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System Dynamics Modeling for UK PFI Programs: Exploring Key Drivers and Interactions

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Sara Biziorek

Abstract

Governments globally have embraced Public-Private Partnerships (PPPs) to reduce fiscal burdens and transfer responsibilities to the private sector. However, the long-term viability of this approach remains uncertain due to social and economic limitations.

To offer decision-makers involved in PPP initiatives worldwide with valuable insights for shaping their PPP programs, this thesis undertakes a comprehensive analysis of the lasting social and financial implications of the United Kingdom's Private Finance Initiative (PFI) and its subsequent iteration, PF2. The PFI and PF2 programs in the UK were chosen as the unit of analysis because they represent one of the largest PPP programs around the globe, encompassing a diverse portfolio of over 700 projects.

By leveraging System Dynamics (SD), the study unveils the intricate interplay between PPP development, societal concerns, public policy, and financial constraints. Through the creation of SD causal-loop diagrams, the research elucidates the causal structures within the system and estimates the far-reaching financial effects of PPPs on both the government and society. These diagrams offer valuable insights into the complex dynamics of PPP projects and shed light on their impacts across various stakeholders. By providing evidence-based recommendations, this research endeavors to guide decision-makers in optimizing the outcomes of infrastructure portfolios in PPP projects and maximizing the enduring social and financial benefits derived from such collaborations.

By facilitating informed decision-making and effective policy formulation, this research seeks to enhance the overall outcomes of PPP programs, not only within the United Kingdom but also across diverse nations. The findings and recommendations put forth in this study aim to enrich the understanding of PPP dynamics and provide governments with suitable policies to optimize the outcomes of infrastructure portfolios in PPP projects. This, in turn, ensures the long-term sustainability and triumph of these collaborative partnerships.

Furthermore, this study evaluates potential policies geared towards enhancing the effectiveness of PPP programs. It acknowledges the dynamic nature of PPP projects and considers the multifaceted interactions among stakeholders, regulatory frameworks, and economic factors. Several challenges associated with PPPs are examined, including the intricate nature of these partnerships, potential cost overruns, and their social impact.

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Introduction

PPP programs have gained global prominence as a means to advance infrastructure development and improve public service delivery. Numerous countries have adopted PPPs to harness the expertise, resources, and financing capabilities of the private sector. These programs create contractual agreements where the private sector contributes expertise, resources, and funding to develop and manage projects in sectors such as transportation, healthcare, energy, and education. The specifics of PPP programs vary between countries based on local regulations and priorities.

The United Kingdom stands out with its Private Finance Initiative (PFI) and Private Finance 2 (PF2) programs. Australia has undertaken significant projects in transportation, healthcare, and energy sectors through PPPs. Canada has extensively utilized PPPs for infrastructure initiatives, and in the United States, PPP usage varies across states, showcasing notable applications in transportation, water management, and education. Moreover, countries like Brazil, India, South Africa, and China have embraced PPPs to drive diverse infrastructure endeavors. These examples underscore the global recognition and effectiveness of PPPs in addressing infrastructure requirements and delivering public services.

PPPs alleviate fiscal pressure by transferring responsibilities to the private sector. In the UK, PFI and PF2 are the main forms of PPPs. PFI projects involve contracts between public authorities and private entities, while PF2 replaced PFI in 2012. The UK has implemented over 700 projects with a value of £57 billion. In 2018, the government decided to end PFI projects due to complexity and asset management challenges.

This thesis undertakes an extensive examination of the termination of the PFI and PF2 programs in the UK, aiming to address a critical research gap and provide a comprehensive analysis of their long-term social and financial implications. These programs, once lauded for their innovative approach to public-private partnerships, were eventually discontinued, raising substantial concerns regarding their effectiveness and sustainability. Thus, the research presented herein seeks to unravel the underlying dynamics and multifaceted factors that contributed to the decision to discontinue these programs.

To accomplish this research objective, a thorough exploration is conducted utilizing advanced System Dynamics modeling techniques, allowing for an in-depth investigation into the intricate interplay among key elements such as PFI development, societal concerns, public policy, and financial constraints. By adopting this modeling approach, the research uncovers the complex relationships and feedback loops within the PFI and PF2 programs, shedding light on the challenges and dynamics that shaped their eventual termination.

Moreover, this thesis aims to offer valuable insights and actionable recommendations to enhance the outcomes of future infrastructure projects and PPP initiatives. By identifying and analyzing the weaknesses and complexities inherent in the PFI and PF2 programs, it provides a robust foundation for understanding the drivers behind their discontinuation and informs the development of strategies to address these challenges in future endeavors.

The findings of this research significantly contribute to the existing body of knowledge on PPPs and offer a comprehensive understanding of the long-term social and financial implications associated with large-scale infrastructure projects. By unraveling the dynamics and complexities of the PFI and PF2 programs, this thesis equips policymakers, governments, and stakeholders with invaluable insights to improve the design, implementation, and management of PPP initiatives, fostering more efficient and effective outcomes in the future.

In summary, this thesis represents a crucial exploration of the PFI and PF2 programs, providing a comprehensive analysis of their discontinuation and offering insights into the underlying dynamics that influenced their outcomes. By employing System Dynamics modeling and drawing on interdisciplinary perspectives, this research contributes to the existing literature on PPPs, highlighting opportunities for improvement and informing decision-making processes in infrastructure development.

1. Background of the Public-Private Partnerships

Public-Private Partnerships (PPPs) are collaborations between the government and private sector to develop and operate public infrastructure. They bring together resources and expertise to improve efficiency and service quality. Proper planning, legal frameworks, and governance are crucial for successful PPPs.

1.1. PPP Programs

In the context of PPP projects, it can be observed that discussions and analysis can occur at both the project and program levels. At the project level, PPPs involve the collaboration between a public authority and a private sector entity on a specific infrastructure or public service initiative. This partnership allows for the joint undertaking of project development, financing, operation, and maintenance, with shared responsibilities and resources.

Public-private partnerships (PPPs) are a project delivery model that involves collaboration between the public and private sectors, leveraging private sector efficiency and reducing the financial burden on the public sector. The World Bank website defines a PPP as *"a long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance"*. They are employed to optimize the economic value generated by infrastructure projects. PPP agreements are utilized when traditional procurements are scarce, and they can be a tool for fostering innovation, entrepreneurship, and economic growth, leading to increased GDP and employment (IRES, 2018). This cooperative framework encompasses diverse public sector initiatives within the infrastructure domain (Cui et al., 2018). Moreover, PPPs aim to optimize the goals of all parties involved by leveraging resources and management knowledge through collaborative and innovative approaches. The synergy created through these partnerships allows for the attainment of outcomes that would be difficult to achieve independently (Jomo & Chowdhury, 2009). PPPs are selected for their advantages, including off-balance sheet financing, risk transfer to the private sector, and improved efficiency in infrastructure development and management. These benefits drive their adoption as a way to leverage private sector resources and expertise for public infrastructure projects (McQuaid & Scherrer, 2010).

On the other hand, at the program level, PPPs encompass a broader framework that includes multiple projects or initiatives within a specific sector or jurisdiction. These program-level PPPs involve strategic planning, coordination, and oversight to ensure the successful implementation of PPP projects on a larger scale.

PPP programs aim to maximize value for money by leveraging private sector expertise and resources to deliver efficient and effective public infrastructure projects. The agreement encompasses the expenses related to design, finance, build, and management (Castelblanco & Guevara, 2022). Additionally, the private sector entity assumes responsibility for handling project risks, including potential delays or cost overruns. In exchange, the government provides the private sector company with periodic payments throughout the duration of the contract.

Since the 1980s, Public-Private Partnerships (PPPs) have gained significant popularity and have been widely adopted globally. PPPs have emerged as a procurement mechanism to alleviate fiscal pressure on the public sector while transferring responsibilities to the private sector. PPPs provide an opportunity for the private sector to participate in all stages of public sector projects, from financing to maintenance (Lakshmanan, 2008). They entail contracts between public authorities and private sectors, wherein the private sector assumes responsibility for designing, financing, building, and managing various public services such as healthcare, education, and transportation (Froud, 2003). These contracts typically span 25 to 30 years (HM Treasury, 2020).

PPPs benefit both the public and private sectors. The public sector gains reduced risk, cost-effectiveness, improved services, and faster project completion. PPPs also optimize public capital investment by combining public and private funds. The private sector benefits from implementing innovative solutions, accessing long-term investment opportunities, and leveraging their capabilities for operational efficiencies. PPPs foster collaboration and mutually beneficial outcomes for both sectors (Oktavianus et al., 2018).

PPPs are essential in Europe for addressing infrastructure needs, promoting efficiency, and driving economic growth. By partnering with the private sector, governments can access funding, expertise, and innovative solutions. PPPs distribute risks, create jobs, and foster regional development. Successful examples in countries like France, and Germany highlight the benefits of PPPs. Transparency, rigorous procurement, and risk management are important for ensuring value for money and public trust. PPPs are crucial for Europe's development and success.

In Europe, the significance of public-private partnerships continues to grow. The Fig. 1 presents the total number and the value of PPP projects done in Europe from 1990 till 2021. As it can be seen, the peak of the projects have been reached in 2006. Although after 2006 the PPP projects have decreased a bit; they are still quite popular and numerous in terms of number of the projects and in its value.

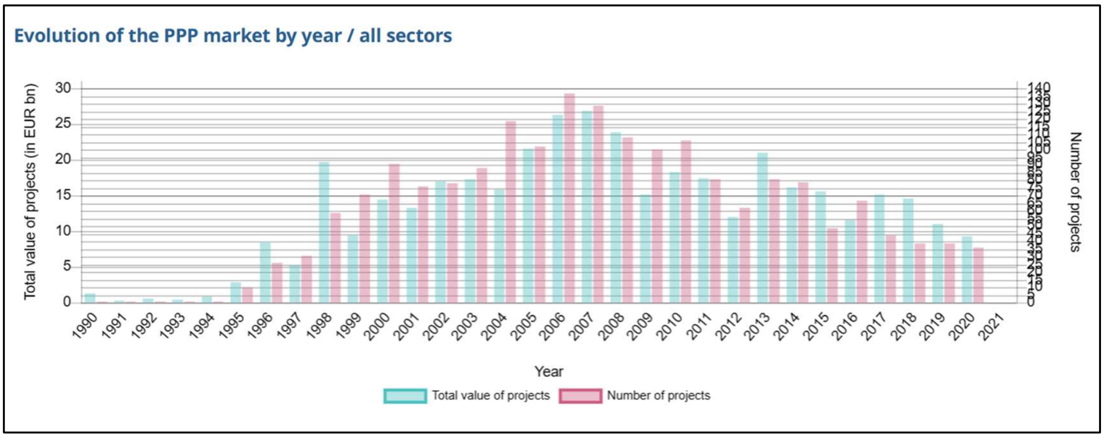

FIGURE 1 PPP PROJECTS IN EUROPE
(SOURCE: HTTPS://DATA.EIB.ORG/EPEC/SECTOR/ALL)

The Fig. 2 demonstrates the total value of European PPP projects with the division to the sectors. The Transport sector is on the first place in terms of value of the projects, with more around 225 bln EUR.

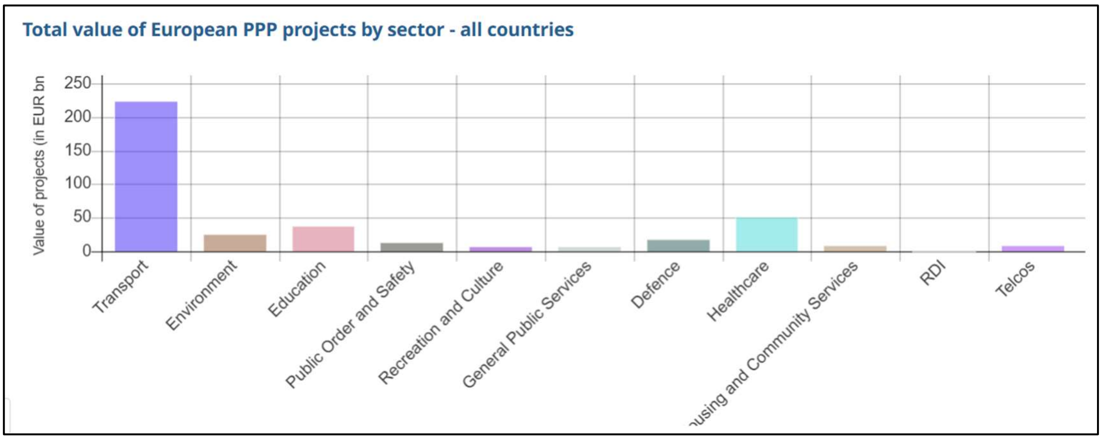

FIGURE 2 TOTAL VALUE OF EUROPEAN PPP PROJECTS BY SECTOR
(SOURCE: HTTPS://DATA.EIB.ORG/EPEC/SECTOR/ALL)

The Fig. 3. demonstrates the number of European PPP projects by sector. As already mentioned, on the first place, also in case of number of PPP projects is the sector of Transport. The lowest number of the PPP projects in the RDI (Research, Development, and Innovation) sector, as there are just 2.

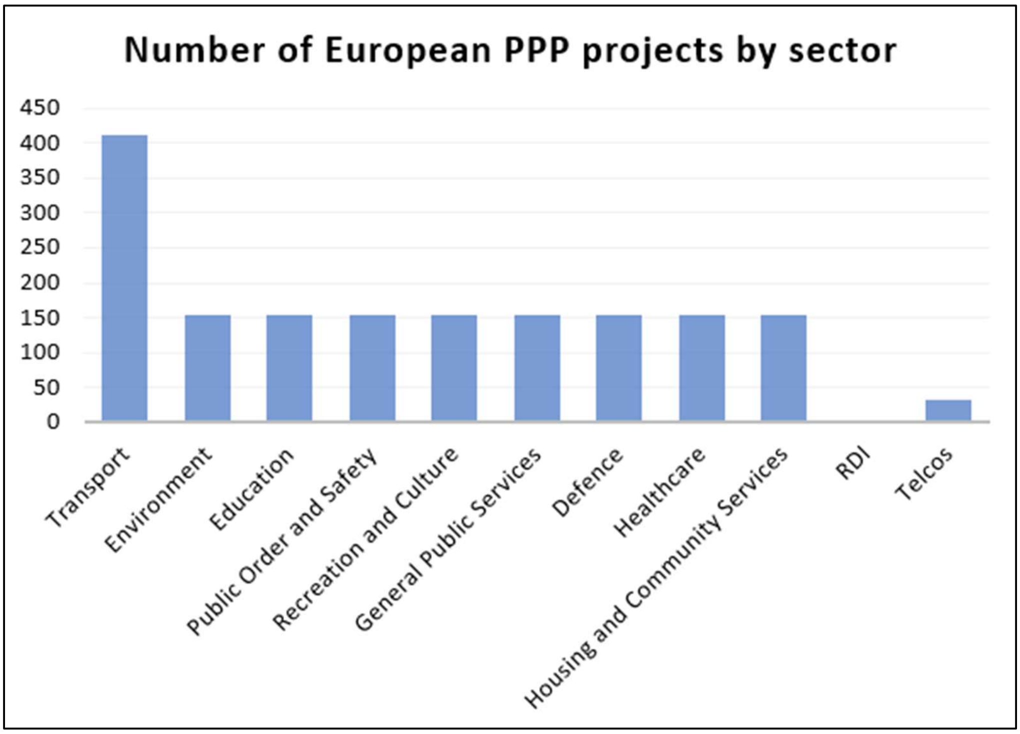

FIGURE 3 NUMBER OF EUROPEAN PPP PROJECTS BY SECTOR
(SOURCE: HTTPS://DATA.EIB.ORG/EPEC/SECTOR/ALL)

The total number of projects in the Europe is 1799, which value equals to 368.3 EUR bln.

