Transit Research-Informed Practice

e-Bus Transit Systems

Knowledge Series 01

Transit Electrification Literature Review

August 2022

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Knowledge Series – 01
Transit Electrification Literature Review

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Executive Summary

This Stage (Knowledge Series 01) provides a knowledge synthesization-based assessment of transit electrification through discovering and further linking the knowledge domains/gaps of previous studies.

This knowledge synthesization model (Figure 1) is carried out through a novel mixed-method approach that utilizes a scoping review model (qualitative analysis) and machine-learning-based text-mining (quantitative analysis) to analyze research progress over the past two decades. The qualitative-based scoping review achieves the required depth to analyze existing knowledge, while the machine-learning-based quantitative approach facilitates studying a large volume of previous (breadth) studies in a systematic manner. Together, this integration provides a unique approach to inform the Changing Transit Needs in Canada through international best practices.

Overall, there are several saturated domains of knowledge, including infrastructure, comparative assessment, emissions, and battery performance. However, the knowledge established in these domains is not translated into effective policy solutions to advance the adoption of e-Buses in transit systems. It could be argued that the intersectionality between research and application is yet to be established in the e-Bus literature.

In a nutshell, this stage has identified two areas of interest for the Transit Electrification domain. These areas are tagged saturated knowledge (Blue Oceans) and Knowledge gaps (Red Oceans). The latter refers to significant gaps in previous studies that should be targeted through directed research grants to advance knowledge gaps. While Blue Oceans demonstrates well-established knowledge domains, these should not be the target of future research to prevent reinventing the wheel. However, transit providers should feel confident applying saturated knowledge in practice.

Blue Oceans include i) the joint analysis of infrastructure allocation and their environmental impact, ii) the impact of e-Buses infrastructure on transit network performance under disruption, iii) re-thinking transit provision models from an e-Bus perspective, and iv) developing e-Bus-oriented operational policies and practices guidelines.

Lastly, the authors of this report would like to acknowledge the support from the Natural Resources Canada (NRCan), Zero Emission Vehicle Awareness Initiative (ZEVAI), project# PCA-032_CA. The opinions expressed are those of the authors and do not represent the views of the funding agency.

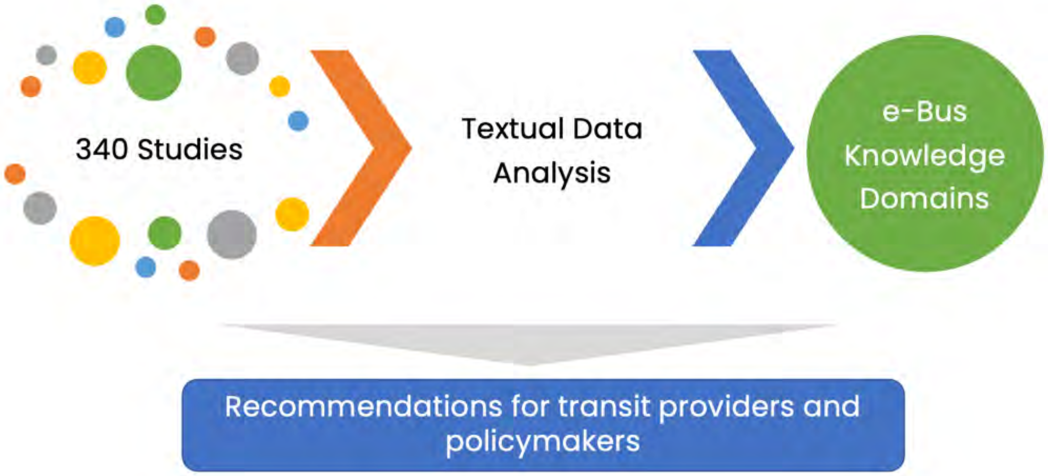

Figure 1. Scope of Knowledge Series 01

CHAPTER ONE

1. Chapter 1 – Introduction

1.1. Background

Climate change is the most monumental threat to social, economic, and environmental systems on a worldwide scale. The National Round Table on the Environment and the Economy estimated that climate change in Canada alone could cost $21 to $43 billion per year by 2050. As stated by the Government of Canada, "GHG emissions from the transportation sector are the second-largest source of emissions in Canada, representing 24% of total GHG emissions in 2015". In hopes of considerably reducing transportation-related greenhouse gases (GHG), sustainable transportation solutions are a promising solution. In particular, increasing transit ridership coupled with the electrification of powertrain technology is considered the optimal synergetic solution to achieve substantial GHG reduction from the transportation system.

Increasing transit ridership will indeed alleviate car dependency and reduce the soaring emission rates of single-occupant vehicles. Coupled with electrification of transit solution, the per passenger -kilometre carbon emissions could be eliminated.

In Canada, there are several initiatives supporting transit investments and the transition to electric mobility. The Government of Canada approved a mandate to provide $2.75 Canadian billions in funding over five years, starting in 2021, to enhance public transit systems and switch them to cleaner electrical power, including supporting the purchase of zero-emission public transit and school buses and a commitment to help purchase 5,000 zero-emission buses over the next five years. The Canada Infrastructure Bank also has a target to invest $5 billion in public transit, including $1.5 billion over the next three years specifically for zero-emission buses and associated infrastructure as part of its Growth Plan. Furthermore, the recent Canadian commitment at the COP-26 United Nations Climate Summit is also a clear indication of the federal government's support to achieve substantial emission reduction across all economic sectors.

Although these initiatives require significant research efforts, there is a plethora of research studies investigating various aspects of transit improvements. Therefore, the overarching aim of this project is to inform the decision-making process of transit improvement and transit electrification. Our target is to capitalize on the existing body of knowledge to derive insights for policymakers.

There is a notable lack of knowledge synthesization that brings together previous findings in a single, public-facing-oriented, self-contained study. In other words, several previous studies try to "*reinvent the wheel*" and fall short to capitalize on the existing resources available in the literature. Therefore, knowledge synthesization models are implemented herein to provide a more holistic assessment of transit improvement through discovering and further linking the findings of previous studies. This, in turn, will create a blueprint for the decision-making process for transit electrification, as well as highlighting areas for future research activities.

1.2. Objectives

Knowledge Series 01 objective is to quantify the knowledge associated with ZEV research. This includes knowledge gaps, saturated knowledge, and knowledge linkages. This is carried out in three tasks.

Task 01 - Established-Knowledge and Knowledge-Gaps: At this stage, both established knowledge domains and knowledge gaps will be identified.

Task 02 - Topical Progression Over Time: The temporal distribution of topics will be developed to study the temporal variation in topics.

Task 036 - Knowledge Domains Linkage Matrix: The last task II is to connect the established knowledge and knowledge gaps across the identified domains. We will develop a topic linkage matrix to quantify the relationship between the extracted topics. The matrix presents a comprehensive tool for academics, funding agencies, policymakers, and stakeholders to identify saturated topics and knowledge gaps.

1.3. Data Collection

For the analysis, Web of Science was used to collect previous studies conforming to the aim of each research objective. Web of Science is a platform that stores comprehensive databases of academic literature of various research domains. While Google Scholar was also an option that was briefly explored, Web of Science “All Databases” was used as it provided more accurate and comprehensive curated content, including a lot of older citations.

1.3.1. Electric Bus

The dataset associated with electric bus (e-Bus) knowledge synthesization models was extracted from the Web of Science. The process is initiated with the keyword “e-Bus” which returned thousands of records. Therefore, a revised list of keywords was developed based on a sample of e-Bus studies as follows:

"Electric bus" OR "battery electric bus" OR "e-Bus" OR "ebus"

Since the aim is to assess the current literature regarding e-bus advancements in the last two decades, any results preceding the year 2000 were excluded. While in terms of document types, only articles and review articles were used in the dataset to ensure sources were credible and scientifically accurate. Lastly, research domains that did not relate to e-bus literature were excluded from the search. The initial dataset returned 425 articles and review articles. Figure 2 shows the number of e-Bus articles published since the year 2000.

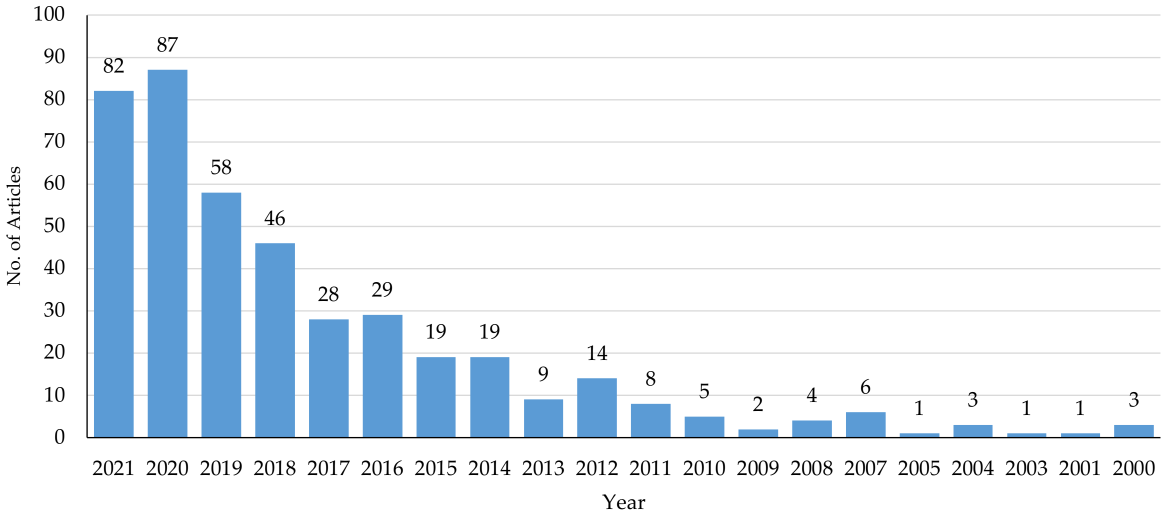

Figure 2. Number of e-Bus articles published in peer-reviewed journals (2000-2021)

