MOTT MACDONALD

Impact assessment of zero emission development activities

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Purpose

Mott MacDonald were commissioned by Transport Scotland to identify methods of appraising the return on investment for zero emission / decarbonisation mobility innovation projects to support future development of an innovations assessment methodology.

At present, the assessment of the impact of innovation work in this area is ad hoc, therefore a standard approach would assist project development and evaluation and help prioritise zero emission / decarbonisation mobility projects.

This study reviews cross-sector best practice, across a wide range of research and innovation literature, to provide a framework from which a future assessment methodology can be developed for zero emission / decarbonisation mobility innovation projects.

Approach

The methodology for the literature review was systematic, in that it was replicable and transparent whilst providing a comprehensive, methodical, and critical assessment of the scope and quality of available evidence from the literature.

A long-list of 156 documents was compiled, with 32 selected for detailed review. Following this review, and the extraction and collation of evidence, a stakeholder workshop was held with Transport Scotland to discuss the findings.

The findings from the literature review, and insights from the workshop, are captured within this report.

Summary of findings

The collated evidence highlighted a range of assessments that have been undertaken to examine the value of research and innovation projects in economic and social terms. This encompassed alternative evaluation techniques to establish the strength of relationships between investment in research and subsequent outcomes.

A wide range of individual outputs, outcomes and impacts from research and innovation investment are listed across the reviewed literature, alongside specific metrics to quantifiably capture the benefits.

The reviewed papers also presented evidence on the monetary scale of returns on research investment. Despite a broad range being presented across the papers, a lower and upper bound of 10% and 85% rate of return is suggested, with a central estimate of 20% to 40%.

However, the papers also identify a series of key factors that influence benefit realisation. These factors suggest both positive and negative effects and provide a balanced insight into what may help or hinder the causal chain of research and innovation from input to impact.

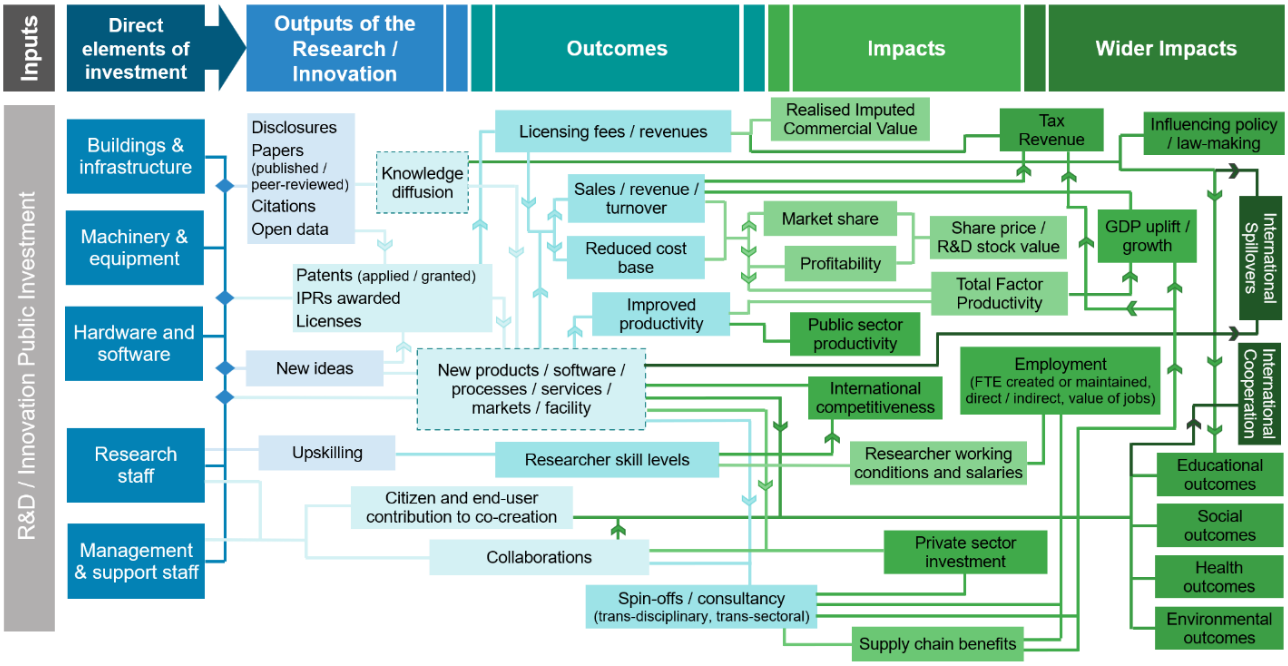
Logic mapping

The collated evidence on outputs, outcomes, and impacts has been used to produce an overarching logic map that sets out how a financial investment in research / innovation translates through direct outputs into outcomes and wider impacts across economies and societies.

Developing a generic logic map for research and innovation projects is challenging, reflecting the fact that research and innovation can be across all sectors of the economy, focus upon a wide range of technical areas, and require different types of inputs to achieve aspired outputs and outcomes.

The overall logic map, as presented within Figure 0.1, provides our interpretation of the collective view presented by the literature review, of linkages between inputs, outputs, outcomes, impacts and wider impacts. These linkages were often presented in short form within individual papers, or indeed not discussed at all, and so this should be seen as an indicative mapping process that helps to highlights key elements and linkages.

Figure 0.1: Logic map



A consideration for further investigation would be to utilise case study evidence from individual zero emission / decarbonisation mobility projects to refine this logic mapping process to become more bespoke.

Framework for estimating returns

The literature review indicates there is a wide scale of potential returns from research and innovation (Section 3.4) and that there are a significant number of factors that affects the outcomes and impacts (Section 3.5). There are a range of potential logic chains by which bespoke investment in research and innovation can feed through from outputs into outcomes and impacts (Section 4.2) and the mechanisms for achieving wider economy, societal, governmental, and international impacts are complex, reliant upon individual context, and have not readily quantified (Section 4.3).

Utilising this information, a framework has been developed that seeks to identify a check list of elements that would be used to evaluate each individual zero emission / decarbonisation mobility project to flag the likely areas where impacts may be derived. This has been done by considering:

1. What are the main factors that are likely to determine the benefits that can be derived from zero emission and decarbonisation mobility research and innovation?
2. What are the implications for forecasting the scale of potential impacts?

Six broad categorises of factors have been identified that can affect the scale of potential returns:

a. The type of research and innovation being undertaken
b. The component element of the research approach and development process
c. The precise technical nature of the research and innovation

d. The area of research and the networks and talent available to support the delivery of projects and maximise the outcomes.

e. The context and conditions of the sectors / industry in which the outcomes from the research and innovation may be applied

f. The context and conditions of the country of origin of the research and innovation, in this case being Scotland.

These six categories encompass a total 21 individual component factors that the literature review has indicated will impact upon the scale of returns from zero emission / decarbonisation mobility research and innovation projects. Alongside the evidence of quantified economic rates of return, these can be used to forecast the potential impacts of public sector investment within individual research and innovation projects.

The central case forecast of economic and social rates of return of between 20% to 40% offers a generic starting point for implied research and development impacts. By then considering the extent to which an individual zero emission / decarbonisation mobility project is likely to perform against the 21 identified component factors, it would then be feasible to make a judgement as to whether the rates of return for that project are likely to be greater or lower than core estimates.

A potential approach would be to establish a proforma of questions relating to each of the 21 component elements. The responses to each component would provide an indication as to whether benefits are likely to be higher or lower than average. Summing this cumulatively would provide a basis upon which to conclude whether, overall, a project is likely to deliver higher, lower, or comparative rates of return to the core estimates.

It is recommended that these forecast estimates remain a range, reflecting the level of uncertainty that remains. Table 0.1 provides an indication of the potential ranges that could be employed.

Table 0.1: Indicative scale of potential rates of return

Scenario	Rate of return range
Minimum	0% to 20%
↕	10% to 30%
Core	**20% to 40%**
↕	30% to 50%
	40% to 60%
	50% to 70%
	60% to 80%
Maximum	70% to 90%

Source: Compiled evidence from literature review

An indicative proforma of questions has been developed as a basis for adjusting the forecast rate of return range. This is presented within Table 4.2 in the main body of the report.

Next steps

It has always been recognised that this literature review of best practice will form an initial, albeit important, phase of a wider process in developing an assessment methodology for research and innovation into zero emission / decarbonisation mobility projects. The following three aspects have been identified as key next steps in the process:

1. Social impacts. Collate additional case study evidence from individual zero emission / decarbonisation mobility projects to improve the understanding of causal relationships from inputs and outputs from these projects leading through to wider social impacts relating to topic areas, such as health, wellbeing, social capital, and environment.

2. Testing. Subject the provisional framework to some initial practical testing on case study examples. This can then lead to a period of refinement and further development of the framework, and specifically the proforma, to ensure it becomes a viable practical tool that can be readily applied across all future projects.

3. Integration. Consider how the framework can be best integrated within existing appraisal tools. Part of this will involve the dissemination of the approach to relevant stakeholders to ensure a consistent understanding of the framework, but also obtain feedback on how it aligns with other existing appraisal frameworks. Particularly consideration will need to be given to how the framework would align to Scottish Transport Appraisal Guidance and its potential integration.

1 Introduction

1.1 Purpose of project and study

Mott MacDonald were commissioned by Transport Scotland to identify methods of appraising the return on investment for zero emission / decarbonisation mobility innovation projects to support future development of an innovations assessment methodology.

At present, the assessment of the impact of innovation work in this area is ad hoc, therefore a standard approach would assist project development and evaluation and help prioritise zero emission / decarbonisation mobility projects. The development of impact assessment protocols would not only support work in the decarbonisation of transport but would also have learning applicable to other modes of transport.

The overall project will be multi-phase, with this initial study focused upon information gathering, through a detailed literature review, to provide initial insight into a potential framework for assessment. Subsequent phases will build upon the framework, with the potential to develop more formal guidance on appraisal processes for zero emission / decarbonisation mobility innovation projects.

1.1.1 Scottish zero emissions / decarbonisation mobility context

Transport is the largest contributor to emissions in Scotland and in response to the climate emergency, Scottish Government has committed to reducing emissions by 75% by 2030 and a legally binding target of reaching net zero by 2045[1]. To meet these targets and the scale of change required, it is recognised that investment and support in the growth of zero emission mobility is required.

As such, Scottish industries and academia have continually invested in zero emission mobility to maximise the economic benefits to Scotland and, in doing so, have become one of the global leaders in this space. The Scottish Government have also invested in a number of innovative projects, such as:

- Investing an initial £113m towards zero emission buses and supporting infrastructure as part of the first phase of the Scottish Zero Emission Bus Challenge Fund (ScotZEB) to accelerate the uptake of zero emission vehicles.
- To grow and attract investment in electric vehicle charging, developing a £60m fund to enable local authorities to develop and deliver partnerships with the private sector.
- Setting up the Bus Decarbonisation Taskforce and Zero Emission Truck Taskforce which brings together senior leaders across sectors to work collaboratively and develop a pathway to enable a just transition to new technologies.
- Bringing together industry, academia, and enterprise through technology innovation centres.
- Building a hydrogen economy through hydrogen demonstration projects and the creation of regional hydrogen hubs across the country.

1.1.2 Overarching project aims

The overarching aims of the project is to review best practice to inform the development of an assessment methodology for demonstrating the economic and social returns on investment in zero emission / decarbonisation mobility innovation projects.

Through the current study, empirical evidence is sought to identify the magnitude of impacts on research and development investment, with due consideration of the distribution of impacts and how 'Just Transition' can be achieved during periods of change resulting from innovations. As part of this process, an initial output is to generate a logic map that sets out how public sector investment in zero emission / decarbonisation mobility

[1] Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 (legislation.gov.uk)

innovation projects translates through inputs and direct outputs into specific outcomes and economic and social impacts (including identification of metrics).

1.1.3 Focus areas of this study

To support the overarching project aims, several focus areas for the initial review of best practice were identified:

- Identify casual links between research and development / innovation funding and outputs, outcomes and impacts.
- Generate an understanding of how public sector research and development / innovation funding can stimulate wider private sector activity (particularly within the context of sustainability initiatives).
- Identify metrics that can be utilised to assess outputs and impacts.
- Compile an empirical evidence base of the scale / magnitude of the generated outputs, impacts per unit of funding.
- Consider the extent of Just Transition within the context of public research and development / innovation funding leading to equitable distribution of benefits via private sector activities.

1.1.4 Exclusions and limitations

The following are limitations to the scope of this study:

- The current study is not intended to produce a new assessment methodology or a definitive approach, but rather to provide a framework of ideas which could be taken forward / explored further.

The following elements were excluded from the scope of this study:

- Creation or roll-out of an assessment methodology.
- Economic modelling of the assets.
- Recommendation on a singular best practice of assessment.
- Research and modelling of energy consumption, generation, production, transportation, distribution and transmission.

1.1.5 Definitions and assumptions

The following terms are use throughout the report and are defined below:

- **R&D** - Research and Development.
- **Rate of Return** – for the purposes of this study, the rate of return indicates the economic and social benefits resulting from an investment, expressed as a percentage of the value of the investment itself.
- **Indicators** – factors used to measure the impact of R&D investment, these include employment impacts, GDP growth and private sector investment that is encouraged as a result of the public sector investment being made.
- **Total Factor Productivity** – a measurement of productivity that focusses on the efficiency of how inputs are utilised to produce outputs. This primarily relates to an increase in output that is not attributable to an increase in inputs, such as capital or labour. Total Factor Productivity instead focusses on how productive efficiency can be impacted without significant changes to inputs, thereby capturing the impact of greater efficiency on productivity rather than an increase driven by a proportionate increase in inputs.
- **Spillovers** – Wider impacts of an action that may not have been intended or which may be the result of seemingly unconnected activities. In relation to R&D investment, spillovers generally relate to impacts outside of the economic sector or geography in which the investment was made.
- **Knowledge diffusion** – The spread of knowledge, innovation or insight that leads to a wider impact on society or the economy. Where one actor innovates, knowledge of the results of this innovation can quickly spread throughout the economy, often across multiple sectors.

- **Decay effect** – the decay effect refers to how the impact of an intervention decreases over time or as the distance from the intervention increases. For the purposes of this study, the decay effect relates to how the benefits of innovation decreases over time, primarily driven by the increased obsolescence of innovation over time, as new technologies and practices develop.
- **Econometric analysis** – umbrella term for a range of statistical analytical approaches that are used to develop and test relationships between two or more variables.

1.2 Structure of report

The remaining sections of the report are structured as follows:

- **Section 2:** Approach – outlines the methodology followed for reviewing best practice.
- **Section 3**: Summary of findings – provides an overarching summary of the areas reviewed, including outputs, outcomes, wider impacts, metrics, scale of returns and the key factors to benefit realisation.
- **Section 4**: Interpretation of findings – interprets the findings of the best practice review, developing an overall logic map that provides an understanding of the potential direct and indirect consequences of investment, considering the impacts that may arise and outlining how a framework for estimating return on investment could be developed.
- **Section 5**: Summary and next steps – provides a summary of the findings and suggested next steps for Transport Scotland.

2 Approach

2.1 Introduction

To identify methods of appraising return on investment in zero emission / decarbonisation mobility innovation projects, a review of best practice was undertaken. The methodology for the literature review was systematic, in that it was replicable and transparent whilst providing a comprehensive, methodical, and critical assessment of the scope and quality of available evidence from the literature. Following the review and collation of evidence, a stakeholder workshop was held with Transport Scotland to discuss the findings.

2.2 Literature review methodology

A literature review was undertaken to collate evidence relating to appraising the return on investment for zero emission / decarbonisation mobility innovation projects. The methodology provided a comprehensive methodical and critical assessment of the scope and quality of available evidence from the literature. The literature review was comprised of the following seven steps:

1. **An inception workshop** to confirm the extent of literature to be included, the type of decarbonisation projects and key outcomes to explore.
2. **Identifying literature** to compile a long-list of candidate material for closer examination. A bibliography of 156 pieces of literature was identified which included government, industry, and academic publications. This was a two-stage process, with an initial focus on papers which focused specifically upon zero emission / decarbonisation mobility projects. However, on review it was acknowledged that the initial long-list did not encompass enough information on the impacts of projects on the economy and society. As a result, a broader secondary search of literature was undertaken focusing on the economic and social impact of innovation projects.
3. **Prioritising the longlist** to determine an agreed shortlist of articles to be reviewed. The long-list of 156 papers were scored by two reviewers, with a score between zero (lowest) to four (highest) based on their abstract, to prioritise those most relevant to the research question. From the long-list, 32 papers scored a four and, upon agreement with transport Scotland, were taken through to a short-list for a more detailed review.
4. **Creation of a review template** to ensure that insights from reviewing the literature could be appropriately structured. This included defined categories and a combination of population lists (to ensure consistency in reporting key metrics) and open text fields (to provide more descriptive commentary).
5. **Primary review of articles** by a team of a three primary reviewers and completion of the review template for each article. A pilot review of eight papers was used to test the extraction framework and amend accordingly. An additional high-level review was also undertaken by two technical leads to verify the information presented and ensure consistency across the primary reviewers.
6. **Secondary detailed review** of those papers considered to offer the greatest insight and to draw out further detailed information (above and beyond the review template). 18 core papers were considered to provide the greatest insight into causal linkages originating from research and innovation, provided evidence of specific metrics, and provided empirical estimates of the scale of impacts. Alongside an additional six papers that provided insights into specific topic areas, the secondary review of these 24 papers provided the main narrative for the development of the logging mapping process.
7. **Synthesis of findings** to collate evidence across key dimensions from the data extraction sheet and identify how many studies provide evidence across different outcome measures and what approaches were used.

2.3 Stakeholder workshop

Following on from the literature review stage, a stakeholder workshop was held on the 22nd April 2024, attended by the project team and subject matter experts within Transport Scotland. The workshop included a process of open and constructive dialogue to ensure the input of stakeholder expertise, and contained the following activities:

- The project team presented the preliminary findings identified to date from the literature review. This included the headline outputs, outcomes, impacts and metrics.
- Discussion on the implications of the findings for appraising zero emission / decarbonisation research and innovation:
  - What is the evidence of quantified social returns?
  - What are the logic chains to delivering impacts?
  - Consideration of the transferability from other geographies and sectors?
  - Evidence gaps and how they might be filled?

2.4 Reporting

The findings from the literature review, and insights from the workshop, are captured within this report. This includes the development of the logic mapping process and a framework for establishing the returns from research and innovation into zero emission / decarbonisation mobility projects.

3 Summary of findings

3.1 Overview

The collated literature on the impact of research and innovation is varied in both analytical approach and the research questions it seeks to answer, driven by the fact that identifying a holistic view of cause and effect of research and innovation investment is recognised to be challenging.

This literature review focused initially on a shortlist of 32 documents, identified from an initial long-list of 156 documents. Approximately half of these documents were published journal articles, one third published papers, and the remainder reports, chapters in books, thought pieces or business insights. All documents were published between 1998 and 2023, with 70% published in the last eight years. While only 17% of these papers related specifically to the UK, it is considered 77% relate to a socio-economic context that has ‘strong’ or ‘general’ similarities to the Scottish economy.

The shortlisted papers were chosen for providing a focus on how to measure the economic and social returns from research and innovation investment, and innovative activities. Rather than taking particular interest in sector-specific effects, the review explored how investment can stimulate economic and social activity, and whether a relationship exists between research and innovation investment and social returns.

3.1.1 Insights from shortlisted papers

As set out within Chapter 2, a primary assessment of the 32 shortlisted papers was conducted and was used to populate a structured review template. In particular this was utilised to identify the range of inputs, outputs, outcomes and impacts identified across the papers (reported below within Section 3.2).

From the primary assessment, the papers were categorised into four classes, based on the specific level of insight provided. While some of the papers ultimately transpired to offer relatively limited insight, 18 were considered to provide valuable evidence, with a further six giving insight on specific issues. Table 3.1 shows the relative classification of papers.

