<td>91119</td>
<td>100.0</td>
<td>216560</td>
</tr>
</tbody>
</table>

Figure 18
3. Define a Poisson distribution and get the rate of arrival and departure based on the port data (which is number arrivals in last 24h), this will give us a statistical model of arrivals and departures.

4. (Order in terms of largest port downwards) To do this we will need to use the statistics of number of vessels in port at any time, plus type of vessel (size, type of use etc). Statistics likely to be Poisson.

5. Cost benefit analysis: Cost per ship of putting in the shore power facilities, cost of using it (time spent in port is a factor), cost of shore based installation etc.

4.5.1 Supply data/questions

Ports map: [14].

Transmission grid map (whole europe zoom to the UK): [4].

Main UK ports (basic read): [8].

Some statistics for UK ports: [15].

Number of ships in port: [9].

Initial brainstorming questions:

1. Types of shore power available and Equipment available in ports

   • Generally good proximity to the main electricity grid and nearby plants also available

   • Southampton (passenger and cargo): 3 Gas power plants in proximity, total 1.17GW capacity, transmission lines available, substation available Fawley (20 miles away)

   • Felixstowe (massive conrainer trade port): 1 Wind farm available in proximity 500MW capacity, 1 Nuclear plant 1.2GW capacity, substation at Sizewell (30 miles away).

   • London (cargo): clearly access to grid and power plants nearby

   • Liverpool (cargo): at least 2Fosil gas plants available in neighborhood, capacity 1GW, wind farm 254MW, transmission lines close, substation available at Birkenhead (3miles from Liverpool city centre).

   • Immingham (cargo): Gas plants and Wind farms nearby, close to the main grid, substation at Grimsby, 7 miles away.
• Aberdeen: Wind farms nearby, 300kV transmission grid available to Persley (substation)

2. Cost of building power plants and or transmission lines from the main electricity grid
3. Cost of building a power transmission station (transformer) to extract electricity from the main UK grid
4. Cost, capacity, emission, benefits and problems for using: Hydrogen, battery, or Hydro storage
5. Existing infrastructures: Main electricity grid, substations nearby
6. Wind power available at ports: amount produced, feasibility of usage
7. Cost of retail electricity at port
8. Cost of wholesale electricity (this is time dependent)
9. How much better is it to charge at off peak times?
10. Main supply issues: “The most important issues to address are electricity charging mechanisms, and planning for infrastructure development.”

There was consensus among interviewees that shore-power as a business proposition suffers from four main problems:

• Shore-power projects are highly capital-intensive, particularly for ports, competing with many other potential projects in what are now very challenging economic circumstances.

• Uptake of almost all solutions to environmental problems requires some combination of financial or regulatory policy support. Neither are in place in the UK for shore-power.

• In the absence of supportive policy, shore-power’s viability stands on a business-case which is perceived to be very weak: returns are seen as being low, long and uncertain for both ports and ships.

• Shore-power projects are viewed as complex and difficult.

**Some questions following modelling and analysis:**

1. Is it economically feasible for a retail distributor to create a power transmission station?
2. How much time would it take to recover the initial investment?
3. If not, is government intervention needed, and how should this intervention be achieved: carbon tax, funding projects, etc.

**4.5.2 Growth in UK power supply**

**4.5.3 Demand data/questions**

Demand factors to consider: stick or carrot, price, timescale (weekly, daily, hourly), number of berthing slot, alternative demand sources, technical capability to take power, reasons for
need?

See number of ships in port in the UK: [9].

**Plymouth**

We called Cattewater Harbour Commissioners in Plymouth.

They can have one tanker at any one time. It comes in and out on the tides, typically staying for 24 hours. They average one tanker every two days.

What is the demand for this berth?

**London**

Interactive graph gives hover over details of vessels berthed.

**Dover in March**

Interactive graph gives hover over details of vessels berthed.

**Liverpool in March**
Figure 23

Consumption over all UK (on top ports), in GW

Nports=6
Nports=12
Nports=18
Nports=24
Nports=30
Nports=36
Nports=42
Nports=48

1M, 2M, 3M, 4M, 5M, 6M, 7M, 8M, 9M, 10M

-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
Energy used per day in the port of London over March 2021-2022

Figure 25
Figure 26

Hours Vessels are Berthed at the Port of Dover
Figure 27
Energy used per day in the port of Liverpool over March 2022

Interactive graph gives hover over details of vessels berthed.

