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Logic Models for the Challenge Areas of The National Physical Laboratory

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National Physical Laboratory (NPL)

Logic Models for the Challenge Areas of The National Physical Laboratory

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We are the UK's National Metrology Institute (NMI), a world-leading centre of excellence that provides cutting-edge measurement science, engineering and technology that underpins prosperity and quality of life in the UK.

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Contents

Acknowledgements

This study is the result of a collaborative effort drawing on the expertise and insights of numerous contributors across NPL. We gratefully acknowledge the valuable inputs provided by the challenge area heads, the science team, and the programme team, whose knowledge and experience were instrumental in shaping this report.

This report builds upon a foundation of previous work, including the NMS Reformulation 2025-26 and the benefit maps. We also wish to thank all participants in the stakeholder workshops facilitated by Briscoe Advisory Limited in 2024, whose contributions helped refine the theories of change and meta-level logic models that underpin this study.

Abstract

This study explores the development of tailored logic models for the four challenge areas of the National Physical Laboratory: Advanced Manufacturing and Materials, Life Sciences and Health, Energy and Environment, and Security and Resilience. These areas align with the UK's national priorities and government strategies, aiming to address pressing societal and economic needs. The existing logic model for the National Measurement System programme was found to be too broad in a previous case studies project, prompting the need for more specific models to better capture the unique dynamics and impacts of each challenge area. Through workshops conducted by Briscoe Advisory Limited in 2024, key internal stakeholders collaborated to map customer touchpoints and define expected outcomes. The methodology employed includes the use of meta-level logic models and theories of change which serve as foundational tools for visualising causal pathways and justifying programmatic interventions.

Introduction

National Challenge Areas

The national challenge areas aim to align with the UK's current and future requirements. The National Physical Laboratory (NPL) connects to four strategic areas: Advanced Manufacturing and Materials, Life Sciences and Health, Energy and Environment, and Security and Resilience.

- **Advanced Manufacturing and Materials** aims to shift the UK's industrial landscape towards achieving net-zero carbon emissions, prioritising societal wellbeing, driving the need for innovation and investment in measurement infrastructure to unlock market opportunities and ensure economic growth, and align with government strategies such as the Industrial Strategy and the Clean Growth Strategy.

- **Life Sciences and Health** aims to enhance and provide metrology expertise to support faster disease detection, sustainable bioeconomy development, reliable data for early diagnosis and precision medicine, and align with government strategies and global life sciences & health sector trends.

- **Energy and Environment** aims to minimise environmental damage caused by greenhouse gas emissions, utilise national science and metrology to aid the transition to a net-zero emissions economy, ensure sustainability, and align with government strategies such as the Net-zero Strategy and Climate Change Act.

- **Security and Resilience** aims to deliver a robust digital measurement infrastructure, support innovation, ensure a resilient infrastructure, and foster public trust in transformative technologies like self-driving vehicles, quantum computing, and Artificial Intelligence.

Rationale for targeted logic models

For the four strategic areas, it is important to have logic models that serve as effective tools to assist in program planning and implementation. The models are visualised as road maps that specify causal pathways and are supported by the underpinning theory of how the intervention works.

The existing logic model for the National Measurement System (NMS) programme is considered too broad to be applied to NPL's challenge areas and therefore through further research and analysis, individual logic models are required for each area.

Furthermore, the previous case studies undertaken by Briscoe Advisory Limited (BAL) to gather insights into interactions between NPL and its customers also recommended to develop individual logic models to become more relevant and therefore a more accurate tool for measuring and validating the impact of its programmes.

Therefore, in 2024, BAL conducted workshops with key internal stakeholders to develop consensus on ideas for developing the logic models, further draw out NPL's touch points with customers through facilitated brainstorming and mapping processes, and discuss expected value-added and impacts for each touch point.

Approach to the development of logic models

In the meta-level logic model and accompanying theory of change (ToC) presented for the NMS[1], an understanding of drivers leads to the creation of proposals for funding and work programmes designed to respond to these needs and opportunities from the outset. The programmes maintain or provide resources deployed to create specific outputs that deliver required outcomes and long-term benefits or impacts to society and the economy.

Using the meta-level model as a guide, it is possible to create specific logic models and accompanying ToCs, and systems diagrams for each of NPL's challenge areas. ToCs explain how desired changes (outcomes) are expected to occur after specified activities have taken place. ToCs can be considered the justification for the links and relationships

[1] King, M; Olakojo, S; Gorringe, G (2023) *Evaluation Framework for the National Measurement System: A Framework for Assessing the Impact of NMS Laboratories.* NPL Report. IEA 20

depicted in the systems diagram and the relationships in the logic model. Simple systems diagrams are useful to visualise the ToCs at a high-level before more detailed logic models are created.

Advanced Manufacturing and Materials

As global trade agreements evolve, the UK manufacturers face increasing competition and pressure to enhance productivity, quality, and innovation. The Advanced Manufacturing and Materials challenge area is designed to address national and global economic challenges by leveraging measurement science to drive innovation, enhance industrial capabilities, and strengthen the UK's global competitiveness. By focusing on advanced technologies, industrial processes, and strategic collaborations, this challenge area supports the UK's transition to a sustainable, productive, and resilient economy.

The Advanced Manufacturing and Materials challenge area is grounded in the vision of: "*Enabling the discovery, adoption, industrialisation, and scale up of technologies for economic impact, productivity and national prosperity.*"

- **Economic growth and global leadership:** Enable the discovery, adoption, commercialisation, and scale-up of technologies that enhance the UK's competitiveness in global markets as a leader in advanced manufacturing and materials, semiconductors, clean energy, and advanced materials innovation.