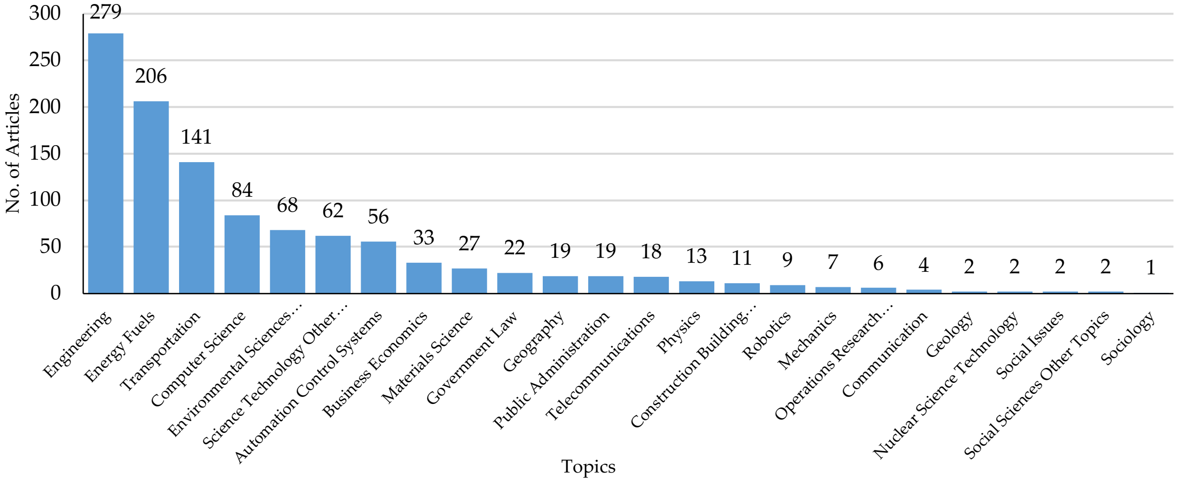

Figure 3. Record count by topic (2000-2021)

Numerous topics were returned from the search results in Web of Science and required modifications. After narrowing down the domains, the topics for e-Buses were consolidated into 24 topics distributed, as seen in Figure 3. It is noteworthy to highlight that these topics represent the topical identification generated by the Web of Science platform and are not reflective of the Scoping Review Analysis.

1.3.2. Study Selection

The filtration of the initial dataset was completed in accordance with the Scoping Review Method. The research question/topic being explored is the current e-bus literature present from 2000 to 2021. This acts as the general aim of the review and provides boundaries related to the scope and context. The topic itself is broad enough, so the volume and general scope of the literature that pertains to the question can be assessed.

When identifying the relevant studies, a comprehensive scoping field is needed. Using sources that provide a wide breadth of information related to the central question is important. The strategy used to search for information starts with identifying and defining the key concepts that are related to the research questions. This study utilizes the Web of Science database, narrowing down the field with parameter criteria that are directly related to the central question/research question.

Irrelevant studies are extracted that had nothing to do with e-bus transportation. Therefore, the initial search results required a filtration process (study selection) to ensure the dataset contained research that pertained to the scope of electric buses. Abstracts of all the articles under the search results of "e-bus" were extracted and reviewed to ensure their relevance fit the scope criteria.

Next, the qualitative data is charted and interpreted. This was completed by sorting the data by year and then using the abstracts of each article to sort them into categories. This take is more of a "narrative review" where the abstract information is broadly analyzed to understand the outcome or aim of each article and their corresponding methods/processes. This allows for a significant understanding of the dataset and a primary take of what the current literature presents.

Each article in the database is communicated in a slightly different way and requires polishing to bring it to a cohesive analysis form. Indeed, there exist slight barriers in the English language that make it harder to immediately grasp what the researchers are trying to state. This is perfectly natural, and it is interesting to see how different researchers present their topics in various ways. The goal of this polishing exercise is to ensure all relevant research is presented in a more accessible format. This meant looking at the abstracts, the core of what each article is about and extracting from that the aim and the method of each paper as well as categorizing them into subcategories for further analysis of each topic in later stages of qualitative analysis.

1.3.2.1. e-Bus Analysis Dataset

In total, 425 articles were extracted from the Web of Science as the initial dataset. From this dataset, 85 articles unrelated to the topic were excluded, resulting in a total of 340 articles in the final dataset. It is important to note that the data for 2021 that has been collected included research studies up to June 2021. This means that there could be more research produced later in the year. To maintain accuracy, analysis was focused on the literature up to and including the year 2020.

1.4. Methodology

The study is carried out through a mixed-method approach and utilizes a scoping review model (qualitative analysis) and machine-learning-based text-mining (quantitative analysis) to analyze research progress over the past two decades.

A surfeit of methods has been utilized in knowledge synthesis research. This study proposes a knowledge synthesis model that integrates both scoping review [1] and metasearch word analysis through text mining [2] to address the Transit Electrification domain.

In a nutshell, **Scoping Review** *"aims to rapidly map the key concepts underpinning a research area and the main sources and types of evidence available"* [1]. In contrast, machine learning (ML) based **Knowledge Discovery in Textual Databases** models *"focus on discovering unknown patterns of interest or extracting knowledge from large textual datasets"* [3]. In this respect, the integration of the two methods provides a unique approach for knowledge synthesis application. It could be seen as an integration of qualitative and quantitative knowledge synthesis models in one approach.

1.4.1. Scoping review

A scoping study is a high-level qualitative method that maps key concepts within a research area. The scoping review method allows researchers to pinpoint which areas of research are underdeveloped and identify research gaps in the existing literature [1] [4].

"Scoping review is a very time-consuming method, and is not practical to review a large volume of studies"

A scoping study possesses a similar framework to systematic reviews. The goal in conducting a scoping study is to achieve results that are both broad and in-depth. The methodological framework of a scoping study can be broken down into five stages: 1) Research question/inquiry, 2) Scope of analysis, 3) Selection of studies, 4) Charting the data, and 5) Reporting [4-7].

1.4.1.1. Identifying the research question(s)

The research question acts as the foundation of the scoping review. It reflects the general aim of the review and provides boundaries related to scope and context. It is recommended to keep the questions broad enough so the volume and general scope of the literature that pertains to the question can be assessed.

1.4.1.2. Identifying the relevant studies

The strategy used to search information starts with identifying and defining the key concepts that are related to the research questions. This study utilizes the Web of Science (WoS) database, narrowing down the field with parameter criteria that are directly related to the research questions.

1.4.1.3. Study selection

The initial search results require a filtration process (study selection) to ensure the dataset contains research that pertained to the scope. Therefore, at this stage, the irrelevant studies are filtered and excluded.

1.4.1.4. Charting the data

In this stage, the qualitative data is charted and interpreted to provide a significant understanding of the data's context data. The goal of this stage is to ensure all relevant research is presented in a more accessible format. Line-by-line coding builds a solid understanding of the concepts presented in the current data; however, it is a very detailed and tedious process. Therefore, focused coding is developed, in which recurrent patterns are identified amongst the open codes. This multi-stage process aids in portraying various interconnections between domains, categories, and topics within the literature, making it an essential component in data synthesis.

1.4.1.5. Collating, summarizing, and reporting the results

A scoping study is not attempting to assess the quality of evidence or how robust a study is. Scoping study is meant to present the researcher's narrative of findings and map the distribution of studies to make comparisons across the evidence presented in the dataset. Once a comprehensive review of the current data exists, gaps in the literature can be identified.

1.4.2. Text-mining through Machine-Learning

Unlike the scoping review, text-mining through machine learning is a quantitative method. The advancement in computational textual analysis allows investigating a massive amount of textual data (e.g., documents, books, abstracts) to identify their themes, patterns, and underlying concepts and discover new information. The main focus of text mining is utilizing statistical analysis along with machine learning to automate the process of extracting useful insights from the given textual data [8].

"Text-mining is very suitable to analyze large volume of studies. However, the researcher should complete a post hoc analysis to attain the required depth of the results."

In this study, an unsupervised machine learning topic modelling approach, namely the Latent Dirichlet Allocation (LDA), was adopted to identify the key themes (topics) of a text corpus [9]. The LDA could be described as a dimensionality reduction technique based on generative probabilistic semantics [10]. The LDA model assumes that various latent topics can be identified based on the co-occurrence probability of the words within the corpus [11]. In other words, within the LDA model, each document consists of several topics, and each topic consists of a number of words. As such, each topic is weighted based on its statistical distribution with the document, and each word is weighted based on its statistical distribution with the topic.

The mathematical formulation of the LDA model is introduced by Blei [10]. The LDA model follows three main steps, as mentioned in [12] as follows:

- First, the model identifies a number of latent topics (K) where the distribution of words in a topic (K) follows a distribution (ψ_k) which is picked from Dirichlet distribution (β).
- Second, each document (d) is examined against the assumed topics based on a distribution (θ_d), which is extracted from another Dirichlet distribution (α).
- Third, the LDA assigns a topic (z_{di}) and a word (w_{di}) for each word in each document based on multinomial distributions (θ_d) and $(\psi_{z_{di}})$, respectively.

The estimation of the LDA model is commonly accomplished using the variational expectation-maximization (VEM) algorithm [10] or the Gibbs sampling algorithm [13, 14]. Both algorithms can estimate the posterior document-topic distribution (θ) and topic-word distribution (ψ) in an efficient way. A study by [15] concluded that comparable key latent topics could be inferred regardless of the utilized algorithm. In the present study, the Gibbs sampling algorithms were utilized to extract the latent topics within our textual data.

1.4.2.1. *LDA Model development for electric buses*

The development of the LDA model could be summarized into four main stages: data cleaning and pre-processing, setting control parameters, identifying the number of topics, and model estimation. Data cleaning and pre-processing is an essential stage to improve the performance and ensure the reliability of any text mining algorithm due to the linguistic noise rooted in the textual data [16].

That said, the raw 340 abstracts dataset was tokenized (i.e., splitting each abstract into a piece of words), treated through eliminating all stop words (e.g., the, a, an, by, from) and punctuation from the dataset, transformed into a lowercase format, and unnecessary words (e.g., article, public, transportation, paper) were eliminated from the dataset. As a result, the processed dataset was reduced from 66,573 raw words to 32,358 cleaned words. **Error! Reference source not found.** shows a comparison between the raw and processed datasets. Then, the processed dataset was structured into a Document-Term Matrix (DTM). The DTM describes the relationship between the documents (M) and words (W), where each row represents a document, and each column represents a term (word).