**Selected Vessel Types in Liverpool**

**Consumption**

Consumption per type of ship estimates:

- Container vessel: 5-10MW
- Dry cargo vessels: 1-4MW
- Ro-ro vessels:
- Tankers

**Want a statistical model for ship arrivals in terms of**

- Time of arrival
- Length of stay (distribution?)
• Size of ship
• Charging time (see [1], page 31)

Outcome: To get [min, max] power requirement?

Power demand: Depends on vessel type. Up to 3 MVA for ferry/RORO, 7.5 MVA for container ships and 20 MVA for cruise vessels. Berths need to have the appropriate infrastructure to meet the maximum power demand (see [2], page 5).

Literature review on shore power demand:

• Barriers to demand: Ships having capability? Ships having capability? Cost?
• Frequency berthed
• Mix of ships (container 1Mw Cruise ships 10Mw Tyndall)
• Assumptions made?
• Economic models (an inverse demand model, sensitivity to price)?

References: [7, 5]

**Power to drive a ship** [2, 1]

T tonnage (assumed proportional to volume)

• To push a ship through the water

\[ O(T^{2/3}) \]

• To keep it in harbour (heating, refrigeration, people support, for example)

\[ O(T) \]

4.5.4 Port specifics

Data tables UK port usage: [6]

Simone’s shipping movements data: [10]
The main UK ports are: 1. Felixstowe 2. Southampton 3. London 4. Immingham 5. Liverpool 6. Aberdeen is probably also important

Portsmouth system architecture includes Digital twin-details say functional is this conjecture or existing?

4.5.5 Existing studies, incentives, benefits

- Costs / Barriers: - costs to obtain low sulfur fuels - costs to remove pollution

  - 35Kw Hydrogen Electrolyser on port (CMDC)
  - Digital Twin of the Port (CMDC)
  - 300HP Hydrogen powered marine engine (CMDC)
  - Shore Power Provision
    - Berth 1 – 1MW
    - Berth 2 - 10MW
    - Berth 3 – 5MW
    - Berth 4 – 5MW
    - Berth 5 – 4MW
    - North Quay – 1MW
    - 30MW needed by 2030

Figure 30: Capacity.
Table 1. Ports using shore power

<table>
<thead>
<tr>
<th>Year of introduction</th>
<th>Port name</th>
<th>Country</th>
<th>Capacity (MW)</th>
<th>Frequency (Hz)</th>
<th>Voltage (kV)</th>
<th>Ship types using onshore power supply (OPS)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2010</td>
<td>Gothenburg</td>
<td>Sweden</td>
<td>1.25-2.5</td>
<td>50 &amp; 60</td>
<td>6.6 &amp; 11</td>
<td>RoRo, RoPax</td>
</tr>
<tr>
<td>2000</td>
<td>Zeebrugge</td>
<td>Belgium</td>
<td>1.25</td>
<td>50</td>
<td>6.6</td>
<td>RoRo</td>
</tr>
<tr>
<td>2001</td>
<td>Juneau</td>
<td>U.S.A.</td>
<td>7-9</td>
<td>60</td>
<td>6.6 &amp; 11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2004</td>
<td>Los Angeles</td>
<td>U.S.A.</td>
<td>7.5-60</td>
<td>60</td>
<td>6.6</td>
<td>Container, cruise</td>
</tr>
<tr>
<td>2005-2006</td>
<td>Seattle</td>
<td>U.S.A.</td>
<td>12.8</td>
<td>60</td>
<td>6.6 &amp; 11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2006</td>
<td>Kemi</td>
<td>Finland</td>
<td>N/A</td>
<td>50</td>
<td>6.6</td>
<td>RoPax</td>
</tr>
<tr>
<td>2006</td>
<td>Kotka</td>
<td>Finland</td>
<td>N/A</td>
<td>50</td>
<td>6.6</td>
<td>RoPax</td>
</tr>
<tr>
<td>2006</td>
<td>Oulu</td>
<td>Finland</td>
<td>N/A</td>
<td>50</td>
<td>6.6</td>
<td>RoPax</td>
</tr>
<tr>
<td>2008</td>
<td>Antwerp</td>
<td>Belgium</td>
<td>0.8</td>
<td>50 &amp; 60</td>
<td>6.6</td>
<td>Container</td>
</tr>
<tr>
<td>2008</td>
<td>Lübeck</td>
<td>Germany</td>
<td>2.2</td>
<td>50</td>
<td>6</td>
<td>RoPax</td>
</tr>
<tr>
<td>2009</td>
<td>Vancouver</td>
<td>Canada</td>
<td>16</td>
<td>60</td>
<td>6.6 &amp; 11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2010</td>
<td>San Diego</td>
<td>U.S.A.</td>
<td>16</td>
<td>60</td>
<td>6.6 &amp; 11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2010</td>
<td>San Francisco</td>
<td>U.S.A.</td>
<td>16</td>
<td>60</td>
<td>6.6 &amp; 11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2010</td>
<td>Karlskrona</td>
<td>Sweden</td>
<td>2.5</td>
<td>50</td>
<td>11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2011</td>
<td>Long Beach</td>
<td>U.S.A.</td>
<td>16</td>
<td>60</td>
<td>6.6 &amp; 11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2011</td>
<td>Oakland(^b)</td>
<td>U.S.A.</td>
<td>7.5</td>
<td>60</td>
<td>6.6</td>
<td>Container</td>
</tr>
<tr>
<td>2011</td>
<td>Oslo</td>
<td>Norway</td>
<td>4.5</td>
<td>50</td>
<td>11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2011</td>
<td>Prince Rupert</td>
<td>Canada</td>
<td>7.5</td>
<td>60</td>
<td>6.6</td>
<td>N/A</td>
</tr>
<tr>
<td>2012</td>
<td>Rotterdam</td>
<td>Netherlands</td>
<td>2.8</td>
<td>60</td>
<td>11</td>
<td>RoPax</td>
</tr>
<tr>
<td>2012</td>
<td>Ystad</td>
<td>Sweden</td>
<td>6.25</td>
<td>50 &amp; 60</td>
<td>11</td>
<td>Cruise</td>
</tr>
<tr>
<td>2013</td>
<td>Trelleborg</td>
<td>Sweden</td>
<td>3.5-4.6</td>
<td>50</td>
<td>11</td>
<td>N/A</td>
</tr>
</tbody>
</table>