- **Fostering collaboration:** Maximise outcomes by partnering with stakeholders across academia, industry, and government and ensure technologies and knowledge developed at NPL are widely adopted and impactful.

- **Enabling innovation:** Driving breakthroughs in next-generation manufacturing, digital tools, and sustainable materials supported by cutting-edge measurement capabilities to keep the UK ahead in global innovation.

- **Support for a resilient and sustainable economy:** Address challenges from global trade pressures, supply chain disruptions, and the need to drive clean growth and energy-efficient practices across industries with a significant focus supporting the UK's Net Zero ambitions, which require advanced metrology to develop and implement sustainable technologies including carbon capture, renewable energy, and energy-efficient manufacturing processes.

The priority themes and capabilities for Advanced Manufacturing and Materials are:

1. Digital Engineering

- Support industrial digitalisation by enhancing trust in data across the product lifecycle - from design to manufacturing to second-life use.

2. Next-Generation Measurements

- Develop cutting-edge measurement capabilities to keep the UK ahead in global innovation.
- Collaborate internationally to set the foundation for future measurement standards and technologies.

3. Applied Metrology

- Deliver critical national measurement standards and services that enable industries to innovate and trade confidently.
- Ensure mutual recognition of UK capabilities in global markets.

4. Clean Growth Technologies

- Facilitate the discovery and adoption of sustainable technologies to meet the UK's Net Zero goals including future energy and mobility, decarbonised industry and manufacturing, and carbon capture and storage solutions.

5. Advanced Materials

- Advance measurement science to support the development of next-generation materials, including 2D materials, meta-materials, polymers, and composites. sustainable materials for extreme environments and specialised applications and developing a materials data repository to accelerate innovation.

6. Semiconductor Technologies

- Strengthen the UK's semiconductor supply chains through collaboration and innovation.
- Emphasise quality verification, in-process monitoring, and adherence to international standards.

A Theory of Change for Advanced Manufacturing and Materials

The following systems diagram provides a stylised depiction of the ToC for advanced manufacturing and materials and is explored in the following narrative.

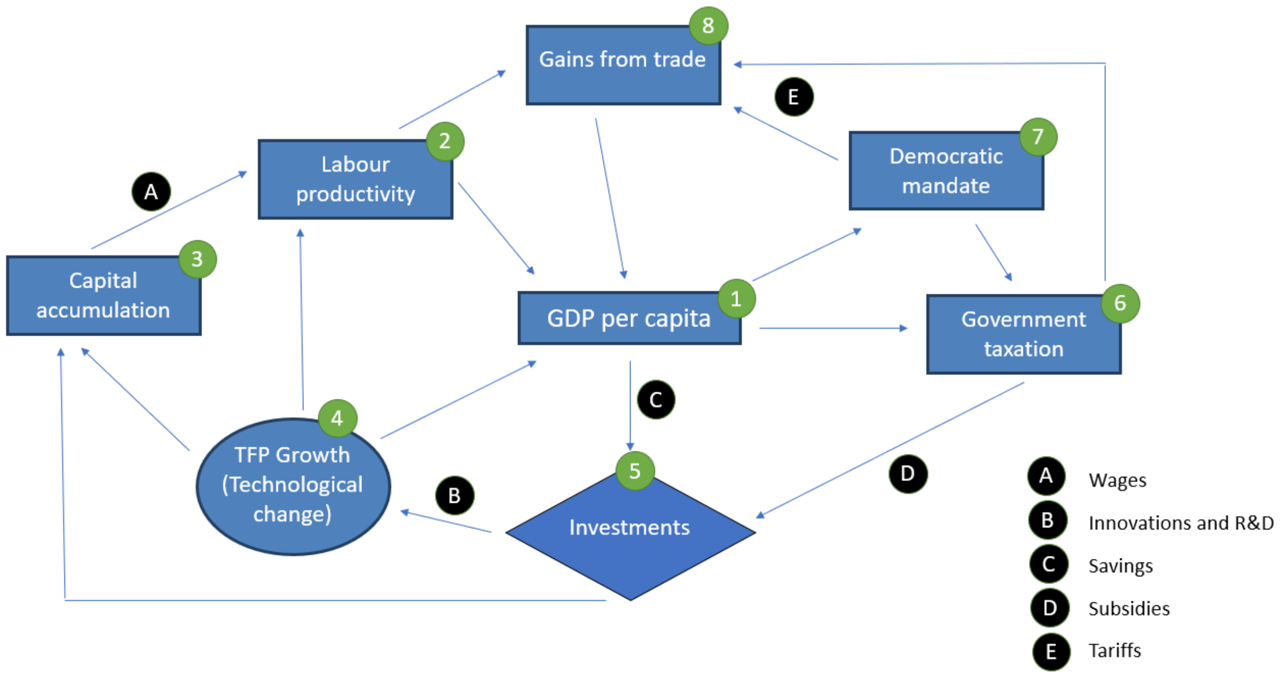

Figure 1 Systems Diagram for Advanced Manufacturing and Materials

Advanced Manufacturing and Materials as a challenge area is the capability that enables the other areas to deliver impact through its measurement infrastructure. It aims to drive novel innovations and foster collaborations to support the UK on its path towards becoming a resilient and sustainable economy.

This systems-level model for Advanced Manufacturing and Materials is grounded in the Gross Domestic Product (GDP) per capita or economic prosperity. GDP is essentially the total value of all goods and services produced in a country each year. Therefore, GDP per capita (1) is the country's economic output per person.

In this model, there are factors that feed into GDP per capita. One such factor that influences GDP per capita is Total Factor Productivity (TFP) growth which fundamentally is technological change. TFP growth (4) measures the increase in the efficiency of production i.e., how much output can be produced from a given amount of inputs.