1.2. Types of PPP models

PPP contracts vary based on project type, risk transfer, investment level, and desired outcomes. They are customized to suit the specific characteristics and goals of each partnership, ensuring effective risk allocation and responsibility sharing between the public and private sectors. The choice of contract type depends on factors such as project nature, level of private sector participation, and ownership and operational transfers.

Types of PPP models encompass:

a) *Build-Operate-Transfer (BOT)* - private companies are contracted by the government to design, finance, construct, and operate public projects. The key reasons for using BOT contracts include mobilizing private sector capital for infrastructure, attracting foreign investments, transferring technology and knowledge, and ensuring efficient project management and operation (Damyar & Dashtaki, 2017). After the concession period, the ownership and operation are transferred back to the public sector;
b) *Build-Own-Operate (BOO)* – this kind of projects are the resemble facility privatization as they typically do not entail transferring ownership to the host government. When a BOO concession agreement reaches its end, there is potential for renegotiating the original agreement to extend the concession period (Glory K. Jonga, 2021);
c) *Build-Own-Operate-Transfer (BOOT)* - in this arrangement, a concession company designs, finances, operates, and maintains a facility. Ownership of the facility remains with the concessionaire during the concession period, and it is transferred to the government at the end without any additional cost (Darrin Grimsey & Mervyn K. Lewis, 2004);
d) *Build-Transfer-Operate (BTO)* - the concessionaire builds infrastructure, transfers ownership to the government, and gains the right to operate the facilities for a defined period. BTO agreements are usually funded through user fees, enabling the private sector to recoup construction and operational expenses (Lee et al., 2022);
e) *Design-Build-Finance-Operate (DBFO)* - the private sector takes on the design, construction, financing, and operation of the project, assuming full responsibility. In return, the private entity has the opportunity to recoup its investment through user fees or payments received from the public sector. This arrangement allows for a shared risk and reward between the private and public entities involved;

f) *Design-Build-Operate (DBO)* - the private entity is responsible for operating and maintaining the asset. They collaborate with the public partner on utilizing a managed capital investment fund. The contract involves a single contractor handling design, construction, and management, with the public client providing the funding;
g) *Build-Lease-Transfer (BLT)* - private sector investors assume the responsibility of financing, designing, and constructing a facility while retaining legal ownership for a predetermined duration;
h) *Build-Lease-Maintain-Transfer (BLMT)* - an SPV/private partner finances, builds, and maintains a public facility, which is later rented to the government. At the end of the concession period, the facility is transferred to the government (Ahmad et al., 2018);
i) *Design-Construct-Maintain-Finance (DCMF)* - the private entity constructs a structure based on public specifications and returns it. Contractors adhere to Public Administration requirements under the DCMF. The completed work is then leased to the client, and ownership may not be transferred to the public entity;
j) *Operation & Maintenance (O&M)* - a private entity manages and upkeeps a public infrastructure in PPP projects. The contract establishes service standards, duration, and responsibilities. The entity conducts inspections, repairs, and ensures compliance, while sharing risks and enabling innovation;
k) *Service Contract* - the government engages a private entity to deliver services that were previously handled by the government (Deloitte, 2006);
l) *Management Contract* - in contrast to a service contract, a management contract entails the private entity assuming full responsibility for all operational and maintenance aspects of the facility specified in the agreement (Deloitte, 2006).

1.3. PFI programs in the UK

The United Kingdom is recognized as a country that has extensively embraced Public-Private Partnerships (PPPs). Between 1992 and 2018, over 700 projects were procured under two types of PPP programs. PFI projects in the UK involve long-term contracts, typically lasting 20 to 30 years or more, outlining the responsibilities of the private sector consortium in delivering and maintaining infrastructure services. The key principles of the PFI involve procuring services instead of assets, ensuring value for money, collaborative risk management, leveraging private sector expertise, and integrating life cycle costing in infrastructure projects (Mustafa Alshawi, 2009). During the procurement process of the PFI, the public sector forms a project team and develops a business case or proposal. This documentation clearly outlines the functional aspects as well as the performance or output requirements for the project (Deloitte, 2006).

PFI projects typically involve 13 stages, encompassing activities ranging from needs assessment to handover and involving various stakeholders such as financial advisors, funding suppliers, legal advisors, construction experts, and facilities managers (Carrillo et al., 2008).

It is also said that the utilization of private financing for public services has resulted in several advantages such as enhanced clarity in objectives, innovative ideas, improved planning, and the introduction of competition through wider tendering. However, it has also led to increased focus from top management, higher expenditures on consultancy and legal fees, as well as the inclusion of risk premiums (Spackman, 2002).

PFI projects emphasize the importance of considering the entire lifecycle of an asset, including construction, maintenance, and operational costs, rather than just the initial construction expenses. This lifecycle costing approach aims to ensure that the asset is built to last and can be effectively maintained throughout its operational life.

1.3.1. History and evolution of PFI programs

The government introduced the PFI in 1992 and expanded under the Blair government to encourage private sector participation in providing public infrastructure and services through competitive tendering. PFI operates as a procurement method where the private sector finances, constructs, and operates infrastructure projects while delivering long-term services and facilities management under concession agreements (Practical Law, 2023).

In the UK, two primary forms of Public-Private Partnerships (PPPs) have been extensively implemented: Private Finance Initiative (PFI) and Private Finance 2 (PF2). PFI, introduced in 1992 (Hodges & Mellett, 2012), aimed to foster collaboration between the public and private sectors, allowing the public sector to benefit from private sector expertise in project management (Villalba-Romero & Liyanage, 2016). PF2 was later introduced in 2012 as a successor to PFI, addressing concerns about its cost-effectiveness (HMT, 2016).

The global financial crisis in 2007 affected PFI as private capital sources dried up, leading the government to provide funding directly.

The National Infrastructure Strategy, published in November 2020, reaffirmed the decision not to reintroduce PFI or PF2 for future project procurement and financing. However, the government continues to make substantial annual payments of nearly £10 billion on existing PFI, PF2, and related contracts entered into by previous administrations. To ensure effective contract management, the government is actively reviewing these agreements and supporting authorities in reclaiming PFI assets as contracts expire (Practical Law, 2023).

PFI differs from conventional procurement as it lies under the definition of PPP. Consequently, this project delivery focuses on paying for services delivered rather than the construction of assets. This approach reduces the government's risk of receiving an inappropriate asset for the service requirement. If the asset cannot be utilized to provide the required service, the government is not obligated to pay for it through service charges (UK parliament, 2008).

On the other hand, there are also some challenges when dealing with PFI programs. Challenges in PFI projects involve high bidding costs, lengthy tendering procedures, partnership complexities, lack of experience, skills, and increased workload for the private sector (Zhou & Lowe, 2003). The NHS has been significantly impacted by PFI, with high costs leading to service cuts and job losses. PFI companies have made substantial profits, while staff face worsened employment conditions.

Critics of the UK's PFI raise concerns about the complexity of projects, lack of accountability, and increased workload on staff. Waste is evident in unused facilities and expensive, for example in underutilized hospitals (Wikipedia, 2023).

PFI served as a financial mechanism for acquiring private finance while minimizing public borrowing, ensuring contracts for construction firms, and creating investment opportunities for finance capital (Grout & Stevens, 2003). By March 2018, the UK had undertaken a substantial number of PFI and PF2 projects, totaling 704 with an estimated capital value of £57 billion. The projected payment for these projects over a 30-year period amounted to £188.35 billion (HM Treasury, 2020).

1.3.2. Overview of the PFI in the UK

PFI emerged as a modern public procurement system in the 1990s and has since experienced a remarkable expansion and development, particularly in the last ten years. This approach to financing public projects has gained significant momentum and undergone notable transformations in recent times (Zhou et al., 2005).

PFI projects in the UK faced criticism for their alleged transfer of excessive risk to the public sector, leading to concerns about poor value for money, lack of transparency, and accountability. Evaluating the effectiveness of these projects, which are often complex and long-term in nature, can be a challenging task.

The UK has been at the forefront of PPP initiatives, undertaking a significant number of projects. While PPPs primarily focus on investing in transportation infrastructure, they also encompass schools and hospitals in certain countries (Engel et al., 2020).

PFI projects in the UK have covered a wide range of sectors, including transportation, healthcare, education, defense, waste management, and more. They have involved the construction, renovation, operation, and maintenance of various types of infrastructure assets. Figure 4 presents the overview of the projects carried out in the UK according to the date and Figure 5 represents that Projects in the UK by sector, where it can be noticed that the biggest amount of PFI projects has been implemented for schools and on the second place are projects for the hospitals and acute health. On the Figure 6 is represented the division of the PFI projects in the UK by regions. It is clearly visible that the biggest number of the PFI projects has been done in the England. The reasons, why in this region can be observed the highest number of PFI projects can be several, such as: government promotion, centralized decision-making, higher population and urban concentration, economic strength, or political support.

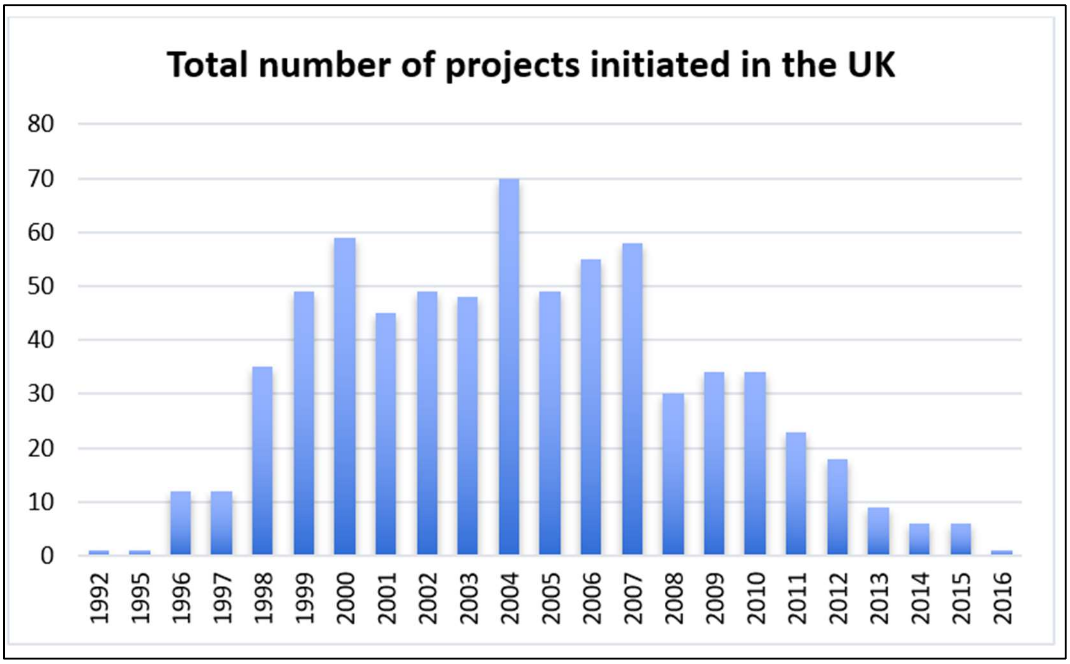

FIGURE 4 TOTAL NUMBER OF PROJECTS INITIATED IN THE UK
(DATA SOURCE: UK HOME OFFICE)

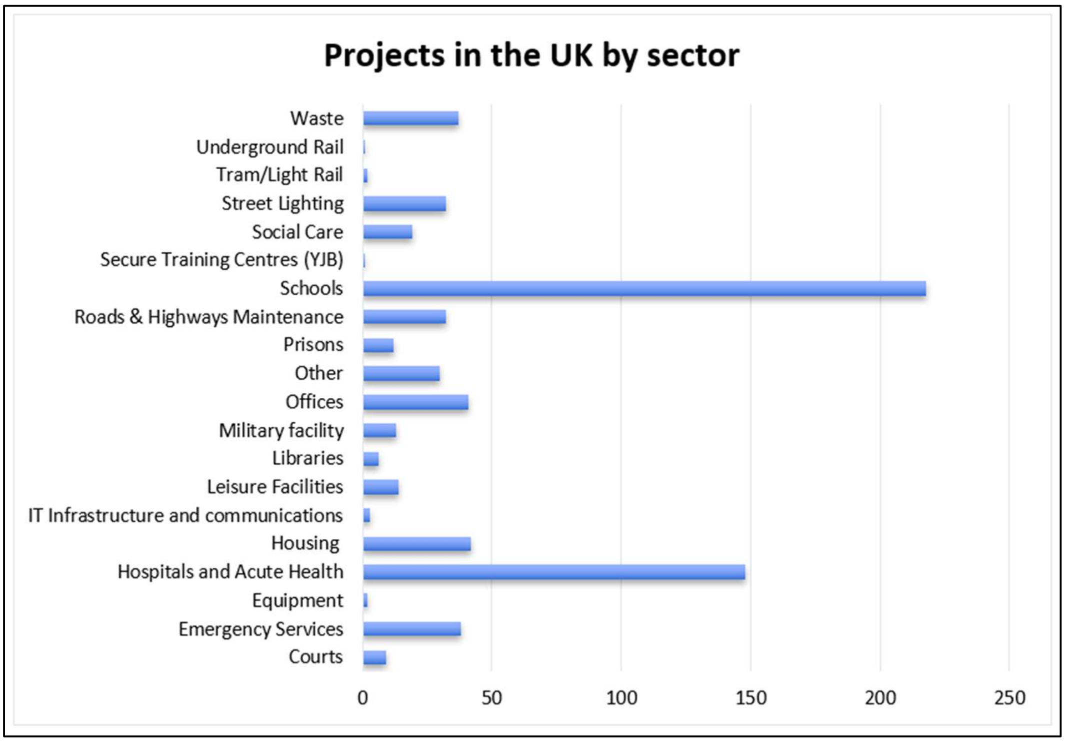

FIGURE 5 PROJECTS IN THE UK BY SECTOR
(DATA SOURCE: UK HOME OFFICE)

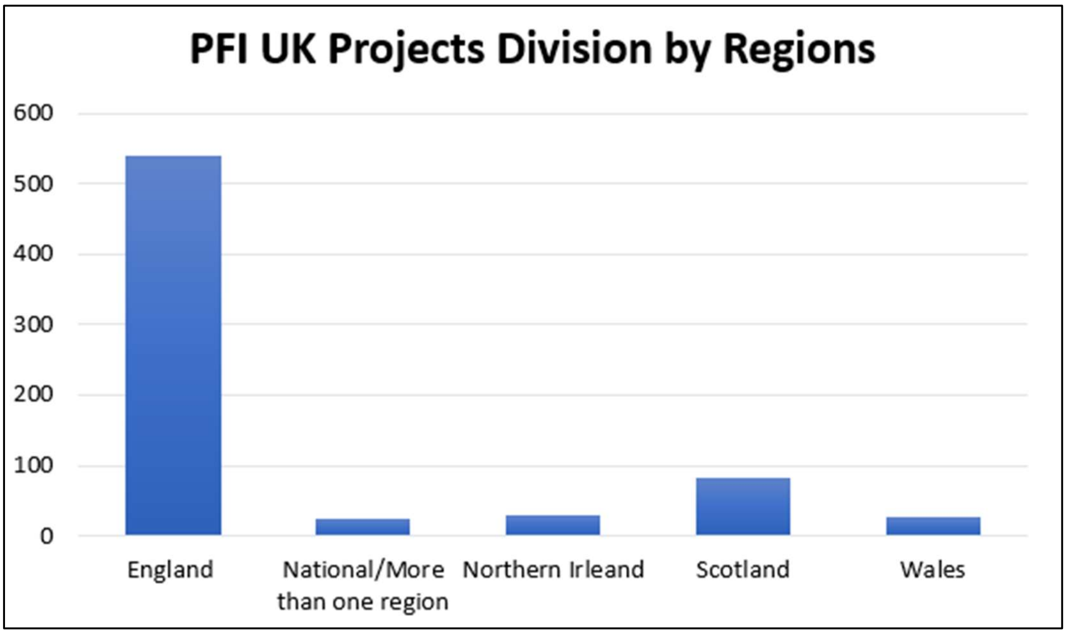

FIGURE 6 PFI UK PROJECTS DIVISION BY REGIONS
(SOURCE: UK HOME OFFICE)

1.3.2.1. Benefits of the PFI

Most PFI projects are often claimed to offer two primary advantages: value for money and the transfer of risk from the public sector to private organizations (Zhou & Lowe, 2003).