Regarding the control parameters, the LDA model requires some basic control parameters $(\alpha \text{ and } \beta)$ for properly unveiling the latent key topics within the dataset. The hyperparameter (α) controls the mean and sparsity of the topic distribution of document d (θ_d) from the underlying Dirichlet distribution. As advocated by Griffiths and Steyvers [14], smaller values for (α) are better suited for sparser distributions over topics, while larger values are better for uniform distributions. A small value of $(\alpha = 0.1)$ was used to allow for a better identification of the key topics within the well-structured, yet focused, electric buses literature. Additionally, the hyperparameter (β), which controls the mean and sparsity of the word distribution of topic k (ψ_k), is set to 0.01 as in [12].

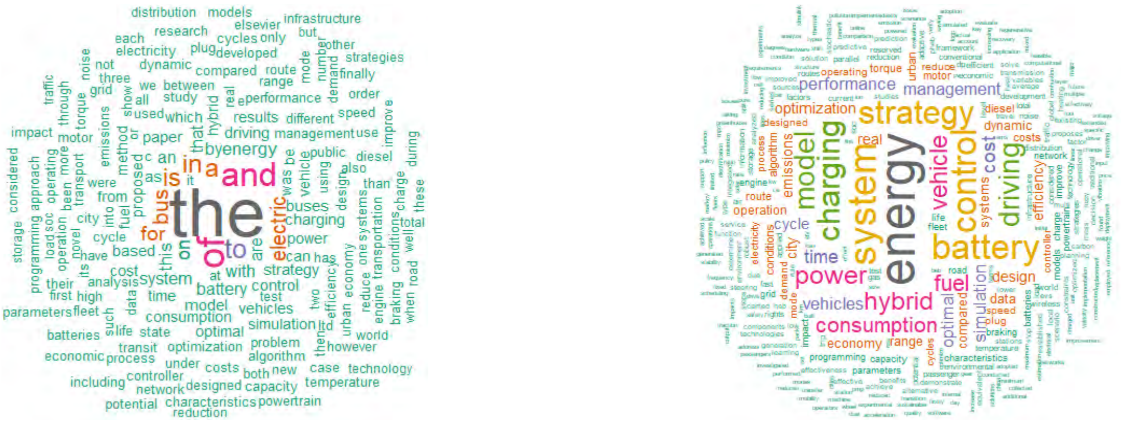

Figure 4. Comparison between raw and clean datasets through word clouds for (Transit Electrification)

Thereafter, the LDA model requires the number of topics to be defined. The optimum number of key topics can be identified based on the following metrics: Perplexity scores [10], Arun2010 [17], CaoJuan2009 [18], Griffiths2004 [14], and Deveaud2014 [19]. These metrics evaluate the performance of a natural language statistical model in predicting a sample. Additionally, the number of topics can be identified based on the subjective analysis, interpretability, and practicality of the developed topics [11, 12]. In this respect, the analysis examined a wide range of a number of topics (K), ranging from 2 to 100 topics.

The analysis concludes that the optimum number of latent topics is around 30, where the minimum values for the perplexity, Arun2010, and CaoJuan2009 metrics are attained. And the number of topics that achieve the highest values for both Griffiths2004 and Deveaud2014 metrics simultaneously is 10 topics. Nonetheless, the present study opts for a 10 topics model for simplicity and to deal with a practical number of key topics, which, in the authors' opinion, represents the themes in the electric buses' literature.

CHAPTER TWO

2. Chapter 2 – Knowledge Domains of e-Bus

2.1. Introduction

The knowledge domains of e-Bus research are analyzed using the methods discussed in Chapter 1. As such, the results are reported for each method independently. Furthermore, the results extracted from both methods are synthesized in the conclusion section.

2.2. Qualitative Results

2.2.1. Initial insights of e-Bus knowledge

The initially extracted categories were created during a preliminary screening of the titles of each article. This charting process provided a significant context of the literature present and how to proceed with organizing the dataset into cohesive parameters. Therefore, after sorting the articles by years published, these initial categories were more broadly sorted into secondary categories, as seen in Table 1.

Table 1. Dataset Parameters from Filtration and Coding

Parameter	Metrics
Initial Dataset	425 Articles
Number of Excluded Studies	85 Articles
Number of Initial Categories (Web of Science based)	56 Categories
Number of Initially Extracted Categories	36 Categories
Total Number of Studies in Final Dataset	340 Articles
Number of Open Codes	848 lines of code
Number of Categories Extracted	587 lines of code
Number of Secondary Categories (Focused Coding based)	8 Categories
Number of Themes	22 Themes

The aim of each article was recorded based on keywords and concepts from the abstract. Deriving a structured aim kept the formation uniform and efficient for the open coding stage. In total, 425 aims were written based on the abstract of each article. From the aims, Open Codes detailing the main points were extracted. There were 848 lines of Open Codes that were categorized into Focused Codes.

There were several recurrent patterns that arose from the Axial Coding stage, interconnecting domains, categories, and topics within the literature. A significant number of codes were focused on the optimization of different aspects of BEBs. These aspects range from BEB's economic impact to energy management, charging infrastructure, BEB mechanics, infrastructure, and the Public's Perception of BEB's, as detailed in Table 2.

Table 2. Number of Focused Codes by Category

Category of Focused Codes	No. of Codes	Sub-categories
BEB Infrastructure R&D	167	28
Optimization	153	21
Energy Management and Consumption	108	6
Economic and Financial	64	16
Charging Infrastructure	58	10
Public Perception	13	7
Environment	12	8
Policy	12	5

By sorting the data by years, every year had one topic that was addressed significantly compared to other years. As seen in Figure 5, different years will have a highlight topic. This could be due to many reasons, such as that topic being the natural "*next question*" after solving another one. In the early 2000s, there was more focus on the possibility of introducing BEBs and their feasibility, in the 2010s, BEB mechanics and infrastructure were heavily discussed, and in the 2020s charging infrastructure, economics, and market penetration were the focal subjects discussed in the literature.

In comparison, 2016 showed the rise of optimization and technological reviews in research as the question transitioned from how can BEBs simply be used to how various technical aspects of the mechanics of the BEB can be improved to its efficient deployment today.

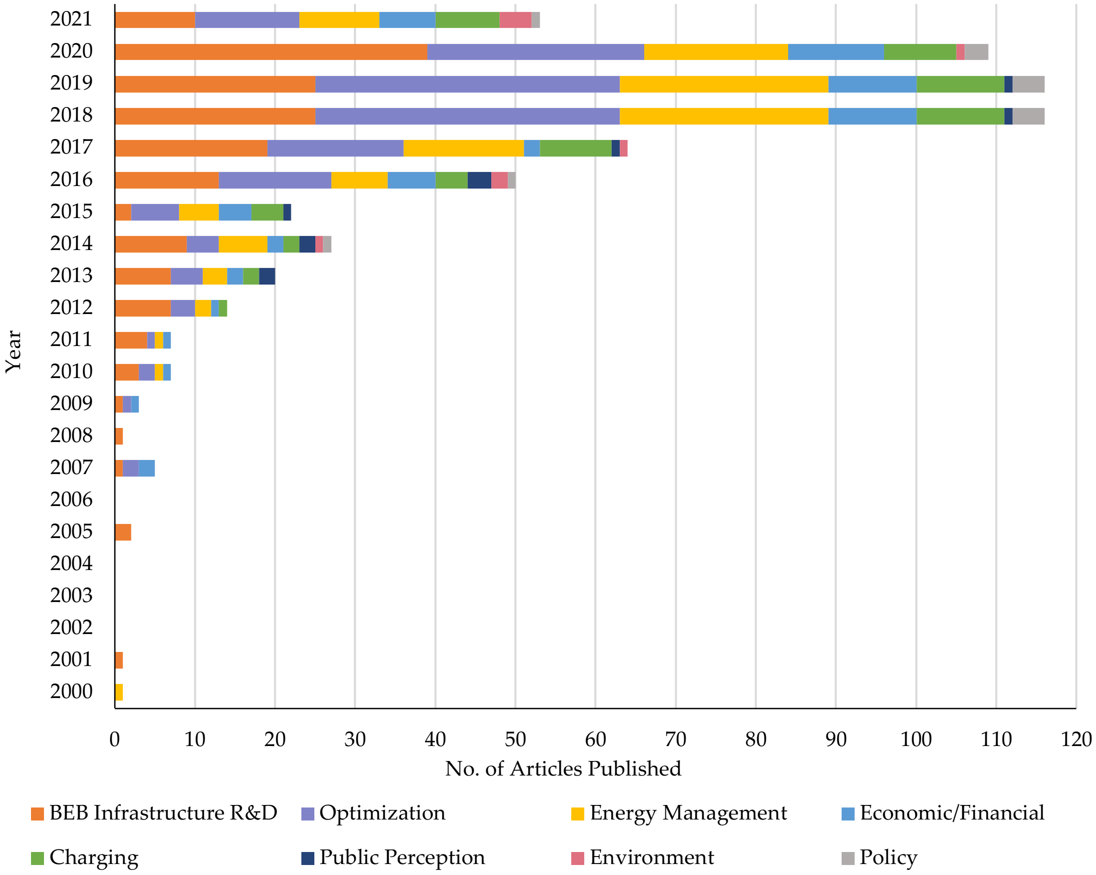

Figure 5. Number of focused code categories per tear from 2000-2021

Surprisingly, there is a lack of environment-focused codes. This was interesting as the importance of environment and climate change was emphasized in the 2015 Paris Climate Agreement, but there are very few articles in comparison to the other categories in the last 20 years. Public perception or the public's awareness and acceptance of widespread BEB deployment have been a subject constantly studied throughout the last two decades. Public opinion is always changing and evolving with time. With the fast-paced, exponential rise of technological innovation, society today in 2021 is vastly different compared to society in 2000. The shift in public perception of BEBs has changed from "is such an idea feasible" to "how can we economically and financially support this transition" with the rising concerns of climate change.