Labour productivity, (2) which is a measure of how much output is produced per unit of labour, is also impacted by TFP growth. Also, labour productivity directly feeds into GDP per capita. It is also important to recognise another common factor, Capital accumulation (3), which is the capital stock that is obtained in the production of goods or services. This capital stock (human capital) affects labour productivity through wages (A).

On the other hand, Investments (5) arise out of GDP per capita through savings (C). And these investments affect TFP growth through research & development and innovations (B). Investments also directly feed into capital accumulation through physical capital stock. As taxes (6) are something that also come out of GDP per capita, they can also help the investments though subsidies (D).

It is important to recognise that democratic mandate (7) from the stakeholder groups is required on government taxation (6) and on the gains from trade (8) which are affected through tariffs (E). To complete the loop, gains from trade at last feed into GDP per capita.

A Simplified Logic Model for Advanced Manufacturing and Materials

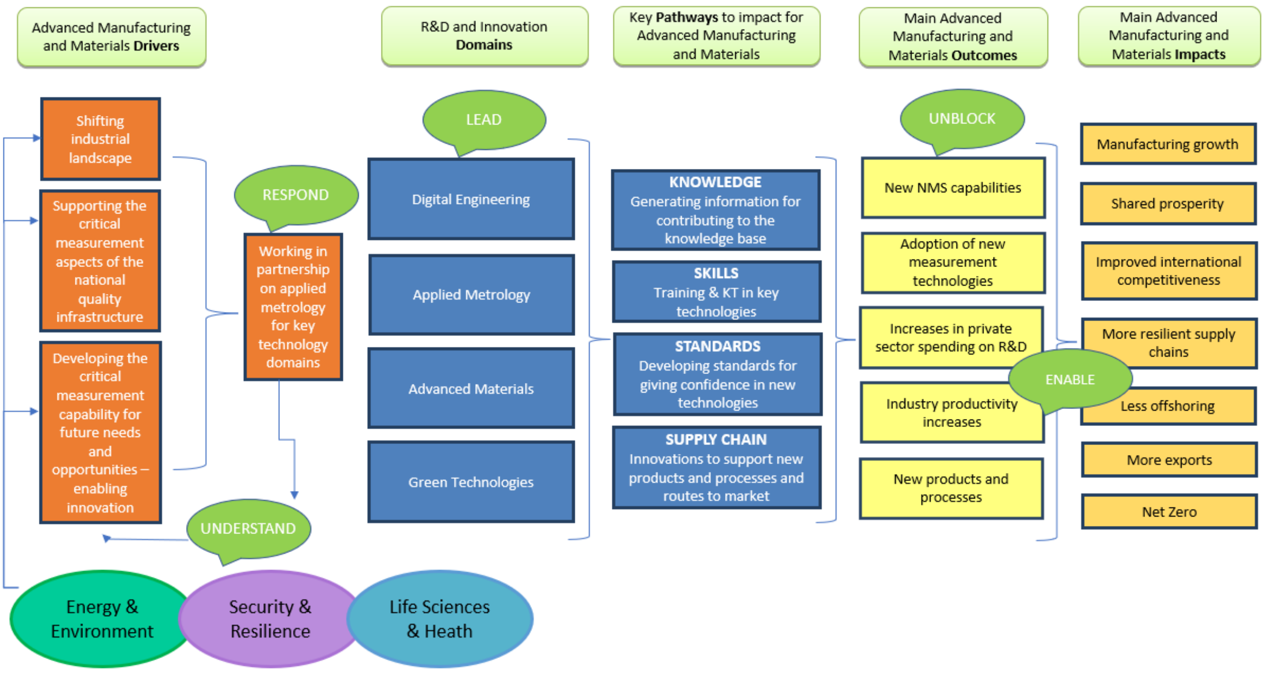

Figure 2 Logic Model for Advanced Manufacturing and Materials

Although a left-to-right logic flow is presented in this simplified model, there are multiple linkages and flows between the main elements.

- **Drivers** represent the understood needs directed through science-based research, industry and government risks and challenges and NPL strategic objectives that drive the design of work done in this challenge area.

- The model includes four technical **Domains** highlighted by the challenge area teams. These domains are complementary and have relevance in multiple sectors of Advanced Manufacturing and Materials and represent the strategic focus of the challenge area. Investing in these areas now supports the capability of the country to respond in the future. The domains reflect the foundations of enabling the UK to address national and global health challenges through its ability to develop, maintain and apply a national science and measurement infrastructure that will tackle a wide range of challenges within Advanced Manufacturing and Materials, i.e., enabling the discovery, adoption, industrialisation, and scale up of technologies for economic impact, productivity, and national prosperity.

- The **Pathways** to impact are grouped into four categories: Knowledge, Skills, Standards, and Supply Chain reflecting the key ways that NPL interacts with its stakeholders. An alternative way to view these pathways is to use impact mechanisms but in this simplified model we have used more summarised categories and reflect the language and descriptions provided by the challenge area team.

- The **Outcomes** are categories of specific benefits generated as a direct result of NPL/NMS activity. These have been drawn from discussions, workshops, and documentary materials such as benefit maps, NMS Reformulation 2025-26, and the workshop. Note that they are not exhaustive of prospective outcomes achievable. Similarly, the **Impacts** are the long-term societal and economic benefits that are sought by stakeholders and to which NPL/NMS contributes and have been derived from the same sources.

Life Sciences and Health

The Life Sciences and Health (LSH) challenge area is embedded within the larger framework of addressing national and global health challenges. Its focus is to develop, maintain and apply a national science and measurement infrastructure that will tackle a wide range of health and life sciences challenges, accelerate technological innovation and enable a sustainable healthcare system and bioeconomy. It aims to:

- Enable people to live longer, healthier and more productive lives.
- Transform the detection, diagnosis and treatment of priority diseases.
- Be at the forefront of leading-edge healthcare and capture value from complex health and population data.
- Usher in the next multi-sector technological revolution that will be built on biology i.e., use biological systems to create a non-fossil fuel economy.