Table 3.1: Classification of relative insight of papers

Classification of insight	Number of papers	Percentage
No substantial insights	8	25%
Some limited insight on specific issues	6	19%
Key insight on specific issues	6	19%
Good insight from across the paper	12	38%
Total	**32**	**100%**

Source: Mott MacDonald

The primary review identified that nearly all papers report statistically significant evidence that investment into research and innovation is an effective use of public and private resources. According to the papers reviewed, research and innovation activities deliver economic and social impacts through a range of mechanisms including but not limited to externalities and spillovers, productivity gains, macroeconomic returns, and diffusion of knowledge between sectors (including between public and private).

While most papers reviewed report that research and innovation investment has a positive and statistically significant impact on social and/or economic metrics, the variability of the magnitude of benefits is high. The literature in general recognises this variability and discusses the reasons for this as well as the casual chain of impacts.

3.1.2 Topic areas of papers

The literature reviewed offered a range of insights across many topic areas. These topic areas align with the general or specific research questions the shortlisted papers look to explore. From attempting to identify the returns to investment at the macroeconomic level, to setting out the ex-ante assessment criteria for innovation in a specific sector, the shortlist offered ranging and comprehensive evidence. Figure 3.1 identifies the key topic areas identified from an initial review of the shortlisted papers.

Figure 3.1: Topic areas for key papers

- **Assessment criteria** for innovative solutions supporting transport decarbonisation
- **Evidence for investment** in research and ways in which the return on this investment can be increased
- **Rate of return** to investment in science and innovation
- **Returns to investment** in R&D
- The **case for expenditure** on R&D
- **Key indicators of economic significance** of the science base
- **Impact of innovation** on regional economic performance
- Relationship between R&D investment and **firm / industry productivity**
- Impact of R&D **upon GDP per capita**
- Relationship between **total factor productivity** and public and private R&D
- **Drivers of innovation**, the role of private and public R&D, and the impact of distribution of innovation
- **Analysis of returns** to R&D investment
- **Returns to publicly performed** R&D
- **Value of** R&D for clean technologies
- **Too much or too little** R&D?
- **Social returns** to investments in innovation
- Public-funded research **role in economic development**
- Approach to **capturing and communicating impacts** of research and innovation funding

Source: Mott MacDonald

These topic areas aim to show the overarching commonalties and differences between the papers, and research questions considered. For example, it is evident that mapping input (i.e., research and innovation investment) straight to impact (e.g., macroeconomic indicators) is common in econometric analyses, with the causal chain of outputs and outcomes left open for interpretation. In a few cases sector-specific approaches (e.g., transport decarbonisation and science) offer more insight into the causal R&D and innovation chain.

3.1.3 Literature evaluation techniques

The literature review highlights that there are difficulties in capturing the economic and social impacts of research and innovation investment. These are partially founded in the time delay, otherwise known as lag, between the investment and realisation of impacts, as well as the widespread impact specific interventions can have (i.e., spillovers and externalities). To fully understand the insights provided by the literature, it is necessary to outline some of the techniques employed to make causal inferences about the effect of research and innovation. Common themes and techniques from the shortlisted papers are identified and discussed below.

Data

Broadly, the metric used by the literature in measuring the inputs to research and innovation is the expenditure, or investment, often as a proportion of GDP in a particular geography. The analyses generally map these data against impact metrics such as Total Factor Productivity and GDP per capita (discussed in more detail in Section 0).

The data requirement of the papers are usually panel or time series datasets to see effects over time (accounting for lags). Outputs and outcomes are not as widely considered in econometric analyses as inputs or impacts (for more information, refer to Sections 3.2.1 and 0 respectively).

Lags

In the context of research and innovation investment, lags refer to the time delay between conducting research and innovation activities and realising the benefits from the output of these activities. The literature uses lags in econometric analysis, assuming the level to which impacts are lagged behind inputs and outputs of R&D. Assuming the duration of the lag is necessary for econometric analyses as it is not certain how an innovation and its effects entirely transpire, even ex post.

Timescales and lags are discussed in more detail in Section 3.5.1.

Level of aggregation

The level of aggregation of data refers broadly to the level of analysis conducted, most commonly changing by geographic and sectoral levels. Most of the papers reviewed use macroeconomic indicators when estimating the impacts of research and innovation, meaning the analysis is economy wide. This approach offers benefits in identifying direct and indirect impacts of research and innovation investment and avoiding bias of considering only successful research and innovation projects.

The constraint on this analysis, however, is that sometimes the causal chain considers only input (research and innovation investment) and impact (e.g., GDP growth), leaving outputs and outcomes open for interpretation.

Econometric approach

The econometric approach employed by several of the papers is regression analysis, ranging from meta-regression models to multiple regression models, and simplest of all linear regression models. Several studies are meta-analyses bringing together insights from a range of sources, developing an idea of a consensus in the literature regarding the rates of return to R&D investment. A small number of studies take a more novel approach such as the following:

A calculation of the social returns to innovation (Jones and Summers, 2024)

The paper develops an economy-wide calculation estimating the social returns to investments in innovation. The equation considers the investment into R&D, productivity growth rate, and the value of this to society via the social discount rate. The intention of the paper is to net out complicated spillovers, to develop a simple calculation of the social return to innovation.

Estimating the Returns to Public R&D Investments: Evidence from Production Function Models (Van Elk et al., 2019)

This paper explores the role production functions have in estimating the effect of R&D investment on economic output. The paper finds that the effects of economic return to public R&D investment is not unambiguously positive with varying estimates across production function models. As opposed to offering causal insights, the paper suggests assuming the production function in econometric analysis may affect causal inferences, which may give indication to robustness of results in the literature.

The evaluation techniques differ (at least marginally) across all papers reviewed as part of this study. This section intends to show some of the common themes, and key differences in quantification that have been deemed important in the development, and therefore interpretation, of econometric results.

3.2 Summary of outputs, outcomes and impacts listed across literature

Research and innovation investment is targeted to enact positive change and progression from the status quo. The causal chain through which this works is key to understanding how the initial investment can become the positive change, and what is necessary to realise it. This section outlines key findings across the literature for each aspect in this casual chain from input (R&D investment) through to impact (e.g., economic and social impact) as shown below.

Figure 3.2: R&D Causal Chain

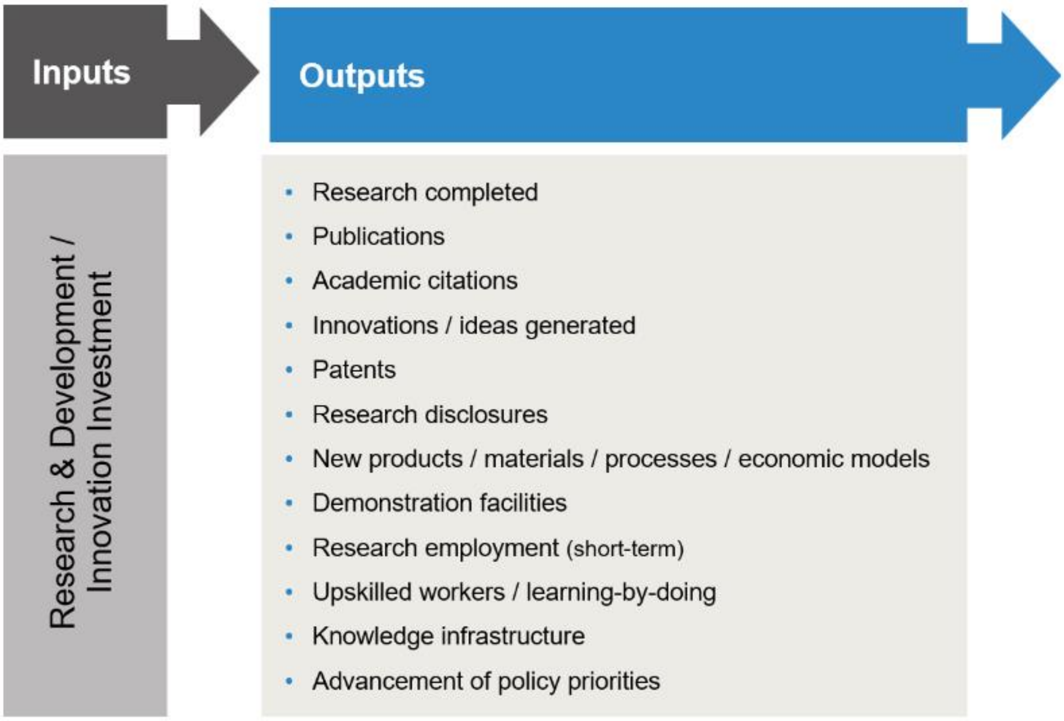
Source: Mott MacDonald

3.2.1 Outputs

The investment into research and innovation is intended to directly deliver outputs. Outputs in this context refer to what research and innovation activities materially deliver in the specific context the investment is targeted.

Outputs, depending on their quality and relevance, can create positive change in outcomes and, therefore, impacts. Figure 3.3 details some of the key expected outputs of R&D activities detailed by the literature reviewed.

Figure 3.3: R&D Outputs



Source: Mott MacDonald

Figure 3.3 shows that the outputs of innovation can be varied depending on the context in which research and innovation is performed. The completion of research, consequent publication of academic literature, obtaining patents, and upskilling workers are all considered to be outputs following investment into innovation. The following example details some the key outputs arising from investment in science and innovation.

Rates of Return to investment in science and innovation (Frontier Economics, 2014)

This paper develops a framework linking science and innovation investment to economic returns. The main outputs of the investment are the development of public and private knowledge stocks (e.g., ideas and methods). With application to business / industry (which is an outcome of R&D) this can stimulate further innovation and outputs (e.g., products and processes). These outputs generate positive externalities such as knowledge leaks, while also negative externalities such as obsolescence of old products and processes.

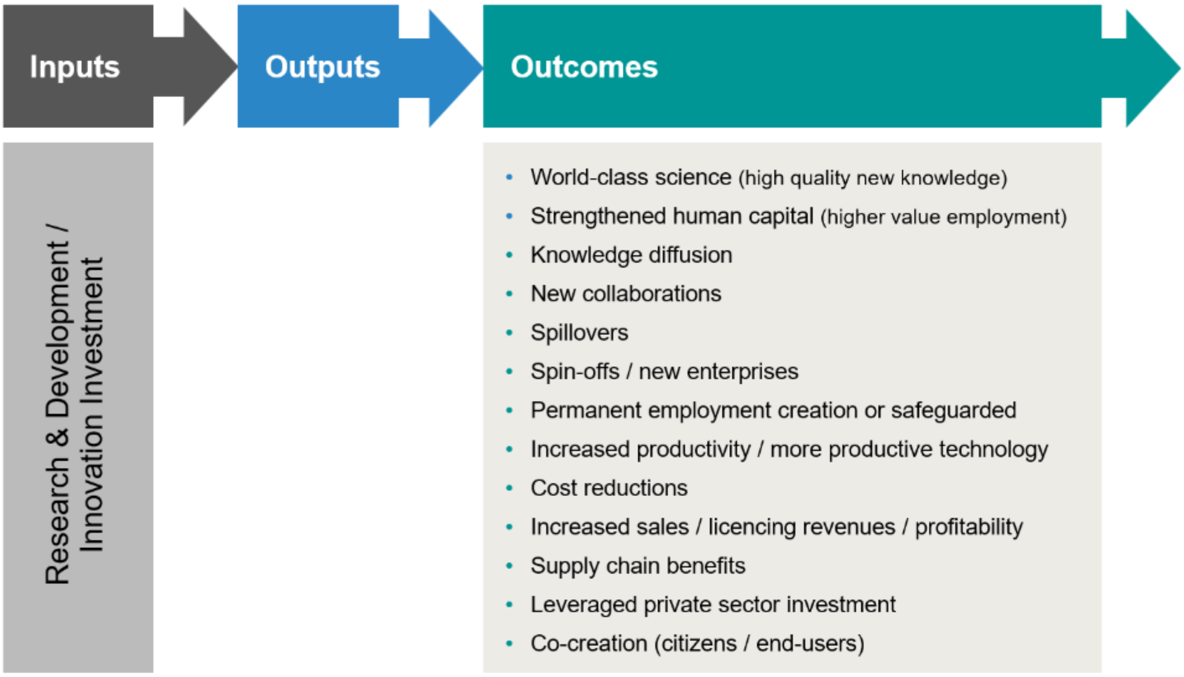
In some instances, outputs can be monitored and measured, for example using academic citations as a metric to review the return to funding academic institutions and research. In other instances, outputs of research and innovation investment are hard to identify in their entirety, for example the broad development of knowledge infrastructure.

Output metrics identified by the literature are shown in Section 173.3.

3.2.2 Outcomes

In the context of research and innovation investment outcomes refer to the benefits or changes that occur as a result of the outputs. Outcomes are often more specific and immediate than impacts, which materialise over time through the cumulation of outcomes. Figure 3.4 details some of the key expected outcomes of R&D activities detailed by the literature reviewed.

Figure 3.4: R&D Outcomes



Source: Mott MacDonald

Figure 3.4 shows that the outcomes that can be realised by outputs of research and innovation investment are also varied depending on the type of activities undertaken. Knowledge spillovers and diffusion, cost reductions, profitability and employment creation / safeguarding are all outcomes commonly associated with innovation.

The literature review validates these associations, identifying these outcomes as some of the core determinants in realising positive change and progress following research and innovation activities.

The following examples find evidence on key positive outcomes of investment into research and innovation.

From Ideas to Growth (Aitken et al., 2021)

This report analyses the factors explaining innovative performance across UK regions and industries. The report finds that higher R&D expenditure leads to more innovation outputs, and that in some regional clusters, there is a positive effect of public R&D funding and knowledge spillovers (outcome) between firms regarding innovation.

Framework for measuring research and innovation impact (Cheh, 2016)

This paper provides a framework for defining and measuring indicators for research, innovation, and enterprise to facilitate estimation and comparison of the economic impact of public-funded technological innovation at the firm, industry and national levels. The direct metrics from research (outcomes) the paper considers are the fees generated from licensing or intellectual property rights, and new ventures (spin-offs), also once again emphasising the importance of knowledge transfer / diffusion.

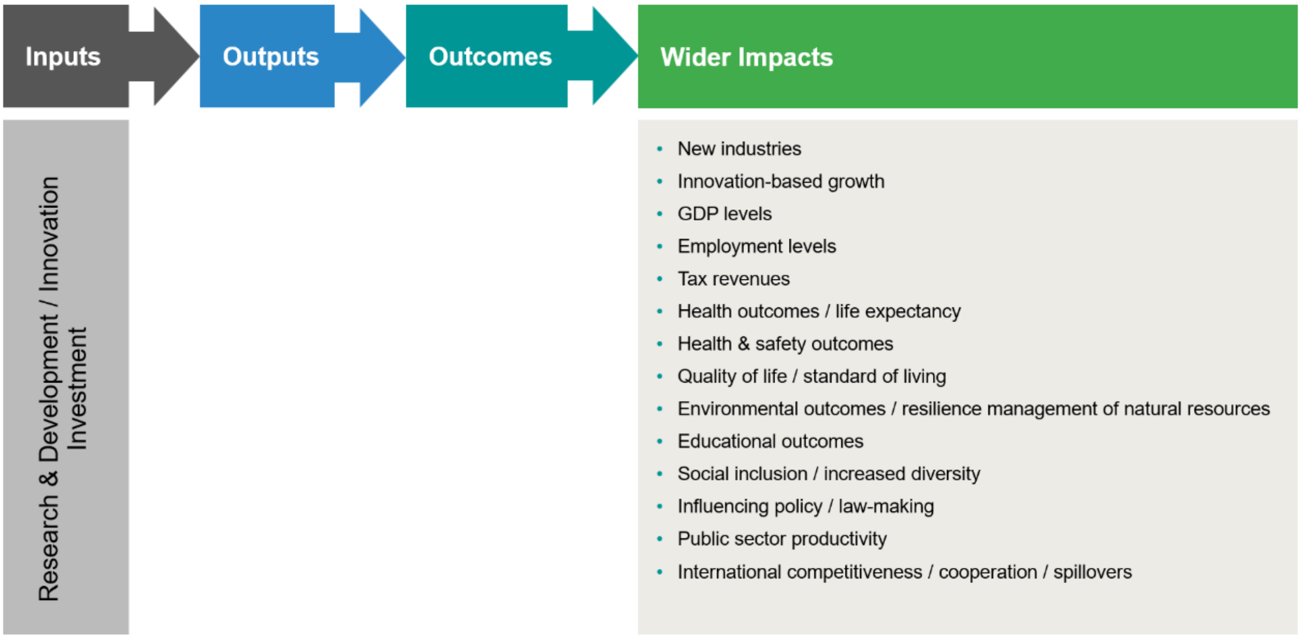
Much like outputs, the ease in capturing outcomes varies due to the availability of appropriate metrics. For example, at the micro level, data regarding cost savings and profitability are relatively straightforward to identify; however in aggregation across an industry, this may be more difficult.

Outcome metrics identified by the literature are shown in Section 173.3.

3.2.3 Wider impacts

In the context of research and innovation investment impacts refer to the long-term effects, or value, created by the outcomes. They are often broader, and more significant, than the outcomes that support the realisation of impacts. Figure 3.5 details some of the key wider impacts of R&D activities detailed by the literature reviewed.

Figure 3.5: R&D Wider Impacts



Source: Mott MacDonald

Figure 3.5 shows the wider impact areas that could result from the outcomes of research and innovation activities. The literature offers evidence to suggest that the private sector is stimulated by public sector research and development, corroborating the significance of knowledge transfer and diffusion.

Additionally, some of the impacts detailed in the literature, such as environmental outcomes and standard of living, align with the Scottish Government's commitment to a 'Just Transition – A Fairer, Greener Scotland'[2]. A Just Transition refers to the following.

Just Transition – A Fairer, Greener Scotland

A Just Transition is a commitment by the Scottish Government in decarbonising its economy to secure high-value jobs in green industries through skills training and education, while ensuring job security for those in industries most affected by the transition to a low-carbon economy. A Just Transition also encompasses the development of energy-efficient homes and sustainable infrastructure, and the equitable distribution of costs and benefits, ensuring that the transition does not burden the least able to pay and that its benefits are universally accessible.

Regarding the analysis of the literature, the types and magnitude of impacts of research and innovation investment are varied with the scale of returns discussed in more detail in Section 3.4.

The following examples give insight into the way in which impacts are realised and captured.

R&D, spillovers, innovation systems and the genesis of regional growth in Europe (Rodríguez-Pose and Crescenzi, 2008)

This paper explores how factors, such as innovative effort, socio-institutional contextual factors, and localised knowledge spillovers, interact and account for growth trends. The paper's multiple regression analysis maps inputs (R&D expenditure) straight to impacts (GDP growth rate), finding 1 percentage point increase in R&D expenditure as a share of GDP contributes to around 0.2 percentage point increase in annual growth rate of GDP.

The Economic Impact of Research and Development (Surani, Gendron and Maredia, 2017)

The paper conducts global cross-sectional analysis on the economic impact of research and development. Once again, to conduct the econometric analysis the paper utilises macroeconomic indicators, finding a positive effect of increasing research and development expenditure (input) on GDP per capita (impact).