This progression over time depicted in Figure 5 could be inferred in three ways. First, there are many "saturated-knowledge" domains. These domains seem to be basic knowledge now, and there is very little knowledge to explore. For example, in Figure 5, there is a rapid increase of research in Energy Management, which includes research in energy consumption up till 2018, and then there proceeded a decline in Energy Management as the topic became a "saturated knowledge" domain. Second, and in contrast, there are many "knowledge gaps" that are being investigated and researched. These knowledge gaps represent emerging themes of "hot-topics" in the BEB domain. Third, there are a set of dynamic topics that evolve over time. The public perception towards BEB adoption exemplifies this category as well as the BEB's impact on the environment (Figure 5).

2.2.2. Key knowledge themes of e-Bus

The process of focused coding required taking the open codes and breaking them further into common themes found within each line. In total, eight themes were discovered during the process of focused coding, which are analyzed in further detail below. It should be noted that several categories are featured across themes, as highlighted in Table 3.

Table 3. Number of Themes within Categories for E-Bus Literature Dataset

Themes / Categories	BEB Infrastructure R&D	Optimization	Energy Management and Consumption	Economic and Financial	Charging Infrastructure	Public Perception	Environment	Policy
Acoustics	6	2						
Battery	**23**	**16**	**4**	5	**8**			
Benefits				1			1	
Charging	**10**	**22**	3	**5**	**27**	**1**		1
Cost	1			**8**				
Design	**6**	**14**	1	1	2			
Economy	4	2		**17**	2	**2**	**2**	
Energy	**68**	**83**	**95**	**15**	**15**		**3**	**2**
Fuels	**5**	**4**	2					
GHG	1	1					**2**	
Mobility	1	1						
Parking	1	1						
Policy	3	1		**9**		**4**	**1**	**8**
Routing	1	1						
Safety		1						
Scheduling	2	2		1	1			
Sustainability	1					**2**	**2**	
Traffic	2	1		1				
Usage	1					**3**		
Utility	**6**	**6**	2	1	2			

Table 3 provides two distinct sets of results. First, empty cells highlight the lack of research activities between some themes and categories. In comparison, the numerical values in some cells refer to the number of studies conducted on the intersection between categories and themes. The former could be interpreted as knowledge gaps, while the latter could be seen as trending knowledge saturation.

2.2.2.1. Theme 1 – BEB Infrastructure Research & Development

Battery Electric Bus (BEB) Research and Development is one of the heaviest themes in the dataset. It contains literature regarding BEB systems and components. This theme was created for technical design changes aimed to improve the BEB application corresponding to its infrastructure. Components of BEB Infrastructure are designed and simulated using software such as MATLAB, Simulink, or Advisor, while numerous models or principles are used to showcase methodology.

Energy: This theme significantly holds the most articles within BEB Infrastructure R&D. Vast amounts of research have been invested in energy management ranging from implementing alternative energy sources, driving ranges, passenger loads and motor performance. Many feasibility studies are completed to compare the designing and manufacturing of BEB infrastructure (motors, chassis, batteries, steering system, gears, AC system). Energy Management Strategies is a common research topic. In terms of additional sources of energy, photovoltaics or solar energy is most researched.

Battery: Within the research and design of BEBs, redesigning batteries is a highly reviewed domain/topic. In this topic, the battery performance of BEBs is analyzed and optimized. Topics range from battery's thermal performance, battery degradation, system design, battery capacity, the possibility of using hybrid energy storage systems, and comparing battery effectiveness. This is the second heaviest discussed theme with 19 articles.

Charging: The charging of BEBs is a key component in its implementation system. A lot of research has gone into the design of BEB charging systems concerning real-time charging, wireless charging and charging topology. This theme is widely discussed throughout the other categories; however, regarding the Research and Design of BEB Infrastructure, the charging theme is connected to charging methods directly or in conjunction with operating the vehicle. Some of the articles connect charging with the battery theme.

Utility: This category centres on grid operations of BEBs. Research is in developing in-vehicle networks and computing load flow for meshed distribution systems. Different analysis methods are used in this process, such as multi-state fuzzy fault tree reliability analysis and grid-tied residential smart grid topology. There is a mix of both qualitative and quantitative research methods being employed in this theme's literature.

Design: The design of BEBs was categorized in the Optimization subcategory instead of the research and development subcategory as the articles are more related to optimizing existing designs. Rather than focusing on BEB infrastructure, the design theme would focus on taking certain aspects of BEB design and improving the performance or application of BEB systems and operations. The Design theme also contains information regarding driving cycles where its parameters are modified for HEB and BEBs. Articles use the Markov Chain or Monte Carlo method for statistical analysis and ADVISOR as simulation software.

Acoustics: Acoustics is a category mainly within the BEB Infrastructure Research and Development theme. There are six articles related to Acoustics within BEB Infrastructure R&D. In this umbrella, various noise or resonance sources are identified, analyzed, and optimized. Noise impacts and electromotor acoustic comfort levels are analyzed, and different types of motors are designed to control BEB resonance transmission.

Fuels: The Fuel theme focuses on the design and operation of BEB fuel cells based on energy storage and system capacity using experimental methods applied to BEB infrastructure components such as the hybrid propulsion system or the fuel cell. Advantageous fuel economy options are discussed sparingly. A gap in this area is improving the fuel economy of BEBs for extreme hot or cold climates for optimal driving.

Economy: In the Economy theme, the benefits of a BEB system are financially analyzed using questionnaires, surveys, and cost-benefit analysis. Various market impacts of BEB as an urban public transportation system are estimated. The research contains several literature reviews where characteristics of different types of electric busses are compared using the grounded theory method.

Policy: Policy is a category that focuses on the feasibility of deploying BEBs, looking into business model relationships and their link to power generation, transportation, and CO2 emissions. These articles review incentive policies that aim to encourage BEB implementation. Factors that affect the transit agencies' decisions to shift towards BEB and financing mechanisms are analyzed. This theme stems from both quantitative and qualitative analysis methods to aid policymakers in identifying technical components that may require investments, funds, legal arrangements in hopes to accelerate the transition to the BEB fleet. Although this theme is incredibly important, it is not heavily discussed within academia and might require more research work.

Sustainability: The category of sustainability emerged from papers looking into different modes of green transportation and travel mode combinations. There exists an overlap between sustainability and greenhouse gas themes, but the key difference is that sustainability focuses on the sustainability of BEB infrastructure mechanisms rather than the GHG contributors, although that is the overarching goal.

2.2.2.2. *Theme 2 – Optimization*

The second popular theme was optimization. Optimization is a theme that is highlighted heavily in the focused coding. With the rapid rise of technological innovation, many researchers are aiming to improve various aspects of literature already present. The theme itself is quite broad and interconnects across many of the other themes discussed in this chapter. Most commonly, the Optimization theme is tied in with BEB Infrastructure, Energy

Management/Consumption or Charging. These topics are heavily discussed and strategized, with a significant spike in academic literature produced since 2016.

Energy: The aim of this category is to optimize the energy sources needed to operate BEBs. Energy management strategies and aims to minimize the consumption of energy are prime topics discussed regularly within this theme. Optimizing energy used in electric buses is the second most discussed theme within this dataset.

Charging: There is an abundance of research related to Charging within the Optimization theme. Various existing charging infrastructures and charging protocols are optimized in this theme. Research regarding optimizing plug-in and wireless charging methods has increased since 2016. Battery size and charging methods are closely related categories as many articles discussing charging optimization also deal with optimizing battery capacity.

Battery: The Battery category plays heavily with the optimization theme. There are numerous optimization methods applied to increase the efficiency of electric bus batteries. Battery capacity, thermal performance and battery degradation are the most discussed components optimized in the literature. There is some overlap between optimization and BEB research and development. Some articles can fall between the two themes. An article might introduce a recent design or development of a BEB component and then proceed to optimize it later.

Design: The design category contains research optimizing BEB systems. Existing mechanics of BEBs are improved, such as the motor, the chassis, braking systems, dual motors, or speed, with the aim to increase efficiency. Common methodologies in this category use stochastic modelling, modelling predictive control algorithms, dynamic or non-linear programming.

Utility: The Utility category in this theme categorizes research about optimizing grid operation for electric bus use. Literature in this theme includes optimizing load congestions for grid-interactive BEB operations and improving grid-tied smart grid topology. Applying renewable energy for Vehicle-to-Grid (V2G) for BEB fleets was introduced in 2021. Common models employed to optimize the utility aspect of BEBs are the BEB energy consumption model, GUMBI optimization model, fuzzy logic controllers and reliability analyses.

Fuels: The aim of this category is to group literature optimizing fuel for BEBs. This includes topics regarding minimizing fuel consumption, improving life-cycle costs, comparing different fuel sources, and minimizing the cost of producing fuel cells.

2.2.2.3. *Topic 3 – Energy Management and Consumption*

Energy Management and Consumption is a key theme in the BEB literature. This theme looks at how to manage energy output from BEBs and how to reduce the consumption of energy as a form of waste control/sustainability control. With the Paris 2015 Agreements established, there has been a massive increase in Energy Management and Consumption literature beginning in 2016.

Different approaches to energy Management Strategies (EMS) dominate literature between 2017-2019. These articles will focus on optimizing BEBs and HEBs motor, fuel consumption, and the most common methods for optimization use Pontryagin's Minimum Principle (PMP), MATLAB for dynamic programming, Markov Decision Process, Monte Carlo Method, or Equivalent Consumption Minimization Strategy.

Energy: This category is vastly populated with research on improving energy storage, renewable energy alternatives, as well as various energy management and consumption strategies for electric bus operations. Energy management strategies are employed in almost all the articles within this theme. Energy is the most researched topic in the entire dataset.

Battery: The Battery category is comprised of research regarding prolonging the battery life of electric buses without sacrificing energy consumption efficiency. The research considers battery degradation and energy storage based on long-term battery state of charge (SOC).

Charging: Research in the Charging category centres on evaluating the energy demand of charging and other power requirements based on BEB operating results.

2.2.2.4. *Topic 4 – Economic and Financial*

The Economic and Financial theme is not as heavily discussed as other themes; however, it is an aspect most important to the implementation and feasibility of BEBs. This theme includes many cost-analysis and life-cycle assessment models to analyze the capital costs and financial impacts of introducing and maintaining BEBs/HEBs/PHEBs in today's market. In Figure 2-6, there is a rapid increase of this them in 2017 with similar levels maintained for the proceeding years. This could be a natural shift in curiosity, the idea that now that there is significant research on BEB design, the next step is to see how financially it can be afforded in today's economy. It is difficult to determine what gaps are in this field and whether the decrease in discussion is due to the introduction of other, more lucrative "hot topics" or the theme has been thoroughly discussed.