The LSH challenge area adopts a systems approach organised around four priority themes, supported by measurement infrastructure:

1. Understanding Biology

- Moving beyond reductionist approaches to embrace holistic, multi-scale, and longitudinal methods.
- Harnessing multi-omics, deep profiling, and longitudinal datasets for precision health insights.
- Identifying new biomarkers for early diagnosis and target discovery to improve patient outcomes.

2. Prediction, Prevention, Detection, and Diagnostics

- Advancing predictive models to identify at-risk populations and address health disparities.
- Enhancing quantitative diagnostics through innovative biomarkers and imaging technologies.
- Focusing on disease prevention strategies and early detection to mitigate pandemics and chronic health burdens.

3. Improved Patient Treatments

- Accelerating the development and adoption of advanced therapies and treatments.
- Promoting precision therapeutics such as ATMPs (Advanced Therapy Medicinal Products) and MRgRT (Magnetic Resonance-guided Radiotherapy).
- Supporting self-management technologies and personalised interventions for out-of-clinic care.

4. Bioeconomy

- Driving the uptake of advanced manufacturing techniques and engineering biology.
- Enabling innovations such as living cells engineered for disease treatment, environmental sensing, or valuable chemical production.

This strategy aligns with national health priorities, supporting the UK's bioeconomy and fostering interdisciplinary collaborations to unlock innovative solutions for the most pressing life sciences challenges.

A Theory of Change for Life Sciences and Health

The following systems diagram provides a stylised depiction of the ToC for life sciences and health and is explored in the following narrative.

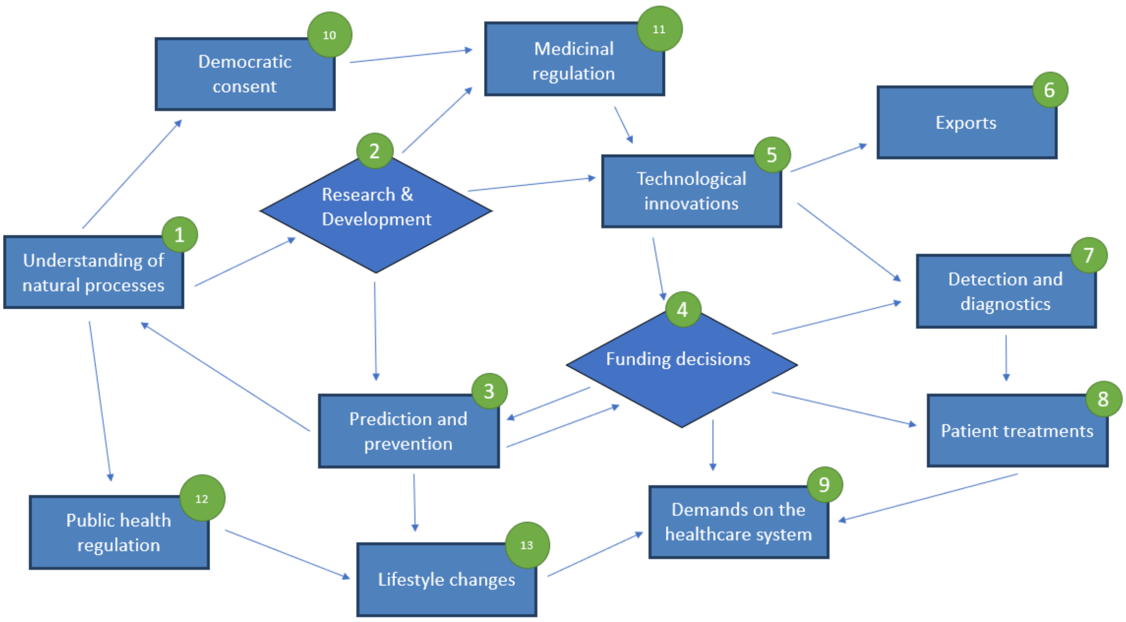

Figure 3 Systems Diagram for Life Sciences and Health

The measurement infrastructure delivered by NPL seeks to tackle various challenges in the life sciences and health sector to enable a sustainable healthcare system. Through its capabilities, NPL aims to address national and global health challenges while also focusing on accelerating technological innovations in the health space.

The first step towards achieving these objectives would be to understand biology and natural processes (1) in depth. This would help gauge what interventions might be needed through further research and development (2). Many actors such as the universities, government, NMIs, etc. come into play at this stage.

On one hand, this research would potentially lead to technological innovations (5) which are techniques that aid in solving or reducing problems faced by the healthcare industry. However, it is important to note that all problems cannot be addressed at a time due to funding constraints (4). NPL will aim to cater to the measurement needs of the industry according to the challenges that need to be addressed today. These difficult decisions would also affect the demands on the healthcare system (9).

These technological innovations would be massively helpful in better detection and diagnosis (6) of diseases. If the patients require any medical procedures to fully recover, technological innovations will also help with improved patient treatments (7). And in turn, this whole process could possibly reduce the pressures on the healthcare system (9). However, on the flipside, restrictive funding decisions (4) could also negatively affect the treatments provided to the patients and thereby increasing the pressures on the healthcare system (9). Moreover, it is important to recognise that the technological innovations could also contribute to exports market (6).

On the other hand, research and development could also lead to better prediction and prevention (3). This is a form of risk management and prediction to identify potential patients before they fall ill. Once again, funding (4) is essential decision factor here. But this time, it could function in both ways. Better funding can help scientists perform more research to develop prediction and prevention methods. And the success rate in developing these methods could in turn affect the funding for the rest i.e., technological innovations, patient treatments, etc.