PFI offers benefits by transferring risks to the private sector and allocating them to the party best equipped to manage them. This approach helps ensure cost control, timely delivery, adherence to quality standards, efficient operation, and mitigation of various risks associated with the project (UK parliament, 2008). Moreover, PFI enables the UK government to deliver new infrastructure and services with minimal upfront capital expenditure and investment (Zhou & Lowe, 2003).

PFI projects offer benefits such as, lower project costs, and accelerated project implementation. They leverage the strengths of both the public and private sectors, enhancing efficiency and value for money (Glory K. Jonga, 2021).

1.3.2.2. Risks of the PFI

Effective utilization of PFI to achieve value for money necessitates the inclusion of risk transfer as an integral component. This strategic transfer of risks between the public and private sectors is essential for optimizing project outcomes and maximizing the benefits derived from such collaborations.

There are two main categories of risks in PFI projects: internal risks and external risks.

Internal risks encompass the risks involved in the project's design, construction, and operation, which can be transferred from the public sector to the private sector. This allows the private sector to assume responsibility and manage these risks effectively. The examples of this kind of risk are design and construction, commissioning and operating, technology and obsolescence, finance and funding (Zhou & Lowe, 2003).

External risks, on the other hand, are more difficult to control and predict, making them challenging for the private sector to manage. These risks may arise from external factors beyond the control of the project stakeholders. Among these risks it can be found development, market, revenue, force majeure, affordability and political such as tax or regulations (Zhou & Lowe, 2003).

There can be also distinguished the interface risk in PFI projects which refers to the potential challenges in managing activities between the public and private sectors, particularly during the contractor-to-operator transition. Mishandling this process can adversely affect the project, SPV, and service delivery, impacting payment arrangements (Zhou & Lowe, 2003).

Lastly, the environmental risk involves factors such as climate change, pollution, and waste management. These risks, though potentially insignificant in conventional procurement, can have lasting impacts on PFI projects spanning 25-30 years (Zhou & Lowe, 2003).

What is more, it has been also found that PFI projects entail risks such as moral hazard, adverse selection, and knowledge asymmetry. These risks involve the agent's potential divergence from the principal's interests, unsuitable agent selection, and the private sector's superior knowledge compared to the government entity (Glory K. Jonga, 2021).

A PPP/PFI project typically involves three distinct stages, namely planning, procurement, and contract management, each of which carries its own set of risks and challenges. To effectively identify risks in PPP/PFI projects and ensure a shared understanding among stakeholders, one approach is to develop a risk checklist or catalogue. This tool helps capture potential risks and provides a systematic method for risk identification. Furthermore, categorizing project risks is essential for stakeholders to gain a clear understanding of the different types of risks involved in the PPP/PFI project (Bing et al., 2005).

Li (Li, 2003) has distinguished three levels of risks, which are reported on the Table 1.

TABLE 1 DIFFERENT LEVELS OF RISK

Type of risk	Description
macro	involves external factors beyond the project's control, such as political, legal, economic, social, and environmental conditions, which can impact the project and its outcomes
meso	involves risks occurring within the project boundaries, including issues related to project demand, location, design, construction, and technology
micro	involves stakeholder relationship risks in PPP/PFI projects stem from differing objectives of the public and private sectors, driven by social responsibility versus profit motives

According to the study conducted by Bing, Akintoye, Edwards and Hardcastle (Bing et al., 2005) the public sector should manage risks like nationalization/expropriation, poor political decision-making, political opposition, site availability, and government stability. Risks related to tax regulation, design changes, inflation, and private sector involvement are better suited for the private sector.

Project finance, construction, operation, and organizational risks primarily fall under the responsibility of the private sector. Certain risks, such as force majeure, legislation change, partnership commitment, and risk distribution, require shared responsibility between both sectors.

1.4. Previous research of PFI with the use of SD

The SD methodology is widely used to evaluate PPP/PFI/PF2 projects. It allows stakeholders to model long-term financial dynamics, assess risks, and analyze project performance. SD incorporates uncertainties and helps in designing robust contractual arrangements. It enables better decision-making and improves project outcomes.

For instance, research that has utilized SD to assess financial and social management strategies within national PPP programs (Pagoni & Patroklos, 2019) and to improve demand forecasting efficiency in PPP projects (Oloruntobi Dada, 2013). Furthermore, SD has been utilized to analyze the impacts of different financing strategies on creditors, the government, and private investors, aiding public authorities in selecting the most suitable financing approach for PPP projects (Zhang et al., 2020). SD modeling has been also used to analyze and develop a concession pricing model for PPP highway projects and this model provided an automated pricing mechanism that considers various parameters and uncertainties (Xu et al., 2012). SD has been used to analyze the evolutionary process in Chinese PPP projects for new energy power construction. The study reveals periodic behavior, convergence, and cost reduction through dynamic punishment measures (Gao & Zhao, 2018). Another study that used system dynamics modeling to enhance decision-making in PPP projects and analyzed the interdependencies among socio-economic concession variables and their impact on PPP effectiveness (Alghamdi et al., 2022). There has been also examined the use of public-private PPP in developing countries for social infrastructure projects and the model has been established to analyze participant strategies and suggests policy implications for ensuring sustainable development in PPP projects (Liu et al., 2021). Moreover, another research paper suggests using a System Dynamics approach to model project finance and risks in toll road projects and it highlights the limitations of traditional methods and concludes that System Dynamics is effective for analyzing project finance and risks (Lukas B. Sihombing, 2017). Another study utilizes SD and its capabilities to model sustainability management in global industrial firms, identifying key variables that contribute to capability growth in sustainability management to fill empirical gaps and explores DC-driven sustainability management using SD in global south countries (Bayu et al., 2022).

2. Methodology

The chosen methodology for this thesis is System Dynamics, a powerful and well-suited approach for analyzing the complex and dynamic nature of PFI projects.

SD provides a unique capability to capture the interdependencies, feedback mechanisms, and long-term dynamics within the research subject. It serves as an effective tool for simulating scenarios and making informed decisions to enhance project outcomes. By employing SD, this study aims to delve deep into the intricate interconnections and feedback mechanisms that shape the behavior and outcomes of the PFI projects over time. The application of this methodology allows for a comprehensive understanding of the subject, resulting in significant contributions to the knowledge within the field and providing valuable insights. Throughout the research process, special attention will be given to resource management to ensure optimal utilization. SD methodology serves not only as a means of analysis but also as a powerful learning tool for decision-makers.

Its qualitative approach, through the use of Causal Loop Diagrams (CLD), complements the quantitative benefits of Stock and Flow (S&F) models, enabling a holistic perspective. Moreover, the potential to model delays within the system further enhances the accuracy and effectiveness of the analysis.

By combining the qualitative and quantitative aspects of SD, the insights gained from the analysis will empower decision-makers to make more informed choices, optimize resource allocation, and improve the overall effectiveness and sustainability of PFI projects.

2.1. System Dynamics approach

The methodology used in this study is SD, which was introduced by Forrester, who was an engineer and professor at Massachusetts Institute of Technology, and took place in the 1960s as a modelling and simulation methodology for dynamic management problems (Sterman, 2000). During the 1960s and 1970s, SD gained recognition and popularity as a tool for understanding and managing complex systems and it was used extensively in research and policy analysis, particularly in the fields of management, economics, and environmental studies. It combines qualitative and quantitative approaches to studying complex systems and relations within them.

SD model consists of CLD that establish the qualitative relationships and cycles between variables that later are transformed into equations in the S&F Diagram (Sterman, 2000) chosen for this thesis is system dynamics, which enables the analysis and model. Moreover, SD models can incorporate detailed data, visualize dynamic behavior, and support policy analysis and decision-making.

SD models are useful tools in management sciences for assessing system adaptability, testing decisions, and optimizing policies. They provide simplified representations based on the analyst's understanding and assumptions about expected behavior. While social systems are complex and present challenges in finding reliable indicators, S&F has successfully developed models for such systems (Grobbelaar & Buys, 2005).

The study on PFI Programs in the UK utilized SD as the methodology. The steps followed included:

1. Problem definition
2. Data collection
3. Model development
4. Validation
5. Scenario analysis
6. Interpretation of the results

These steps enabled a comprehensive analysis of the dynamics, social implications, and financial outcomes of PFI Programs, providing valuable insights for policy decision-making.

2.1.1. Causal Loop Diagrams

CLD are graphical representations that depict the causal structures within a system, where variables are connected by arrows to indicate their links (Delgado-Maciel et al., 2018) (see Fig. 7). Concept of feedback loops, capture the dynamic interactions between variables in a system and allows stakeholders to grasp the fundamental structure and feedback dynamics of a system, fostering a shared understanding of complex issues. CLDs can aid in scenario analysis and policy testing.

By modifying variables or relationships in the CLD, it can be explored the potential consequences of different decisions or interventions and in result, this helps inform evidence-based decision-making and reduces the risk of unintended consequences. Another advantage of the CLD is that fact that they are without limitations as they rely on subjective judgments and assumptions, and their accuracy is contingent on the quality of data and understanding of the system.

The relationships between variables can be either positive (denoted by "+") or negative (denoted by "-"), reflecting their influences on each other (Delgado-Maciel et al., 2018) which capture the dynamic interactions between variables in a system. Positive loops show a reinforcing relationship, where an increase in one variable leads to an increase in another, while negative loops depict a balancing relationship, where changes in one variable trigger counteracting changes in another, maintaining equilibrium or stability.

CLDs consist of two types of loops: reinforcing loops that amplify a behavior, and balancing loops that counteract the effects of a change (Hördur V. Haraldsson, 2004). These CLDs provide insights into the causal dynamics and interdependencies within the system under study (Hördur V. Haraldsson, 2004). An example of both reinforcing and balancing feedback loops are depicted in Figure 8.

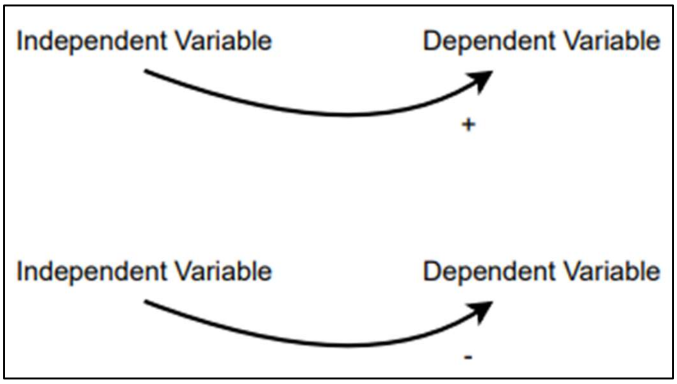

FIGURE 7 THE CAUSAL LINK

(SOURCE: OWN WORK)

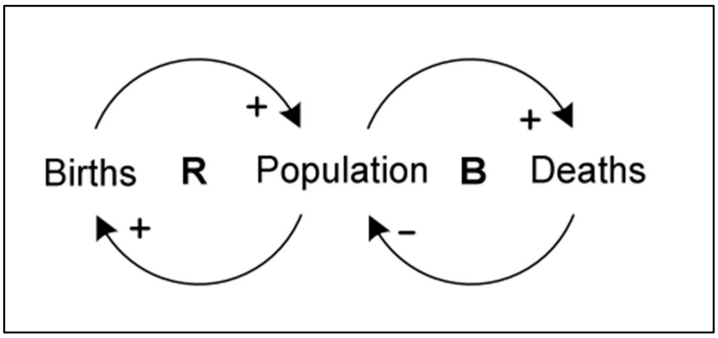

FIGURE 8 EXAMPLE OF REINFORCING AND BALANCING FEEDBACK LOOPS

(SOURCE: HARALDSSON, 2004)

To truly understand a system's behavior, it's important to go beyond feedback and circular causality. The key lies in recognizing the significance of active structure and loop dominance. Systems often exhibit dynamic behavior that evolves over time. For instance, an initial emphasis on reinforcing loops may give way to the growing influence of balancing loops, leading to changes in system behavior. As complexity increases, it can be anticipated multiple shifts in loop dominance.

Causal loop diagrams uncover system dynamics, aid decision-making, and promote understanding. They visualize feedback effects, anticipate outcomes, and identify leverage points.

2.1.2. Stock and Flow diagrams

S&F diagrams offer a higher level of complexity in comparison to causal-loop diagrams, requiring modelers to engage in detailed system analysis and think with increased specificity (Albin, 1997).

They comprise four fundamental components: stocks, flows, auxiliary variables, and connectors (Cagliano et al., 2015; Zenezini & De Marco, 2020) (see Fig. 9):

- **stocks** represent accumulations that can be observed and quantified, such as population, or intangible and abstract, such as levels of fear or reputation; they are quantitatively modeled as integrals, accumulating the quantities provided by inflows and outflows;

- **flows** represent the dynamic changes in stocks, quantified as rates and measured in units of the stock over time; they demonstrate how stocks evolve and can be observed through various examples such as birth rate, death rate, or shipping rate;
- **auxiliary variables** can remain constant over time or undergo changes;
- **connectors**, the final component, depict the relationships between all other components and can exert either positive or negative influence on the system (Albin, 1997; Cagliano et al., 2015; Zenezini & De Marco, 2020).

Another author identifies the components of stock and flow diagram as that the initial stock, "Input Waiting to be Processed," accumulates entities. It is represented by a rectangle and its value reflects its size at a specific time. Flows, shown as arrows with valves, can be inflows or outflows, influencing the stock positively or negatively. The assigned flow value signifies the rate of change of the stock over time, such as processed input items per hour. (Itälä & Helenius, 2013).

S&F diagrams serve as effective tools for simulating the temporal behavior of a model. These diagrams capture the dynamic interplay between stocks and flows, wherein flows are influenced by the levels of stocks and other pertinent factors. This interdependence gives rise to feedback loops that can introduce non-linear behavior, making the overall process more complex and nuanced (Itälä & Helenius, 2013).