Economy: The Economy category is heavily populated with research centred around understanding BEB market penetration, investment costs for BEB development, and the economic implications of BEB operating systems. The research applies power purchase models and cost-benefit theory to complete the analysis.

Energy: In this category, the economic feasibility of using different energy sources to power BEBs are evaluated, including the time and material costs. Literature in this category contains optimizing driving cycles, economic comparisons of transit bus energy consumption and reducing motor energy costs.

Policy: In this category, policy guidelines are researched using economic and financial comparisons to aid policymakers in the decision-making process for BEB transit implementation. Current advantages, drawbacks and financing mechanisms are analyzed to accelerate global e-Bus adoption.

Battery: In the Battery category, research is comprised of optimizing battery management to minimize operational costs and improve economic performance.

Charging: The Charging category is comprised of research regarding factors that affect upscaling BEB charging infrastructure as well as life-cycle assessments (LCA) of different charging options for BEB systems (plug-in charging, wireless charging, onboard charging).

Cost: Research in this category analyses the cost-effectiveness of using electric buses compared to diesel-fuelled alternatives in urban transit using cost structures, time value of money, and forecasting capital costs.

2.2.2.5. *Topic 5 – Charging Infrastructure*

The Charging Infrastructure theme is the most creative and innovative theme amongst the Focused Codes. With this theme, there is literature discussing wireless charging, rapid charging, renewable energy usage for charging stations, grid operation efficiency, battery state-of-charge and life cycles, scheduling models and other types of BEB charging behaviours.

This theme ties heavily with the Optimization and Energy Management themes as well. There has been a proportional increase in the literature regarding Charging Infrastructure since 2017 as a "hot topic." The issue of charging BEBs is treated as a downside in BEB feasibility. Therefore, minimizing the efforts of charging and maximizing energy output has become a key reoccurring solution in current academia.

Charging: The Charging category contains varying research regarding charging battery-electric buses. This includes research in charging station location, charging schedule variations, optimizing charging infrastructure and wireless charging feasibility.

Energy: This category contains research looking into using different energy sources to charge BEBs. This includes assessing energy balances and consumptions of charging stations as well as evaluating the feasibility of using PV to charge BEBs.

Battery: In this category, research is comprised of optimizing the battery's charging capacity and endurance for various driving ranges. There is also research regarding battery exchanging management and evaluating the current performance of lithium-ion batteries in BEBs.

Design: The Design category in this theme is comprised of developing new system designs for BEB charging stations and developing other aspects of BEB infrastructure. This also includes research in fast-charging BEB system designs as well as on-route and off-route charging infrastructure design.

Economy: The research in the Economy category discusses the economic feasibility of charging stations and investment costs of installing charging infrastructure for electric buses. The research will use power purchase models and cost-benefit analyses to compare the economic impacts of BEB charging infrastructure.

2.2.2.6. *Topic 6 – Public Perception*

Public perception is integral if the goal is to create widespread usage of BEBs as the primary form of public transport. Public Perception and passenger context are terms used interchangeably but imply the same message: how does/will the current population respond to the implementation of BEBs or alternate methods of transit? The articles that have discussed this will use machine learning (ML) algorithms to understand public transit usage and perspective/choice preferences. This theme is one of the least discussed themes amongst all the other themes in this chapter.

Policy: The Policy category in the Public Perception theme contains research delving into deployment policies for BEB implementation in public transit. Specifically, variants and scenarios for e-bus public transport based on technological, organizational, economic, and ecological factors are analyzed in a decision-making process system to develop policy guidelines.

Usage: The Usage category contains literature on the public's awareness and usage of various public transport modes, including electric buses. It also contains research regarding preferences for non-homogenous information sources when using transit. Common methodologies employed are literature reviews, internet surveys and questionnaires.

Sustainability: In this category, research is comprised of developing sustainability frameworks for travel mode combinations. The key difference is that case studies and methodologies in this area look at passenger surveys and case studies to develop a framework of implementation.

Economy: Research in this category related to Public Perception is comprised of implementing electric buses in public transit based on the perspective of different stakeholders. Information is extracted using surveys, questionnaires, and literature reviews as qualitative analysis methods.

Charging: This category contains research discussing the effect of different charging methods that alter the feasibility and deployment of BEBs in urban and suburban transit. Case studies are used to engage passenger's perceptions to alternate charging strategies and how they affect the passenger experience.

2.2.2.7. *Topic 7 - Environment*

The Environment theme analyses how electric bus transit will affect the environment and climate change. E-bus is becoming a crucial alternative to save the dying planet from the harmful effects of diesel-fuelled transportation. This theme weighs the pros and cons of implementing BEBs, including the manufacturing, production, and construction stages of BEB infrastructure and systems.

Energy: This theme is comprised of research regarding the environmental stability of using different energy sources to support BEBs such as PV, biomethane (RNG), or compressed natural gas (CNG). It also looks at the harsh environmental impacts of current diesel-fuelled transit systems.

Sustainability: This category is limitingly comprised of research that assesses sustainable green transportation methods. This includes literature regarding travel mode combinations, sustainable manufacturing practices and life-cycle assessments of BEB infrastructure.

Greenhouse Gases: While this category does not contain a lot of direct research on greenhouse gases, it does contain some research looking into carbon footprint estimations of present diesel-fuelled bus and metro trips. There are also estimations of direct CO2 emissions for various mode combinations of trips.

Economy: The category of Economy contains research in the social and environmental cost estimations of adopting electric bus locomotion. Economic analyses, dynamic models and ownership costs are employed to analyze the cost-benefits of using different forms of fuel to power transit and their effect on trip conditions.

Policy: In this category, research centres around providing policymakers with an idea of the environmental impacts of investing and establishing electric bus transit systems. This includes calculations of air pollution and carbon footprint estimations to assess operating and production costs for feasibility analyses.

Benefits: Analysis of environmental effects with employing electric bus transit. This includes research on carbon footprint estimations and literary analyses of BEB environmental stability to prove to transition to electric buses will be beneficial.

2.2.2.8. *Topic 8 - Policy*

While there exists extensive research on BEB design, optimizing the system and increasing operational efficiency, more insight into BEB policy is critical if evolution to BEB public transit is the goal. This theme is one of the least represented and discussed themes in the e-Bus literature, yet it is one of the most important initiatives that must take place.

Policy: This category provides empirical guidance about BEB investments to policymakers. Research in this category usually employs multi-criteria decision-making processes and cost-benefit analyses to aid in e-bus transit planning.

Energy: This category comprises decision-making processes and models to analyze feasibility policies for BEB implementation. Dynamic models, simulations, and literature reviews are used to understand the political hurdles with e-Bus deployment.

2.3. Quantitative Text-mining-informed Results

The second set of findings is extracted from the Machine-Learning based text-mining model. These results represent the quantitative side of the knowledge synthetization modelling.

2.3.1. Initial insights of quantitative knowledge extraction

The LDA model estimation yields the probabilities of each topic k in each document d, (θ_{dk}), and the probabilities of each word w in each topic k, (ψ_{kw}). The words (terms) with the highest posterior probabilities, (ψ_{kw}), in each topic are presented in Figure 6. In total, ten latent topics emerged from the LDA model cover the multiple dimensions of the battery-electric buses development and adoption literature. Table 4 summarizes the possible research area associated with each latent topic.

Table 4. Research areas associated with the emerged topics (Electric buses)

Topic No.	Research Area	Topic No.	Research Area
1	Vehicle Dynamics	6	Emission and Cost
2	Infrastructure Systems	7	Battery Performance
3	Operational Factors	8	Optimization Models
4	Energy Consumption	9	Planning and External Factors
5	Power Management/Utility Impact	10	Comparative Analysis

Another LDA model with 30 latent topics was extracted, which is partially informed by topic number estimation indices. However, the 30-topic extraction delivers a zoom-in analysis for the battery-electric buses literature. This level of analysis unveils the nitty-gritty details of the research questions under consideration. **Error! Reference source not found.**, in appendix A, provides the research areas linked to each latent topic.

As advocated by [14], each group of words with high probability (ψ_{kw}) in each topic k could be associated with a specific research area/theme. For instance, Topic No. 2, in Figure 6, includes the words "*charging, cost, fleet, infrastructure, fast, technology, etc.*" which could be linked to the Charging Infrastructure research area. The words "energy, driving, consumption, cycle, efficiency, range, etc." in Topic No. 4 could be attached to the Energy Consumption research topic.

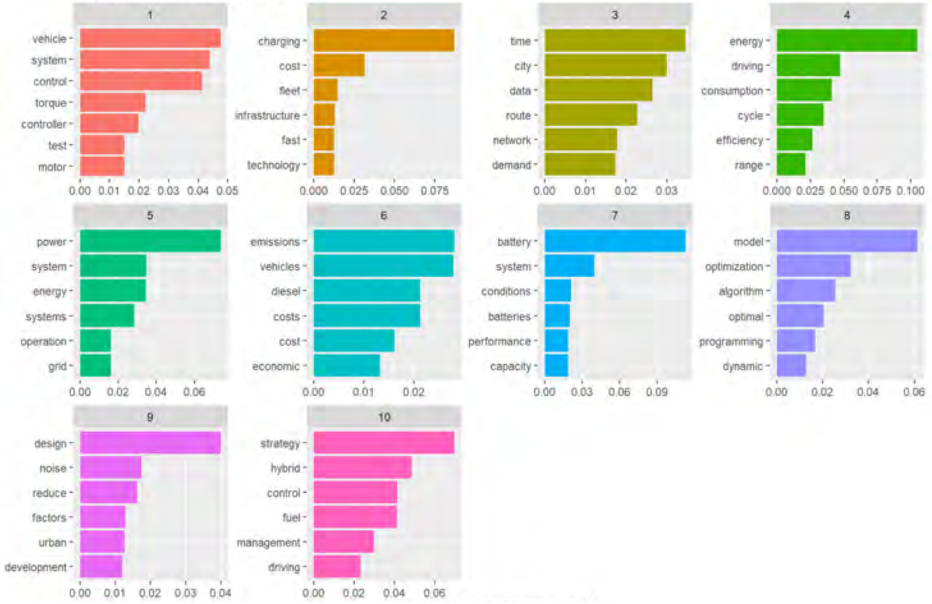

Figure 6. Words with high word-per-topic probability (ψ_{kw}) in each latent topic (k) – Electric buses

1) Vehicle Dynamics
2) Infrastructure Systems
3) Operational Factors
4) Energy Consumption
5) Power Management/Utility Impact
6) Emission and Cost
7) Battery Performance
8) Optimization Models
9) Planning and External Factors
10) Comparative Analysis

2.3.2. Topic distribution over time

The temporal variation of each topics' popularity (inclusion) is analyzed and presented in Figure 7 over the last 20 years. The topic popularity/inclusion reflects how frequently a topic was investigated in a specific year. A topic's popularity (inclusion) is the area between this topic and the prior one.