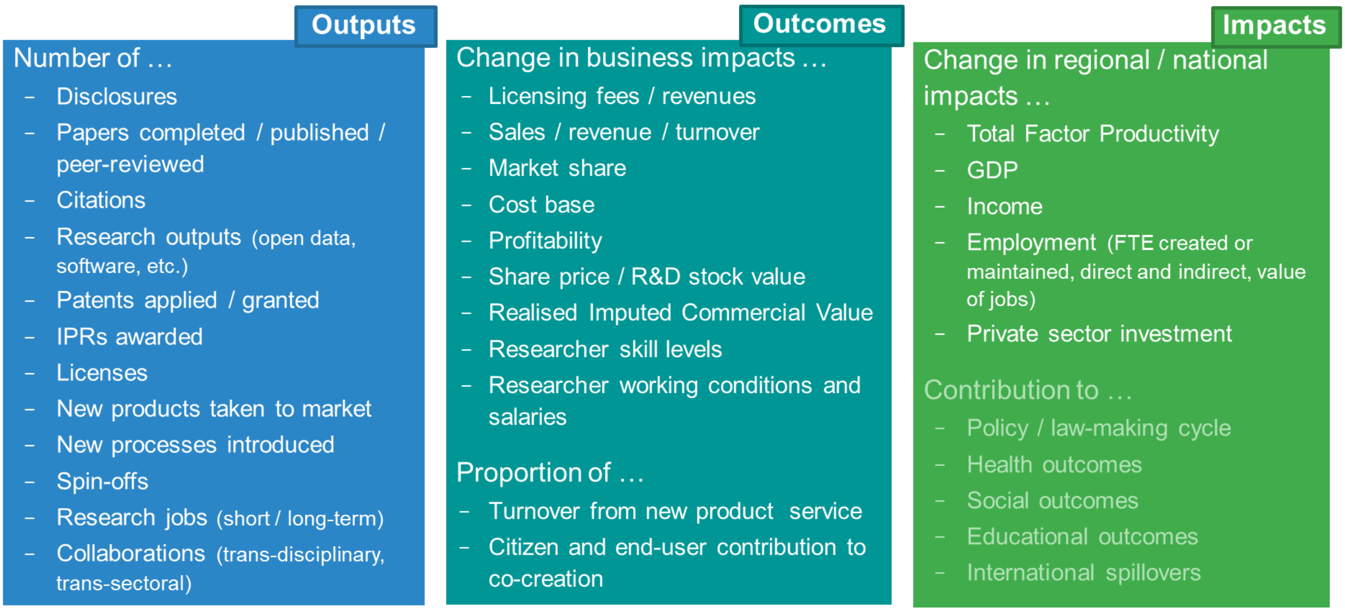
The next section identifies the metrics that the literature has identified for the capture of outputs, outcomes, and impacts.

[2] Scottish Government, 2021. Available at: Just Transition - A Fairer, Greener Scotland: Scottish Government response - gov.scot (www.gov.scot)

3.3 Summary of metrics listed across the literature

The way in which the literature reports how inputs affect outputs, outcomes and impacts has been discussed; however, it is necessary to consider how, in practise, the magnitude of effects of research and innovation investment may be captured across the causal chain. Figure 3.6 exhibits the metrics identified in the literature that can be used in quantification of the effects of research and innovation investment across the causal chain.

Figure 3.6: Research and Innovation Metrics



Source: Mott MacDonald

The particular research question that is under consideration will affect the usefulness of the metrics identified in Figure 3.6. For some types of analyses specific metrics, such as patents granted, market share changes, and FTEs created, may be the most appropriate for the identification of causal effects. In other types of analyses, more general indicators, such as GDP and Total Factor Productivity, may be more appropriate.

As a general observation, the literature often opts for more general indicators (including some of those listed above), to capture the wide-ranging impacts of research and innovation activities. Specific metrics may suffer from underestimation of impacts, through the omission of spillover effects in benefit estimation. Reported scale of returns from research and innovation is discussed in more detail within Section 3.4 below.

3.4 Scale of Returns

3.4.1 Core findings

Following the discussion about the way in which research and innovation investment can lead to positive change, this section outlines the magnitude of returns to research and innovation investment documented by the literature.

The scale of returns is an important consideration given economic decisions are founded in channelling resources into their most efficient and productive use.

3.4.1.1 Economic and social rates of return

Channelling economic resource towards research and innovation activities becomes more justifiable, and hence feasible, where there is a consensus of a material economic or social return to the investment.

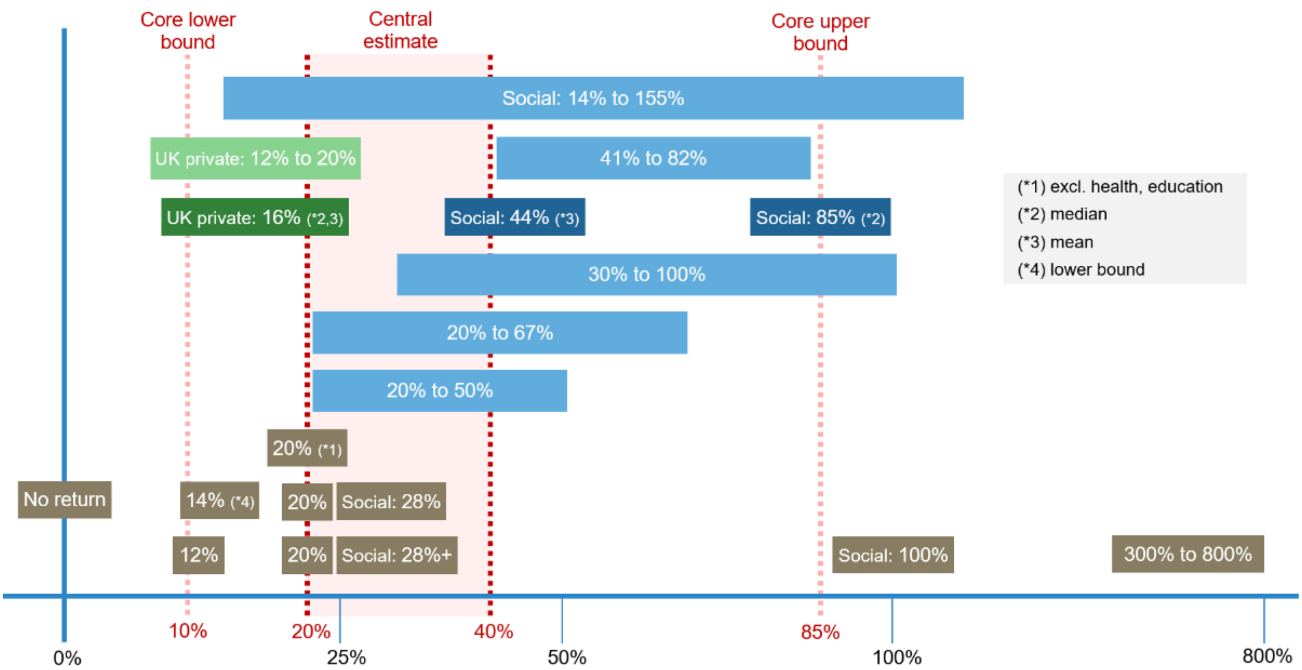
A rate of return refers to the monetary equivalent yielded in impact from input. For example, a 30% rate of return from £100 research investment (input) would yield £130 gross economic return (£30 net) in the impact measure.

Across the literature, multiple studies report a rate of return as the key metric. Many of these are economic rates of return, but some attempt to capture a broader value in social rates of return. The majority of the literature examines returns at a national level, often using a lagged measure of GDP (e.g., GDP one or more years post the recorded value of national research investment) as a core measure. Much of the literature suggests that there tends to be a decline after initial returns on investment are realised.

As the majority of empirical studies examine the impact of research and innovation with a lag below three years, primarily constrained by data availability and confounding factors, the estimates reported will only capture the relatively high initial rate of return before material depreciation in impact occurs. Determining the rate of depreciation is extremely difficult so most studies assume a 15% depreciation rate for returns to R&D investment following Griliches (1998), whereas some other studies assumed 10% or 20% annual depreciation rate. These assumptions are reasonable given that international and UK guidelines estimating lifecycles of R&D assets in the order of 10 years before obsolescence.

Figure 3.7 maps out the key empirical estimates identified of economic and social rates of return to R&D investment. Table 3.2 subsequently matches these estimates with relevant sources.

Figure 3.7: R&D Return on Investment estimate range



Source: Mott MacDonald

Table 3.2: Rate of return to R&D estimates

Source	Type of analysis	Rate of return
S-2 Value of Research - Policy Paper by the Research, Innovation, and Science Policy Experts (Georghiou, 2015)	Meta-analysis of multiple studies	20-50% 300-800%
S-3 Rates of Return to Investment in science and innovation	Econometric / empirical analysis	12-20% (UK private range)

Source	Type of analysis	Rate of return
(Frontier Economics, 2014)		16% (UK private median)
		Social 14-155% Social 85% (median) Social 44% (mean)
S-4 Rate of return to investment in R&D: A report for the Department of Science, Innovation, and Technology (Frontier Economics, 2023)	Meta-analysis of multiple studies	14%
S-5 Why fund research? A guide to why EU-funded research and innovation matters (Hines, 2017)	Guide detailing the importance of research and innovation	20%
S-6 The Economic Significance of the UK Science Base (Haskel, Hughes and Bascavusoglu-Moreau, 2014)	Econometric / empirical analysis	41-82%
S-8 R&D and productivity in OECD firms and industries: A hierarchical meta-regression analysis (Uger et al., 2016)	Meta econometric / empirical analysis	14%
S-13 The rate of return to investment in R&D: The case of research 01infrastructures (Del Bo, 2016)	Meta-analysis of multiple studies	20-67%
		Social 28%
S-22 Measuring the Social Return to R&D (Jones and Williams, 1998)	Theoretical framework / estimation of social value	Social 30-100%
S-24 A calculation of the social returns to innovation (Jones and Summers, 2020)	Framework for social value estimation	Social 100%

Source: See table

The findings of the literature review show that the estimated impact of R&D investment is reported as extremely varied overall, with significant extremes of either zero or up to 800%. However, through synthesis of the evidence, there appears to be a general consensus of a core lower bound of around 10% rate of return, and a core upper bound of 85% rate of return.

Furthermore, clustering of estimates within this range enables the identification of a central estimate for the return to research and innovation investment. This central estimate has been identified as a range of 20% to 40% social rate of return to research and innovation investment.

What is apparent from the literature is that there are a wide range of determining factors that will impact upon the potential rate of return. These factors are discussed further within Section 3.5.

3.4.1.2 Alternative analytical metrics

Beyond rates of return, several other analytical metrics have identified the impact of research and innovation investment. Those detailed within the literature worthy of note include:

- One percentage point increase in R&D expenditure as a share of GDP contributes to a 0.2 percentage point increase in annual growth rate of GDP (Rodríguez-Pose and Crescenzi, 2008).
- One percentage point increase in R&D expenditure leads to increase in GDP per capita by around 10% (Surani, Gendron and Maredia, 2017).
- Average social returns to innovation investment over $20 per $1 spent (Jones and Summers, 2020).

The literature also identifies a relatively broad consensus around an output elasticity from research and innovation investment of 0.07 to 0.08. In practice, this means that by increasing research and innovation investment / activities by 100%, a 7% to 8% rise in outputs could be expected, albeit this is likely to be subject to decay over time (as discussed further within Section 3.5.1). The literature is clear that not all research and innovation activities are successful, and this measure may be useful in managing expectations relating to research and innovation investment.

3.4.1.3 Contextual impacts

Generally, the literature and associated empirical analyses have contextual factors affecting the analyses, such as geography and sector (e.g., public / private). At in some instances these factors are explored as to their impact on realising positive effects of research and innovation, either when considering the robustness of analysis, or when determining the main research question.

For example, Surani, Gendron and Maredia (2017) propose that country specific policy can affect the rate to which there is economic return to R&D investment. The paper finds the UK as a nation has an insignificant effect on returns to public sector R&D investment, whereas Ireland has the strongest positive effect of the 22 OECD countries considered. In contrast, Aitken et al. (2021) find evidence to suggest that productivity boost from innovation is significant in Scotland.

The literature claims that the private sector is likely to underinvest in research and innovation for reasons such as credit constraints due to imperfect capital markets, risk and uncertainty, and short-termism. It is suggested that public subsidies can mitigate these frictions, spurring R&D activities (Martin and Verhoeven, 2022). Indeed, Jones and Williams (1998) suggest in exploration of the social return of R&D, that R&D in the USA should have been four times larger than the amount observed at the time of writing, supporting the notion that the private sector underinvests in R&D.

There are many factors that can affect not only the performance of research and innovation, but also the magnitude of benefits realised from innovative actives. Section 3.5 provides more detail on the key factors affecting benefits realisation.

3.4.2 Summary

To summarise the findings of the literature, the estimates of the rates of return to research and innovation investment vary in magnitude; however, a clustering of key estimates, and consensus in the literature, has enabled the synthesis of estimates of social rates of return on investment:

- Core lower bound: 10%
- Central estimate range: 20% to 40% (most likely return)
- Core upper bound: 85%
- Out of range estimates: Some estimates are considerably higher than the upper bound (i.e., 100% or more)

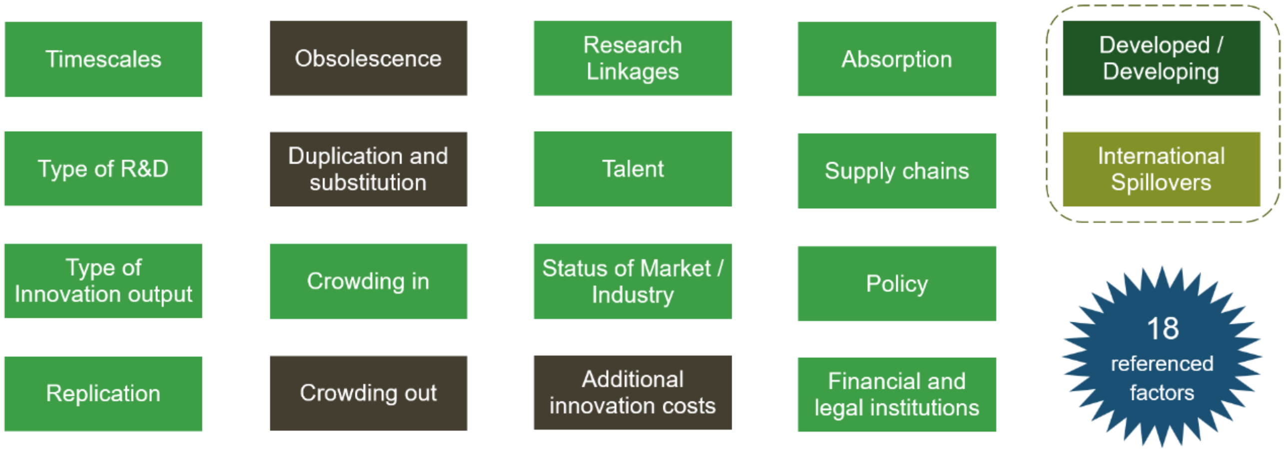
While the robustness of estimates discussed throughout this section and used to develop these boundaries of return is generally high, they may not fully capture the wider social impacts of research and innovation investment, particularly in relation to health and wellbeing. At present, the literature remains limited in capturing these benefits, which in turn means estimates largely don’t include them in the magnitude of benefits. It should be stated that this is not to say that these benefits are not realised following research and innovation investment, but rather the academic and research community is constrained in quantifying these impacts.

This section has outlined the benefits that could be expected from R&D investment; however it has also alluded to the fact the realisation of these benefits depends upon range of key factors. Section 3.5 discusses some of the key factors affecting benefits realisation from R&D investment.

3.5 Key factors to benefits realisation

As highlighted within Section 3.4, the literature identifies a wide range of factors that are likely to affect the scale of rates of return from research and innovation investment. Figure 3.8 provides an overview of the key factors that the literature identifies as likely to affect the realisation of benefits. These factors can affect either the likelihood of the success of research and innovation activities, as well as the magnitude of the positive effects that may be realised.

Figure 3.8: Key factors for the realisation of benefits



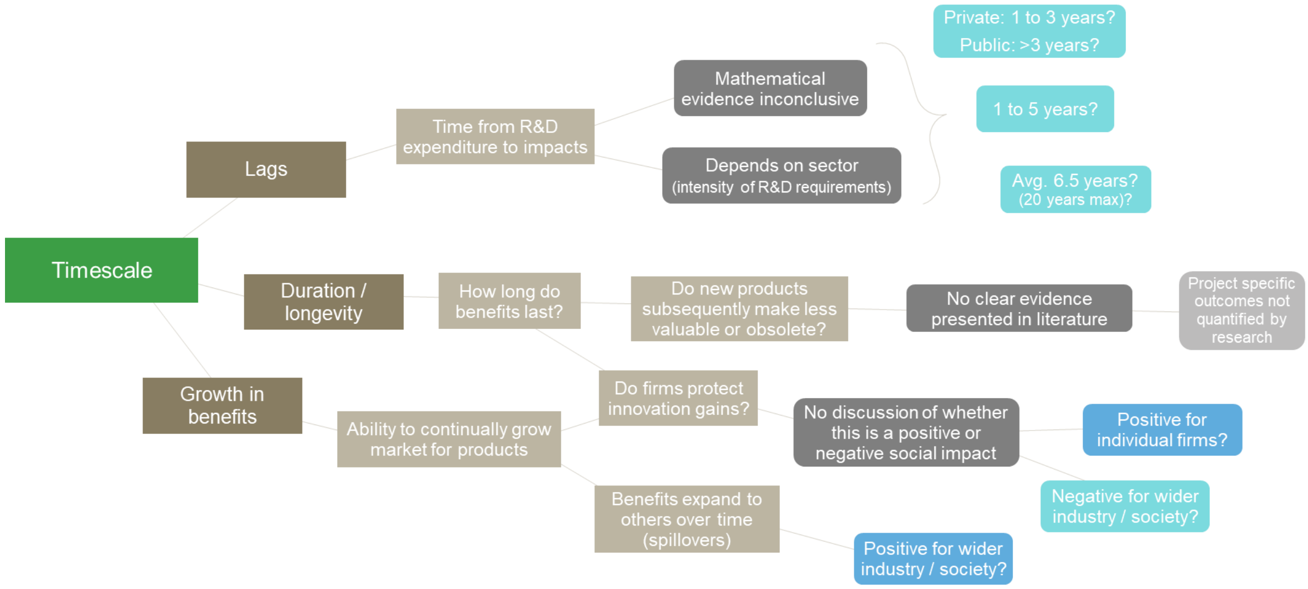
Source: Mott MacDonald

This section details the way in which many of these key factors can influence the process of how research and innovation inputs lead to outcomes and impacts, as well as providing insight into some of the unintended consequences of innovation, both positive and negative.

3.5.1 Timescales

The realisation of the benefits associated with research and innovation investment are subject to timescales. Timescales in this context refers to any duration of time that affects the realisation of positive impacts of research and innovation. This includes lags between input and impact, duration and longevity of impact, and growth in benefits over time. Figure 3.9 maps out the findings and key questions appearing in the literature regarding timescales.

Figure 3.9: Timescales associated with realising benefits of R&D investment



Source: Mott MacDonald

As referenced in Section 3.1.3 the benefits of research and innovation investment are often not immediately realised, with impacts lagged behind inputs. Some of the reasons for this lag include:

- There is time required to conduct research and innovation activities that the investment enables, which intends to produce output(s).
- Once research and innovation activities have been completed successfully, it can take the market time to adopt advancements, such as new technology.
- Once an innovation has been adopted and taken to market, it takes time to realise the benefits in their entirety as the market response may not be immediate, or the benefits accumulate over time.

In the estimation of benefits to research and innovation investment, the literature often must make an assumption regarding the likely duration of lags. Private research and innovation is considered to deliver commercialisation and economic return more quickly (one to three years) than public research and innovation (three plus years) given the latter may tend to be more general, without explicit commercial applications (Frontier Economics, 2014). Jones and Summers (2020) suggest that on average there is a 6.5-year delay until benefits are realised from R&D, while 10-to-20-year delays are considered lengthy lags.