A key feature of S&F Diagrams is their integration of the time dimension. By explicitly considering the accumulation and flow of stocks over time, these diagrams capture the temporal behavior of systems. They are valuable tools for decision support and policy analysis. By simulating different scenarios and policies within the diagram, it can be explored the potential impacts of different interventions or strategies. This enables policymakers to make informed decisions, evaluate the long-term consequences of their choices, and design effective policies that consider the dynamics of the system.

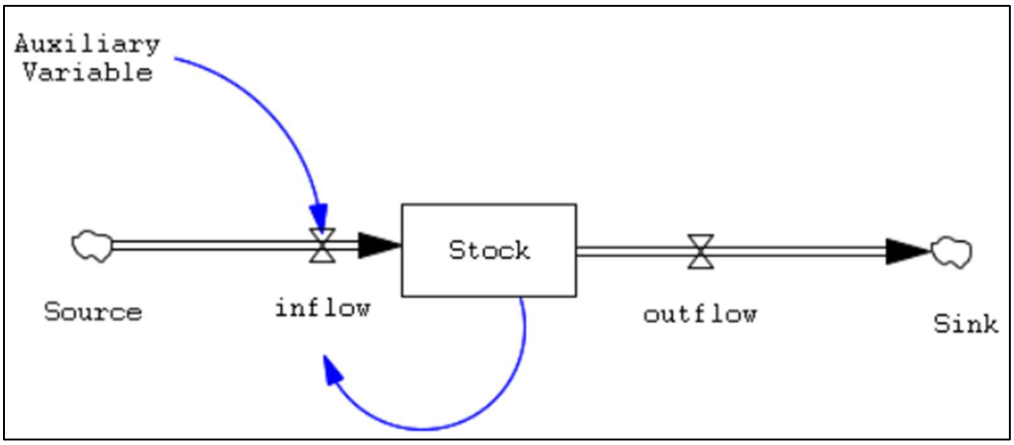

FIGURE 9 STOCK AND FLOWS

(SOURCE: OWN WORK)

2.2. System Dynamics for the PFI research

This section utilizes SD to analyze PFI and assess its financial impacts and risks. The modeling approach enhances understanding and supports decision-making for more sustainable infrastructure development in PPPs.

2.2.1. Problem definition

This thesis fills a significant knowledge gap by delving into the complexities and issues associated with PFI in the UK, specifically focusing on the closure of PFI projects.

By conducting an in-depth academic investigation, this study aims to offer a comprehensive understanding of the implications arising from PFI programs and uncover the underlying factors contributing to their eventual closure and the implications.

2.2.2. Data collection

The data used this thesis has been retrieved from the UK Home Office in the form of the Excel file which shows the current information available as for the date 31.03.2018 with the details of the projects such as: project name, department, procuring authority, sector, region, project status, date of OJEU, date of preferred bidder, date of financial close, date of construction completion, first date of operations, operational period of contract (years), amount of unitary charges, capital value, the list of equity holders and the name of SPV company.

Unique HMT Project I	Project Name	Department	Procuring Authority	Sector	Region	Project Stat	Date of OJEU	Date of prefe bidder
5	RRS Ernest Shackleton	Department for Business, Energy and	UK Research and Innovation	Other	National/More than one region	In Operation	12/1/1997	8/1/1999
7	Two Schools Project (Jo Richardson Community School and Eastbury Community Sc	Department for Education	Barking and Dagenham	Schools (Non-BSF)	England London	In Operation	5/23/2002	10/1/200
8	Barnsley Schools PFI	Department for Education	Barnsley	Schools (Non-BSF)	England Yorkshire and the Humber	In Operation	5/1/2003	5/4/2004
9	Mid-Bedfordshire Upper Schools Project	Department for Education	Central Bedfordshire	Schools (Non-BSF)	England East	In Operation	9/1/2001	9/2/2001
10	Birmingham Group Schools 1	Department for Education	Birmingham	Schools (Non-BSF)	England West Midlands	In Operation	4/4/1997	4/5/1997
11	Birmingham Group Schools 2	Department for Education	Birmingham	Schools (Non-BSF)	England West Midlands	In Operation	7/7/2003	7/8/2003
12	Castle Hill Primary School	Department for Education	Bolton	Schools (Non-BSF)	England North West	In Operation	3/26/1998	3/27/199
13	Hadley Learning Centre and Jigsaw Project PFI	Department for Education	Telford and Wrekin	Schools (Non-BSF)	England West Midlands	In Operation	6/16/2003	Data not prov
14	Bristol BSF	Department for Education	Bristol	Schools (BSF)	England South West	In Operation	11/1/2004	Data not prov
15	Brighton & Hove Group Schools Project	Department for Education	Brighton and Hove	Schools (Non-BSF)	England South East	In Operation	8/14/2000	8/15/200
16	Bristol Group Schools Project (Phase 1A)	Department for Education	Bristol	Schools (Non-BSF)	England South West	In Operation	9/11/2002	Data not prov
17	Bradford BSF - Phase 1	Department for Education	Bradford	Schools (BSF)	England Yorkshire and the Humber	In Operation	9/1/2004	9/1/2005
18	London Borough of Tower Hamlets - Group Schools Project	Department for Education	Tower Hamlets	Schools (Non-BSF)	England London	In Operation	9/25/1998	Data not prov
19	Ellesmere Port & NestOn Schools Project	Department for Education	Cheshire West and Chester	Schools (Non-BSF)	England North West	In Operation	1/1/2001	1/2/2001
20	City of York Council - Four Schools Project	Department for Education	York	Schools (Non-BSF)	England Yorkshire and the Humber	In Operation	1/1/2003	Data not prov
21	Cornwall County Council - Grouped Schools II PFI Project	Department for Education	Cornwall	Schools (Non-BSF)	England South West	In Operation	9/2/2002	9/25/200
23	Caludon Castle School PFI Project	Department for Education	Coventry	Schools (Non-BSF)	England West Midlands	In Operation	10/25/2002	2/17/200
24	Darlington Five Schools Project	Department for Education	Darlington	Schools (Non-BSF)	England North East	In Operation	1/31/2003	Data not prov
25	Derby - Grouped Schools Project	Department for Education	Derby	Schools (Non-BSF)	England East Midlands	In Operation	4/10/2003	4/27/200
26	Chapel-en-le-Frith and Tupton Hall SecOndary Schools	Department for Education	Derbyshire	Schools (Non-BSF)	England East Midlands	In Operation	5/26/2000	Data not prov
27	Derbyshire County Council - RecOnfiguratiOn of Long Eaton & Newbold Schools	Department for Education	Derbyshire	Schools (Non-BSF)	England East Midlands	In Operation	5/26/2000	Data not prov
28	Devon County Council - Exeter Group Schools PFI Project	Department for Education	Devon	Schools (Non-BSF)	England South West	In Operation	9/11/2002	9/12/200
29	Doncaster Schools PFI Project - Edlington and Mexborough	Department for Education	Doncaster	Schools (Non-BSF)	England Yorkshire and the Humber	In Operation	9/27/2005	Data not prov
30	Sir John Colfox County SecOndary School	Department for Education	Dorset	Schools (Non-BSF)	England South West	In Operation	7/1/1996	7/2/1996

Current projects 2018

FIGURE 10 DATA RETRIEVED FROM THE UK HOME OFFICE

2.3. Model Development

The model has been development in the VENSIM® software. VENSIM® has been chosen for model development due to its recognized capabilities and suitability for System Dynamics modeling. With VENSIM®, it can be accurately represented causal relationships, explored system behavior over time, and scenario testing. The reason why this software has been chosen is also the fact that it has received the highest value for the user friendly and learning curve scores (Sapiri et al., 2017).

System dynamics is centered around the interdependencies among quantities and flows within a system, with feedback loops being crucial in influencing system behavior. By utilizing VENSIM® software, two notable benefits are obtained:

- firstly, it simplifies the recognition of cause-and-effect relationships, leading to an improved comprehension of system dynamics;
- secondly, it empowers researchers to examine and adjust parameters or structures to enhance system behavior.

These advantages render Vensim software invaluable in investigating and optimizing system performance (Shahsavari-Pour et al., 2023).

3. System Dynamics modelling

Following the introduction of the SD methodology and the overview of PFI projects in the UK, this chapter focuses on utilizing the SD approach to model PFI projects. It explores the application of SD in analyzing the dynamics and complexities of PFI projects.

3.1. The Causal Loop Diagram

Figure 11, a CLD, serves as a valuable tool for gaining insights into the complex causal structures within the system and their profound influence on the long-term financial implications of PPPs on both the government and society.

This illustrative diagram encompasses two reinforcing loops (R1 and R2) and one balancing loop (B1), providing a visual representation of the dynamic relationships.

Through the analysis of these loops, a deeper understanding of the complex interdependencies and their impact on the overall sustainability and effectiveness of PPPs can be attained.

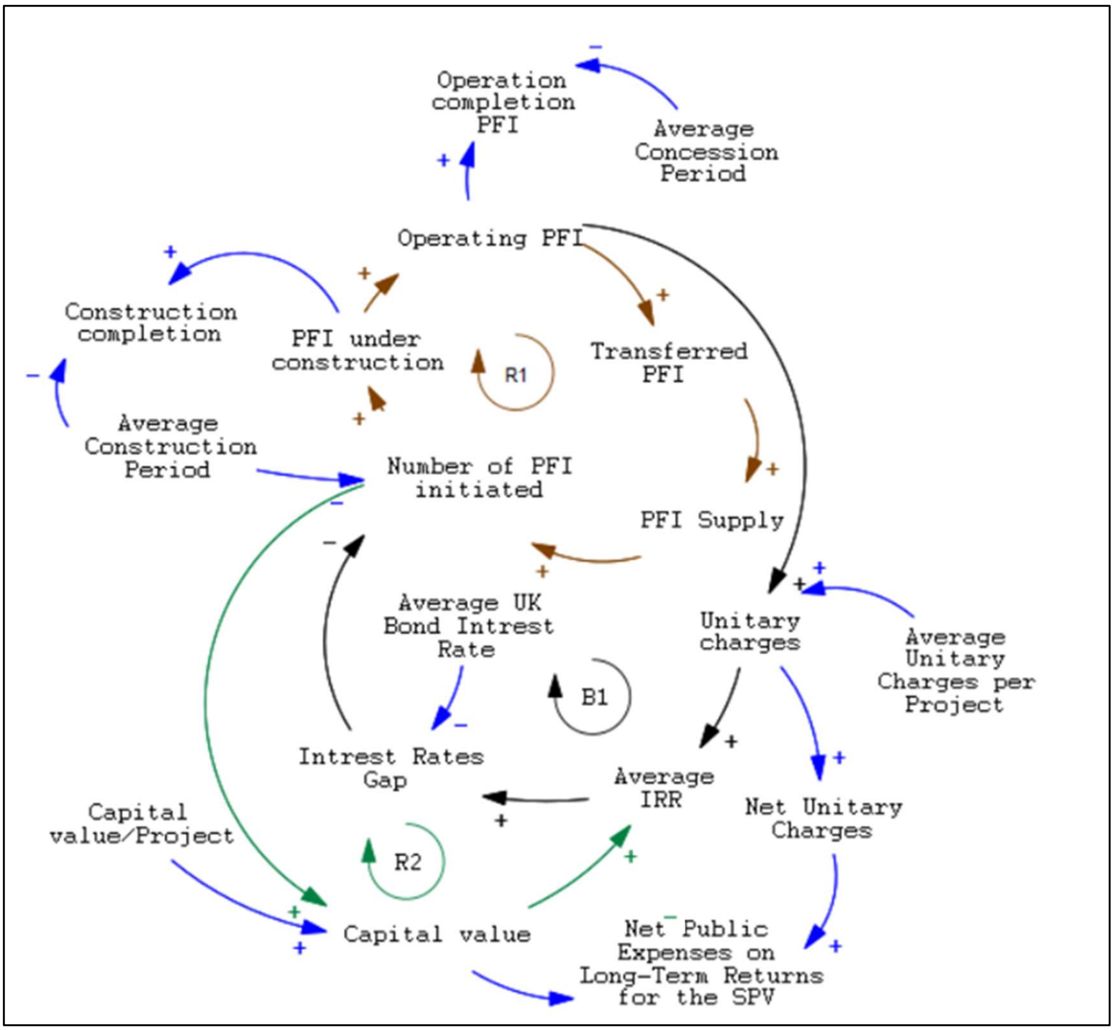

FIGURE 11 CAUSAL LOOP DIAGRAM

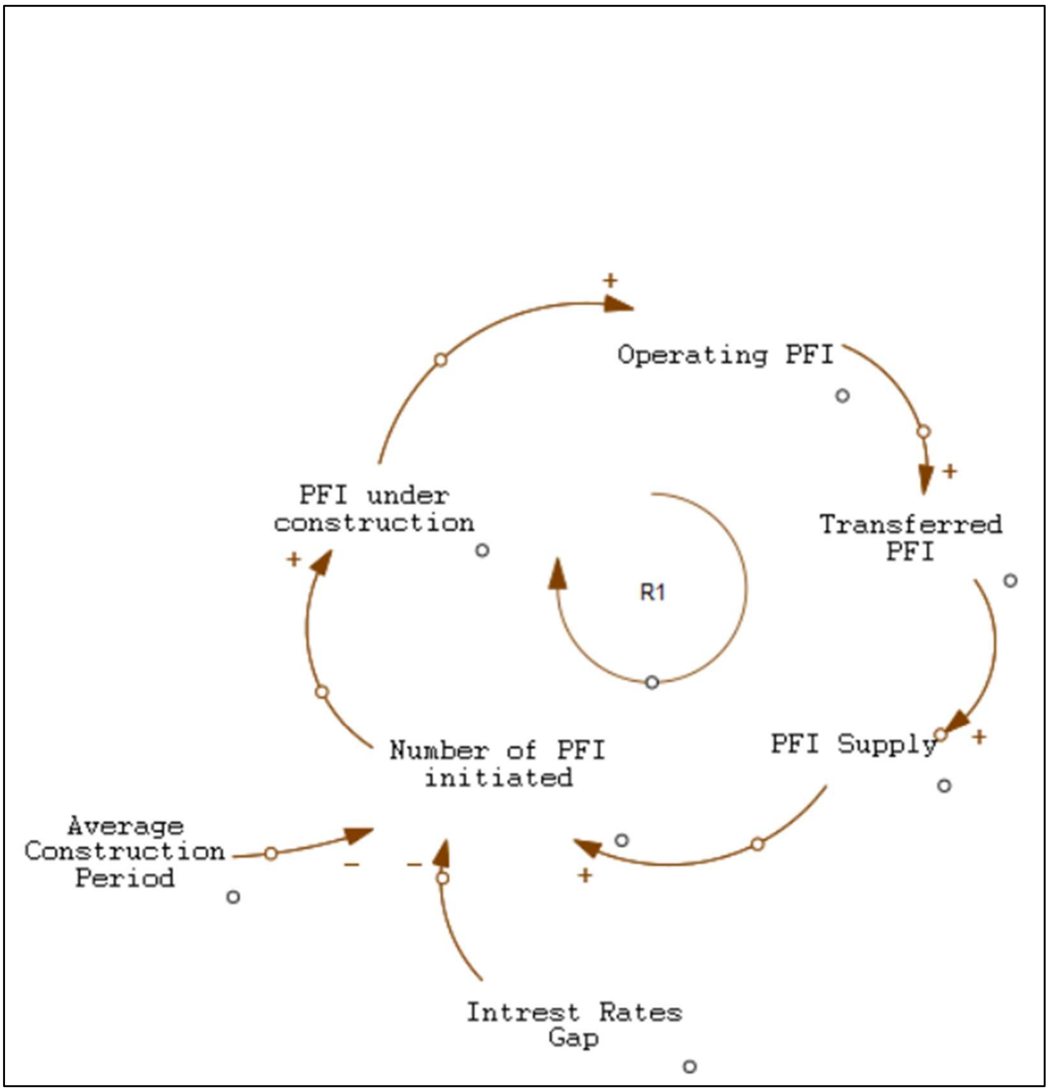

FIGURE 12 REINFORCING LOOP R1

Reinforcing loops, also known as positive feedback loops, are dynamic structures in system dynamics that amplify or reinforce certain behaviors or trends within a system.