Moreover, prediction and prevention also loop back into the understanding of natural processes (1). This would then impact the regulations on public health (12). Together, these would also positively impact the changes in people's lifestyles (13), thereby reducing the demands on the healthcare system (9).

It is also important to consider that there needs to be democratic consent (10) from the involved stakeholder groups i.e., it is a collective understanding of likely threats and opportunities which leads to consensus on medicinal regulation (11) within this Challenge Area. NPL contributes to this consensus-building through its participation in policy-related initiatives (global and national) and forums and its regular communications with the government. It goes without saying that research and development (2) contributes to medicinal regulation (11), and industry must most certainly have to abide by them while developing technological innovations (5). These activities will therefore enable greater convergence that will generate a stream of long-term benefits and powerful paradigm shifts.

A Simplified Logic Model for Life Sciences and Health

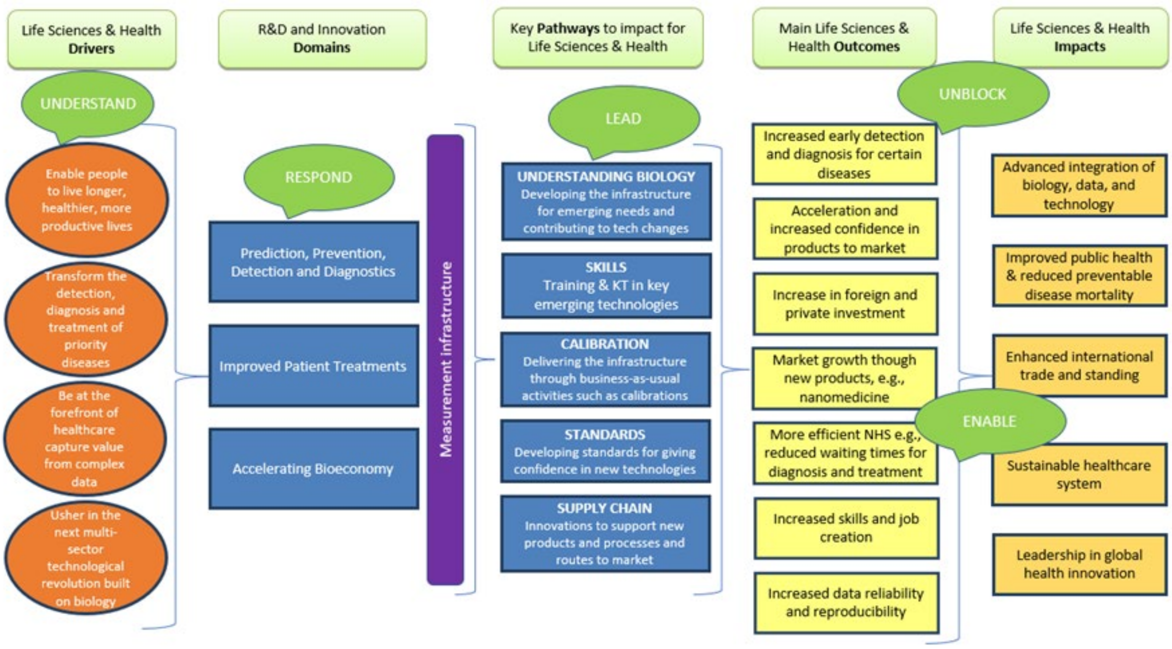

Figure 4 Logic Model for Life Sciences and Health

Although a left-to-right logic flow is presented in this simplified model, there are multiple linkages and flows between the main elements.

- **Drivers** represent the understood needs directed through science-based research, industry and government risks and challenges and NPL strategic objectives that drive the design of work done in this challenge area.

- The model includes four technical **Domains** highlighted by the challenge area teams. These domains are complementary and have relevance in multiple LSH sectors and represent the strategic focus of the challenge area. Investing in these areas now gives the country the capability to respond in the future. The domains reflect the foundations of enabling the UK to address national and global health challenges through its ability to develop, maintain and apply a national science and measurement infrastructure that will tackle a wide range of health and life sciences challenges, accelerate technological innovation, and enable a sustainable healthcare system and bioeconomy.

- The **Pathways** to impact are grouped into five categories: Understanding Biology, Skills, Calibration, Standards, and Supply Chain reflecting the key ways that NPL interacts with its stakeholders. An alternative way to view these pathways is to use impact mechanisms but in this simplified model we have used more summarised categories and reflect the language and descriptions provided by the challenge area team.

- The **Outcomes** are categories of specific LSH-related benefits generated as a direct result of NPL/NMS activity. These have been drawn from discussions, workshops, and documentary materials such as benefit maps, NMS Reformulation 2025-26, and the workshop. Note that they are not exhaustive of prospective outcomes achievable. Similarly, the **Impacts** are the long-term societal and economic benefits that are sought by stakeholders and to which NPL/NMS contributes and have been derived from the same sources.

Energy and Environment

The global climate crisis and growing environmental pressures have created an urgent need for a transition to a sustainable, low-carbon future. Government, industries, and the public are increasingly demanding robust, science-based solutions to mitigate and adapt to the impacts of climate change, pollution, and resource depletion.

As a national measurement institute, NPL provides metrology capabilities to enable a sustainable transition, by providing the scientific foundation, standards, and confidence needed to transform energy systems, industrial processes, and societal behaviours. The scope spans both direct technical impacts as well as the more indirect, systemic changes required.

The Environment challenge area is at the core of this mission, leveraging NPL's world-class metrology capabilities to enable the scientific and technological advancements needed to address these critical environmental issues.