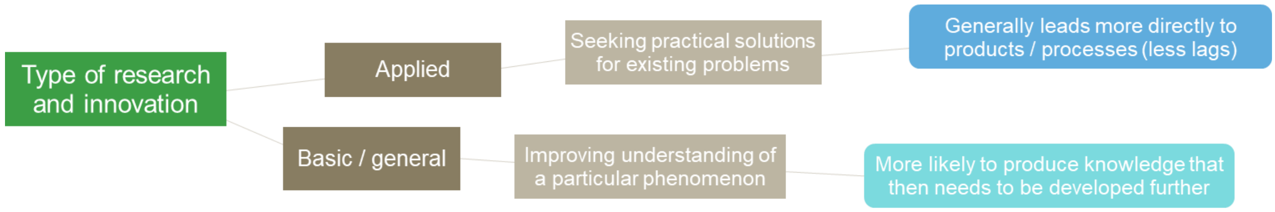
As well as lags, the duration and longevity of benefits is a key consideration. It is recognised that benefits can only accrue for as long as the specific innovation remains relevant, or it becomes obsolete by a superior innovation. There is no clear evidence provided by the literature on the duration of benefits, with project specific outcomes generally not quantified. Nevertheless, it is important to consider that benefits will accrue over a finite period at least partially because of obsolescence and superior innovation, which is discussed in greater detail in Section 3.5.3.

Regarding growth of benefits, the literature generally gives reference to benefits expanding to others over time, in the form of spillovers, which is a positive impact on wider industry and society. However, there is a recognition that, in a competitive landscape, it could be expected the private sector would protect innovation gains that generate returns to the individual firm. In such circumstances the benefits to wider society and industry may not be fully realised. There is no discussion to this point in the literature reviewed, but consideration for the competitive nature of industry is important when considering the likelihood and possibility of spillovers following private research and innovation.

3.5.2 Types of R&D and innovation outputs

The likelihood of success of research and innovation investment and activities, as well as what can be considered a success, can vary depending on the type of research and innovation performed, whether this be applied or general. Figure 3.10 distinguishes between these two types of research and innovation, defining what they are, and what is expected from each type of research and innovation.

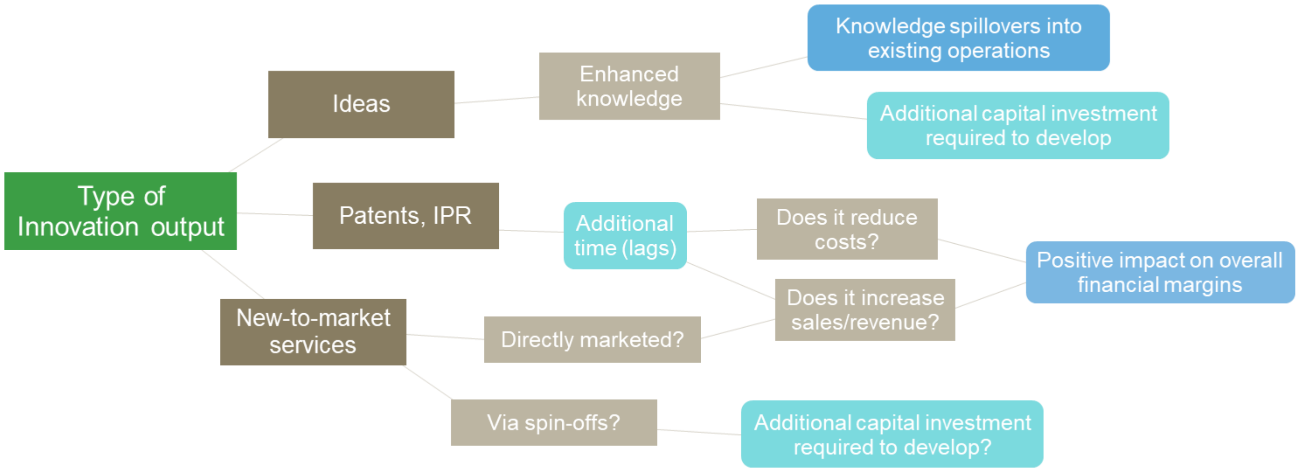
Figure 3.10: Type of research and innovation



Source: Mott MacDonald

In the performance of research and innovation, both applied and general, there is a range of output types that can be delivered by investment. Figure 3.11 shows some of the key types of outputs identified in the literature, showing how these outputs map through to outcomes and impacts.

Figure 3.11: Type of innovation output



Source: Mott MacDonald

The key types of output of innovation include ideas, patents and intellectual property rights, as well as new-to-market services. Ideas enhance knowledge creating spillovers, but are insufficient alone to create tangible change, instead requiring further capital investment to implement the idea.

Patents and intellectual property rights can take time to secure (generating lags), and generally look to increase profitability by either reducing cost or increasing revenue.

New to market services can be aimed at inducing increased revenue and profitability, however, can also be via spin-offs which can require capital investment in development and rollout.

Overall, the types of research and innovation, and the types of outputs of innovation, can both be varied. This can affect the chain of events required to realise the benefits of research and innovation.

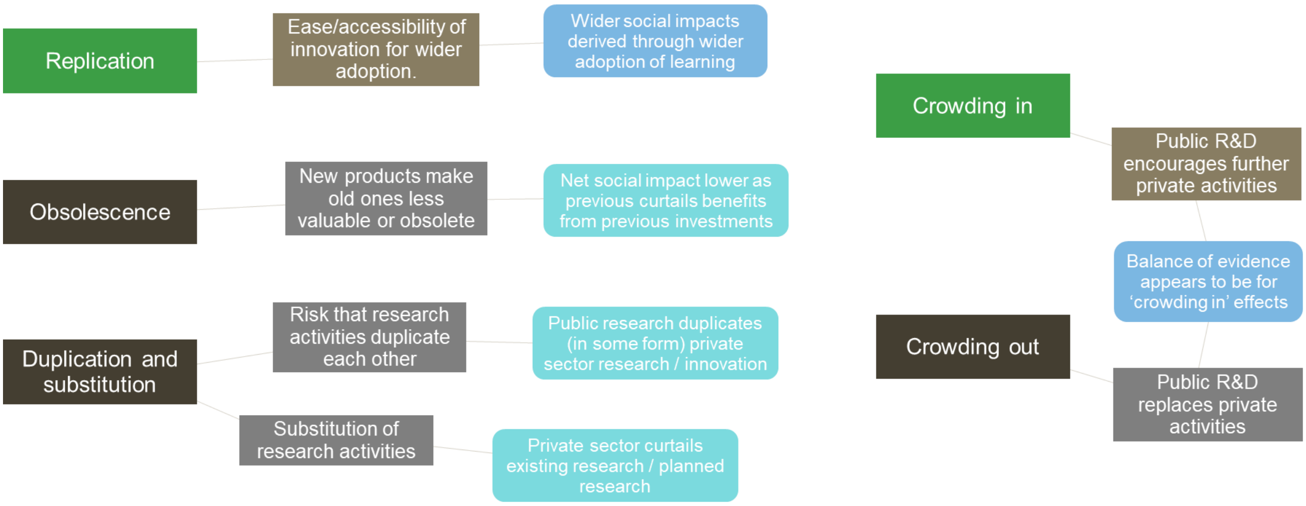
3.5.3 Interactions and unintended consequences of public sector intervention

With public sector intervention in research and innovation there exist interactions and unintended consequences with the private sector and, more generally, the operation of markets and research.

Positive consequences / interactions of research and innovation include replication and ‘crowding-in’; negative consequences / interactions include obsolescence, duplication and substitution, and ‘crowding-out’.

Figure 3.12 details the meaning and associated repercussions of these interactions and unintended consequences that have been identified in the literature.

Figure 3.12: Interactions and unintended consequences of public R&D



Source: Mott MacDonald

With regard to positive consequences / interactions, replication can enable widespread adoption of the outputs of research and innovation which can derive wider positive social impacts, while ‘crowding-in’ catalyses further research and innovation investment. The countering negative consequence / interaction to the latter would be ‘crowding-out’, which would see public research and innovation replace private activities; positively, the literature finds greater evidence that public research and innovation ‘crowds-in’ further private sector R&D activities.

Regarding other noted negative consequences / interactions in Figure 3.12, obsolescence refers to new products replacing or superseding old ones, which reduces the net social impact of research and innovation, and its outputs, as the benefits of previous research and innovation are curtailed.

Duplication and substitution refers to the risk that new research and innovation activities are replicating research that is already on-going, or that other research activities are curtailed because of the new activity. This is not only unproductive, but also acts as an inefficient use of public funds if the private sector has intended to perform such research and innovation.

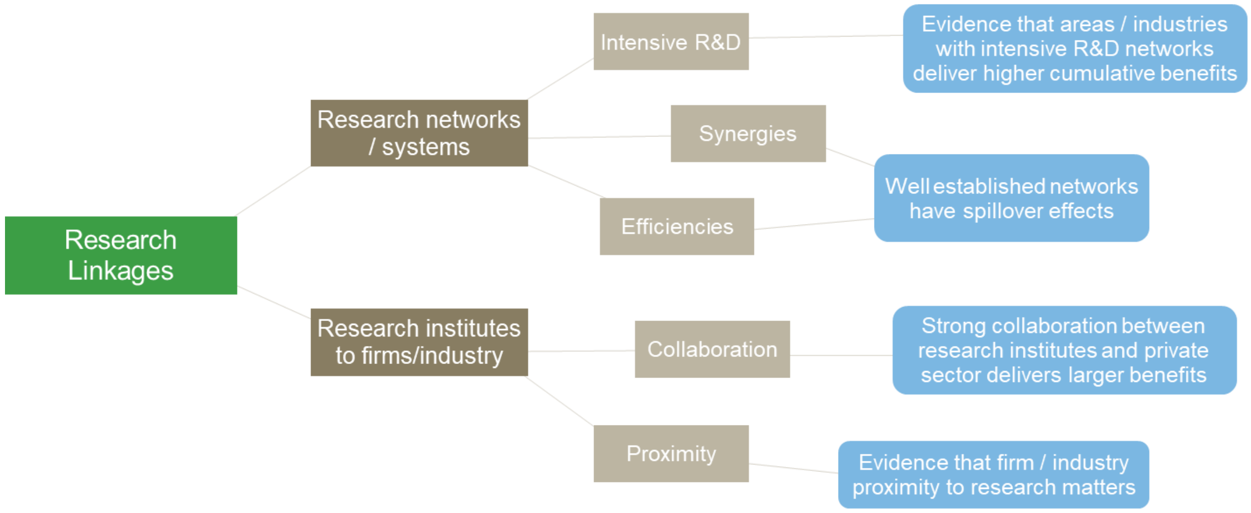
Interactions and unintended consequences can be considered the byproducts of innovation in one sense but also a key factor affecting the realisation of benefits and their magnitude. The literature indicates that they should be a key consideration of what constitutes the efficient use of public resource to perform research and innovation.

3.5.4 Influence of existing research networks and available talent

The performance of research and innovation builds on an existing stock of knowledge and research networks. These research linkages can increase the productivity and likelihood of success of research and innovation activities, also helping to maximise the realised impacts.

Figure 3.13 identifies key research linkages, and the effects they have on research and innovation.

Figure 3.13: Influence of existing research networks



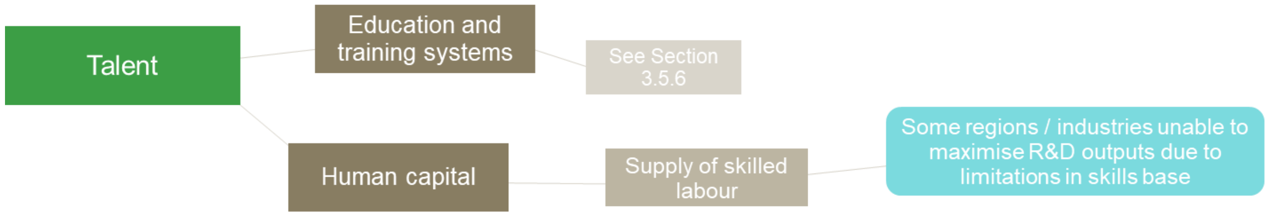
Source: Mott MacDonald

Figure 3.13 shows that research linkages through networks and between institutes and industry, can bring about benefits such as increasing the intensity, synergy, and efficiency of R&D, as well as increasing the collaboration between industry and research institutes. There is evidence that more intensive research and innovation networks deliver higher cumulative benefits and spillovers, increasing the returns to research and innovation.

Additionally, linkages between research institutes and industry fosters strong collaboration to deliver larger benefits; however, it is suggested that geographic proximity of the firm to research institutes affects returns (Rodríguez-Pose and Crescenzi (2008) and Frontier Economics (2014)).

Additional to research linkages, availability of talent is identified as a key factor affecting research and innovation activities. Figure 3.14 identifies that the stock of human capital, and therefore the supply of skilled labour, affects the ability to perform research and innovation, also affecting the ability to successfully realise the benefits from it. The literature most notably identifies this as a restriction on regions with limitations in skills base.

Figure 3.14: Influence of talent

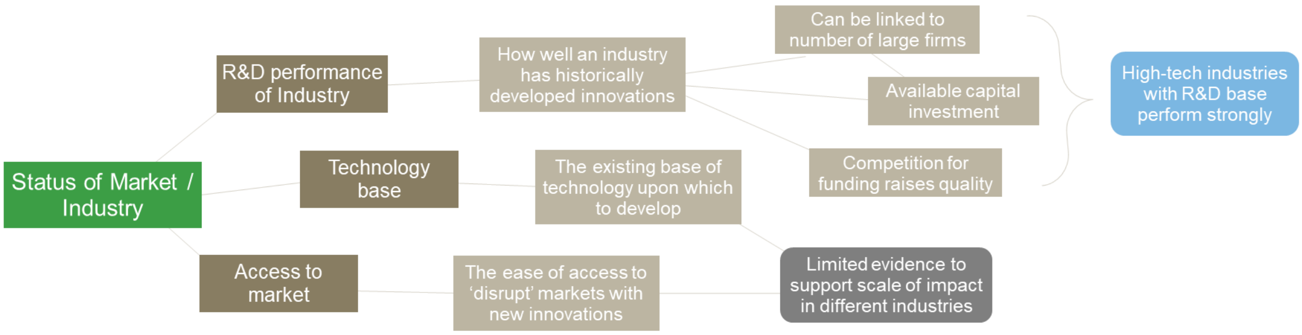


Source: Mott MacDonald

3.5.5 Market / industry factors

The extent to which research and innovation is performed, and is successful, can be dependent on the type of industry performing it, and the historical success of innovation upon that research and innovation activities build upon. Figure 3.15 details the way in which market and industry factors could affect R&D activities.

Figure 3.15: Market / Industry factors



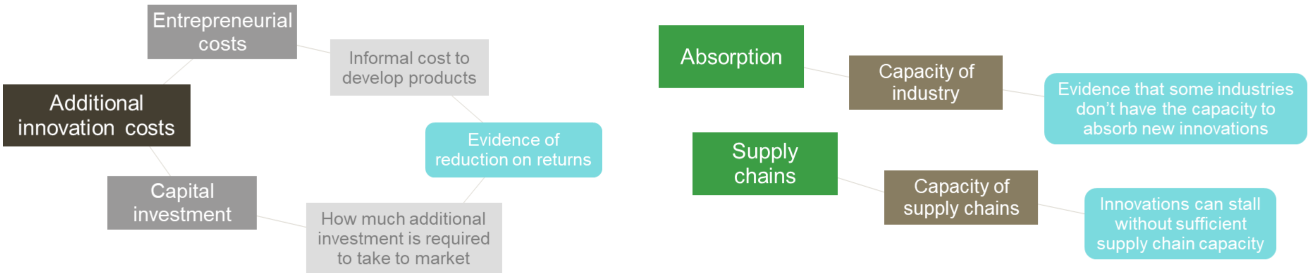
Source: Mott MacDonald

The historical performance of research and innovation by an industry can determine the number of firms that are actively involved in, and can benefit from research and innovation and, therefore, the availability of capital funding. The greater the competition is for funding, the greater the quality of research and innovation, given the increasing need to evidence superior innovation to successfully access funding.

The literature finds evidence to suggest high-tech industries with a strong R&D and technology base to build on perform strongly in research and innovation activities. On the contrary, there is limited evidence to support differing scales of impact by industry, which restricts understanding in practise of the importance of access to market, and the ease of disrupting markets with new innovations.

These market and industry factors raise questions about how the absorbative capacity of markets for developing new concepts can affect the success of research and innovation, as well whether such markets support research and innovation through robust supply chains. Figure 3.16 details findings of the literature regarding these key questions, as well as the additional costs to innovations

Figure 3.16: Additional costs to innovation and absorbative capacity of the market



Source: Mott MacDonald

Entrepreneurial costs, the informal costs of innovating (e.g., product development), and capital investment, the investment required to take an innovation to market (including the cost of obtaining capital), are evidenced to reduce the returns of research and innovation.

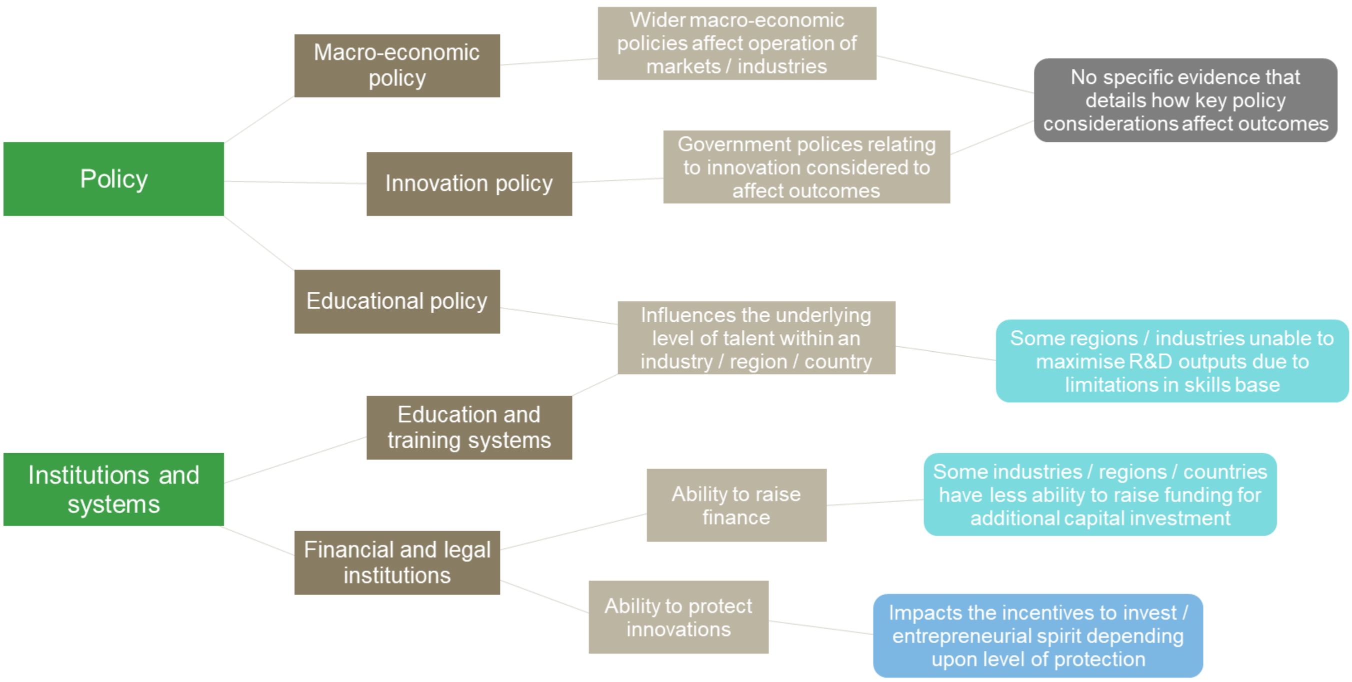
Additionally, regarding absorbative capacity of markets, the literature finds some evidence to suggest some industries don't have capacity to absorb new innovations, and that innovations can stall due to limited supply chain capacity.

Evidence in the literature of these additional costs and constraints on research and innovation shows that the nature and maturity (in relation to R&D) of the industry / market can be important in realising the benefits of research and innovation.

3.5.6 Policy and structural systems

A key factor influencing the ability for research and innovation to deliver successful outcomes can include overarching policy and structural systems of a country or region. This includes macroeconomic policy, as well as specific policy pertaining to research and innovation activities and educational policy and systems that could affect the availability of skills (as referenced in Section 3.5.4). Figure 3.17 shows the key policy influences identified by the literature, and what they mean for R&D.