\(^a\) RoRo or “roll-on/roll-off” ships carry wheeled vehicles or cargo. RoPax or “roll-on/roll-off passenger” ships are essentially RoRo vessels with passenger accommodation. \(^b\) Information provided by Port of Oakland.


Figure 31
Figure 32
Policies in other countries [16]

Policy: The California Air Resources Board (ARB), for example, requires ships in Los Angeles, Long Beach, Oakland, San Diego, San Francisco, and Hueneme to use shore power or equivalent control techniques to reduce at-berth emissions by 80% by 2020 (At-Berth Regulation, 2007).

International Maritime Organization (IMO) regulations now require ships calling at U.S. ports to use cleaner, low-sulfur marine, gas or diesel oil, which can be up to 60% more expensive.

maritime pollution: Ships entering the Emission Control Areas (ECA), which include the 200 nautical miles from the coasts of the US and Canada, the Baltic Sea, and the North Sea, are required to burn fuel with a maximum sulfur content of 0.1% (1,000 ppm) as of January 1, 2015 (International Maritime Organization, 2015). The higher cost of lower sulfur fuels will alleviate cost concerns about using shore power.

9 million per year to run, around 2% of cargo costs to adjust to use shore power.

Benefits: - Significant reduction of carbon emission (BPA, p.16), needs to be mitigated with source of electricity production (and projections for the next years) - Shipping is the most energy efficient way of transport (lowest CO2 / tonne-km)

infrastructure requirements: - an industrial substation to receive power transmitted from the local grid, normally at 34.5 kilovolts (kV) - a transformer to bring the voltage down to be compatible with the ship's electrical specifications (i.e., 6.6 kV or 11.0 kV 3-phase, 60 Hz). - A list of onshore infrastructure requirements includes: distribution switchgear, circuit breakers, safety grounding, underground cable conduits, electrical vaults, and power and communications receptacles and plugs. - An existing berth must be modified to accommodate the installation of shore power cables and accessories. - For the construction of a new berth, technical requirements and specifications of shoreside electrical and infrastructure can be included in the design phase. - Ships participating in a shore power electrification program will require the installation of shore power cable receptacles and an associated electrical management system. Retrofits can be made to the existing fleet without the capacity of shore power.

4.6 Cash flow

Simone
4.6.1 Overview: Shore power transition

The British Ports Association (BPA) considers different aspects for the Shore power cost.