As it is shown on the Figure above, all of the components of the loop have a positive sign, so it can be noticed that it is reinforcing loop.

It represents the dynamic relationship within the PFI and PF2 programs regarding the pipeline of projects. It illustrates how the initiation of new projects leads to an increase in the number of projects in construction and operation within the PFI framework. As these projects reach the operational stage, they are transferred to the public sector, resulting in a higher number of PFIs being transferred overall. This increased supply of PFIs further stimulates the initiation of new projects, as the availability of completed projects creates opportunities for future procurements (Pagoni & Patroklos, 2019).

Reinforcing loop R1 demonstrates the self-reinforcing nature of project initiation, construction, operation, and transfer. As more projects are initiated and successfully completed, it creates a positive feedback loop that leads to a continuous cycle of project development and transfer, on the other hand the transfer of PFIs to the public sector raises concerns about long-term maintenance, operational costs, and accountability.

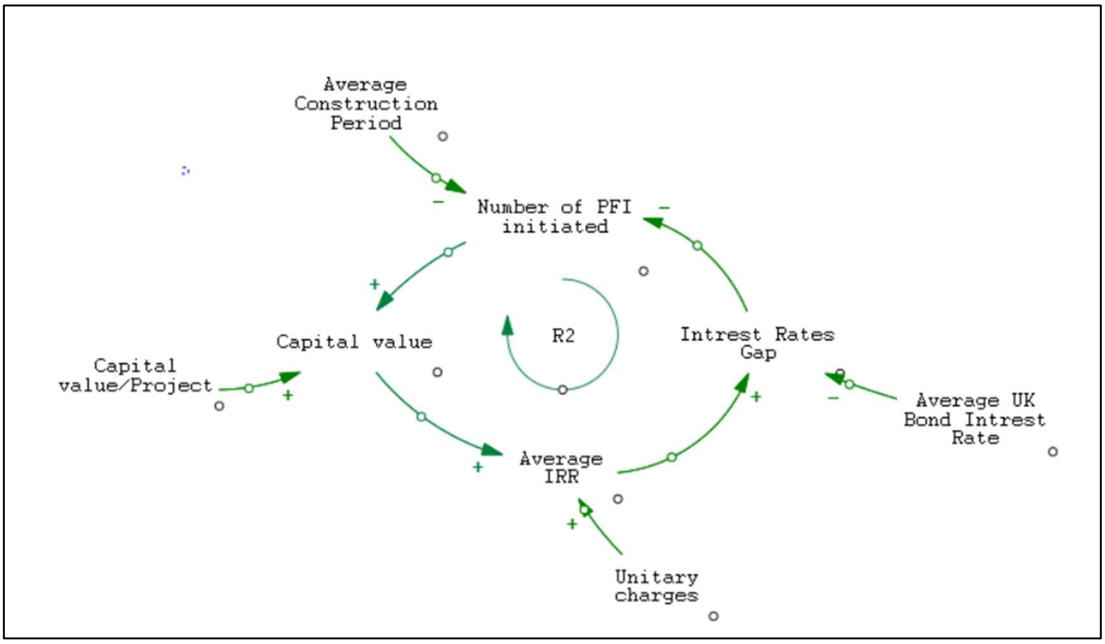

FIGURE 13 REINFORCING LOOP R2

Reinforcing loop R2 (Fig 13) demonstrates the positive relationship between PFI initiated and Capital Value.

When more PFIs are initiated, it attracts increased private sector investment, resulting in a higher Capital Value. This, in turn, has implications for financial metrics such as the Average Internal Rate of Return (IRR) and the Interest Rates Gap. As the Capital Value grows, the Average IRR may become restricted, indicating potentially lower returns on investment. The narrowing of the Interest Rates Gap indicates a decrease in the difference between the private sector's cost of capital and the public sector's cost of borrowing, influencing investment decisions.

These dynamics create a self-reinforcing loop, stimulating further PFI initiations and perpetuating the cycle. It highlights the importance of carefully managing financial aspects and evaluating the long-term implications of PFI projects.

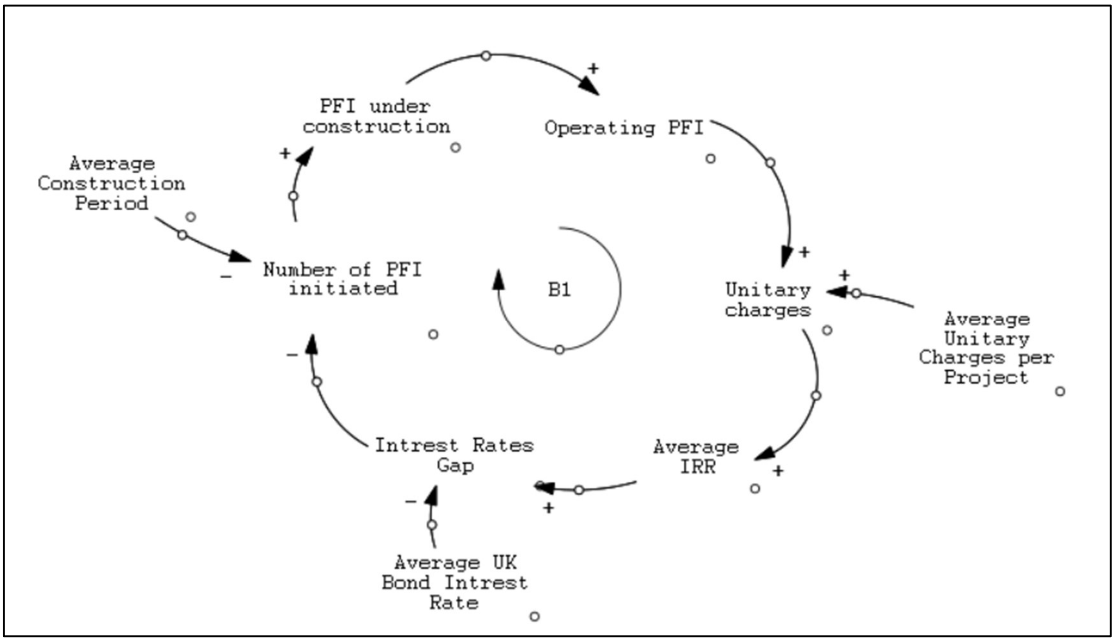

FIGURE 14 BALANCING LOOP B1

The operation of Balancing loop B1 (Fig. 14) is crucial in maintaining a controlled number of PFI initiations. As projects move into the operational phase, the unitary charges paid by the public sector to concessionaires gradually rise. This escalation in costs leads to higher IRR and a larger Interest Rates Gap, exceeding the Average UK Bond Interest Rate. The widening Interest Rate Gap prompts an upsurge in social and political opposition, resulting in a decline in the number of PFI initiations. Consequently, there is a notable reduction in the overall count of projects under construction and operating within the PFI framework.

The CLD (Causal Loop Diagram) depicted in Figure 11 offers a holistic view of the causal structures within PFI and their wide-ranging implications. By examining the interconnected relationships between various factors, the CLD aids in estimating the long-term financial effects of PFI on both the government and society. It allows for a deeper understanding of how different variables interact and influence one another, shedding light on the complex dynamics at play in PFI projects. This comprehensive understanding is invaluable in making informed decisions, developing effective policies, and ensuring the sustainability and success of PFI initiatives.

3.2. The Stock & Flow Diagram

The S&F Diagram, derived from the CLD and represented in Figure 15 and it forms the basis of the model developed for this study. It incorporates four stocks: PFI under construction, Operating PFI, Transferred PFI and Net Public Expenses on Long-Term Returns for the SPV.

The diagram allows for the identification and quantification of key variables and their interactions, enabling the modeling of different scenarios. By assigning mathematical equations to the variables, the diagram facilitates the simulation and analysis of the system's behavior under various conditions.

This modeling approach helps uncover the underlying dynamics, relationships, and dependencies within the system, providing valuable insights for decision-making and policy formulation and it provides a comprehensive understanding of the causal structures and their implications for estimating the long-term financial effects of PPPs on the government and society. Moreover, it provides a visual and quantitative representation of the system's structure and behavior, allowing to better understand the complexities and interdependencies involved.

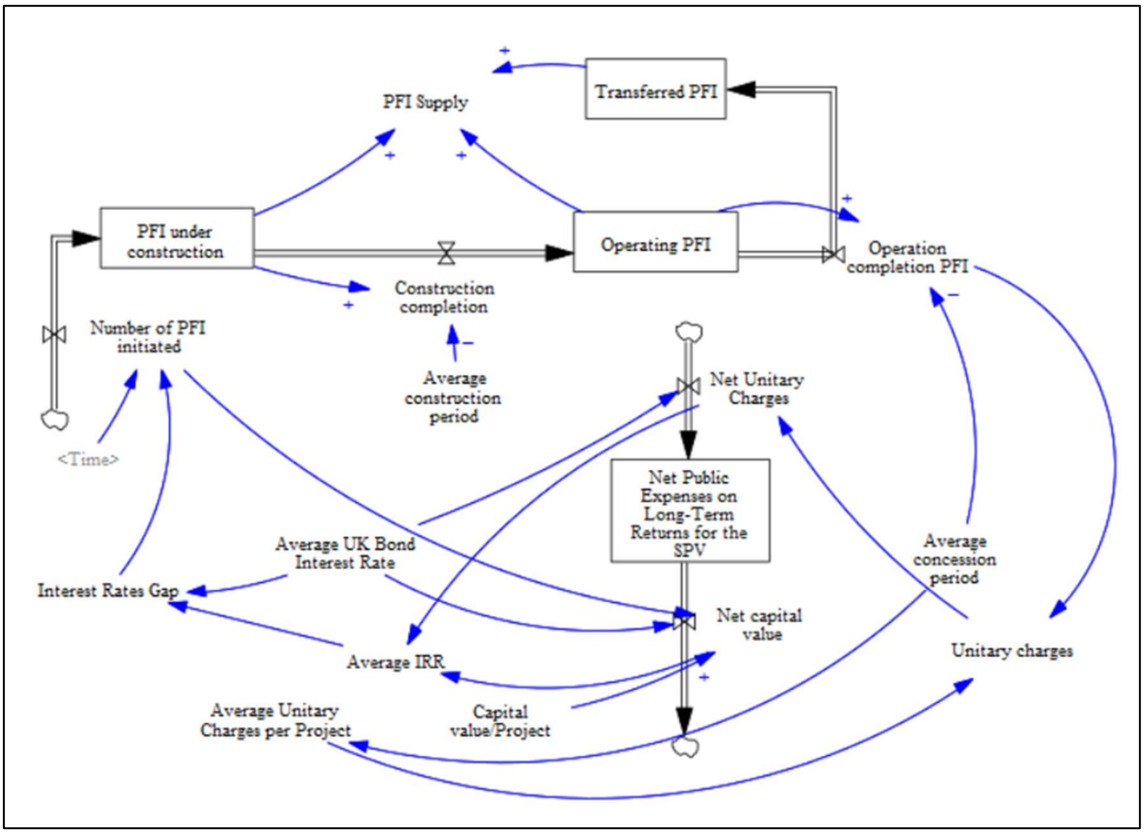

FIGURE 15 STOCK AND FLOW DIAGRAM

4. Model explanations

This section explains all the SD model created in detail.

4.1. Model settings

The model employs a "year" as the unit of time, commencing from 1993, which marks the inception of the first PFI project in the UK. The total time period for which the model has been run is 50 years as this amount of time allows to study the behavior of different variables which describe the project and permits to make a reliable conclusion.

The choice of the shorter period of the analysis could result in not understanding the PFI projects' evolution, trends, or patterns. The study of PFI projects over a 50-year period provides valuable insights into successes, failures, and long-term consequences. It guides future planning, enhances project implementation, and sheds light on the lasting financial, operational, and socio-economic effects.

4.2. Model explanations – variables set

This part will demonstrate the comprehensive explanation of the variables used in developing a system dynamics model using Vensim. Variables play a crucial role in capturing the essential elements and relationships within the system, enabling us to understand its behavior over time.

The variables used for the modeling of the system in Vensim are as follows:

a) **Stocks**:
   - PFI under construction – demonstrates the number of projects which are under construction in each year of the analysis, and it can demonstrate the magnitude of the PFI programs and it' trend, the units of this stock

are “projects”; the formula used for the calculation of this is: *Number of PFI initiated-Construction completion*; the initial value set for this stock is 0;

- Operating PFI – are the projects which are already in the state of “In Operation”, it is useful for the comparison of the construction process of the projects and the time and number when they were available for the population; the units of this stock are “projects”; the formula used for the calculation equals *Construction completion-Operation completion PFI*, similarly to the Stock of the PFI under construction; also in the case the initial value is set to 0;
- Transferred PFI – are the PFI projects transferred from the private sector entity to the public sector entity, so this means that the asset becomes publicly owned, it shows the number of the projects and can help to see the number of the projects and after how much time they became finally publicly owned; units used for this stock are “projects”; formula for the stock corresponds to *Operation completion PFI (Operating PFI/Average concession period)*; also in this case the initial value is 0;
- Net Public Expenses on Long-Term Returns for the SPV - quantifies the net financial impact of the public sector's involvement with the SPV, considering both expenses and expected returns over an extended period, serves as a measure to evaluate the project's financial implications and viability from the public sector's standpoint; the units if this stock are mln £; formula equals: *Net Unitary Charges-Net capital value*; in order to that the model runs correctly, the initial value has been set to 0.

b) **Variables**:

- Average construction period – is an auxiliary variable, it has an influence on the “Construction completion”, this variable as the name says shows the average construction period; it is explained in the units of years; the value is set as *constant and it equals 3*, it has been calculated by taking the average time of the construction based on the database retrieved from the UK Home Office of all the projects;
- PFI Supply – demonstrates the amount of the PFI projects available for the country; the units set for this variable are projects; the value for this variable is calculated as follows: *Operating PFI+PFI under construction + Transferred PFI*;