Figure 3.17: Influence of policy and institutions / systems



Source: Mott MacDonald

Relating to macroeconomic policy and innovation policy, which could both be expected to affect the ability to perform successful research and innovation and affect the operation of markets, there is no specific evidence presented on how key policy considerations affect outcomes. Surani, Gendron and Maredia (2017) suggest that country specific policy can affect the rate to which there is economic return to research and innovation investment, showing differences in the return to R&D across 22 OECD countries (as discussed in Section 3.4.1.3).

Educational policy and training systems influence, and are key determinants of, the development of talent and skills base within industries, regions and nations. As has been discussed, some regions fail to maximise the benefits of research and innovation because the amount, or quality of research and innovation, that can be performed is constrained by a limited skills base.

Financial institutions affect the ability to raise finance which can constrain or incentivise research and innovation activities, depending on whether institutions are set up to support such capital investment.

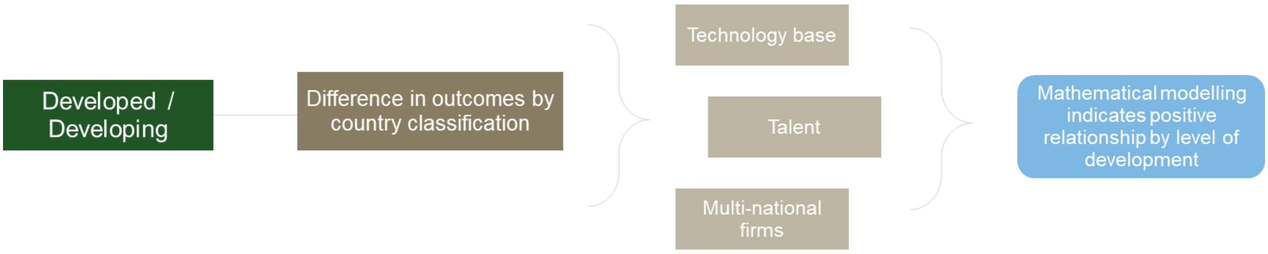
Legal institutions affect the ability to protect innovations, which in turn can affect the propensity of investment into research and innovation in industry.

Overall, policy and institutions hold weight in fostering an environment, whether this be in specific industries, regions or countries, that encourages successful research and innovation. Observed disparities at the national level between developed nations (OECD) is postulated to be founded in policy environments (Surani, Gendron and Maredia (2017)).

3.5.7 Research in developed or developing nations

Research can be influenced by the country in which it is performed, more specifically by whether the country is considered developed or developing. How developed a country's economy is a reflection of a wide range of aspects, encompassing a number of factors already discussed within this section, including financial and legal structures, educational attainment, and technology base, amongst many others. The literature reviewed demonstrates that the overall maturity of a country's economy affects the ability for benefits to materialise from research and innovation. Figure 3.18 shows the impact of developed status on research and innovation activities and the associated return.

Figure 3.18: Impact of developed status



Source: Mott MacDonald

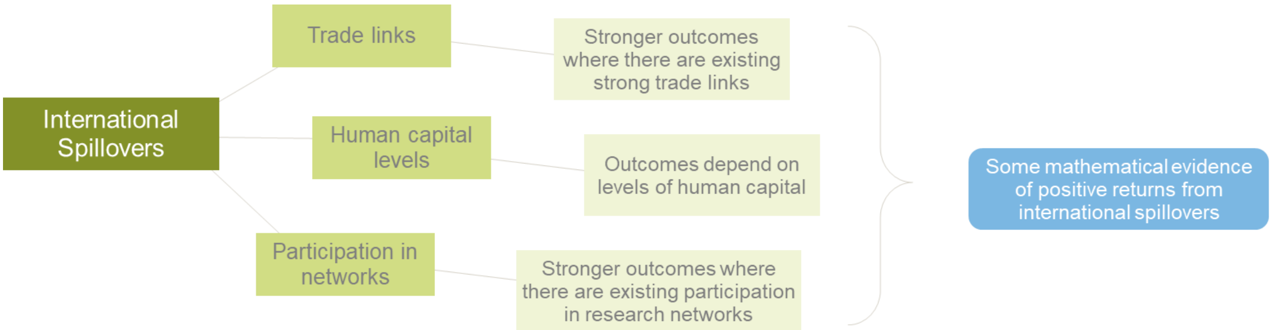
The status of a country's economic development can affect the returns to research and innovation; however, this is intrinsically linked to many other factors such as policy, talent, industry, and technological base. There are differences in outcomes dependent on a country's classification of developed or developing, with modelling indicating that the more developed a country is, the more it can benefit from R&D (Surani, Gendron and Maredia (2017)).

A question worth consideration is whether limited returns (relative to developed countries) in turn affects propensity to perform research and innovation in developing countries, which then affects the magnitude of returns that can be realised.

3.5.8 International spillovers

Some benefits of research and innovation may be derived within international markets that are not directly captured by the country where the public sector investment originated. This effect, as had been alluded to previously, is known spillover, which generally sees the wider adoption or application of the outputs of research and innovation. Figure 3.19 details the ways in which international spillovers can materialise.

Figure 3.19: International spillovers



Source: Mott MacDonald

Trade links, the stock of human capital, and network participation are all considered key in enabling international spillovers.

Trade links and participation in networks enable the diffusion of knowledge via the process of trade and collaboration, fostering stronger outcomes across existing trade links and networks.

Human capital stock is a key determinant of international spillovers, as it is necessary that the secondary nation (benefiting from spillover) can apply insights from original research and innovation.

The literature exhibits some mathematical evidence of positive returns from international spillovers, suggesting the benefits of research and innovation are realised beyond the primary nation within which the research and innovation investment is made (Frontier Economics, (2014) and Jones and Summers (2020).

3.5.9 Summary

Overall, this section has discussed the factors that the literature has identified as being key in realising the benefits of research and innovation investment. From a holistic perspective, the factors identified have been suggested to both positive and negative effects on the likelihood of realising benefits. This has provided balanced insight into what may help or hinder the causal chain of research and innovation from input to impact.

It should be stated that the factors affecting benefits realisation identified in this section are not exhaustive, but intend rather to show the common themes identified in the literature identified as being the most useful for this study.

4 Interpretation of findings

4.1 Introduction

Having provided a direct summary of the findings from the literature review within Chapter 3, this chapter seeks to interpret the findings within the context of potential zero emission and decarbonisation mobility innovation projects. This focuses around three core elements:

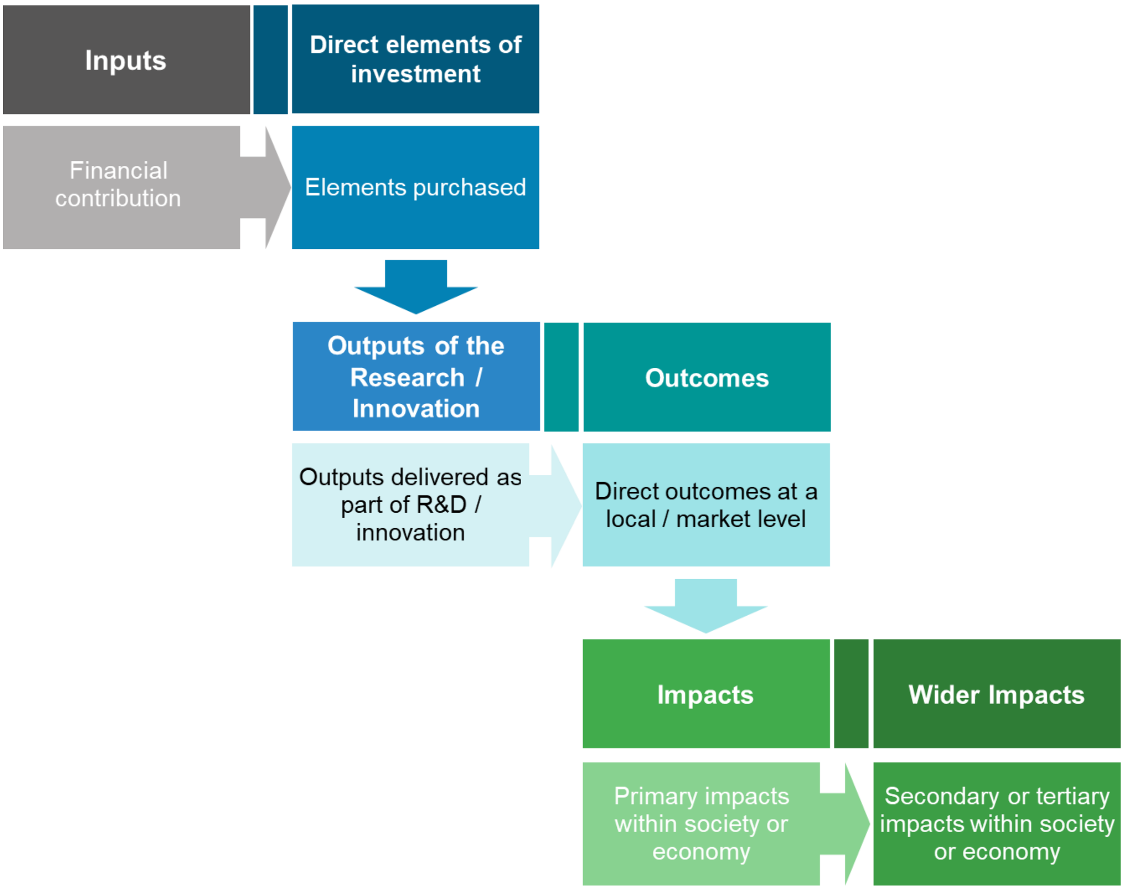
1. The development of an overall logic map that provides an understanding of the potential direct and indirect consequences of investment in R&D, or innovation.
2. Consideration of the individual economy, societal, governmental, and international impacts that may arise
3. How the literature review evidence can be used to develop a framework for estimating the potential returns on investment from bespoke zero emission and decarbonisation mobility innovation projects.

4.2 Development of an overarching logic map of impacts

Section 3.2 provided an overview of the key outputs, outcomes and wider impacts of research and innovation projects that were identified across the literature review. These can be used to produce an overarching logic map that sets out how a financial investment in research / innovation translates through direct outputs into outcomes and wider impacts across economies and societies.

Figure 4.1 provides a summary structure for the overarching logic map, showing the generic steps in the process. Each of these steps is then considered within the sub-sections that follow.

Figure 4.1: Logic map structure

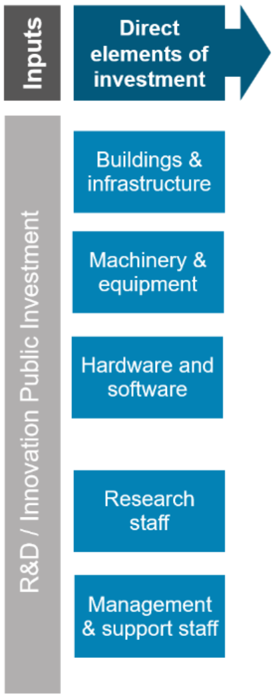


4.2.1 Direct elements delivered from investment

Public sector funding in research / innovation projects provides the investment to cover the capital and revenue costs associated with the research activities. Whilst this investment will be bespoke to each individual zero emission or decarbonisation mobility project, there are a core range of elements that are identified within the literature review relating to capital and people. These are set out within Figure 4.2 and described below:

- **Buildings & infrastructure:** in which to conduct research or that forms part of the research project (e.g., hydrogen hub)
- **Machinery & equipment:** required to conduct research or forms part of research project (e.g., battery storage, demonstrator projects of emerging zero emission vehicles)
- **Hardware and software:** required to conduct research or forms part of research project (e.g., mobile apps, battery innovation, charging infrastructure e.g., wireless charging and v2g technology)
- **Research staff:** directly involved in research and innovation
- **Management & support staff:** wider organisational staff co-ordinating set-up or role out of research

Figure 4.2: Logic Map – Inputs



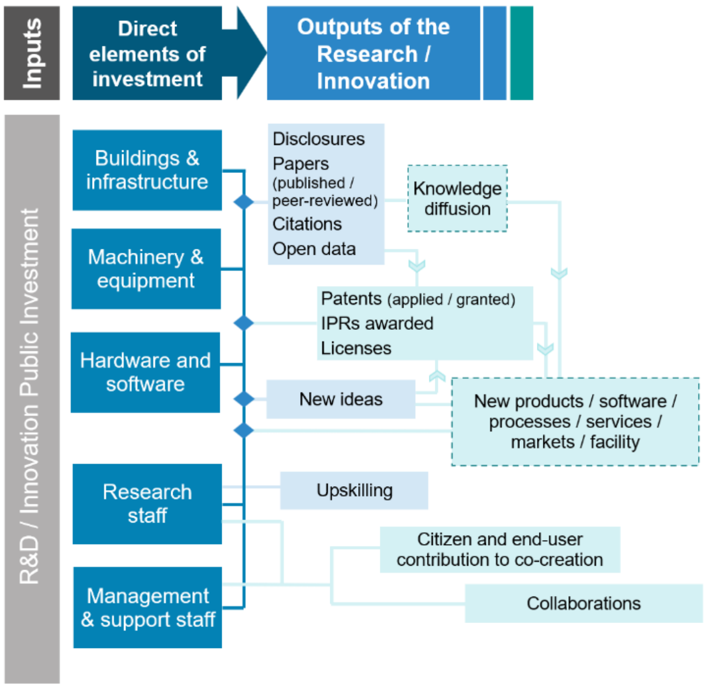
4.2.2 Outputs from the completed research / innovation

The research investments in capital and people enable a series of research innovation activities to be undertaken that result in a set of immediate outputs. Section 3.2.1 provides an overview of the range of outputs described across the literature reviewed and these have been used to identify the main immediate outputs. These can be broadly categorised into four areas:

1. **Knowledge**: the production of disclosures, research papers, citations or delivery of open data that shares knowledge to other parties. Much of the literature also focuses on how this leads to specific patents or Intellectual Property Rights (IPR), although this is less common for public sector investment, or at least until the point of private sector involvement and investment. Within the context of zero emission / decarbonisation mobility projects, this increase in knowledge could relate to demonstrator projects and trials that disseminate knowledge on the performance of emerging vehicle types and technologies.
2. **New concepts:** the delivery of new products, software, process, or services within a specific area, or, potentially, new market areas. Within the context of zero emission / decarbonisation mobility projects, new concepts could relate to new vehicle types (e.g., zero emission heavy vehicles or specialist vehicles), innovations in battery technology, or catenary systems and new charging solutions (e.g., Charging as a Service, smart metering).
3. **Upskilling:** new leant skills, both in terms of research and innovation process, as well as within specific technical areas. Within the context of Zero emission / decarbonisation mobility projects, this increase in skills could relate to installing and maintaining infrastructure (e.g., hydrogen production plants and refuelling stations), or servicing and maintaining zero emission vehicles.
4. **Collaboration:** involvement in other parties, including local communities, to become aware and help shape new innovations to make them relevant to society and the local economies. Within the context of zero emission / decarbonisation mobility projects, this collaboration could relate to working with communities to raise awareness of certain technologies (e.g., hydrogen to remove negative public perceptions).

Figure 4.3 provides these elements within the context of the next step within the logic map.

Figure 4.3: Logic Map – Outputs



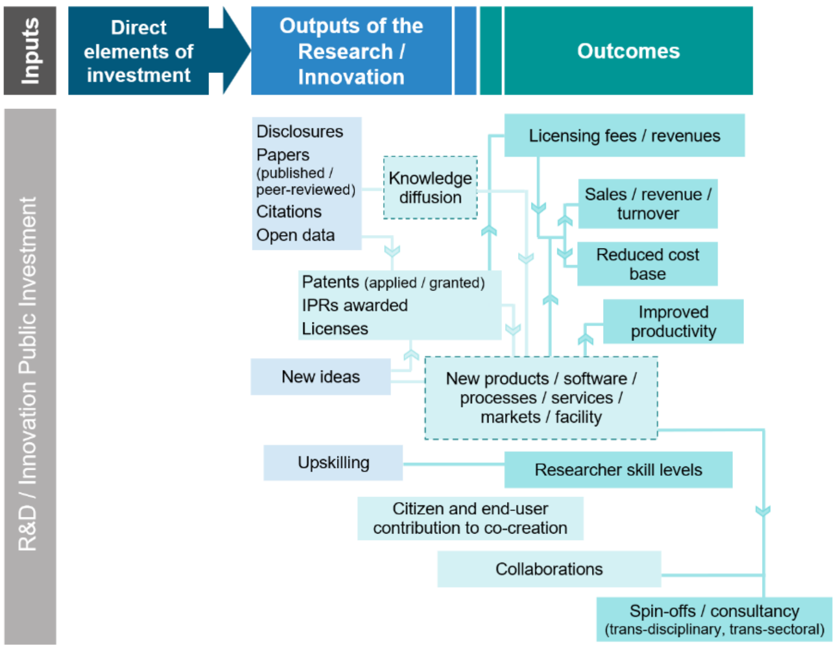
4.2.3 Direct outcomes of the research / innovation

The literature review identifies how the diffusion of knowledge, new concepts, upskilling and collaboration translate into tangible outcomes that can be observed within the economy or society. Section 0 provided an overview of the main identified elements, with much of the literature focuses upon potential commercial implications within the following broad areas:

- **Revenues / sales / costs:** the ability to generate new revenues (either through licensing arrangements or direct products / processes), increase existing sales through enhanced offers to the market, or generate cost reductions through greater efficiency in product or processes. The literature refers to these outcomes primarily in the context of private sector firms. Therefore, in relation to zero emission / decarbonisation mobility innovation, they are primarily likely to occur where projects involve private sector partners, either in terms of collaborations, or where public sector grants have helped private firms to innovate. Examples could include where the private sector look to roll out new electric vehicle charging infrastructure developed in collaboration and generate new revenue streams, or vehicle manufactures that are able to commercialise new battery technology.
- **Productivity:** improve underlying levels of productivity through efficiencies delivered by innovation. The literature identifies these productivity benefits across public and private sector operators. Within the context of zero emission / decarbonisation mobility projects, this increase in productivity could relate to more efficient production of battery technologies that becomes feasible through new research in production techniques.
- **Skill levels:** improve underlying levels of researcher skills within a local economy, both in terms of generic skills, as well as individual technical areas of excellence. Within the context of zero emission / decarbonisation mobility projects, this will obviously relate to specific skills relating to zero emission / decarbonisation that could be applied both within the transport sector but also, potentially across other sectors.
- **Spin-offs:** facilitate the generation of new enterprises to promote and market research outputs and innovations, as well as enable the provision of new consultancy services. Within the context of zero emission / decarbonisation mobility projects, spin-offs could relate to new charge point operators that are established to commercialise development of new charging technologies.

Figure 4.4 indicates where these outcomes fit within the context of the logic mapping process.

Figure 4.4: Logic Map – Outcomes



4.2.4 Impacts and wider impacts

Across the range of literature reviewed, the classification of outcomes, primary impacts and secondary / tertiary impacts is not always consistent, reflecting both context within different sectors and countries, as well as the interpretations of individual authors. The summary provided within Section 3.2.3 is a general reflection of the literature, seeking to demonstrate the impacts of the outcomes throughout the economy and society that can be measured, or observed, either within individual firms / market or at a regional / national level.