1. First, there is a need for grants or loans to help with high capital costs. **No port worldwide has implemented shore-power without such support.** A green maritime fund to support shore power in the UK is clearly needed to help meet prohibitive costs, particularly around energy networks and generation (e.g. various ranges for Government support were mooted, from 50-100%. It was noted that in Germany, Government support was 90%).

2. Action must be taken to improve the margin between grid electricity and power from on-ship diesel. The UK Government can partially address this competitive disadvantage for grid electricity by exempting ships from electricity taxes, as has been done in countries like Germany, France, Sweden and Denmark.

3. Price of electricity in the UK is much higher than in countries where shore power is provided. Most ports with shore power provision have support to help make electricity as a marine fuel more competitive and that needs to be replicated in the UK.

4. There is a lack of consistent demand from vessels calling in the UK for shore power. Government needs to address this. The BPA is putting forward a zero emission berth standard for discussion with industry and Government which would drive up demand for emissions abatement technology and provide certainty for investors.

The price each UK port pays for electricity varies, and is commercially confidential. BEIS reports that the average electricity price for a medium-sized UK industrial user is **12.8p/kWh**, with 4.6p/kWh of that being various environmental taxes. On average a further 5p/kWh of the final cost comes from three electricity network charges: transmission, distribution and balancing services. The remainder is the wholesale cost of electricity.

### Requirements of Different Vessel Types

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Typical maximum power requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>RORO/Ferry</td>
<td>6.5 MVA</td>
</tr>
<tr>
<td>Container Vessel</td>
<td>7.5 MVA</td>
</tr>
<tr>
<td>Cruise</td>
<td>16/20 MVA</td>
</tr>
<tr>
<td>LNG / Tanker / FSU / FPSO</td>
<td>10 MVA</td>
</tr>
</tbody>
</table>

*Source: ABB*
Table 2: Typical system specs for the different power requirements

<table>
<thead>
<tr>
<th>Power Capacity</th>
<th>Typical specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100kW</td>
<td>230/400/440V – 50/60hz</td>
</tr>
<tr>
<td>100 – 500kW</td>
<td>400/440/690V – 50/60hz</td>
</tr>
<tr>
<td>500-1000kW</td>
<td>690V/6.6/11kV – 50/60hz</td>
</tr>
<tr>
<td>&gt;1MW</td>
<td>6.6/11kV – 50/60hz</td>
</tr>
</tbody>
</table>

Source: GloMEEP

Figure 34

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>2020 (g/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO(_X)</td>
<td>2.1</td>
</tr>
<tr>
<td>NO(_X)</td>
<td>9.8</td>
</tr>
<tr>
<td>PM</td>
<td>0.38</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>610</td>
</tr>
</tbody>
</table>

The BPA suggest that vessels at berth in the UK used over **641,086,164 kWh** of energy in 2019. Removing vessels that were at berth for less than two hours, that number falls to **502,411,805 kWh**.

Research by Frontier Economics for the Department for Transport in 2019 forecasted energy demands from UK ports from shore power under a business as usual scenario to be around **5GWh** in 2026.

Total Power Usage of Vessels at Berth in 10 largest UK ports in 2019 (monthly totals in kWh)

**Cost for Shore power transition**

**Emission intensity from Marine Diesel Engines**

The diesel fuel used by OGVs is rich in sulfur but low in price. The International Maritime Organization (IMO) has established that fuels cannot contain a sulfur level higher than 5000 parts per million (ppm).

Together with fuel quality standards, IMO also set up regulations for engines Pollutant and energy efficiency. These are Tier I through Tier III. We assume that after 2020 all ships belong to the Tier II category. The Emissions intensities are showed in the table below:

The chart above shows demand variance throughout the year, however what it does not cap-
Figure 35

<table>
<thead>
<tr>
<th>Category</th>
<th>Components</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid-to-port</td>
<td>Outside the port, any necessary grid upgrades or reinforcement eg substations</td>
<td>Highly variable, from zero to several millions</td>
</tr>
<tr>
<td>In-port</td>
<td>Bringing power from the port-gate to the berth: cabling, transformers etc.</td>
<td>Highly variable, from zero to several millions</td>
</tr>
<tr>
<td>Port-to-ship: shore-power voltage/frequency management</td>
<td>More expensive if a frequency convertor is required (if a ship runs at 60Hz rather than grid 50Hz)</td>
<td>For a 2MW connection: £0.3-0.4m without frequency conversion; £0.8-1.0m with frequency conversion</td>
</tr>
<tr>
<td>Port-to-ship: cabling systems</td>
<td>Fixed-point cranes or moveable systems. Low voltage systems require more cabling</td>
<td>£10k to £1m, with fixed-point cranes most common at around £100k</td>
</tr>
<tr>
<td>On-Ship</td>
<td>Hatch, socket, cable to main switchboard, potentially more switchgear</td>
<td>Negligible % cost for a new-build, more expensive to retrofit, costs highly variable, up to £1 million for largest most complex projects, much lower for average vessels.</td>
</tr>
</tbody>
</table>
ture is that for every port there will be many berths.