The most three inclusive (popular) topics throughout the last 20 years are Topic No. 10 (Comparative Analysis) "strategy, hybrid, control, fuel, management, driving, etc.", Topic No. 6 (Emission and Cost) "emissions, vehicles, diesel, costs, cost, economic, etc.", and Topic No. 1 (Vehicle Dynamics) "vehicle, system, control, torque, controller, test, motor, etc.".

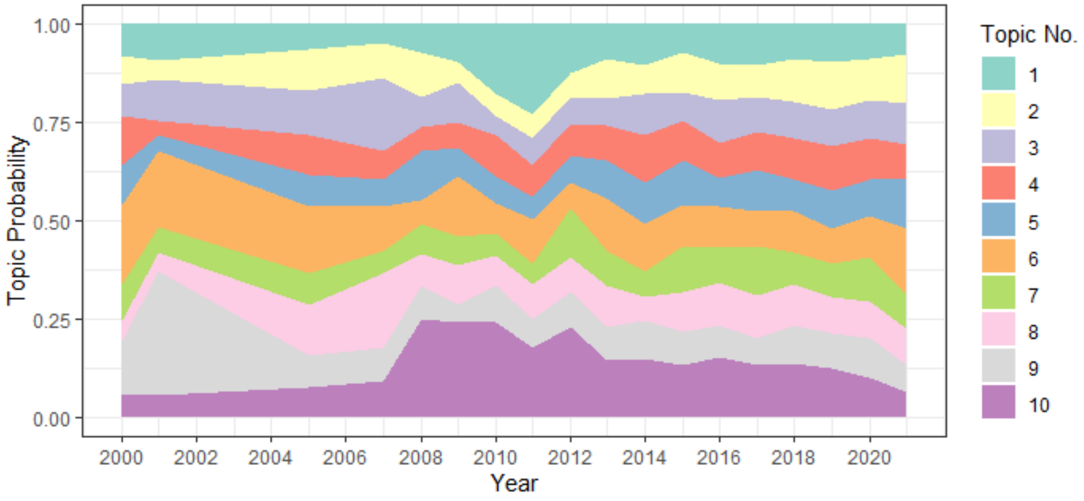

Figure 7. Topic distribution from 2000 to 2021 (Electric buses)

1) Vehicle Dynamics
2) Infrastructure Systems
3) Operational Factors
4) Energy Consumption
5) Power Management/Utility Impact
6) Emission and Cost
7) Battery Performance
8) Optimization Models
9) Planning and External Factors
10) Comparative Analysis

While the least popular topics are Topic No. 7 (Battery Performance) "battery, system, conditions, batteries, performance, capacity, etc.", Topic No. 2 (Infrastructure Systems) "charging, cost, fleet, infrastructure, fast, technology, etc.", and Topic No. 5 (Power Management/Utility Impact) "power, system, energy, systems, operation, grid, etc.".

2.3.3. Emerging and declining research topics

In order to investigate the increase or decrease of a topic's inclusion between two-time windows, an Increase Index (r_k) was calculated as shown in the following equation [12]:

$$r_k = \frac{\sum_{t=2011}^{2021} \theta_k^t}{\sum_{t=2000}^{2010} \theta_k^t}$$

Where $r_k > 1$ indicates an increase in a topic's (k) inclusion (popularity) from (2000-2010) to (2011-2021), while $r_k < 1$ indicates a decrease in a topic's (k) inclusion with respect to the same time windows. The topics with high (r_k) are referred to as *Hot topics*, while the topics with low (r_k) are referred to as *Cold topics*. This index reflects the plethora of studies of a specific topic in a time window compared to another time window. Figure 8 describes the estimated (r_k) for the ten topics in increasing order.

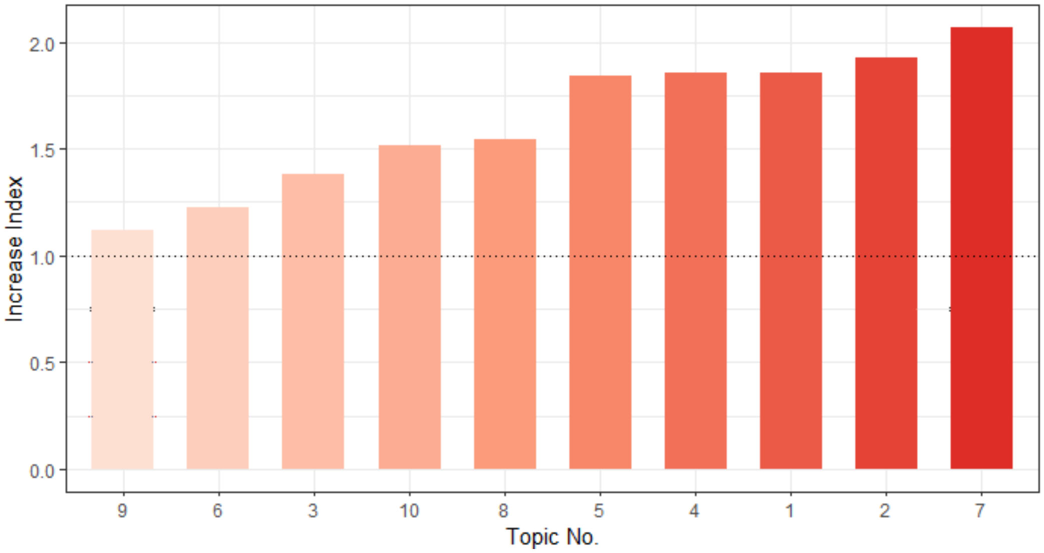

Figure 8. Increase indices of topics from (2000-2010) to (2011-2021) – Electric buses

1) Vehicle Dynamics
2) Infrastructure Systems
3) Operational Factors
4) Energy Consumption
5) Power Management/Utility Impact
6) Emission and Cost
7) Battery Performance
8) Optimization Models
9) Planning and External Factors
10) Comparative Analysis

As shown in Figure 8, all ten topics have an Increase Index (r_k) greater than 1, which indicates that all the topics in battery-electric buses literature are hot and emerging research topics. Nonetheless, some of those topics have a higher (r_k) than the others. For instance, the hottest (i.e., most emerging) topics are Topic No. 7 (Battery Performance), Topic No. 2 (Infrastructure Systems), Topic No. 1 (Vehicle Dynamics), Topic No. 4 (Energy Consumption), and Topic No. 5 (Power Management/Utility Impact). In comparison, the least emerging topics are Topic No. 9 (Planning and External Factors), Topic No. 6 (Emission and Cost) and Topic No. 3 (Operational Factors). In general, the trend analysis reveals that the research corresponding to the feasibility of electric buses is declining and replaced by the research related to the implementation and performance of electric buses.

2.3.4. Topics correlation matrix

A correlation matrix has been developed to investigate the associations between the ten topics and quantify the strength of the relationships. The correlation between two topics reflects the co-occurrence of those topics in the considered documents.

Figure 9 provides the interlinkage matrix for the ten topics (a detailed version is offered in Figure 10). The visualization of the interlinkage between the topics could be a valuable tool to identify future research directions

[11]. For example, Figure 9 shows that Topic No. 6 (Emission and Cost) and Topic No. 2 (Infrastructure Systems) are highly interlinked (i.e., commonly studied together). The same also applies for topics No. 2 (Infrastructure Systems) and No. 3 (Operational Factors), for topics No. 5 (Power Management/Utility Impact) and No. 7 (Battery Performance), and for topics No. 8 (Optimization Models) and No. 10 (Comparative Analysis).

On the other hand, the interlinkage matrix shows that Topic No. 2 (Infrastructure Systems) and Topic No. 10 (Comparative Analysis) are negatively associated (i.e., rarely studied together). The same applies for topics No. 6 (Emission and Cost) and No. 10 (Comparative Analysis), and for topics No. 1 (Vehicle Dynamics) and No. 2 (Infrastructure Systems). Surprisingly, Topic No. 3 (Operational Factors) "time, city, data, route, network, demand, etc." is not interlinked with any other topics, which opens an avenue for future research efforts given the importance of considering operational factors (e.g., routes) in regard to other research areas such as infrastructure systems and battery performance.