- Average concession period – is the constant variable set to show how long is the concession period of each of the project; it is explained in the units of year; the constant variable set for *this equals 28*, and it has been calculated by taking the average concession based on the database retrieved from the UK Home Office of all the projects;
- Unitary charges – shows the amount of unitary charges to be paid every year for all the projects, it demonstrates the magnitude of the yearly spending of the government on the projects; the units adopted are mln £; the formula for the calculation of the unitary charges in Vensim is as follows: *Operation completion PFI*Average Unitary Charges per Project*;
- Capital value/Project – based on the data available, it demonstrates the capital value calculated for each project, the outcome if this is to see how much every year is the capital value per projects, this helps to verify the trends of the capital values; the units for this variable are mln £; the value for this variable has been set to be constant and equals to 81.1065, it has been calculated based on the database retrieved from the UK Home Office of all the projects by taking an *average amount of the capital value* available in the database;
- Average Unitary Charges per Project – shows the yearly Average Unitary Charges per Project, it helps to verify the yearly changes in this variable in order to also verify the cost for the Government of these projects; the units established for it are mln £; the formula is as follows: *422.206* (1+((Average concession period)*0.02))*, where the 422.206 is a constant of the *amount of average unitary charges* calculated based on the database retrieved from the UK Home Office, the next part of the formula is the value adjusted to the possible inflation rate;
- Average UK Bond Interest – is the average UK bond interest, which has the influence of the "Interest Rate Gap", and this is correlated to the "IRR" which is very important indicator in this analysis; it is showed in the percentile units; this variable has constant value which *equals 0.05*, this value has been set based on the historical data retrieved;
- Interest Rates Gap – illustrates the difference between Average UK Bond Interest Rate and Average IRR of the PFI projects, it facilitates to study the very high IRR for the PFI programs and illustrates the big differences between those the rates; the units of measurement for this are the percentile; formula: *Average UK Bond Interest Rate - Average IRR*;
- Average IRR – it shows the average Internal Rate of Return for the PFI projects available in the database, helps to illustrate the yearly

differences of the IRR and its trends; units applied are the percentiles; the formula applied for this in the Vensim® software is the assigned the values with the use of the lookup function in order to provide precise values for the model.

c) **Inflows and Outflows**:

- Number of PFI initiated – this has been set an inflow for the stock of the “PFI under construction”, it demonstrates the about of projects started it means, that date of financial close of it; the units of this variable are “projects”; and the formula has be set based on the real data on which the linear regression formula based on time has been established and it equals: *IF THEN ELSE(Interest Rates Gap<0, 0 , IF THEN ELSE ((-0.361*Time^2 + 7.8643*Time + 0.7792) > 0 , -0.361*Time^2 + 7.8643*Time + 0.7792 , 0))*, the formula “IF THEN ELSE” has been set in order to avoid any negative number once the model runs;
- Construction completion – the roles of this variable are two: one as an outflow of the stock “Number of PFI initiated” and secondly as an inflow for the stock “of the “Operating PFI”, it shows the number of PFI projects which have completed the construction phase; units for this variable are “projects”; formula equals to *PFI under construction/Average construction period*;
- Operation completion PFI – shows the number of projects which has finished their concession period in every year, it is a measure to see how many projects every year are going to be in the property of the government, the role of this component is outflow of the stock “Operating PFI” and at the same time inflow for the stock “Transferred PFI”; the units associated to this variable are projects; formula used: *Operating PFI/Average concession period*;
- Net Unitary Charges – have been used as an inflow for the stock “Net Public Expenses on Long-Term Returns for the SPV”; this variable *equals to the “Unitary charges”*;
- Net capital value – it is an outflow of the stock “Net Public Expenses on Long-Term Returns for the SPV”, it represents the value for the projects which has been carried out every year, as the model has set the time frame which is equal to the year, once the model is run, it will be possible to see on the graph yearly net capital values of the projects; the units of this are mln £; and the formula which has been

put into the Vensim® is *Capital value/Project"*Number of PFI initiated*.

5. Model simulation

After creation of the model and assigning the values and/or formulas to it, the base model was subjected to comparison with various scenarios to draw conclusions regarding the impact of specific variables on the system's components.

The implementation of SD model simulation allowed for the identification of significant issues associated with the PFI & PF2 programs, which ultimately led to the discontinuation of these PPP initiatives.

5.1. Baseline scenario

The base case represents the initial scenario in a series of comparisons, allowing for the derivation of implications and conclusions. It serves as the reference point against which subsequent scenarios are assessed, facilitating a comprehensive analysis of the system's dynamics and findings. The formulas used in this simulation are as mentioned in the section 4.2 and the exogenous parameters and listed on the Table 2.

TABLE 2 LIST OF EXOGENOUS PARAMETERS

Name	Constant	Units
Capital value/Project	81.1065	mln £
Average construction period	3	years
Average concession period	28	years

In order to give provide an overview of the situation in the UK in case of PFI projects, this section will focus on describing the status of the PFI programs in the UK.

The Fig. 16 demonstrates the baseline scenario considering the number of PFI initiated. The time 0 = 1993.

In general, it can be observed the progression of PFI initiations, initially witnessing an upward trend, reaching a peak, and subsequently declining. As it can be noticed the peak of the initiated projects has been reached in year 2002 and after that the number has been gradually decreasing and reached 0 in 2015. This pattern reveals a growing sense of skepticism within the government towards these projects, as evidenced by the decreasing slope post-peak.

Till 2002, the UK saw a rise in PFI projects due to government policy promoting private sector involvement, a need for improved public services, risk transfer advantages, and private sector interest.

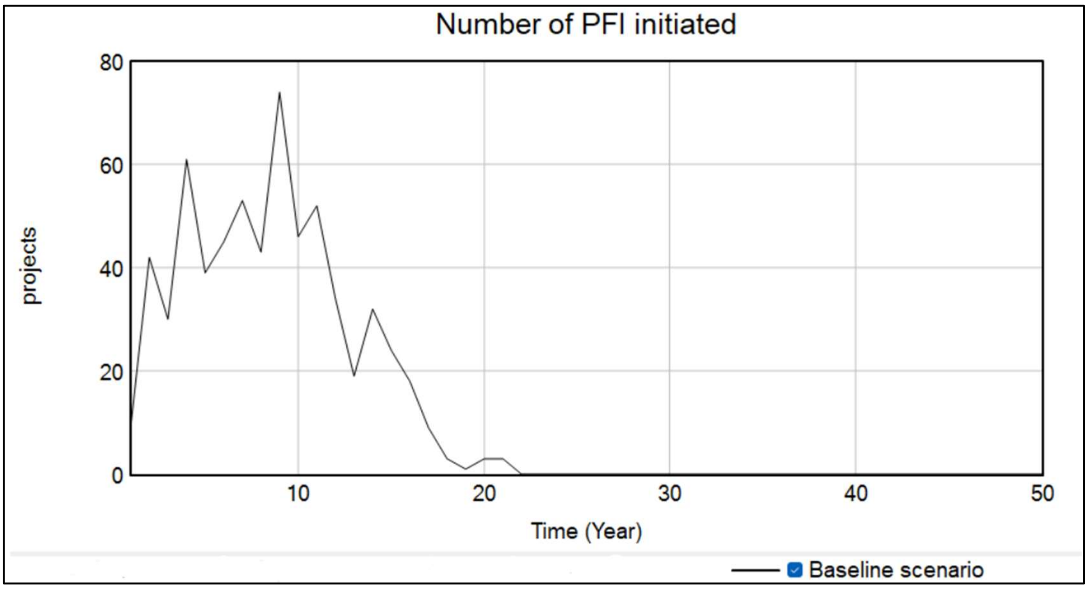

FIGURE 16 NUMBER OF PFI INITIATED_BASELINE SCENARIO

Comparing the Fig. 16 and Fig. 17 it can be observed that in case of the peak of the operating PFI there is the year 2012 and it can be attributed to a combination of factors, including increased government investment and support for PFI initiatives, the completion of several projects that had been initiated earlier, and the overall popularity of the PFI model during that time. It is worth to mention that according to the database used for this research, the average construction time equals to 3 years, and this explain the starting increasing point of the curve on the 3rd year of the simulation since the first project could become operating after approximately 3 years.

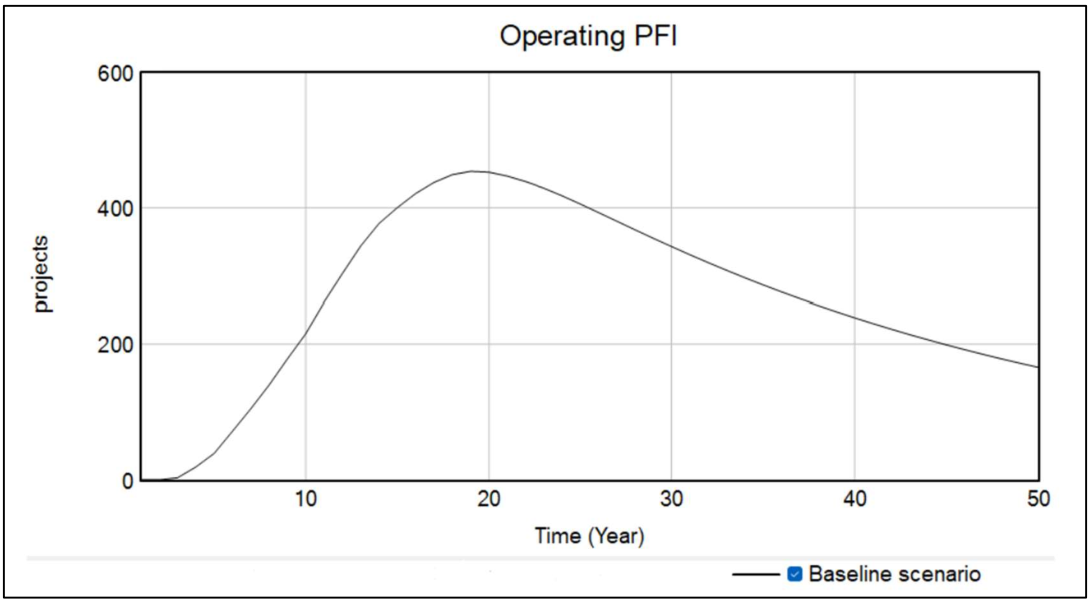

FIGURE 17 OPERATING PFI_BASELINE SCENARIO

Unitary charges are regular payments from the public sector to the private sector to cover project costs. As it can be seen on the Fig. 18, the peak has been reached in year 2012, the same as peak of the operating PFI as at that year the highest number of projects was in use. The amount of the unitary charges in that year equals to 6840,79 mln £. In comparison to the GDP of the UK in 2012, the total amount of unitary charges is 0.4419%.

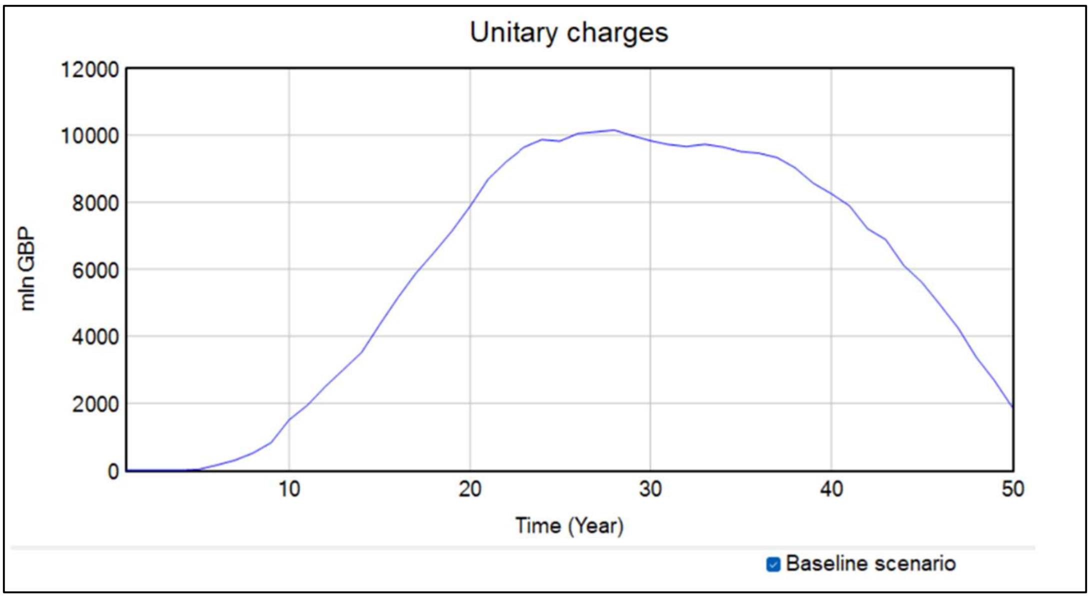

FIGURE 18 UNITARY CHARGES_BASELINE SCENARIO

Fig. 19 shows the net capital values of the PFI projects in each year. As it can be noticed the peak has been reached in year 2002, as also at the same year the highest number of PFI can noticed (74 projects).

Net capital value in this year was equal to 6001,88 mln £. Net capital value higher than unitary charges indicates a financial imbalance in the PFI project, impacting its viability and profitability.

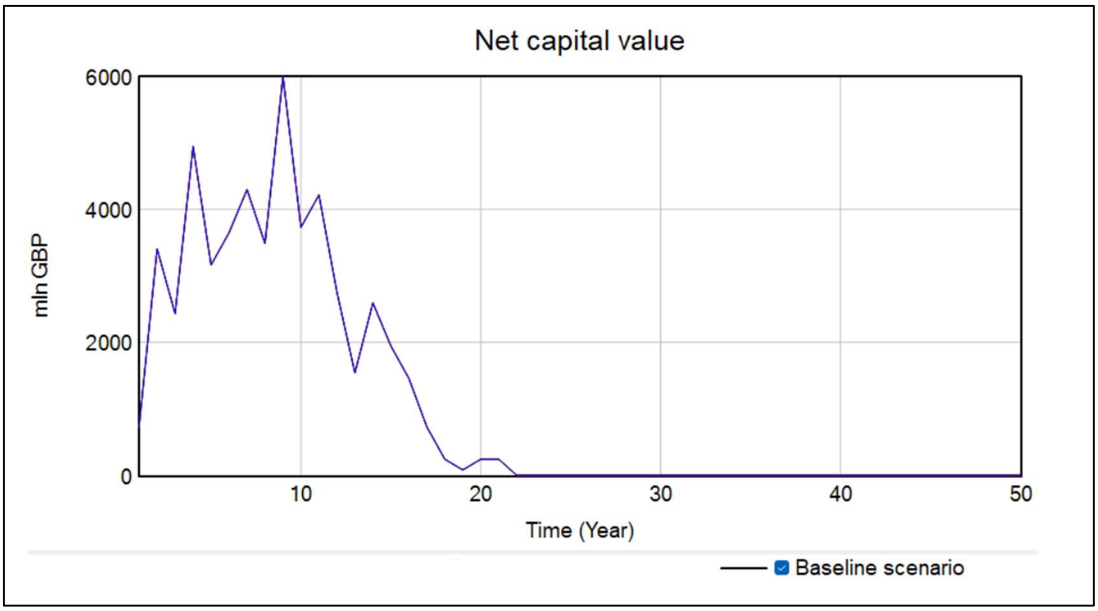

FIGURE 19 NET CAPITAL VALUE_BASELINE SCENARIO

The profitability of PFI projects was assessed by calculating the IRR based on initial investments and projected payments providing an assessment of profitability for private investors.

The Average IRR for the 704 projects is 16.3%, while the average interest rate of the UK 10-year Government Bond is 5.2% (IEO, 2009). This significant gap between the private sector's IRR and the public debt interest rate used for traditional projects highlights the financial disparity.

The long-term concession periods in PFI projects result in higher Unitary Charges and tax payments compared to shorter-term project deliveries like Design-Build. Additionally, the high debt leverage in PFI programs restricts funding flexibility, as debt repayment is obligatory regardless of revenue generation (Santandrea et al., 2016).