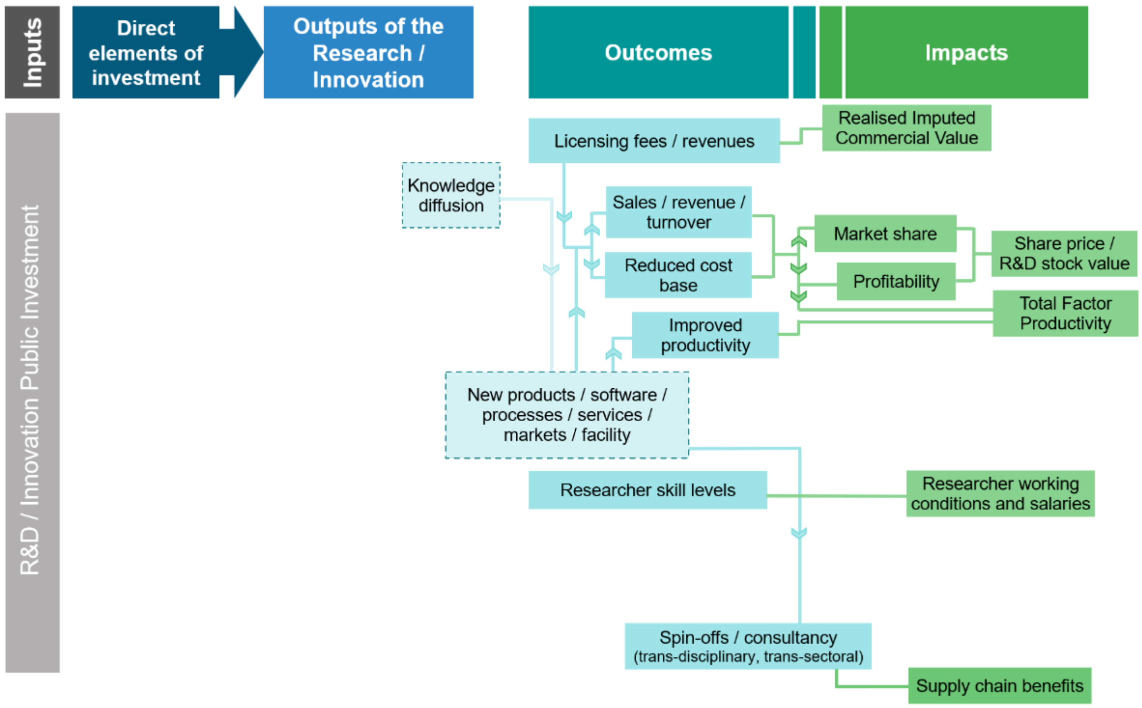
In developing the logic mapping process, we have sought to consider direct (primary) impacts that result more directly from research and innovation for firms and in markets, and then wider (secondary / tertiary) impacts as benefits flow through the economy and society.

The direct (primary) impacts can broadly be classified as:

- **Commercial value:** the literature presents a range of generic and bespoke measurements of commercial value, from measures of market share, profitability, and share price / stock values, as well as measures of Total Factor Productivity (*how much output can be produced from a defined amount of input*) and Realised Imputed Commercial Value (*a representation of actual recurrent commercial revenue from intellectual property rights*).
- **Employee benefits:** enhanced working conditions for researchers and salaries that result through research investment and upskilling. Within the context of zero emission / decarbonisation mobility projects, employee benefits could relate to improved facilities and wages for researchers within academic organisations specialising in transport technologies and/or climate change.
- **Supply chain benefits:** multiplier effects through the economy from increase outputs requiring additional inputs from supply chains. Within the context of zero emission / decarbonisation mobility projects, there might be many forms of supply chains but an indicative example could be consumable materials utilised within day-to-day research activities.

Figure 4.5 indicates where these direct impacts fit within the context of the logic mapping process.

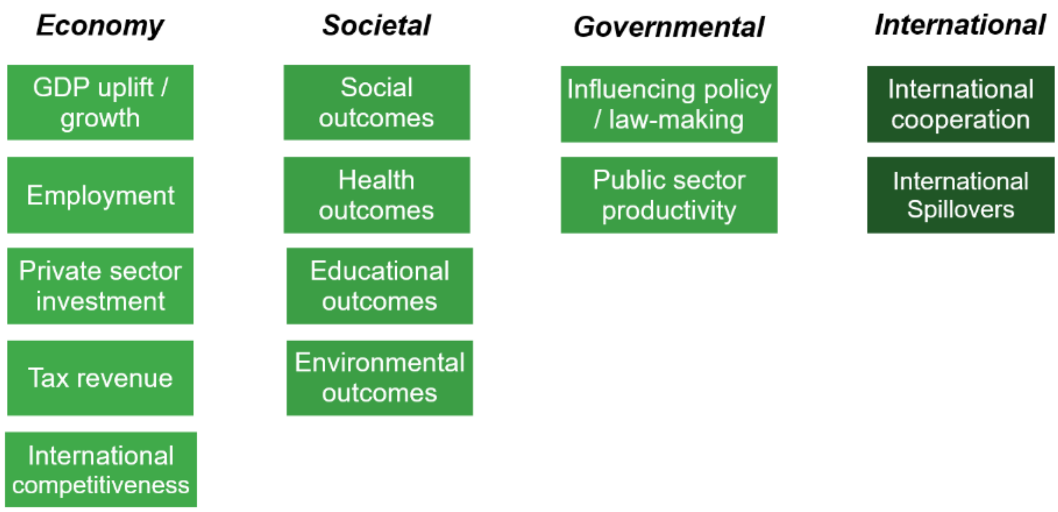
Figure 4.5: Logic Map – Direct (Primary) Impacts



The reviewed literature highlights a range of economic, societal, and governmental impacts that may arise at regional / national level, through research and innovation. In addition, there is a broad discussion around the potential global impacts that may occur beyond the reach of the country of origin of the research.

Figure 4.6 provides a summary of the range of identified wider impacts, grouped by category.

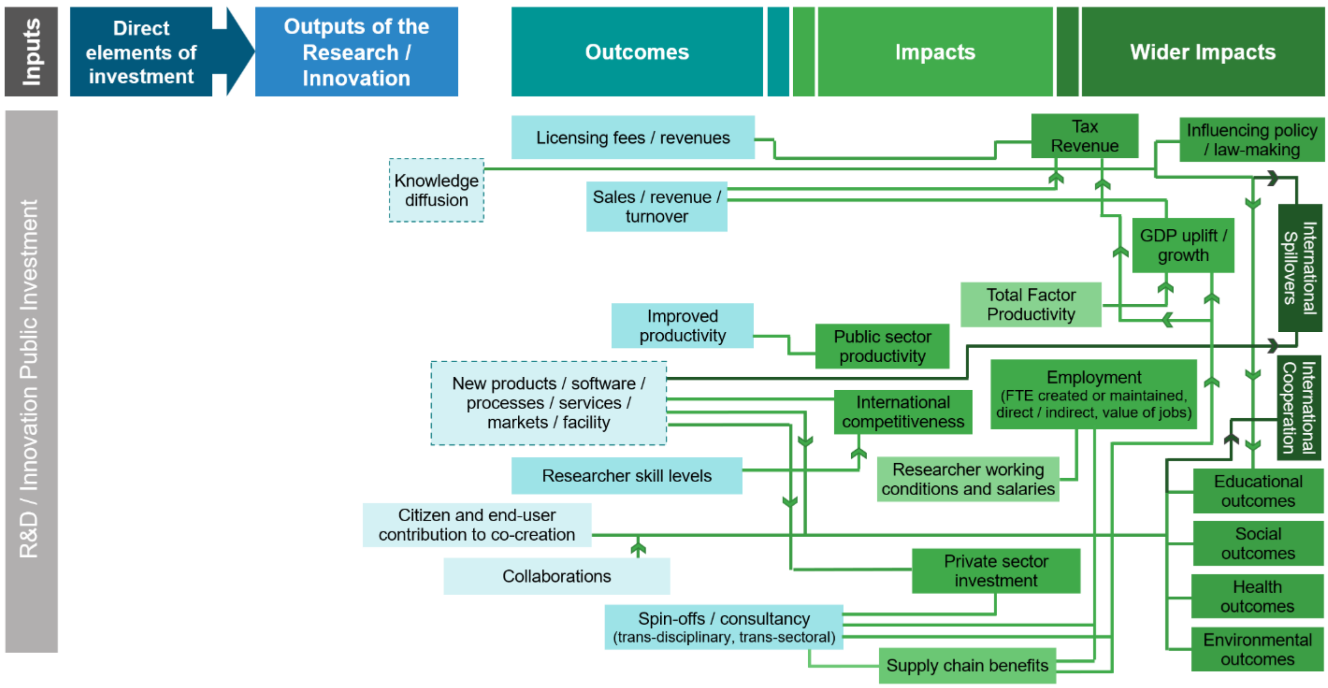
Figure 4.6: Categorisation of Wider (Secondary/Tertiary) Impacts



The reviewed literature focuses primarily upon each of these wider impacts as the key economic and societal benefits of research and innovation. Section 0 examines each individual element in detail.

Figure 4.7 indicates where these wider impacts fit within the context of the logic mapping process.

Figure 4.7: Logic Map – Wider (Secondary/Tertiary) Impacts

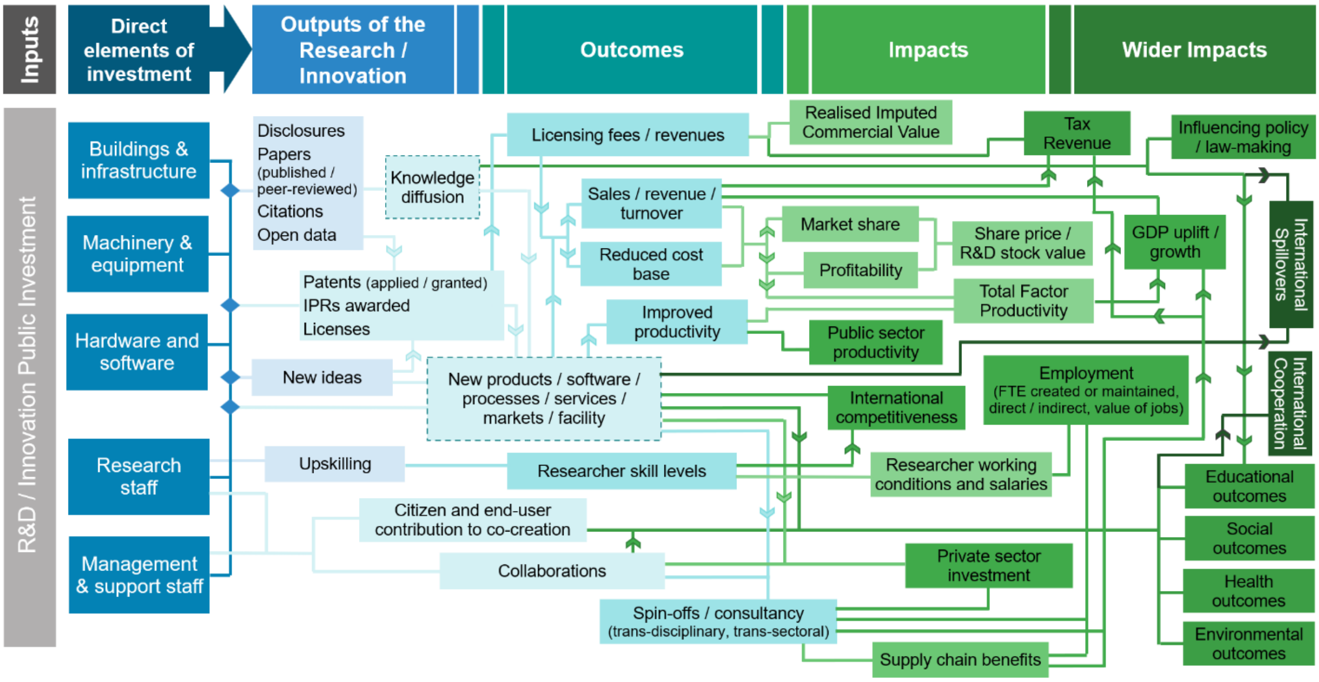


4.2.5 Summary

Developing a generic logic map for research and innovation projects is challenging, reflecting the fact that research and innovation can be across all sectors of the economy, focus upon a wide range of technical areas, and require different types of inputs to achieve aspired outputs and outcomes.

The overall logic map, as presented within Figure 4.8, provides our interpretation of the collective view presented by the literature review, of linkages between inputs, outputs, outcomes, impacts and wider impacts. These linkages were often presented in short form within individual papers, or indeed not discussed at all, and so this should be seen as an indicative mapping process that helps to highlights key elements and linkages.

Figure 4.8: Logic Map – Overall



A consideration for further investigation would be to utilise case study evidence from individual zero emission / decarbonisation mobility projects to refine this logic mapping process to become more bespoke. This is discussed further within Sections 4.4 and 5.2.

4.3 Consideration of economy, societal, governmental, and international impacts

As discussed in Section 4.2.4, and presented within Figure 4.6, the evidence from the literature review identifies a range of impacts and wider impacts that can be classified in terms of economy, societal, governmental, and international. The mechanisms by which these impacts occur, and any evidence of the scale of each impact reported within the literature, is set out within the following sections.

4.3.1 Mechanisms for delivering economy impacts

The literature identifies a range of impacts of research and innovation investment upon regional / national economic metrics, including levels of Gross Domestic Product (GDP), employment, private sector investment, and tax revenues, as well as international competitiveness. The mechanisms for realising these impacts, and any individual metrics and quantification identified within the literature, is considered for impact below.

GDP

As highlighted previously within Section 3.4, research and innovation projects are reported to impact upon GDP either in terms of a permanent uplift or an uplift in the growth rate over time. Figure 4.9 shows this mechanism, alongside the previously reported extent of potential change in economic output, with a core estimate suggested across the literature of between 20% and 40% return on investment.

Figure 4.9: Mechanisms by which GDP impacts occur and evidence of scale

It is clear from the literature that GDP impacts from research and innovation investment are highly variable and are dependent upon a wide range of factors, as outlined within Section 3.5 on benefits realisation. By its nature, research and innovation is unpredictable in terms of outcomes and, hence, how this might feed through to regional / national economies in terms of medium or long-term GDP. However, the potential magnitude of benefits can be better understood through consideration of generic regional / national context and by consideration of key factors relating to specific research or innovation investment.

In terms of regional / national context, recognising how policy and institutional structures will facilitate research outcomes being able to filter through into the wider economy is a key aspect. For example, are there incentives to encourage risk taking or, alternatively, might legal structures hinder entrepreneurship?

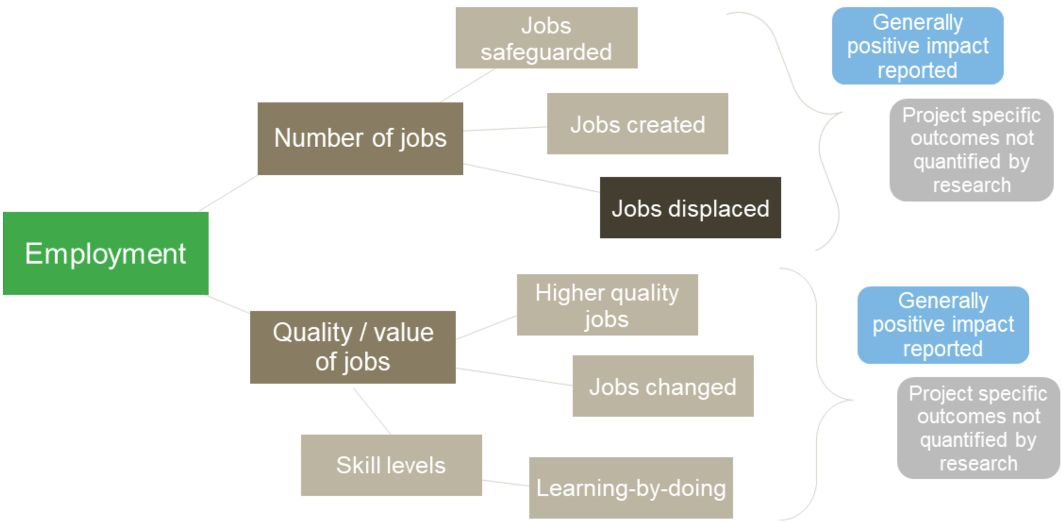
At an individual research or innovation project, by considering key factors outlined within Section 3.5 (e.g., the type of research, potential lags, existing research linkages and talent, as well as the status of markets for absorption), a better understanding can be made as to whether an investment is likely to deliver GDP benefits at the higher range of estimates or the lower.

How this might be applied within the context of zero emission / decarbonisation mobility projects is discussed further within Section 4.4.

Employment

The logic mapping process demonstrates a range of employment impacts, from direct employment upon the research and innovation projects, to longer-term employment generated from the outcomes from the research. The economic value of these changes in employment is reported within the literature in terms of both the quantity and quality of employment opportunities. This is presented diagrammatically within Figure 4.10.

Figure 4.10: Mechanisms by which employment impacts occur and evidence of scale



In terms of the quantity of jobs, the literature reviews identifies three areas of influence of research and innovation investment, in term of potential jobs safeguarded that would otherwise have been lost, new jobs created, but also the potential for jobs to be displaced.

As with GDP, the scale of medium / long-term job safeguarding or creation is recognised to be influenced by a wide range of factors that are bespoke to individual research and innovation investment (as discussed previously within Section 3.5).

The literature recognises that there can also be a disruptive nature from research and innovation outputs upon how specific markets operate and the potential for obsolescence of products or, indeed, entire markets. This relates to the concept of '*Just Transition*' and how economies can transition from different market structures and/or technologies without disadvantaging those within established markets / sectors / industries. The reviewed literature is sparse in terms of attempting to quantify the employment impacts of such disruption, again recognising the bespoke nature of impacts. However, these impacts can be mapped out in terms of the risks of who and when specific employment groups could be impacted.

Measures can also be implemented to manage such transition periods but it needs to be recognised that this inevitably comes with some level of associated resource/cost requirement that may dampen the positive impacts from other economic benefits of a research and innovation project.

The issue of Just Transition and job displacement has a particular relevant to zero emission / decarbonisation mobility projects, recognising the influence upon the established fossil fuel industry and is discussed further within Section 4.4.

Private sector investment and tax revenues

The focus of this study is to consider the impacts of publicly funded research and development. The literature recognises that this is often required to de-risk projects for the private sector and reduce barriers to progress and development. Having initial public funding can 'pump-prime' subsequent private sector investment, in terms of additional research and innovation, or capital investment to develop products and commercial operations. These are mostly reported as positive outcomes within the literature, helping to multiple the benefits of an initial public sector investment across the economy.

In economic terms, this private sector investment must still be treated as a negative private sector impact, but still help to reduce the financial burden on the public sector of fully realising the benefits of new research and innovation outputs. The scale of these impacts is not captured within the reviewed literature and is, again, recognised as being bespoke to individual research and innovation.

How this might be considered within the context of zero emission / decarbonisation mobility projects is discussed further within Section 4.4.

Some of the reviewed papers also recognise the potential long-term public sector tax revenue impacts that may occur through the increased output within the economy. This, potentially, acts as a mechanism for the public sector to reclaim some of the value from investments over the longer-term. No specific evidence is presented around the potential scale of these returns.

Figure 4.11 provides a diagrammatic summary of the private sector investment and tax revenue impacts.

Figure 4.11: Mechanisms by which private sector investment and tax revenues occur and evidence of scale

International competitiveness

Much of the literature focuses upon economic benefits for individual countries investing in research and innovation, as captured within the metrics of GDP, employment etc. There is recognition, however, that research outcomes can deliver a competitive advantage to sectors / industries within international markets. No specific evidence is presented about the potential scale of benefits, which will be dependent upon individual outcomes. Figure 4.12 provides a diagrammatic representation of the impacts.

Figure 4.12: Mechanisms by which international competitiveness occur and evidence of scale

4.3.2 Mechanisms for delivering societal impacts

The literature suggests a range of societal impacts of research and innovation investment within the context of social, health, educational and environmental outcomes. The mechanisms for these impacts, as outlined within the literature, are each considered below.

Social outcomes

The literature often refers to a range of potential positive social outcomes as being key impacts from public sector investment in research and innovation. The individual elements referenced often vary in language and focus, but can be broadly summarised in terms of three areas:

- Equality, Diversity and Inclusion (EDI)
- Social cohesion
- Quality of life

Promoting EDI through research and innovation is outlined both as part of the research and innovation process itself, as well as an impact derived from the outcomes of research and innovation projects. The literature reviewed provides a narrative on how to capture these impacts, rather than presenting much evidence of the likely scale of impacts.