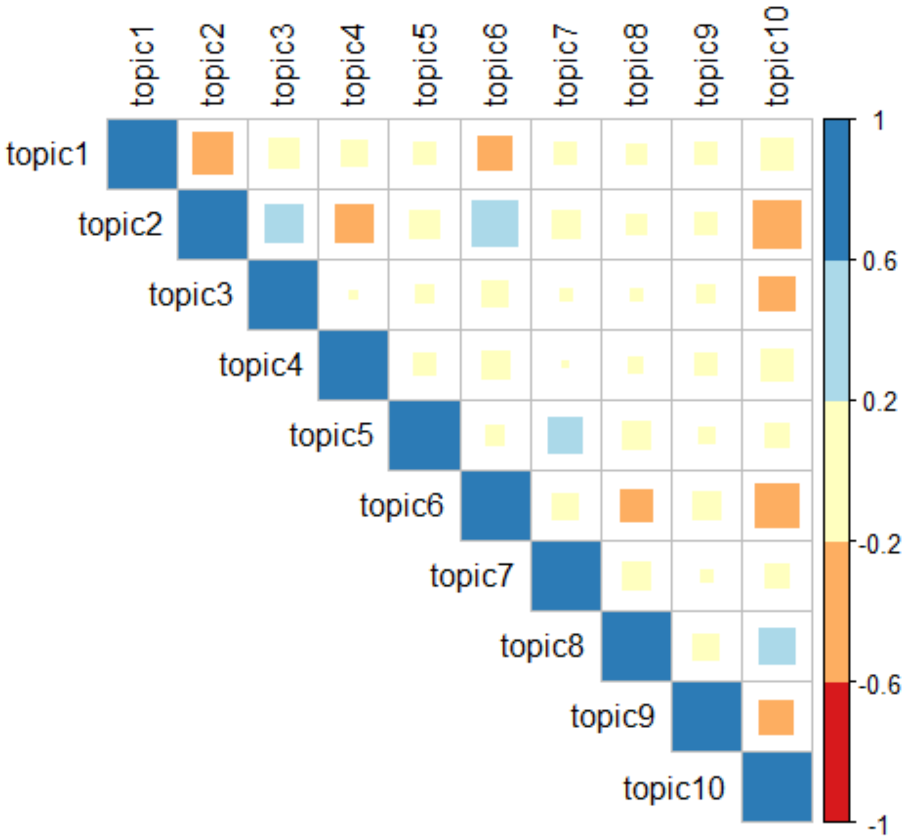

Figure 9. Topics' interlinkage matrix

1) Vehicle Dynamics
2) Infrastructure Systems
3) Operational Factors
4) Energy Consumption
5) Power Management/Utility Impact
6) Emission and Cost
7) Battery Performance
8) Optimization Models
9) Planning and External Factors
10) Comparative Analysis

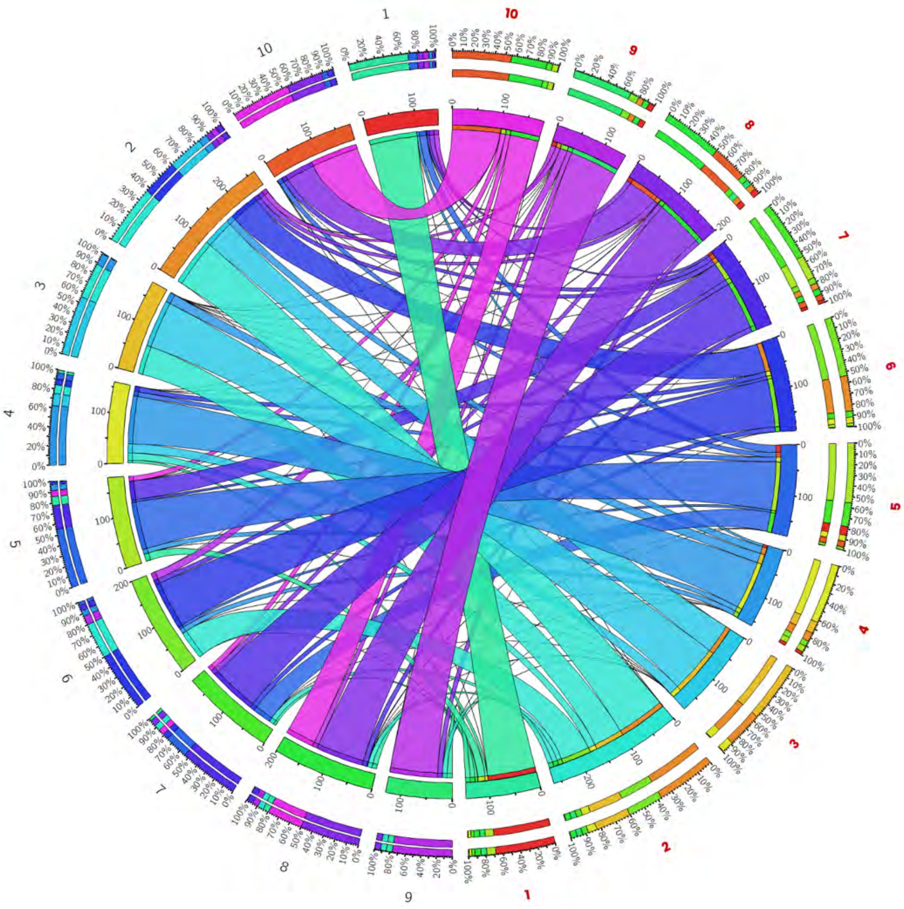

Figure 10. Topics' interlinkage matrix (detailed)

2.3.5. Extracting e-Bus knowledge from research topics

As highlighted before, the developed latent topics cover the primary aspects of the battery-electric buses development and implementation. It is worth noting that two identified latent topics, namely: Topic No. 1 - Vehicle dynamics and Topic No. 10 – Hybrid technology, are found in a significant portion of the literature on electric buses. These two topics focus solely on the mechanical, technological, and manufacturing aspects of electric buses, which is not the focus of this report. The following section summarizes the main findings for the rest of the identified topics.

2.3.5.1. Topic No. 2 - Infrastructure Systems

"Charging, cost, fleet, infrastructure, fast, technology, wireless, models, EV, model, etc."

The research on the electric buses infrastructure systems has concluded the following findings:

- Research efforts in estimating the minimum number of charging stations and their associated locations and capacities are proved to be successful through the utilization of various optimization and decision-making techniques (e.g., interval type-2 fuzzy multi-criteria decision-making approach, mixed integer-linear mathematical programming, stochastic integer models, reinforcement learning) while accounting for the spatial-temporal dimensions of the problem such as schedules, stops/terminals and empty driving mileage.
- Energy storage systems (ESS), vehicle-to-grid (v2g) smart charging strategies and renewable energy sources such as photovoltaic solar generation could be integrated into battery-electric bus charging strategies, which lower the external cost of the electricity grid as well as buses emissions. For example, the use of ESS could be a potential remedy for high-demand charges from fast charging strategies. In addition, a pricing-aware real-time charging scheduling, using the Markov decision process, is approved to reduce the charging cost dramatically.

- The application of the opportunistic dynamic wireless charging systems influences the size of the batteries and hence bus weight which induces an overall reduction in battery-to-wheel energy consumption. Additionally, the dynamic wireless charging systems outperform the terminal charging technology regarding the total cost as well as the total infrastructure cost.
- Buses' replacement plans should be formulated in fleet replacement-like optimization problems while considering electric buses' purchase costs, operating costs, charging infrastructure investments, salvage revenues, and electricity demand charges.

2.3.5.2. Topic No. 3 - Operational Factors

"Time, city, data, route, network, demand, real, traffic, trip, information, etc."

The research on the operational factors of electric buses has concluded the following findings:

- A more precise estimation of the electric buses' energy consumption could be achieved by generating a set of speed profiles for the studied route. Also, a two-stage electric vehicle routing problem, which accounts for the detailed topography and speed profiles, offers high accuracy of energy estimations.
- Smart (i.e., static, and dynamic) scheduling strategies for electric buses support cost efficiency and help avoid en-route breakdown by accounting for schedules, battery range, recharging plans, and, indeed, the stochastic nature of urban traffic. Optimizing scheduling plans can also help reduce idle times, which in turn could stop the accumulation of stochastic volatilities.
- Geometric process-based battery management optimizing policy offers a significant improvement in the performance of the electric buses' energy consumption through accounting for the deterioration of the battery after repeated charging and discharging.
- In addition to the conventional factors, a reliable energy consumption model for electric buses should account for the driving behaviour, which is proved to affect battery range. The heterogeneity embedded in the driving behaviour leads to a high variation in energy requirements for different routes and at different times of the day. Therefore, proper training of electric buses drivers is crucial to ensure efficient operation and increase battery range.

2.3.5.3. Topic No. 4 – Energy Consumption

"Energy, driving, consumption, cycle, efficiency, range, braking, simulation, characteristics, urban, etc."

The research on the energy consumption of electric buses has concluded the following findings:

- Efficient energy consumption must account for vehicle characteristics, route characteristics, driving cycles, driving behaviour, and atmospheric conditions, and time windows. It has been found that energy consumption is lower at nights, over weekends and during cooler seasons. Moreover, the optimal driving speed is time-sensitive and ranges from 11 to 18 km/hr. Those results are case-specific and might differ from one region to another.
- Managing the braking systems of battery-electric buses could increase the driving range and energy recovery due to powertrain losses. For instance, one-pedal driving offers a high energy efficiency through managing the regenerative braking operation. Additionally, a composite brake control strategy based on fuzzy logic optimization, a decoupled braking energy recovery system can improve the braking energy recovery. An optimal control strategy should consider the motor speed and state of charge.
- A significant reduction in energy consumption could be achieved by adopting a cruise control system that limits the speed from significantly exceeding the average speed as aggressiveness and energy consumption have been highly correlated. Moreover, fully autonomous driving can further reduce the energy consumption of electric buses. For high-speed routes, a low drag body could reduce energy consumption.
- The energy consumption of electric buses is less influenced by passenger loadings compared to conventional buses, which is attributed to the electric buses' ability to recapture energy.

2.3.5.4. Topic No. 5 – Power Management/Utility Impact

"Power, system, energy, systems, grid, operation, storage, load, distribution, vehicles, etc."

The research on the power management and utility impact for electric buses implementation has concluded the following findings:

- Successful integration between electric buses systems and the electricity grid must account for charging cost, battery cost and additional range. The required energy could be extracted during off-peak hours and stored in high-capacity storage systems to stabilize the grid through peak shaving and valley filling. The utilization of energy storage systems can significantly help reduce the fast-charging stations' overall investment and charging cost.
- The impact on the power distribution systems could be mitigated through adopting stochastic energy management for charging stations that consider various charging strategies, actual electricity prices, vehicle scheduling, and account for the depreciation cost of the batteries.
- Rapidly charging the electric bus at every bus stop is an alternative option worth investigating to reduce the required energy storage and weight, hence improving energy consumption and cost. This charging strategy has been reported as a viable alternative for some contexts. Additionally, it is worth noting that charging electric buses to full capacity at every available opportunity is not the optimal solution for energy cost minimization.

2.3.5.5. Topic No. 6 – Emission and Cost

"Emissions, vehicles, diesel, costs, cost, economic, impact, life, environmental, gas, etc."