Key focus areas include:

1. **Environmental monitoring and assessment**

- Enhancing the understanding of past, present, and future environmental conditions.
- Identifying emerging risks and issues through improved monitoring and data analysis.

2. **Decision support for policymakers and Industry**

- Providing data-driven insights to inform policy development and business strategies.
- Enabling the optimisation of trade-offs between environmental, economic, and social priorities.

3. **Standards and regulations for sustainable systems**

- Developing measurement standards and test methods to support environmental regulations.
- Ensuring the integrity and reliability of emerging technologies and markets (e.g., hydrogen, carbon capture and storage).

4. Driving innovation and technological change

- Accelerating the development and adoption of clean energy solutions, circular economy approaches, and other environmental innovations.
- Enabling a "fail fast, succeed faster" mindset through improved measurement capabilities.

5. International collaboration and influence

- Leveraging NPL's scientific expertise and leadership to shape global environmental agendas.
- Participating in international forums and partnerships to drive progress on shared challenges.

A Theory of Change for Energy and Environment

The following systems diagram provides a stylised depiction of the ToC for energy and environment and is explored in the following narrative.

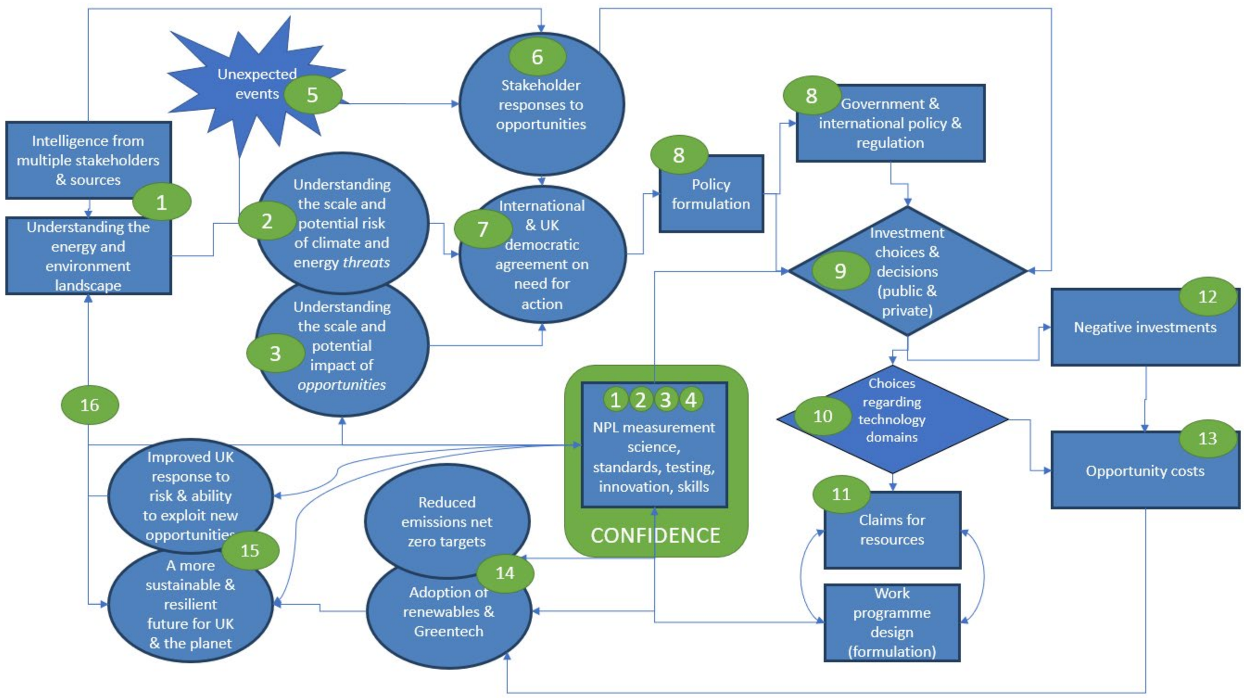

Figure 5 Systems Diagram for Energy and Environment

The systems diagram illustrates the complex, interconnected nature of the challenge area. NPL's capabilities act as an enabler, interacting with various stakeholders to drive intermediate outcomes that ultimately lead to positive societal and environmental impacts. There are a range of outcomes and impacts that the UK government and its agencies seek to achieve including net zero targets and Greentech adoption however fundamentally, overriding aims are to improve the UK response to the risks and enable the exploitation of new opportunities in response to the risks and ultimately to move to a more sustainable and resilient future for the UK and the planet. This high-level model can be further refined and expanded to capture the nuances and specific focus areas within energy and environment.

Alongside Government and other actors, NPL and its partner agencies in the NMS, proactively seek to understand, anticipate, and evaluate the potential environmental and energy-related risks and threats facing the country and measure the stability of the system on which society and the economy depend (1). It does this through its ongoing communication with the government; its participation in the highest scientific forums and communities internationally; and through its engagement with customers and industry.

As well as seeking to understand and respond to the challenges of *today*, NPL seeks to anticipate and evaluate the potential impact of the challenges of *tomorrow* (2). Both dimensions are characterised by high levels of uncertainty. However, such challenges (existing or new) also bring about opportunities. The need for novel solutions often results in technologies with worldwide markets and NPL’s innovation-related activities help the UK take advantage of such potential for growth (3).

It does this by constantly monitoring the scientific and technical environment and providing intelligence related to the systems and infrastructures that depend on accurate measurement capacity and capability (underpinned by world-class metrology) (4). The research and development conducted at NPL provide a fundamental source of knowledge about the potential scale and impact of threats and their relative importance to our environmental systems. This knowledge can either be classified as “Hard technology” which includes physical, mechanical, and electrical elements; or “Soft technology” which is the application of science to change the ways in which we interact and respond. As not all risks can be accurately forecasted, all stakeholders must sometimes respond quickly to unexpected events which are a characteristic of this domain (5).