This disparity is demonstrated in on the Fig. 20 as the difference between IRR and an Average Bond Interest Rate, which can be labelled as the Interest Rates Gap. A positive gap signifies a greater detrimental effect on public finance.

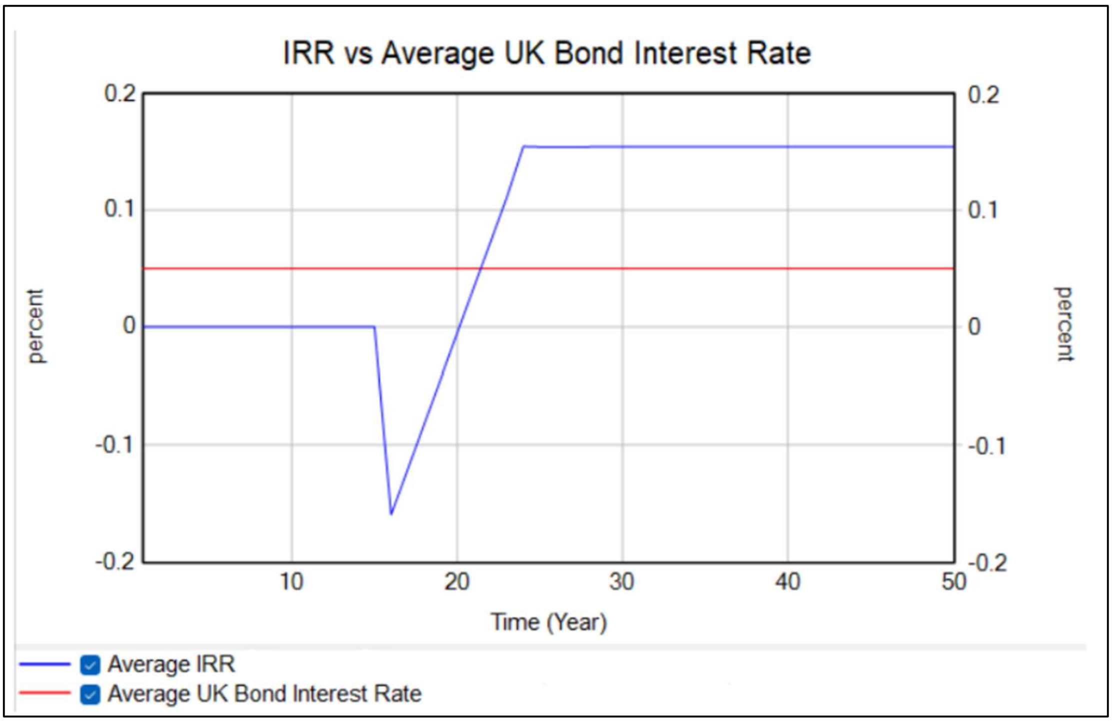

FIGURE 20 IRR VS. AVERAGE UK BOND INTEREST RATE

In the context of the PFI program, Figure 21 provides a comprehensive view of the total capital value and unitary charges associated with 704 projects spanning from the program's inception in 1993 (year 0 in the model) to 2043 (year 50).

The data presented in the Figure 21 has been derived using a regression model based on real data values, ensuring accuracy and reliability. The capital value depicted in the figure represents the cumulative sum of equity and private debt required to achieve financial closure for the PFI projects. This capital value typically corresponds to the funding necessary for capital expenditures during the construction phase of the projects. Unitary charges refer to the annual payments made by the public sector to the private entities operating the projects throughout the operation period.

A notable observation from Figure 21 is the substantial difference in magnitude between the private investment, represented by the capital value, and the public payments, represented by the unitary charges. This discrepancy emphasizes the significance of securing long-term profitability for the private entities involved in the PFI projects. However, it is important to consider the potential financial implications for the public sector and taxpayers arising from the longer concession periods associated with PFI projects.

With an average concession period of 28 years, there is a risk of increased costs in public financing. Taxpayers may bear a heavier burden as they are required to provide ongoing payments through unitary charges over an extended period. Furthermore, longer concession periods can result in unfavorable circumstances once the PPP agreement concludes, and ownership of the facilities is transferred. This transition can pose challenges in terms of maintaining the infrastructure and ensuring efficient management beyond the involvement of the private investor. The potential consequences of such circumstances underscore the need for careful evaluation and consideration when determining the duration of concession periods in PFI projects.

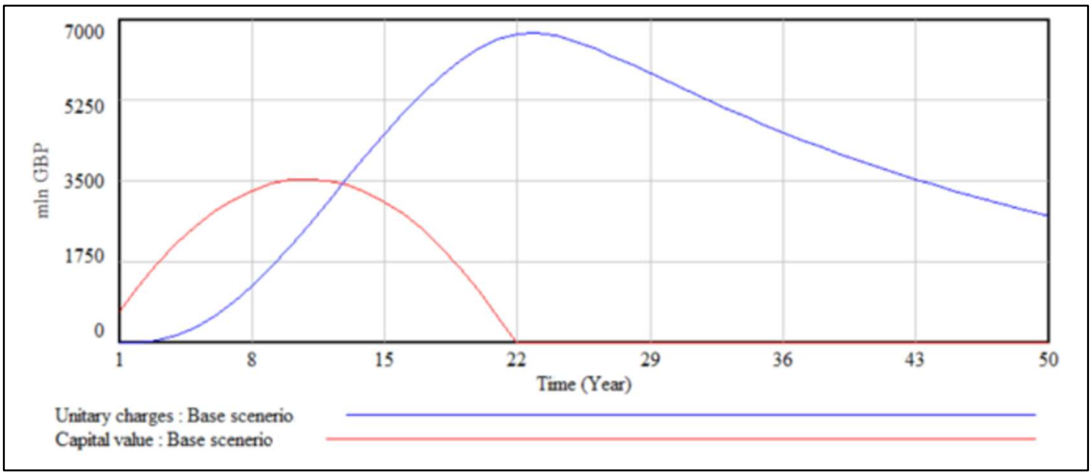

FIGURE 21 UNITARY CHARGES VS. CAPITAL VALUE_BASELINE SCENARIO

Figure 22 visually represents the PFI Supply, reflecting the cumulative sum of Operating PFI, PFI under construction, and Transferred PFI. The PFI under construction stock diminishes upon completion of construction, influenced by the average construction period. In contrast, the Operating PFI stock grows with each completed construction. The Transferred PFI stock expands as projects reach the operational phase.

These stocks collectively contribute to the PFI Supply variable, representing the total number of projects at all stages (PFI under construction + Operating PFI + Transferred PFI).

The line exhibits a steady upward slope, indicating a progressive increase in the number of projects accessible to society over time. As contracts reach completion, the projects undergo a transfer of ownership to the government. As the line approaches approximately 700 projects, it levels off, signifying the attainment of a stable state where no further project initiations occur, and all existing projects have been fully transferred into the ownership of the government. This plateau reflects the culmination of the PFI initiative, with all projects integrated into the public sector domain.

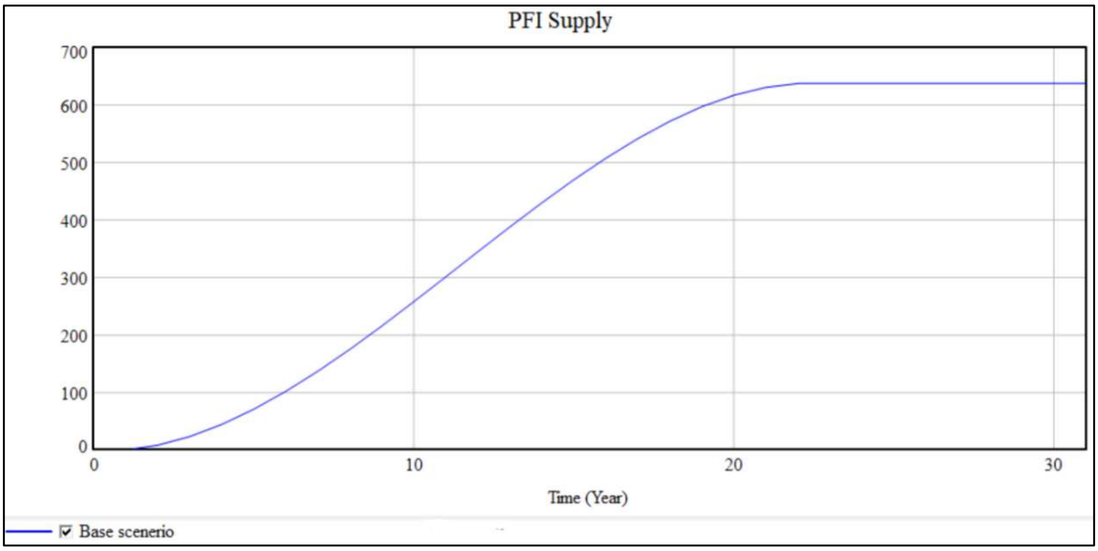

FIGURE 22 PFI SUPPLY_BASELINE SCENARIO

5.2. Scenario 2: change in the length of the concession period

After the run of the baseline scenario which demonstrated real situation of the PFI projects, the next step was to run different scenarios in order to get the answer to the research questions.

The first focus was to analyze the costs incurred by the Government in different settings, so the analysis of the Net Unitary Charges.

Figure 23 demonstrates the results of the model run.

In this case, there have been run 5 different scenarios with the differences in in the concession period. Table 3 shows the change of the settings applied in the model run.

TABLE 3 SCENARIO 2

Model name	Variable	Baseline value	Current value
Baseline scenario	Concession Period	28	28
Conc_Period – 10 yr	Concession Period	28	18
Conc_Period + 10 yr	Concession Period	28	38
Conc_Period – 5 yr	Concession Period	28	23
Conc_Period + 5 yr	Concession Period	28	32

Fig. 23 shows the differences in the net unitary charges based on the concession period with the setting mentioned in the Table 2. The relationship between the concession period and Net Unitary Charges is evident, as a longer duration leads to a decrease in charges, while a shorter period corresponds to higher charges. This dynamic has significant implications for both the government and taxpayers.

On the one hand, a longer concession period can be advantageous for the government's spending, as it reduces the immediate financial burden. However, it also exposes the project to potential risks, such as mismanagement or project failure, which could result in taxpayers bearing the financial consequences without receiving optimal services. This highlights the importance of careful project management and oversight to ensure that the private investor effectively maintains and operates the infrastructure.

Moreover, any changes in the Average Concession Period can have a considerable impact, with a 2% variation resulting in changes in the Average Unitary Charges. Therefore, a thorough assessment of the concession period's length and its implications is crucial for ensuring the overall viability and financial sustainability of the project.

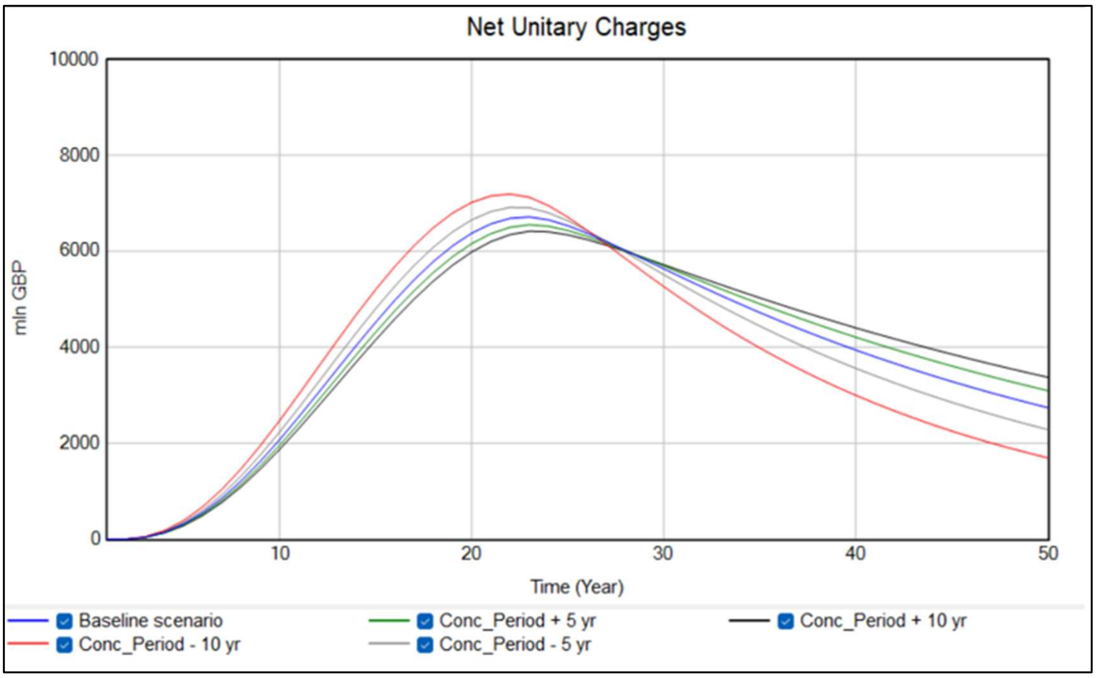

FIGURE 23 NET UNITARY CHARGES_ DIFFERENT CONCESSION PERIOD

The visual representation in Figure 24 demonstrates a clear correlation between the length of the concession period and the corresponding changes in Unitary Charges. This observation reinforces the hypothesis that an extended concession period is associated with higher expenses on investments. The graph provides a graphical illustration of how variations in the concession period directly impact the financial burden placed on the public sector.

By showcasing this relationship, it becomes evident that the duration of the concession period plays a crucial role in determining the financial implications and costs associated with infrastructure projects. This emphasizes the need for careful analysis and decision-making regarding the optimal length of concession periods to ensure cost-effectiveness and financial sustainability.

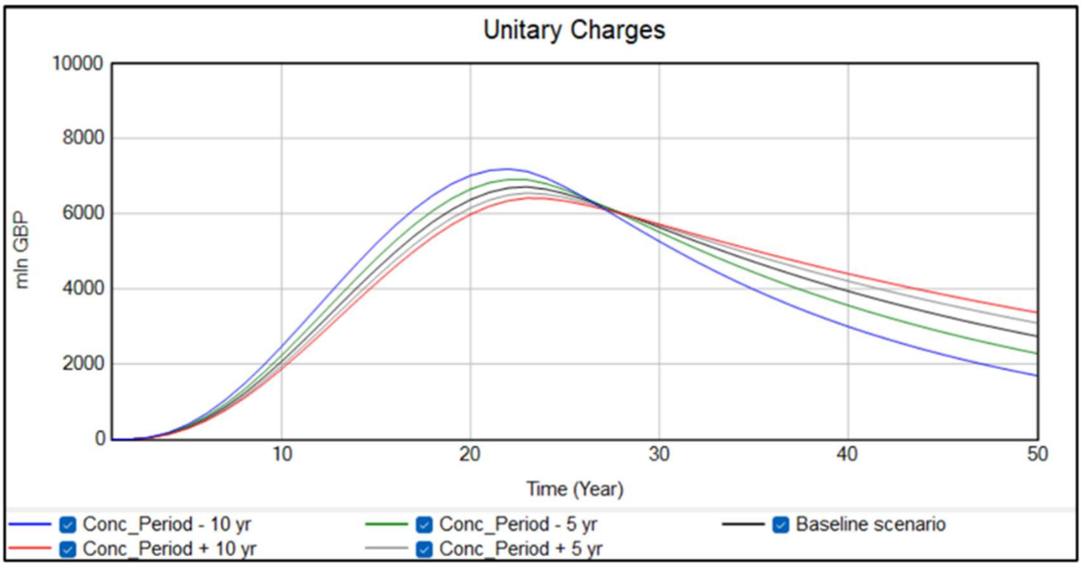

FIGURE 24 UNITARY CHARGES_DIFFERENT CONCESSION PERIOD

In addition to the aforementioned analyses, another critical aspect examined is the Net Public Expenses on Long-Term Returns for the SPV, as illustrated in Figure 25.