4.6.2 Methodology: discounted cashflow (DCF)

The DCF approach models the cost effectiveness of onshore power. Under this approach, the starting year is 2017 and the capital investments are made in equal amounts in three years between 2017 and 2019. The costs would be fully depreciated by 2035. The 15-year lifetime is in line with assumptions made by Environ and CARB. In addition to capital investment, the recurring costs include terminal O&M costs and extra costs of replacing diesels with electricity. We used a 10% discount rate in this analysis. Consistent with the prior sections, we assumed the onshore power would begin to operate in 2020. The benefits of applying onshore power to reduce emissions accrue between 2020 and 2035. The emissions reduction due to onshore power includes emissions reductions of NO\textsubscript{X}, SO\textsubscript{X}, PM, and CO\textsubscript{2}.

\[
\text{Cost Benefit} = \frac{\text{Net Present Value of Net Cash Outflow}}{\text{Emissions Savings}}
\]

The above equation represents the average cost effectiveness of onshore power for all container ships visiting the Port, but the cost of reducing one tonne of pollutant from each individual ship may vary. In this analysis, 6,000 (twenty-foot equivalent units) TEU container ship have been used as an example for a case study to demonstrate the effectiveness of a policy that encourages frequent callers to use onshore power to reduce overall compliance costs.
The Emission for all ships at berth for pollutant $j$ is given by

$$E_j = \sum_i (AE_i \cdot H_i \cdot EF_j \cdot LD_{i-AE} + Bo_i \cdot H_i \cdot EF_j \cdot LD_{j-B}) \cdot \frac{1}{10^6},$$

where

1. $E_j$ is the total tonnage of emission $j$
2. $AE_i$ represents the auxiliary engine power of ship $i$ (Kw)
3. $LD_{i-AE}$ is the load of the auxiliary engine
4. $H_i$ is the total hours a ship stays at the port
5. $EF_j$ is the emission factor (grams per KWh) for emission $j$
6. $LD_{j-B}$ is the load of boilers
7. $Bo_i$ represents the power used in the boiler of ship $i$ (kW)

The total emissions reduction from switching to shore power can be determined using life cycle analysis and depends mainly on emissions from auxiliary engines and the emissions reduction rate from shore power. Boilers have to operate during the hoteling period regardless. In addition, connecting and disconnecting shower power with ships takes about three hours, during which auxiliary engines are running to produce electricity. The emission reduction is given by

$$E_j = \sum_i (AE_i (H_i^{-3}) EF_j) \cdot \frac{RR_j}{10^6},$$
where $RR_j$ is the reduction rate for emission $j$ from shore power for $\text{NO}_X$, $\text{SO}_X$, PM, and $\text{CO}_2$.

**Data and assumption**

The most important components in the previous equations are the total number of ships and their hoteling hours at the berth.

Emissions from container ships are showed in the table below in terms of twenty-foot equivalent unit (TEU). Because auxiliary engine power is sparsely populated, default values for auxiliary engine and auxiliary boiler power from Ng et al. (2013) are used. The default values assume certain auxiliary engine power for each ship size category.

The emission factors of $\text{SO}_X$, $\text{NO}_X$, PM, and $\text{CO}_2$, in grams per kWh, are obtained from different sources. Emission factors of $\text{SO}_X$ and PM based on the 0.5% sulfur level in marine fuels is used, as it came in effect as standard requirement in 2020. The emission factor for $\text{NO}_X$ is taken from Ng et al. (2013), which is based on a 2007 emissions inventory. Ships built between 2007 and 2012 generally meet higher $\text{NO}_X$ engine standards. We applied the average $\text{NO}_X$ emission factor in the global fleet to calculate $\text{NO}_X$ emissions in 2020 based on [13].