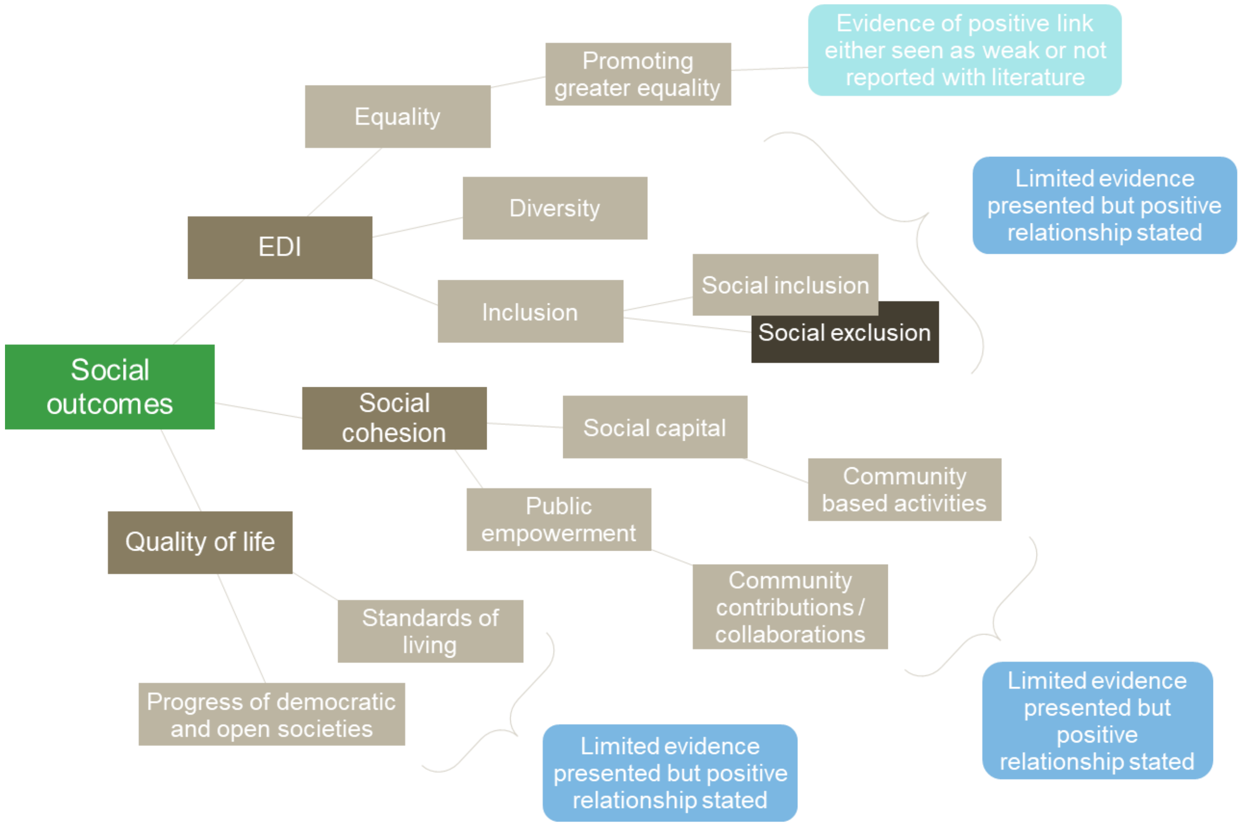
In terms of equality, the limited narrative available suggest that, whilst mechanisms should be available to promote equality, in practice this link is weak, perhaps suggesting that it has not been an active priority outcome from investment.

The literature refers to social cohesion in terms of involvement of the general public (citizens) within the process of shaping research and innovation outcomes, as well as benefiting more broadly from the actual outcomes. There is reference to building social capital (shared values or resources that enable society to function more effectively) through research and innovation processes, as ensuring that society shapes how innovation and advancement is applied within communities. The literature reviewed tends to present these processes in broad terms, with limited description of how to capture the benefit within appraisal.

Similarly, there is wide-ranging references throughout the literature related to the ability for innovation and knowledge to improve the quality of life, in terms of standards of livings, as well as democratic processes. This is, again, presented as a positive impact from research and innovation but not quantified.

Figure 4.13 provides a diagrammatic summary of the social outcome impacts.

Figure 4.13: Mechanisms by which social outcomes occur and the evidence of scale



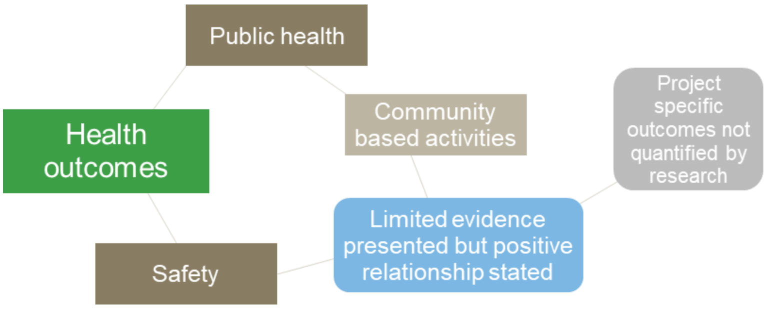
Health

There are references across the literature reviewed that highlight the potential health benefits from research and innovation; however, these broadly tend to relate directly to research within a health industry context, as opposed to more general health benefits that may arise from cross-sector research and innovation.

The exception relates to a discussion within some areas of the literature around the how involving communities within research and innovation process can have positive influence of health and wellbeing, either through community-based activities or engendering a sense of belonging within a community that is actively involved in making positive change. This is, again, very much a theoretical discussion, with no reference to quantification.

Figure 4.14 provides a diagrammatic summary of the health outcomes impacts.

Figure 4.14: Mechanisms by which health outcomes occur and the evidence of scale



Educational

Unsurprisingly, the literature highlights a wide range of potential educational areas where research and innovation can deliver wider impacts. This tends to focus upon three areas: i) establishing, or re-enforcing educational networks; ii) training; and iii) community-based activities.

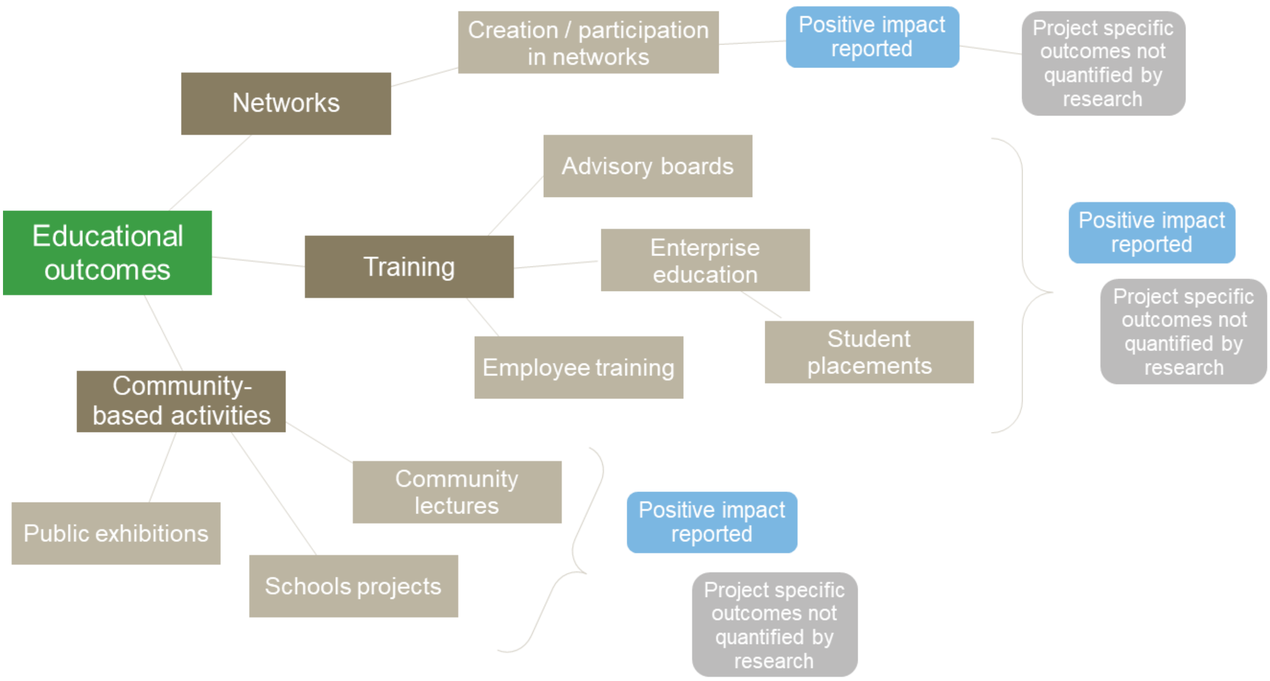
The ability to generate new networks between organisations and community groups, or to re-enforce existing networks, is referenced throughout the reviewed literature as universal positive outcomes from research and innovation. This helps to diffuse knowledge, and accelerate the development of ideas and concepts, helping to bring applied outcomes. The scale of impacts if recognised to relate to the type of research / innovation area.

Most research and innovation is also considered to further training and development of others through a variety of formal and informal mechanisms. Clearly different research and innovation projects will approach this in different ways, and so outcomes will also differ, but the literature recognises the potential for significant positive outcomes across educational institutions, as well as individual market sectors.

Some of the reviewed literature also references the specific role of community learning that can flow from research and innovation projects. Again, this will be bespoke to individual projects, but a range of positive outcomes are identified through public exhibitions of ideas, schools projects, and community lectures.

Figure 4.15 provides a diagrammatic summary of the educational outcomes impacts.

Figure 4.15: Mechanisms by which educational outcomes occur and the evidence of scale



Environmental

As with health, the majority of references to positive environmental outcomes relate to specific research and innovation projects that are designed to directly deliver positive change in this area. Clearly this will be the case for the zero emission and decarbonisation mobility projects, but the literature does not identify more generically any positive environmental impacts that are encompassed by all research and innovation projects.

Figure 4.16 provides a diagrammatic summary of the environmental outcomes impacts.

Figure 4.16: Mechanisms by which environmental outcomes occur and the evidence of scale

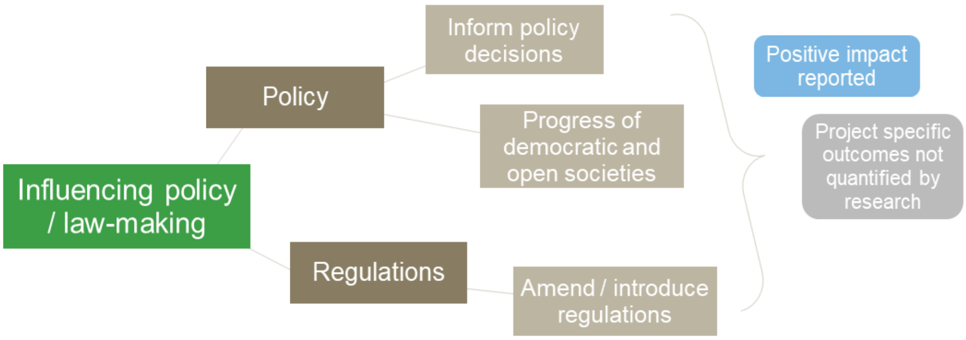
4.3.3 Mechanisms for delivering governmental impacts

Some of the literature reviewed makes reference to the potential impacts that research and innovation can have upon governmental outcomes, in terms of the establishment of policy and setting of regulations. Research and innovation outcomes can provide the knowledge to better inform government decision-making, and provide the evidence to justify specific policy interventions or the requirement for new regulation.

The extent to which this occurs, and the value to society, is not specifically referenced within the literature, only the inference of a positive impact.

Figure 4.17 provides a diagrammatic summary of the governmental policy and law-making impacts.

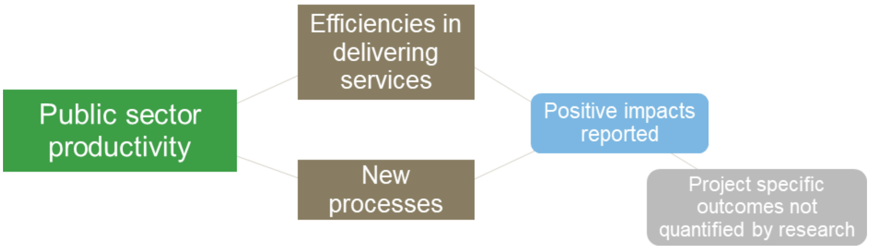
Figure 4.17: Mechanisms by which policy and regulatory outcomes occur and the evidence of scale



A few of the papers reviewed also specifically highlight the potential role of research and innovation in delivering productivity enhancements for the public sector. This refers the opportunities for more efficient delivery of public sector services through implementation of new products or processes developed through research and innovation. Again, the extent to which this occurs, and the value to society, is not specifically referenced within the literature but a positive relationship is identified.

Figure 4.18 provides a diagrammatic summary of the public sector productivity impacts.

Figure 4.18: Mechanisms by which public sector productivity outcomes occur and the evidence of scale



4.3.4 Mechanisms for delivering international impacts

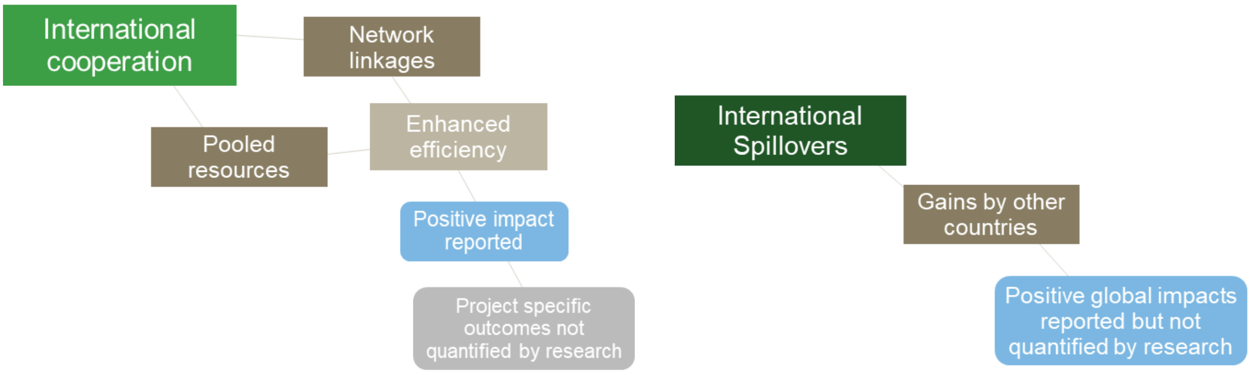
The final area of potential wider impacts identified within the literature review relates to international impacts. These focus upon two area: i) international cooperation (working collectively for advancement), and ii) international spillover (benefits derived within countries beyond the county of origin of the research or innovation).

The literature recognising the range of additional benefits that can be derived by being able to cooperate with other countries in area of research. This can not only pool overall resources and strengthen networks, by may strengthen wider relationships between those countries involved. The scale of benefits will be dependent upon individual research and innovation projects and the extent to which cooperation occurs across the project, but the literature recognises the net impacts can be greater than the sum of completing individual research projects in isolation.

The concept of international spillovers recognises, over time, benefits from research and innovation in one country are likely to extend to other countries (either by design or naturally). While some countries may attempt to limit these spillovers (to maintain competitive advantage for the economy of the country of origin of the research), the literature suggests that overall benefits are increased through these spillovers. This may include for the country of origin through enhanced international reputation.

Figure 4.19 provides a diagrammatic summary of the international impacts.

Figure 4.19: Mechanisms by which international impacts occur and the evidence of scale



4.4 A framework for estimating returns from research and innovation into zero emission / decarbonisation mobility projects

The review of the literature has indicated that there is a wide scale of potential returns from research and innovation (Section 3.4) and that there are a significant number of factors that affects the outcomes and impacts (Section 3.5). There are a range of potential logic chains by which bespoke investment in research and innovation can feed through from outputs into outcomes and impacts (Section 4.2) and the mechanisms for achieving wider economy, societal, governmental, and international impacts are complex, reliant upon individual context, and have not readily quantified (Section 4.3).

This section seeks to examine how these findings from the literature review can be best utilised to provide the basis for a framework with which to assess the potential impact of public sector investment in research and innovation into zero emission / decarbonisation mobility projects. This is done by considering:

1. What are the main factors that are likely to determine the benefits that can be derived from zero emission / decarbonisation mobility research and innovation?
2. What are the implications for forecasting the scale of potential impacts?

The framework seeks to identify a check list of elements that would be used to evaluate each individual zero emission / decarbonisation mobility project to flag the likely areas where impacts may be derived. These can subsequently then be assessed to consider the potential scale of impacts (e.g., low, medium, high). Based upon the overall number of areas likely to derive benefits, and the potential scale of those benefits, then the likely overall rate of return from a research and innovation project could be estimated.

Chapter 4.4 then considers what further evidence would help Transport Scotland to develop this framework into a formalised process for assessing the potential impacts of individual investment in research and innovation for zero emission / decarbonisation mobility projects.

4.4.1 Key considerations in determining impacts from zero emission / decarbonisation mobility research and innovation

Section 3.5 provides a discussion of a range of key factors that the reviewed literature indicates can impact upon the achievement of benefits from research and innovation. These range from the detailed aspects of research through to the characteristics of industries, regions, and nations in which the research is taking place. Six broad categorises have been identified:

a. The type of research and innovation being undertaken
b. The component element of the research approach and development process
c. The precise technical nature of the research and innovation
d. The area of research and the networks and talent available to support the delivery of projects and maximise the outcomes.
e. The context and conditions of the sectors / industry in which the outcomes from the research and innovation may be applied
f. The context and conditions of the country of origin of the research and innovation, in this case being Scotland.

The sections below consider each of these impacts within the context of zero emission / decarbonisation mobility research and innovation to help identify how much influence they may have in the derivation of outcomes and impacts.

4.4.1.1 The type of research and innovation

The literature review indicates that the achievement of benefits is likely to directly corelate with a number of factors that relate to the type of research and innovation being undertaken.

Each individual zero emission and decarbonisation mobility project will be formed of specific aspects and will be anticipated to deliver targeted outputs, within defined timeframes. These factors will all combine to influence when wider impacts will be derived and the overall potential rate of return from investment. An impact framework, therefore, needs to incorporate a check list of the **type of research** encapsulated by an individual project. This could include:

- Applied or basic research
  - Is the research applied, targeted to develop a practical solution to an existing problem? Or is it basic research into an area to improve understanding of general principles?
- Targeted research outputs (ideas / patents / new services)
  - Is the aspiration of the research or innovation to develop at specific output and what type of output is that to be? A new product or process that can potentially be taken to market? Or less tangible ideas to further insight within a specific research area?
- Timescales
  - What is the proposed programme for the research? Are there staged outputs over time? If products or processes are being developed, when are they targeted to be ready for implementation?
- Additional development costs
  - Will the direct outputs from the research or innovation project still require additional investment to develop products or processes? Additional research investment or capital investment in product delivery? If so, what is the likely source of the funding required?

By understanding what an individual project is likely to deliver, the timescales involved and the need for additional supporting investment, this will affect when economic returns will occur and what the ratio of overall investment (costs) and benefits for the project might be.

Indicative examples:

A 2-year applied research project that delivers a new piece of mobility technology that can immediately be adopted by manufactures with limited additional investment costs will likely engender higher than average rates of economic return from public sector investment in the project.

A 3-year basic research project to develop greater understanding of how to improve the efficiency of hydrogen fuels that will then require subsequent time and investment to develop into a useable product will likely engender lower than average rates of economic return from public sector investment in the project.

4.4.1.2 The component elements of the research approach and development process

The literature review indicates that the component elements of any individual research or innovation project have a direct impact upon specific output metrics, as well as potentially longer terms influence over outcomes and impacts.