Industry and other stakeholder groups, e.g., the academic community, also seek to understand threats and opportunities, although their drivers might be different, e.g., commercial, and competitive rather than concerned with national capabilities. The stakeholder groups develop their own responses (6) but are also dependent for success on a collective understanding of likely threats and opportunities which leads to consensus on priorities (7).

For instance, Greenhouse Gas Emissions Measurement and Modelling Advancement (GEMMA) programme is a UK lead consortium led by NPL, and it aims to demonstrate measured UK emissions through a monthly national emissions dashboard. This system will allow the UK to accurately measure and assess changes in greenhouse gases which consequently builds trusted evidence that can be used to influence policy while reducing uncertainty and delays in decision making.

Within the context of the challenge area, this consensus is not limited to national risks and interests but international too. NPL contributes to this consensus-building through its participation in policy-related initiatives (global and national) and forums and its regular communications with the government (4, 8).

However, it is not possible to address all threats and opportunities with equal attention and decisions need to be taken where resources should be directed. Such choices are reflected in policy and manifest through regulation and funding decisions (9). Industry also makes investment decisions (not least in research and development) and NPL also must respond to their metrology-related needs to contribute to the viability and sustainability of enterprises which are essential (because of their commercial focus and scaling potential) to achieve the desired long-term impacts for the country.

NPL responds to such investment choices (public and private) by bidding for funding to support its research, development, and innovation services (11). However, before doing this, it must make some difficult decisions regarding which technology domains to operate in (10). NPL’s deep understanding of which systems depend on accurate measurement both now and in the future determines where it directs its resources to conduct primary research and innovation support activity, however, because resources are constrained, it is not able to operate in all areas.

The logic model highlights the technology domains that NPL has determined are most relevant today for achieving the required outcomes and impacts in this challenge area. However, decisions *not* to invest (12), whether at the country, industry, or NMS level, can have unintended consequences and inevitably there is always an opportunity cost (13). Examples exist whereby arguably taking a follower position has led to national vulnerability and missed opportunities (13). By sitting at the vanguard of the standards creation process, which is a vital mechanism to opening new markets where the UK can make and take a significant share, NPL is helping to ensure the UK does not miss out, nor is put at risk. This work also provides a measure of protection for safeguarding the value of the assets the country has already invested in.

Once investment decisions and technology domain choices have been made, NPL undertakes a formulation process and designs work programmes that embrace a mix of pathways (or impact mechanisms). In this challenge area, NPL delivers outputs and achieves outcomes mainly through the knowledge, routes to market, and policy & decision making pathways. NPL delivers meaningful outcomes and contributes to the impacts depicted in the logic model because its work creates confidence in other actors and the system in general. This enables them to make their own investment decisions and build the infrastructures, products, and services on which the energy and environmental sectors depend.

Confidence is created at several points in the technology maturity cycle. Confidence in the science leads to the creation and acceptance of standards. When adopted by industry, this delivers confidence in the infrastructures, technologies, products, and services that are created. Traceability back to national standards is a vital building block of any innovation. Furthermore, for any innovations to be successful, the organisations involved in implementation need to be able to depend on effective supply chains. The resilience of these supply chains is dependent on confidence in solutions which in turn is dependent on good measurement practice supported by an independent and impartial authority such as NPL.

The confidence delivered through NPL's activities both unlocks and enables barriers that can prevent other organisations (and the country in general) from making progress in this challenge area. The improvements in confidence lead to changes in understanding and behaviour such as Greentech adoption and reduced emissions towards net zero targets

(14) which in turn lead to further activity and investments that, when combined, deliver the expected long-term impacts required by stakeholders (15). The understanding of these impacts in turn leads to a revised assessment of threats and opportunities (16) in a continuous process, as long as momentum is maintained.