We remark that the second column is consistent with the Emissions intensity table showed in the Section **Emission intensity from Marine Diesel Engines** for the UK scenario.
<table>
<thead>
<tr>
<th>Ship size (TEU)</th>
<th>Auxiliary engine (kW)</th>
<th>Boilers (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1,000</td>
<td>300</td>
<td>136</td>
</tr>
<tr>
<td>1,000-2,000</td>
<td>388</td>
<td>232</td>
</tr>
<tr>
<td>2,000-3,000</td>
<td>650</td>
<td>232</td>
</tr>
<tr>
<td>3,000-4,000</td>
<td>913</td>
<td>313</td>
</tr>
<tr>
<td>4,000-5,000</td>
<td>643</td>
<td>393</td>
</tr>
<tr>
<td>5,000-6,000</td>
<td>1,307</td>
<td>534</td>
</tr>
<tr>
<td>6,000-7,000</td>
<td>1,307</td>
<td>393</td>
</tr>
<tr>
<td>7,000-8,000</td>
<td>1,320</td>
<td>586</td>
</tr>
<tr>
<td>8,000-9,000</td>
<td>1,488</td>
<td>586</td>
</tr>
</tbody>
</table>

Figure 40

<table>
<thead>
<tr>
<th></th>
<th>Engine emission factor (g/kWh), 2012</th>
<th>Engine and boiler emission factor (g/kWh), 2020</th>
<th>Boiler emission factor (g/kWh), 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SO_x$</td>
<td>12.0</td>
<td>2.1</td>
<td>16.1</td>
</tr>
<tr>
<td>$PM$</td>
<td>1.4</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>$CO_2$</td>
<td>620</td>
<td>610</td>
<td>620</td>
</tr>
<tr>
<td>$NO_x$</td>
<td>15</td>
<td>9.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Figure 41
With the aforementioned data, assumptions, and methodology, it is possible to calculate the cost effectiveness of using onshore power for the container ship fleet visiting the port.

Two important variables influencing the cost-benefit analysis are the adoptability of onshore power by ships visiting a given port (penetration rate) and the number of ships already equipped with vessel-side onshore power infrastructure due to similar initiatives elsewhere.

Higher penetration rates will result in greater reduction of emissions and thus improve cost effectiveness. Higher percentages of ships already equipped with vessel-side infrastructure will reduce the investment requirements directly attributable to a given port’s shore power initiative and result in lower total costs as well.

Cost of reducing pollutants using onshore power for 80% penetration rate in Shenzhen

**Results**
In this case study, we used the emission factors introduced in the previous Section to calculate savings of NO\textsubscript{X}, SO\textsubscript{X}, PM, and CO\textsubscript{2} between 2020 and 2035. The auxiliary engine power is also the same as the default value for a 6,000 TEU ship. We assumed the container ship uses 20 hours of onshore power per visit and the fuel cost is 700 pertonne.

The figures below show the cost and benefit of NO\textsubscript{X} and PM reduction under different penetration rates and shares of ships originally equipped with onshore power visiting the Port of Shenzhen. Under the best scenario, where 60% of ships are already equipped with vessel-side equipment and the shore-side infrastructure is 50% utilized, the average cost of reducing one tonne of pollutant is only a quarter that of the worst scenario, defined as 40% of ships already with vessel-side equipment and 10% utilization rate. Both figures point to an important policy insight: policies that are designed to attract ships already equipped with onshore power will significantly boost the cost effectiveness of onshore power in the port.

References:

[1] [18] [2] [12] [3] [11]

Cost-benefit equations Reference from [17]

\[
benpvt_{i,j} = (m - e_j) \times ener_{i,j} \times o_{i,j}
\]
4.7 Modelling questions

- Capacity and mix of charging sources eg. Hydrogen/renewables
- Emission reduction
- Cost/benefit analysis
- Capacity vs need
- Uncertainty
4.7.1 Modelling

cost model capacity model benefit model

General notes

Government Tools

• Exploring the potential of government’s coordinating function. For example, commissioning research, producing guidance for port operators concerning planning and energy network requirements, and facilitating collaboration across the sector as well as information sharing. This could also include exploring other potential measures to unlock private investment.

• Exploring the potential of government mandates through regulation. This could include requiring vessels and ports to report on the usage of shore power, requiring vessels to use shore power when in port, and requiring ports to install shore power infrastructure.

• Exploring the potential of market-based measures. This could include economic instruments based on the “polluter pays principle”, to incentivise the adoption of shore power by vessel and port operators.