This analysis aims to assess the financial implications for the public sector when financing long-term projects like PFI/PF2, where payments are spread out over an extended period during the operational phase.

By contrast, alternative project delivery methods such as Design Build involve shorter-term payments during the construction phase.

The findings reveal a notable relationship between the concession period and the Net Public Expenses on Long-Term Returns for the SPV. Specifically, a longer concession period is associated with higher net public expenses, while a shorter concession period corresponds to lower expenses.

This observation aligns with the earlier conclusion drawn from the analysis of Net Unitary Charges (Figure 23).

A shorter concession period offers the potential for increased efficiency in public investment, leading to cost savings for the government. Conversely, longer concession periods result in reduced net public expenses but may necessitate additional investments in the short and medium term.

These findings highlight the trade-off between long-term financial implications and immediate investment requirements, emphasizing the need for careful consideration and strategic decision-making in public-private partnerships.

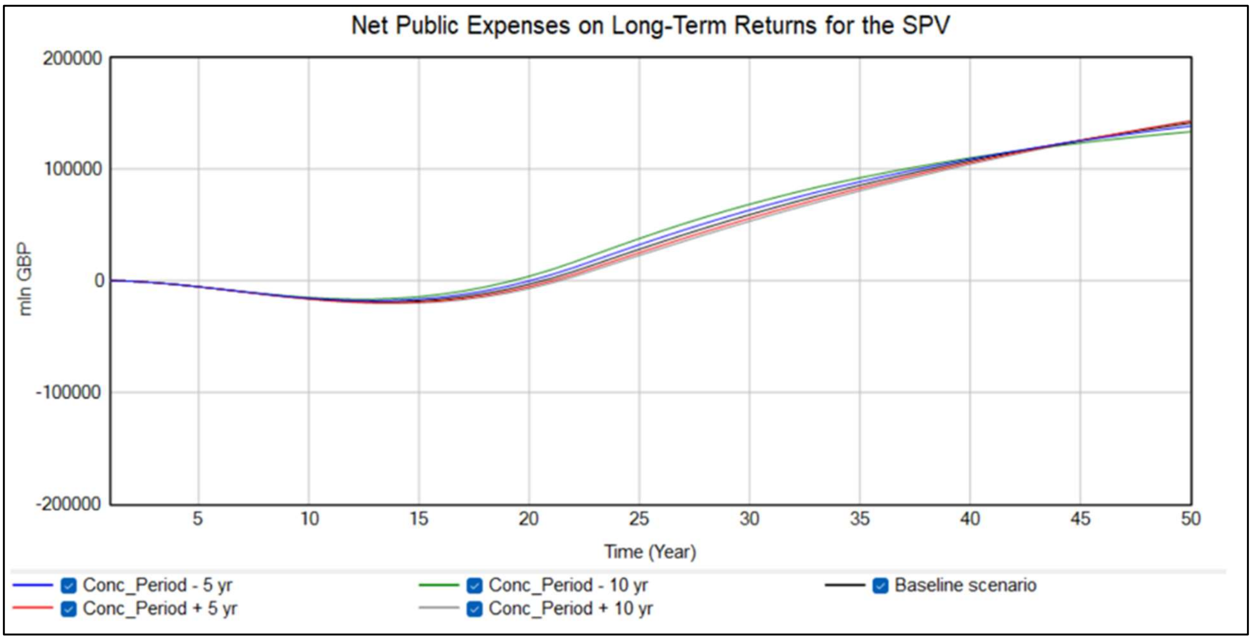

FIGURE 25 NET PUBLIC EXPENSES ON LONG-TERM RETURNS FOR THE SPV_DIFFERENT CONCESSION PERIOD

5.3. Scenario 3: cost overrun

Another scenario has been run in order to get the answer to the research questions and verify the problems which lead to the closure of the PFI programs in the UK and the model has been modified accordingly (Table 4).

TABLE 4 SCENARIO 3

Model name	Variable	Formula
Baseline scenario	Unitary charges	Operation completion PFI*Average Unitary Charges per Project
Cost overrun	Unitary charges	(Operation completion PFI*Average Unitary Charges per Project)*1.24

The prevalence of cost and time overruns in the PFI/PF2 program has significant implications for project outcomes and financial commitments. These overruns have been well-documented in various studies and reports (Gaffney et al., 1999; IEO, 2009; Leahy, 2005).

While the original expectation was a cost overrun of 12.5% or more for public sector projects under PFI, the actual figures ranged between 22% and 35% during the early 2000s (Gaffney et al., 1999; IEO, 2009). In contrast, conventional procurement projects demonstrated a narrower range of cost overruns between 2% and 24% (Leahy, 2005).

To visualize the impact of cost overruns, Figure 26 presents the capital value of PFI projects in two scenarios: a base scenario without overruns and an overrun scenario with an assumed average cost overrun of 24%. The figure clearly demonstrates that any cost overrun increases the capital value of the project, indicating escalating costs. It complements the analysis by depicting the government's unitary charges in PFI/PF2 projects. It reveals that cost overruns, including the assumed 24% overrun scenario, lead to higher payments incurred by taxpayers.

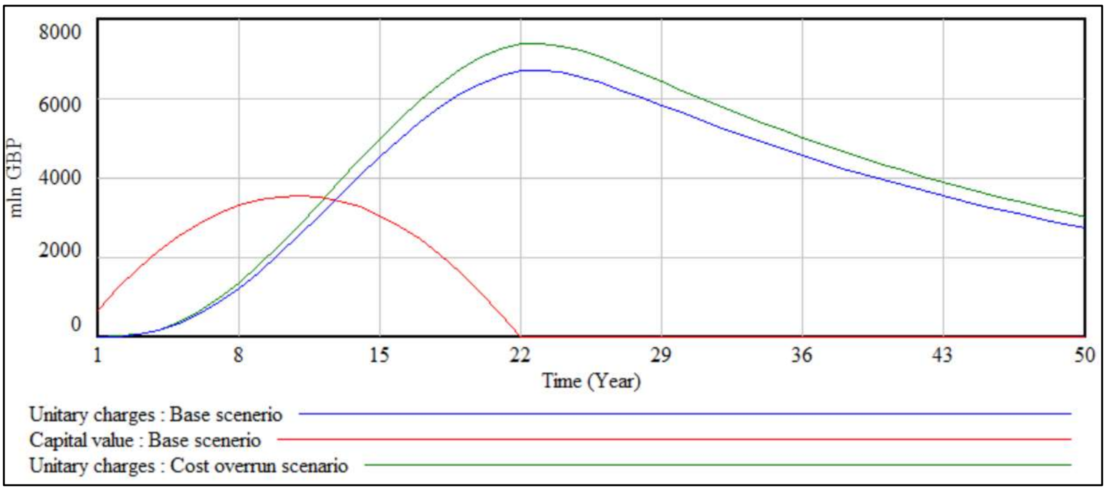

FIGURE 26 UNITARY CHARGES VS CAPITAL VALUE_COST OVERRUN

Examples of specific projects with cost overruns further highlight this issue. The London Underground Jubilee Line extension serves as a notable case, experiencing a delay of more than two years and exceeding the budget by £1.4 billion (Hodge & Graeme, 2010). Despite some PFI projects being completed on time and within budget, the overall trend of cost and time overruns persists, as evidenced by the mentioned cases.

In addition to cost overruns, the government can find itself contractually obligated to pay for services that are no longer required, leading to inefficient resource allocation. An illustrative case is the Liverpool City Council's commitment to paying approximately £4 million annually for an empty Parklands High School until the contract's end, amounting to an estimated £47 million (UK NAO, 2018). The long-term financial implications of such obligations raise concerns about the sustainability and value for money of PFI/PF2 projects.

These overruns and obligations contribute to significant financial burdens. Although no new PFI/PF2 projects are being initiated in the UK, future charges associated with existing projects are estimated to amount to £199 billion, extending until the 2040s (Foreman-Peck, 2021). The abandonment of projects also incurs financial losses for the government, such as the £32.4 million cost of cancelling the "Defence Training Rationalisation project" (Whitfield, 2017).

Moreover, specific examples demonstrate substantial cost overruns. The Crown Prosecution Service's case management system, initiated in 2001 for a 10-year period, experienced a 70% cost increase, amounting to an estimated outturn cost of £408 million (Whitfield, 2017). Time overruns further compound the issue, leading to additional costs.

The "Northern Ireland Vehicle Licensing Agency" project serves as an example, experiencing a delay of six years and incurring a final cost of £623 million, including significant overspending (Whitfield, 2017).

The healthcare sector is not exempt from these challenges, with taxpayers spending £10.7 billion between 2010 and 2015 solely on Unitary Charges for hospitals and healthcare facilities constructed under the Private Finance Initiative (Centre for Health and Public Interest, 2017).

These findings highlight the substantial weaknesses of the PFI/PF2 program, emphasizing the need for careful evaluation and management of projects to mitigate cost and time overruns. The financial consequences and implications for taxpayers underscore the importance of exploring alternative project delivery methods and ensuring value for money in public infrastructure investments.

6. Model Validation

The validation of a system dynamics model during is crucial for several reasons:

- it guarantees that the model faithfully captures the dynamics of the real-world system, enabling accurate simulations,
- enhances confidence in the model's ability to provide reliable insights for decision-making.

Model validity in system dynamics ensures accuracy, reliability, transparency, and the practical value of the model in guiding decision-making processes.

In this case, a time frame of 50 years, starting from 1993, is utilized. This enables a comparison between the real data spanning the period of 1993-2043 and the projections generated by the simulations. The primary aim is to assess the model's validity by evaluating its consistency with real-world outcomes.

The thing to be verified is the “PFI Supply”, which is the stock in the model, and it consist of “PFI under construction”, “Operating PFI” and “Transferred PFI”. For all the scenarios the output was the same, so it was enough just to demonstrate the real data in comparison to the simulation (Fig. 27). The validation process appears to demonstrate consistency. Even though there can be observed some differences, but this is the result of the lack of data of some projects, such as: Date of financial close which demonstrates the starting date of the construction process, First date of operation which is crucial for calculating the number of Operating PFI or some missing dates of the end of the construction process. In general, it can be observed that the behavior of the PFI supply in the Vensim software and in the real data has the same trend with quite similar dynamics.

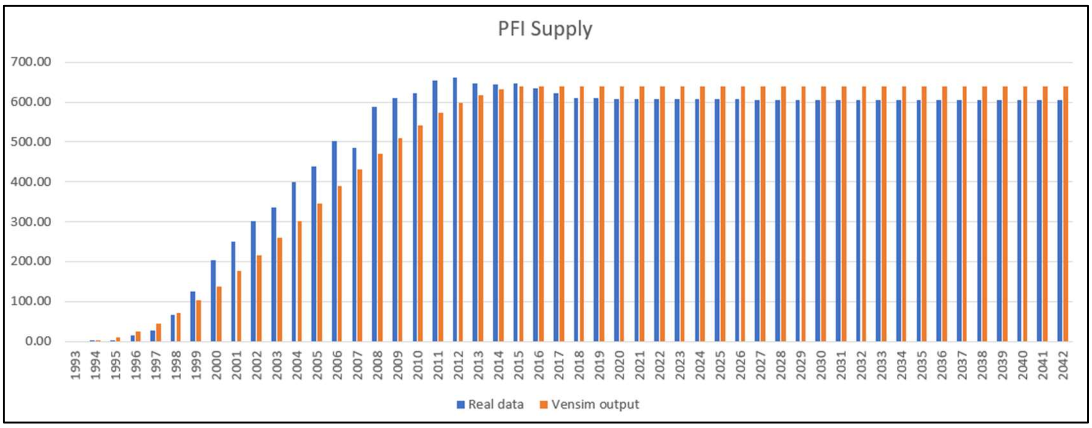

FIGURE 27 PFI SUPPLY_REAL DATA VS. VENSIM OUTPUT

As already mentioned, the database was missing some data, it rises a weakness of the PFI program which is the limited transparency in PFI/PF2 contracts, resulting in insufficient information regarding the actual financial details to detect potential cost overruns. The publicly available information primarily revolves around the "business case," encompassing planned cash flows, contract duration, and the date of project initiation. However, critical financial information necessary to identify cost overruns is lacking, as observed in the Excel file containing project data. Consequently, concerns regarding accountability and the possibility of private sector entities exploiting their advantageous positions have emerged, contributing to political opposition.

Prior to 2012, most PFI programs were treated as off-balance sheet for the government, encouraging the public sector to prefer this financing approach. In an effort to address the transparency problem, the government introduced PF2 projects, which aimed to enhance transparency through measures like government annual reports and improved control or equity return publication. Despite these efforts, the transparency issue persists to some extent.

During the data collection phase, it became apparent that public information primarily focuses on the business case, lacking timely updates on project status, potential deviations, and renegotiations. Moreover, access to financial data is scarce.

Overall, the lack of transparency regarding real financial information hinders public accountability and raises concerns about potential exploitation by private sector companies and information asymmetry.

7. Conclusions

7.1. Conclusions and implications

In response to the challenges posed by the decision of the UK government to terminate the project, it has been decided to develop a model that utilizes the System Dynamics methodology. This study aims to enhance the understanding of the reasons behind the termination and explore the dynamic relationships between various factors, including PPP development, societal concerns, public policy, and financial constraints. By employing the System Dynamics approach, it was possible to capture the complex interdependencies and feedback loops that influence the outcomes and dynamics of the project.

This research with the use of different scenarios analysis identifies key drivers that shape the interaction between PPP development, societal concerns, public policy, and financial constraints, with the aim of establishing a more stable model for future projects.

The analysis of the PFI and PF2 programs reveals several weaknesses that ultimately led to their termination:

- the high costs of these projects, combined with the significant profitability of private investments in the long term which further raised doubts regarding the cost-effectiveness and value for money,
- the repeated occurrences of cost and time overruns have exacerbated doubts about the financial viability of these projects, leading to heightened scrutiny and criticism,
- the lack of transparency in PFI and PF2 contracts raised questions about the accountability of private sector companies and their potential to exploit their position, leading to information asymmetry issues.

These weaknesses eroded the social legitimacy of the PFI and PF2 programs, leading to heightened political opposition and their eventual termination. These findings shed light on critical areas of concern that played a significant role in the decision to terminate these programs.

This study aims to enhance understanding of the challenges faced in PFI/PF2 programs by providing quantitative measurements and analysis. By doing so, it has been contributed to the body of knowledge on PPPs and offered a benchmark for assessing similar programs worldwide. The study research supports the UK government's concerns over excessive costs and complex contractual arrangements, providing valuable insights for informed decision-making in PPP initiatives globally.

7.2. Future research

Future research should focus on comparing different infrastructure types and public owners at various levels. Exploring alternative financing and delivery models for public infrastructure can enhance the UK Home Office's program. These models offer a more sustainable and equitable approach, addressing challenges in traditional PPP programs. The study highlights the need for a holistic and collaborative approach to infrastructure development, emphasizing transparency, accountability, and stakeholder engagement to reduce financial costs and renegotiations.

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