Each individual zero emission / decarbonisation mobility project will include a range of standardised input elements, to varying quantities. The scale and combination of these elements will influence overall outcomes. An impact framework, therefore, needs to incorporate a check list of **component elements** in which an individual project could have influence. This could include:

- Employment
  - How many individuals will be employed within the internal operation of the research project? How long for? What types of roles will be created? What types of opportunity will there be for technical career development?
  - Are the outcomes of the research anticipated to generate further employment? Permanent or temporary? What types of roles?
- Training
  - Does the project include specific training and development proposals, either directly within the project or as part of wider dissemination of knowledge?
  - This could include employee training, student placements, enterprise education (capabilities and skills that enhance employment opportunities), advisory roles, etc.
- Community learning
  - Does the project specifically incorporate community-based activities to enhance understanding and spread understanding?
  - This could include public exhibitions, community lectures, schools projects, etc.
- Social capital
  - Does the project seek to involve local communities in the development of the research or innovation outputs or outcomes?
  - Are the research or innovation outputs or outcomes specifically targeted to improve community cohesion or engagement?
- Equality, Diversity and Inclusion
  - Will the internal operation of the research project positively promote equality, diversity and inclusions?
  - Which social groups are the outcomes of the research anticipated to benefits and is the project set up to positive influence inequalities?

By understanding the component elements involved within an individual zero emission and decarbonisation mobility in terms of how it will affect employment, skills, community engagement, and EDI, this will affect both economic and social rates of return.

Indicative examples:

A research project employing 15 staff and 3 apprentices, with a programme of student placements, and active engagement with citizens over 3 years period. Includes a programme of knowledge dissemination with research networks and local communities. Leads to a roll out of a series of enterprises that will continue to employ technical staff, with a strong focus upon supporting disadvantaged communities. This is will likely engender higher than average rates of economic and social return from public sector investment in the project.

A research project employing 5 staff over 2 years working in isolation. No future enterprise opportunities have been identified and the research outputs are not anticipated to target specific communities. This will likely engender lower than average rates of economic and social return from public sector investment in the project.

4.4.1.3 The technical nature of the research and innovation

The derivation of benefits will, inevitably, be affected by the precise nature of the research and innovation that is being sought. Many of the papers that were reviewed have considered research and innovation across all sectors, or generically at a national level. There is, however, reference to how certain technical areas of research and innovation will result in specific types of impacts, most notably health and environmental, but also potentially across other impact areas.

Clearly research and innovation within the technical area of zero emission / decarbonisation mobility will be expected to deliver environmental benefits, in relation to emissions. There may also be the potential for other health and societal benefits, depending upon the precise nature of individual projects.

An impact framework, therefore, needs to incorporate a check list of **technical nature** of an individual project, or the technical areas in which it could have influence. This could include:

- Quality of life
  - Does the project include targeted outcomes that will impact upon individual standards of living? This could include improved travel options, the affordability of travel, etc.
  - Does the project include targeted outcomes that will progress democratic and open society? This could include approaches that enhance inclusiveness or accountability of organisations, etc.
- Public health
  - Does the project include targeted outcomes that could result in improvements to public health outcomes?
  - This could include encouraging greater levels of physical activity, reducing harmful emissions, reducing stress, etc.
- Safety
  - Does the project include targeted outcomes that will reduce the risk of accidents or improve personal safety?
  - This could include improved safety provision for vulnerable people whilst travelling, etc.
- Environment
  - Does the project include targeted outcomes that will improve environmental outcomes?
  - This could include reduced emissions, improved air quality, reduced embodies carbon, etc.

By understanding the technical nature of the individual zero emission / decarbonisation mobility projects in terms of what they may deliver for quality of life, health, safety, and environment will affect social rates of return.

Indicative examples:

A zero emission / decarbonisation mobility project will be a major facilitator of reducing vehicles emissions, but will also facilitate greater levels of, safer, and more affordable, active travel. This is will likely engender higher than average rates of social return from public sector investment in the project.

A zero emission / decarbonisation mobility project will facilitate reduced vehicle emissions but may increase overall levels of vehicular traffic on roads and makes active travel less attractive. Whilst the project will offer some positive environmental returns, overall social returns from public sector investment in the project may be lower than average.

4.4.1.4 Research area - networks and talent

The literature review highlights the role of existing, or emerging, research networks, as well as the available pool of talent available within a technical / market area, in influencing benefits realisation.

The existing context of zero emission / decarbonisation mobility research area will be an influencing factor within the derivation of benefits. An impact framework, therefore, needs to consider the status of this **area of research** in terms of:

- Existing research linkages
  - Is there an established research network relating to overall zero emission and decarbonisation mobility projects? If so, does the focus area of an individual research project fit within this established network, or does it extend into alternative research specialities? How easy will it be to connect with wider networks where there are overlaps with the specifics of the individual zero emission and decarbonisation mobility project?
- Talent
  - Is there an established pool of talent that can successfully deliver the individual project?
  - Is there a wider pool of talent that can maximise the outcomes from the project and ensure it can be scaled up over a regional and/or national economy?

By understanding the context of research networks and available talent, the potential implications upon economic rates of return can be projected.

Indicative examples:

A zero emission / decarbonisation mobility project is within a technical area with a well-established research network, of which the sponsors of the project are already a core part of. There is also a highly skilled pool of talent to draw upon for both the research project itself, but also for subsequent development of outcomes. This is will likely engender higher than average rates of economic return from public sector investment in the project.

A zero emission / decarbonisation mobility project is within a new technical area with very limited previous research and now established network. The pool of available talent with specialist skills is limited and it is not known how easy it will be to transfer skills across from other technical areas. This will likely engender overall economic returns from public sector investment that are lower than average.

4.4.1.5 Sectors and industry

The literature review identifies a range of factors relating to the sector or industry in which research and innovation projects are undertaken that can impact upon the scale of benefits derived. The zero emission / decarbonisation mobility projects will sit primarily within the transport sector but may encompass additional elements that are more general to decarbonisation. An impact framework, therefore, needs to consider the how established these **sectors / industries** are in terms of:

- Status of market / industry and potential for 'crowding-in' / 'crowding-out'
  - How much existing research and innovation is undertaken within the sector / industry? Would additional public sector investment stimulate additional innovation or substitute / duplicate private sector research?
  - What is the technology base of the industry? Are there likely to be early adopters for new research and innovation? Is there an entrepreneurial 'spirt' within the sector?
  - Is the sector / industry set-up for replication and expansion of ideas to ensure outputs and outcomes of research and innovation are widely adopted?

- Is there private sector capital available to develop ideas and concepts further?
- Is there a risk of making previous research and investments obsolete and can the sector / industry respond positively to change?

- Absorption
  - What is the existing capacity of the sector / industry to adopt ideas, products, processes that arise out for the research and innovation project?
  - Are structures and processes in place that will enable organisations to readily adopt new ways of working or integrate new technologies into their products?
- Supply chains
  - What is the capacity of the supply chain to support the delivery of new concepts, product, or processes?
  - Can supply chains readily scale-up in areas of expansion or can new supply chains from other sectors be brought in?

By understanding the context of the sector / industry in which the zero emission / decarbonisation mobility research outputs will relate to, the potential implications upon economic rates of return can be projected.

Indicative examples:

The outputs from a zero emission / decarbonisation mobility project will relate to a sector / industry that has a strong track record of innovation, as well as a strong technology base. There is evidence of a high absorption rate of previous innovation and supply chains are well understood and flexible. This is will likely engender higher than average rates of economic return from public sector investment in the project.

The outputs from a zero emission / decarbonisation mobility project will relate to a sector / industry with no track record of innovation and relatively low use of technology. There is evidence that previous market innovations have had limited absorption and supply chains are limited in capacity and fixed. This will likely engender overall economic returns from public sector investment that are lower than average.

4.4.1.6 Scottish context

Much of the literature review focuses upon national impacts and the extent to which different countries benefits the most from research and innovation investment. Much of this focuses upon the maturing of individual economies and the support policy and regulatory framework in which the public and private sectors operate.

As set out in Section 1.1.1, it is recognised that the area of zero emission / decarbonisation mobility is seen as policy priority within Scotland. A range of structures are already in place to support this project work and the economy, as a whole, has the maturity to maximise the benefits of research and innovation investment. On this basis, the majority the factors listed within the reviewed literature relating to the influence of national context should be viewed positively within the context of Scotland. These factors relating to the **country of origin** should be captured within the impact framework in terms of:

- Maturity of economy
  - What are the underlying conditions and structures of the economy to support the implementation of research and innovation outcomes.
- Policy
  - How do national and regional level policies and strategies support research and innovation in general, as well as within the specific area of zero emissions and decarbonisation mobility?

- Institutions
  - How do the financial and legal structures and institutions support the ability to raise funding for development of innovation outputs and provide sufficient protection for taking ideas and new products to market?

By understanding the context of the Scottish economy, policies, and institutions in relation to specific zero emission / decarbonisation mobility projects, the potential implications upon economic rates of return can be projected.

Indicative examples:

A zero emission / decarbonisation mobility project aligns strongly with UK, national, and local policies and strategies and it can be demonstrated that the economic, financial, and legal structures will all create conditions that will support the dissemination and development of research outcomes. This is will likely engender higher than average rates of economic return from public sector investment in the project.

Whilst a zero emission / decarbonisation mobility project generally with UK, national, and local policies and strategies there are certain elements of the research that contradict some policies. Economic, financial, and legal structures are not ideally suited to the dissemination and development of research outcomes. This may engender overall economic returns from public sector investment that are lower than average.

4.4.2 Implications for forecasting impacts

Section 4.4.1 has presented 21 component factors, across six categories, that the literature review has indicated will impact upon the scale of returns from zero emission / decarbonisation mobility research and innovation projects. Alongside the evidence of quantified economic rates of return, presented within Section 3.4, these can be used to forecast the potential impacts of public sector investment within individual research and innovation projects.

The central case forecasts of economic and social rates of return of between 20% to 40% offer a generic starting point for implied research and development impacts. By then considering the extent to which an individual zero emission / decarbonisation mobility project is likely to perform against the 21 identified component factors, it would then be feasible to make a judgement as to whether the rates of return for that project are likely to be greater or lower than core estimates.

A potential approach would be to establish a proforma of questions relating to each of the 21 component elements. The responses to each component would provide an indication as to whether benefits are likely to be higher or lower than average. Summing this cumulatively would provide a basis upon which to conclude whether, overall, a project is likely to deliver higher, lower, or comparative rates of return to the core estimates.

It is recommended that forecast estimates remain a range so, for example, a project that is anticipated to perform better than average may have a project rate of return between 30% to 50%, whilst a project anticipated to perform lower may have a project rate of return between 10% to 30%.

Table 4.1 provides an indication of the potential range, with the full extent of the range based around the core upper (85%) bound presented within Figure 3.7.

Table 4.1: Indicative scale of potential rates of return

Scenario	Rate of return range
Minimum	0% to 20%
	10% to 30%
Core	**20% to 40%**
	30% to 50%
	40% to 60%
	50% to 70%
	60% to 80%
Maximum	70% to 90%

Source: compiled evidence from literature review

Table 4.2 provides an indicative check list that could form the basis of the assessment of how an individual zero emission / decarbonisation mobility projects will perform against the 21 component factors. The cumulative scoring could be used to determine the extent to which the rate of return for a project should be adjusted from the core.

Table 4.2: Indicative 'check list' of component factors affecting performance of research and innovation investment

Categories	Components	Implications of research and innovation project	Impact upon economic and social returns	Indicative types of scoring
1. Type of research	a. Applied or basic research	• Is the project targeted at producing a practical solution or more general research in an area?	• Applied research more likely to generate immediate economic and social returns	• +1 applied • 0 mix of applied and basic • -1 basic
	b. Targeted research outputs	• Is the project anticipated to produce tangible products / process that can be immediately deployed within markets / society? • Is it more likely to produce evidence / knowledge that will then require further development?	• Tangible products more likely to generate immediate economic and social returns	• +1 clear tangible products • 0 unknown • -1 ideas / concepts only
	c. Timescales	• What is the length of the project? • What are the anticipated timeframes to produce / take tangible products / process into markets / society? • Is there a single market / social application or could innovations be applied across multiple markets or areas of society? Are benefits likely to grow over time? • Are products / processes likely to have limited lifespans? If so, what might they be?	• Longer lags between initial public sector investment and realisation of products / processes will reduce value for money • Research outcomes with potential multiple applications will increase potential for economic and social returns • Defined useful lifespans of research outcomes will constrain benefits streams	• +1 short lags • 0 medium lags • -1 long lags • +1 multiple applications • 0 single application • +1 long lifespan • 0 medium lifespan • -1 short lifespan
	d. Development costs	• Are there likely to be additional research or development costs beyond the initial public sector investment?	• Additional future costs will reduce overall value for money from public sector investment.	• 0 no additional costs • -1 additional costs
2. Component elements	e. Employment	• What level of direct employment is there on the project? Does it include opportunities for upskilling? • Is the likelihood of on-going employment requirements post-project high? What type of roles might be required?	• The higher the level of direct employment, and the greater the potential for upskilling, the greater the economic returns. • The higher the potential for on-going employment, and the higher the value of that employment, the greater economic returns	• +1 high employment • 0 standard employment • -1 low employment
	f. Training	• Does the project incorporate specific training requirements for employees? Does the project include apprenticeships, student placements, enterprise education?	• Involvement of training opportunities on projects will increase the economic and social returns	• +1 training opportunities • 0 none
	g. Community learning	• Are there plans for disseminating research findings to local communities or schools?	• Dissemination of findings to local communities within projects will enhance social returns	• +1 community learning • 0 none
	h. Social capital	• Does the project involve any collaborations with local communities around research outcomes? • Will the outcomes of the research have the potential to change social behaviours?	• Collaboration with local communities within projects will enhance social returns	• +1 citizen collaborations • 0 none

Categories	Components	Implications of research and innovation project	Impact upon economic and social returns	Indicative types of scoring
	i. EDI	• Will the project positively promote equality, diversity, and inclusion? • How are the research outcomes anticipated to affect different social groups? Will they contribute positively to reducing deprivation and social inclusion?	• Projects that can demonstrate they will have a positive outcome in relation to equality, diversity and includes will enhance social returns	• +1 positive EDI activities • 0 none
3. Technical nature	j. Quality of life	• Does the project have targeted outcomes that will improve the standard of livings?	• Projects that can demonstrate they will have a positive uplift in relation to quality of life will enhance social returns	• +1 targeted standard of living improvements • 0 none
	k. Public health	• Does the project have targeted outcomes that will improve public health?	• Projects that can demonstrate they will have a positive uplift in relation to public health will enhance social returns	• +1 • 0 none
	l. Safety	• Does the project have targeted outcomes that will improve safety?	• Projects that can demonstrate they will have a positive uplift in relation to safety will enhance social returns	• +1 • 0 none
	m. Environment	• Does the project have targeted outcomes that will improve aspects of the environment?	• Projects that can demonstrate they will have a positive uplift in relation to the environment will enhance social returns	• +1 • 0 none
4. Area of research	n. Research linkages	• Is there an established research network relating to zero emission / decarbonisation mobility or specific elements of the individual research project? • How easy will it be to connect into wider research networks?	• Projects that can demonstrate existing linkages with wider research networks, or a strong ability to develop these linkages, will have a positive uplift in economic returns	• +1 strong research networks • 0 standard research networks • -1 no / weak research networks
	o. Talent	• Is there an established pool of talent that can successfully deliver the project? • Is there a wider pool of talent that can maximise the outcomes from the project?	• Projects that can demonstrate an existing pool of talent within the specific research area will have a positive uplift in economic returns	• +1 large established talent pool • 0 small established talent pool • -1 no established talent pool
5. Sectors / industry	p. Status of market	• Is there a track-record of innovation and or a strong technology base within the sector / industry? • Is there private sector capital available to develop new products / concepts? • Are the direct outputs / outcomes of the research likely to generate obsolescence of existing products / processes?	• Project that can demonstrate they are operating within a sector / industry with a strong record of innovation and technology base will have a positive uplift in economic returns • Project that can demonstrate they are operating within a sector / industry a strong record of private sector investment will have a positive uplift in economic returns • Projects that are likely to create obsolescence will reduce overall rates of economic returns	• +1 strong record on innovation and technology base • 0 standard record on innovation and technology base • -1 poor record on innovation and technology base • +1 strong record of investment • 0 standard record of investment • 0 standard risk of obsolescence • -1 increased risk of obsolescence

Categories	Components	Implications of research and innovation project	Impact upon economic and social returns	Indicative types of scoring
	q. Absorption	• Does the sector / industry have a good track record of absorption of new ideas / products and the capacity to respond to change?	• Project that can demonstrate they are operating within a sector / industry a strong record of absorption will have a positive uplift in economic returns	• +1 strong record of absorption • 0 standard record of absorption
	r. Supply chains	• Can the project demonstrate that there is an existing supply chain that can support commercial delivery of outcomes from the research or that the supply chain can be developed?	• Projects developing outcomes where there are no existing supply chains will reduce overall rates of economic returns	• 0 good existing supply chains • -1 no existing supply chains
6. Country of origin	s. Maturity of economy	• Do the underlying conditions and structures of the economy to support the implementation of research and innovation outcomes?	• Demonstrating the conditions and structure of the Scottish economy support the specific targeted outcomes of the research will have a positive uplift in economic returns	• 0 conditions supportive • -1 conditions not supportive
	t. Policy	• Do national and regional level policies and strategies support research and innovation within the area of zero emissions and decarbonisation mobility?	• Demonstrating UK, Scottish, and local authority policies and strategies support zero emission / decarbonisation mobility will have a positive uplift in economic returns	• +1 project fully support policies • 0 project mainly supports policies • -1 project in conflict with some policies
	u. Institutions	• Do the financial structures and institutions support the ability to raise funding for development of innovation outputs • Do the legal structures and institutions provide sufficient protection for taking ideas and new products.	• Demonstrating how the financial and legal structures and institution will support delivery of zero emission / decarbonisation outcome will have a positive uplift in economic returns	• 0 structures and institutions supportive • -1 structures and institutions not supportive

5 Summary and next steps

5.1 Summary

The literature review has provided evidence of the potential range of economic and social benefits that can be delivered through public sector research and innovation projects, as well as the potential magnitude of those benefits. Furthermore, it has highlighted a wide range of factors that can influence the scale of benefits that are realised.

In combination, this evidence has been used to formulate a framework that can be applied to assess the potential returns from investment in individual zero emission / decarbonisation mobility projects. This framework highlights the type of questions that should be asked about the aims, design, and context of individual projects that will influence the likely level of success. Through application of the framework, it should be feasible to estimate an indicative value for money from investment in individual projects and help prioritise between areas of investment.

5.2 Next steps

This literature review of best practice fulfils an initial, albeit important, phase of a wider process in developing an assessment methodology for research and innovation into zero emission / decarbonisation mobility projects. The following aspects have been identified as key next steps in the process:

1. Social impacts. Since the focus of the literature review has been upon cross-sector research and innovation investment, the findings from the review are relatively generic in terms of the description of potential impacts. This is particularly the case in relation to the social benefits that can be derived from research and innovation projects.

   It is advocated that additional case study evidence is sought from individual zero emission / decarbonisation mobility projects to improve the understanding of causal relationships from inputs and outputs from these projects leading through to wider social impacts relating to topic areas, such as health, wellbeing, social capital, and environment.

2. Testing. The proposed framework, and outline methodology, remains theoretical in nature and should be subject to some initial practical testing on case study examples. This can then lead to a period of refinement and further development of the framework, and specifically the proforma, to ensure it becomes a viable practical tool that can be readily applied across all future projects.

3. Integration. Once the framework and approach has been refined, consideration then needs to be given to how it can be best integrated within existing appraisal tools. Part of this will involve the dissemination of the approach to relevant stakeholders to ensure a consistent understanding of the framework, but also obtain feedback on how it aligns with other existing appraisal frameworks. Particularly consideration will need to be given to how the framework would align to Scottish Transport Appraisal Guidance and its potential integration.

A. List of papers

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