Policy support

• Ports are generally owned by the state (e.g. Canada, Spain, US), the muniplicities (e.g. Norway, Sweden), local government (e.g. China), or other public institutions (e.g. Germany).

• Public fundings are the main funding source: 1. Transport Canada received regional fundings and investment from other public sources. Other projects have been funded by federal and other public sources. 2. German government announced 140m Euros for shore power in German ports. 3. Norway has several standing grant schemes and one state funding body Enova is financed with between £160m and £320m partly by electricity levy and partly by state funding. 4. Spanish National Ports Agency has undertaken a 6m Euros for shore power in Spanish ports, which has been co-financed with 1.4m Euros from the EU’s Connecting Europe Facility. 5. Ports in Sweden have accessed public funding through the KlimatKlivet (‘Climate Leap’) fund. 6. Same for the US, e.g. California. 7. p.s. China has also received some private investment and private operations, but in partnership with the state as joint ventures.

• Further policy is necessary to improve the benefit. 1. (Vancouver Fraser Port Authority) Vessels only pay for their metered energy and not the peak demand. The port also offers
a 47% discount to vessels that have the ability to connect. 2. German government proposed to remove a large portion of a tax on electricity, e.g. 80% for shoreside electricity by mid-2020, and also to allow special arrangements for the supply of power to shore connections, plus discount on the price. 3. Spanish government lowered tax from 5% to a "symbolic sum" of 0.05 Euro per kWh. 4. Swedish government reduced tax on shoreside electricity by 98%.

4.8 Summary & Future Work

4.8.1 Recommendations

1. Public fundings are necessary. For example,
   - regional and federal fundings (C$19.5m) in Canada,
   - government fundings in German (€140m) and the US ($1bn for California).

Furthermore,

   - Enova in Norway is partly financed by electricity levy (overall between £160m and £320m);
   - Spanish National Ports Agency (€6m) has also been co-financed with €1.4m from the EU’s Connecting Europe Facility.

2. Ports to be publicly owned. e.g. by the state (e.g. Canada, Spain and US), the municipalities (e.g. Norway and Sweden), local government (e.g. China), or other public institutions (e.g. Germany).

3. Further policy is necessary to improve the benefit.
   - Reducing tax for shoreside electricity:
     - 80% by German government,
     - 98% by Swedish government.
     - Spanish government lowered tax from 5% to a "symbolic sum" of 0.05 Euro per kWh.
   - Lowering the electricity price:
     - 47% discount in Vancouver, and vessels are only required to pay for their metered energy but not the peak demand.
     - German government also allows special arrangements for the supply of power to shore connections, plus discount on the price.
4. Grid substations require government subsidisation.

5. Carbon tax or reduced tax for vessels to compensate the retrofitting of the vessels.

6. Other renewable energy plants can be constructed to support ports and coastal regions
   - Mocean tidal energy harvest.

7. Demands calculations are done for part of London and part of Liverpool.
   - Full dataset is required to obtain the entire consumption for UK.

4.8.2 Conclusions

The environmental benefits are high and there is good capacity in the grid to support the delivery of shore power. However, costs are high, so government support is needed to kick start.

References


5 Conclusions

Over the study group, potential solutions were developed and these were presented on the final day. The outcomes are summarised in the following.

- **Group 1:**
  Three possible modelling techniques were considered to model trustworthiness at the border:
  - A Simple Linear Model
  - A Structural Equations Model
  - A Dynamic Network Model (Agent Based Model)

  In future work, subject matter knowledge can be used along with data in order to build more complex models. Furthermore, the models can be retrained and we can possibly prepare a web interface.

- **Group 2:**
  The following questions were explored during the study group:
  1. What is the likely demand for shore power?
  2. Can we supply this demand?
  3. What is the cost to (i) the ship owner (ii) the port operator?
  4. What is the environmental benefit?

  The group concluded that the environmental benefits are high and there is good capacity in the grid to support the delivery of shore power. However, costs are high, so government support is needed to kick start.
**Newton Gateway to Mathematics**
Isaac Newton Institute
20 Clarkson Road
Cambridge
CB3 0EH

Telephone: +44 (0)1223 765580
Email: gateway@newton.ac.uk
[https://gateway.newton.ac.uk/](https://gateway.newton.ac.uk/)
@NewtonGateway

**Contact:**
Maha Kaouri
gateway@newton.ac.uk