The research on the emission and cost of electric buses implementation has concluded the following findings:

- The environmental and societal benefits of operating electric buses are much higher than other policy measures such as carbon taxation in transportation and could be viewed as a fruitful investment for the cities. Electric buses adoption could reduce around 50% of the acidification and eutrophication impacts linked to bio-methane fuelled buses. Compared to diesel buses, battery-electric buses' life cycle GHG emissions are lower while the life cycle costs are higher.
- A successful transition towards electric powertrain in the transit sector requires exceptional support from governments in the form of incentivizing the purchase and operation of electric buses and adopting innovative business modes that mobilize both public and private sectors resources to reduce financial risks. Financial support is required due to the different levels of costs between diesel and electric buses. Also, transit agencies need actual, real-life, operational data, standardization, and demonstration projects to transition to electric buses properly.
- The adoption of electric buses is highly sensitive to the advancements in electric motors, batteries capacities and charging technologies, as well as the operational context. Most small and medium communities seem to be suitable for electric buses operation given the technological advancement in the battery capacity. Also, if battery cells become more efficient and their price declines, the benefits over cost (B/C) ratio of introducing the new battery-swapping electric bus system will increase.

2.3.5.6. Topic No. 7 – Battery Performance

"Battery, system, conditions, batteries, capacity, performance, temperature, heat, low, heating, etc."

The research on the battery performance of electric buses have concluded the following findings:

- Batteries' life span can be extended by keeping the state of charge within a low and narrow range. Moreover, utilizing both lithium-ion cells and supercapacitors in a hybrid energy storage system is a promising solution for improving the efficiency of energy storage systems. A significant reduction in the battery capacity loss for the optimal charging strategy could be reached through the coupled modelling of electro-thermal and ageing properties (e.g., capacity fading and degradation) of lithium-ion batteries.
- Battery temperature control is critical to the safety, life span, and performance of electric buses. The large-scale Lithium iron phosphate ($LiFePO_4$) battery has a higher specific capacity and superior safety performance regarding heat release features after comparing with previous lithium-ion batteries (LIB). It is worth mentioning that hazards of 26650 $LiFePO_4$ batteries are not caused by chemical activity; instead, it is attributed to the collapse of the integrity of the separator due to excessive battery temperature.

- The energy consumption of AC systems could be minimized by optimizing the speeds of the compressor, evaporator fans and condenser fans simultaneously. The ambient temperature highly influences the heat transfer coefficient of the battery thermal management system. It is noteworthy that preheating process becomes necessary with decreasing ambient temperature; however, the preheating demand declines as the driving range grows. The vapour injection heat pump can be more beneficial when the heating capacity does not meet the heating demand, especially with a short driving range.

2.3.5.7. *Topic No. 8 – Optimization Models*

"Model, optimization, algorithm, optimal, dynamic, prediction, predictive, parameters, functions, etc."

The utilization of optimization models in the battery-electric buses literature has yielded the following findings:

- Various optimization techniques and algorithms have been investigated to answer many questions regarding the complex procedures of electric buses operations and adoption. This complexity is attributed to, among others, the large number of variables, bi-directional interaction between variables, fundamental uncertainty, limited predictability, change over time and non-linearity.
- A data-driven approach based on artificial neural networks could be utilized to overcome the complications caused by the nonconvex relationships. However, a Markov chain approach is significantly superior to the artificial hack propagation neural network, especially in computational efficiency. It is also found that an improved chaotic particle swarm optimization algorithm can greatly improve the convergence speed and optimization precision compared to standard particle swarm optimization.
- A support vector machine regression model based on the grey wolf optimization algorithm offers higher estimation accuracy and shorter training time than the genetic algorithm-back propagation neural network model and grid-search support vector machine regression model.
- Vehicle scheduling problems with routes and fuelling time constraints (VSPRFTC) could be solved using multiple ant colony algorithms (ACA), a metaheuristic approach inspired by the foraging behaviour of real colonies of ants. Additionally, a stochastic model predictive control can considerably save the online computation and operation time while achieving the goal of real-time online control.

2.3.5.8. *Topic No. 9 – Planning and External Factors*

"Design, noise, reduce, factors, urban, development, constraints, motor, process, structure, etc."

The research on planning and external factors of battery-electric buses implementation has yielded the following findings:

- Noise and vibration problems of electric buses are attributed to the coupling vibration of the powertrain and rear drive axle, which amplifies the resonance of the driveline. A gradient-based nonlinear sequential programming could be used to reduce high-frequency noise and vibrations by optimizing the magnetic embrace for the minimized torque ripple. Additionally, reducing the electromagnetic noise could be achieved by thickening the motor shell and end cover, which lessens the possibility of electromagnetic resonance's appearance.

The design process of reducing the mass of electric buses could be reached through adopting a monocoque sandwich-structured fibre-reinforced approach. Also, utilizing Continuous and discrete gradient-based optimizers for constructing an aluminium-steel multi-material electric bus body structure enhances electric buses' structural performance and structural weight. Furthermore, utilizing a multi-material topology optimization can decrease the total mass of the electric bus's roof through lightweight optimization of the interfacial area between the different materials.

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CHAPTER THREE

3. Chapter 3 – Key Remarks and Conclusions

The findings in this report highlight several avenues that require urgent interventions. A clear lack of transforming research findings into effective policy interventions is evident in the findings. Therefore, and in addition to the key findings reported in Chapter 2, we conclude with the following policy recommendations (Figure 11). It should be noted that these are high-level, and the findings in previous chapters should be carefully studied.

3.1. Transit Electrification

The knowledge of Transit electrification is advancing rapidly and encompasses almost all the technical, environmental, regulatory, and economic elements associated with the widespread adoption of e-Buses. That said, there are key issues that require further investigation:

- The performance of a full e-transit network is yet to be reported in the literature. Current research is based on partial fleet replacement, which provides a limited perspective on full network operation.
- The perspective (e.g., barriers and enablers) of service providers towards transit electrification is understudied.
- There is a clear lack of monetary support to incentivize transit electrification. The Not in My Back Yard (NIMBY) syndrome is still a key barrier.
- The performance of an e-Transit network under disruption (e.g., electricity outage, equipment malfunction) is not studied at all.
- Lastly, there is a dire need to rethink transit provision models, including service provision, network design, and procurement, with the advent of e-Buses.

Policies associated with the procurement process must be updated to facilitate different ownership models (e.g., leasing, owning, financing).

At the operation level, policies and guidelines should include several safeguards to address the cascading impacts of service disruption.

Monetary incentives to enable transit providers to study, analyze and test electric buses in operation.

Technology awareness, knowledge mobilization and educational programs are required to further educate stakeholders on the costs and benefits of transit electrification.

Figure 11. e-Bus policy implications

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APPENDICES

4. References

[1] Arksey H, O'Malley L. Scoping studies: towards a methodological framework. International journal of social research methodology. 2005;8(1):19-32.
[2] Feldman R, Dagan I. Knowledge Discovery in Textual Databases (KDT). Conference Knowledge Discovery in Textual Databases (KDT), vol. 95. p. 112-7.
[3] Gupta V, Lehal GS. A survey of text mining techniques and applications. Journal of emerging technologies in web intelligence. 2009;1(1):60-76.
[4] Munn Z, Peters MD, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC medical research methodology. 2018;18(1):143.
[5] Tricco AC, Tetzlaff J, Moher D. The art and science of knowledge synthesis. Journal of clinical epidemiology. 2011;64(1):11-20.
[6] Kastner M, Antony J, Soobiah C, Straus SE, Tricco AC. Conceptual recommendations for selecting the most appropriate knowledge synthesis method to answer research questions related to complex evidence. Journal of clinical epidemiology. 2016;73:43-9.
[7] Whittemore R, Chao A, Jang M, Minges KE, Park C. Methods for knowledge synthesis: an overview. Heart & Lung. 2014;43(5):453-61.
[8] Feldman R, Fresko M, Hirsh H, Aumann Y, Liphsta O, Schler Y, et al. Knowledge management: A text mining approach. Conference Knowledge management: A text mining approach. p. 9.1-9.10.
[9] Debnath R, Bardhan R, Darby S, Mohaddes K, Sunikka-Blank M, Coelho ACV, et al. Words against injustices: A deep narrative analysis of energy cultures in poverty of Abuja, Mumbai and Rio de Janeiro. Energy Research & Social Science. 2021;72.
[10] Blei DM, Ng AY, Jordan MI. Latent dirichlet allocation. the Journal of machine Learning research. 2003;3:993-1022.
[11] Ezzeldin M, El-Dakhakhni W. Metaresearching Structural Engineering Using Text Mining: Trend Identifications and Knowledge Gap Discoveries. Journal of Structural Engineering. 2020;146(5).
[12] Sun L, Yin Y. Discovering themes and trends in transportation research using topic modeling. Transportation Research Part C: Emerging Technologies. 2017;77:49-66.
[13] Geman S, Geman D. Stochastic relaxation, Gibbs distributions and the Bayesian restoration of images. Journal of Applied Statistics. 1993;20(5-6):25-62.
[14] Griffiths TL, Steyvers M. Finding scientific topics. Proc Natl Acad Sci U S A. 2004;101 Suppl 1:5228-35.
[15] Hofmann M, Chisholm A. Text mining and visualization: case studies using open-source tools: CRC Press, 2016.
[16] Salloum SA, Al-Emran M, Monem AA, Shaalan K. Using text mining techniques for extracting information from research articles. Intelligent natural language processing: Trends and Applications: Springer; 2018. p. 373-97.
[17] Arun R, Suresh V, Veni Madhavan CE, Narasimha Murthy MN. On Finding the Natural Number of Topics with Latent Dirichlet Allocation: Some Observations. Conference On Finding the Natural Number of Topics with Latent Dirichlet Allocation: Some Observations, Berlin, Heidelberg. Springer Berlin Heidelberg, p. 391-402.
[18] Cao J, Xia T, Li J, Zhang Y, Tang S. A density-based method for adaptive LDA model selection. Neurocomputing. 2009;72(7-9):1775-81.
[19] Deveaud R, SanJuan E, Bellot P. Accurate and effective latent concept modeling for ad hoc information retrieval. Document numérique. 2014;17(1):61-84.

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