A Simplified Logic Model for Energy and Environment

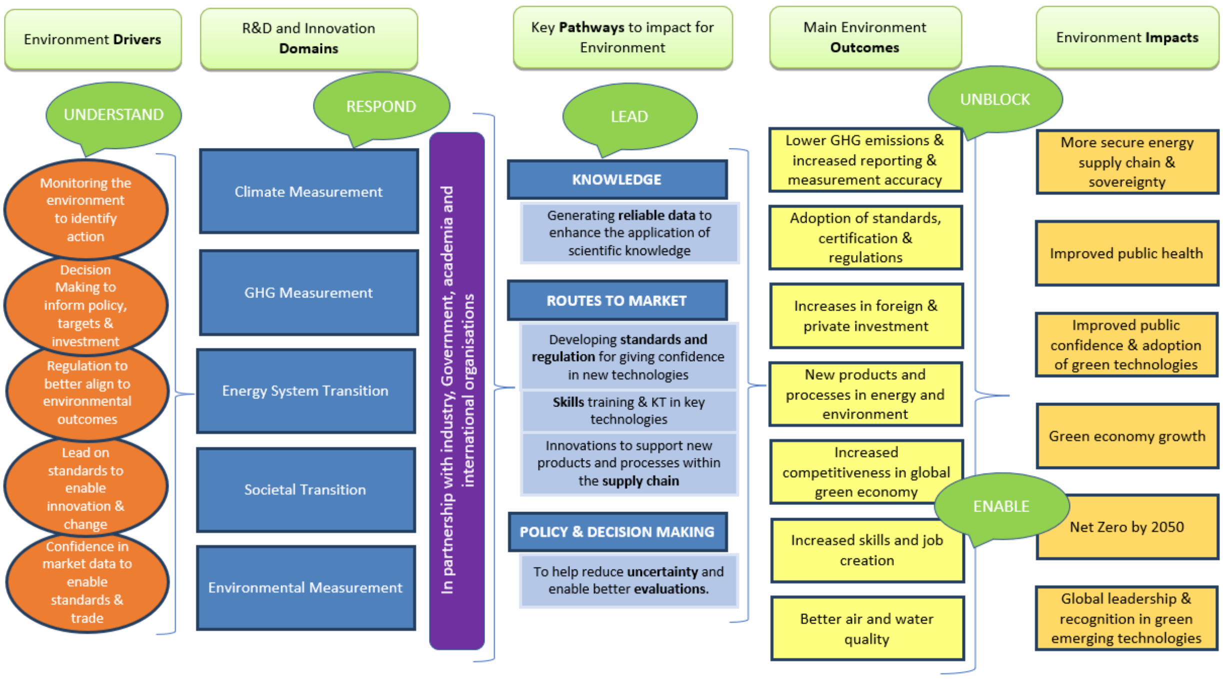

Figure 6 Logic Model for Energy and Environment

Although a left-to-right logic flow is presented in this simplified model, there are multiple linkages and flows between the main elements.

- **Drivers** represent the understood needs directed through science-based research, industry and government risks and challenges and NPL strategic objectives that drive the design of work done in this challenge area.

- The model includes five technical **Domains** highlighted by the challenge area teams. These domains are complementary and have relevance in multiple sectors and environmental and energy challenges. Investing in these areas now gives the country the capability to respond in the future. The domains reflect the foundations of enabling the UK to build capability and capacity and take advantage of the market opportunities afforded as well as respond to global threats from climate change. Taking a leading position in determining standards for these technologies contributes to the global position of the UK. Due to the national and international nature of energy and environmental themes the importance of partnerships is highlighted in the model running across all domains.

- The **Pathways** to impact are grouped into three categories: Knowledge, Routes to market, and Policy & decision making, reflecting the key ways that NPL interacts with its stakeholders. An alternative way to view these pathways is to use impact mechanisms but in this simplified model we have used more summarised categories and reflect the language and descriptions provided by the challenge area team.

- The **Outcomes** are categories of specific environment-related benefits generated as a direct result of NPL/NMS activity. These have been drawn from discussions, workshops, and documentary materials such as benefit maps, NMS Reformulation 2025-26, and the workshop. Note that they are not exhaustive of prospective outcomes achievable. Similarly, the **Impacts** are the long-term societal and economic benefits that are sought by stakeholders and to which NPL/NMS contributes and have been derived from the same sources.

Security and Resilience

In the last decade, the world has changed considerably with new and different threats to society. In addition to the chronic risks caused by geographic, political, and diplomatic change which often cause conflict and instability, other global shifts such as mass migration and climate change threaten the norms and infrastructures on which the UK's society is based. Rapid technological change, whilst bringing about many benefits, has also resulted in increased cyber and digital-related threats which as well as affecting individuals and organisations in a relatively minor way, can even bring about wholesale systems failures. The consequences of such failure range from minor disruption to societal collapse.

The Security and Resilience domain encompasses the challenge of managing the risks to national security. It concerns the need to maintain resilient infrastructures (which come in many forms) so that society can function, and citizens and organisations can go about their daily activities with confidence. The scope therefore includes the systems and structures on which society depends (sometimes inadvertently) such as digital technologies, timing, communications, transport, banking, and healthcare.

This challenge area is largely concerned with ensuring confidence in the intelligent and effective use of data and the infrastructures that provide it. The country's reliance on digital technologies is pervasive and often unknown. This requires a resilient infrastructure and reliable data; however, the UK cannot act independently. Technologies and infrastructures are evolving rapidly and on a global rather than national scale. Data that was once the province of nation-states or major corporations is now freely available to anyone.

The Security and Resilience challenge area reaches across many other industries, domains, and areas of responsibility. In this respect, NPL works very closely with the three key departments of State that are primarily responsible for security, i.e. The Home Office, The Foreign Office, and the Ministry of Defence. However, NPL also works with other departments including DSIT and Transport that have an intrinsic interest in data security and new technologies.

At NPL, science leads to security through knowledge creation and know-how. Firstly, inventions can be developed from the research conducted at the lab, especially for key emerging areas like Quantum Technologies. Secondly, this knowledge can be verified using measurement expertise through Testing & Analysis and Verification & Validation. Lastly, pre-exiting scientific knowledge can be applied to find solutions in an industry to exploit or in combination with technology for programmes like the UK Telecom Labs.

A Theory of Change for Security and Resilience

The following systems diagram provides a stylised depiction of the ToC for security and resilience and is explored in the following narrative.

Figure 7 Systems Diagram for Security and Resilience

In the face of large-scale and fundamental change, the overarching aim of the government and its agencies is to keep its citizens secure and maintain or improve the country's resilience – i.e., its ability to respond to threats. The government also seeks to obtain benefits to society and the economy by exploiting the opportunities that technological change affords. Fundamentally, these are the two main impacts sought under the Security and Resilience challenge area: improvements to sovereign capability and economic success.

The NMS performs several activities that both help to preserve and improve sovereign capability and build the foundations for future success in emerging technologies and markets. Alongside Government and other actors, NPL and its partner agencies in the NMS, proactively seek to understand, anticipate, and evaluate the potential risks and threats facing the country and measure the stability of the infrastructure (the system) on which society and the economy depend (1). It does this through its ongoing communication with the government; its participation in the highest scientific forums and communities internationally; and through its engagement with customers and industry.

As well as seeking to understand and respond to the challenges of today, NPL seeks to anticipate and evaluate the potential impact of the challenges of tomorrow (2). Both dimensions are characterised by high levels of uncertainty. However, such challenges (existing or new) also bring about opportunities. The need for novel solutions often results in technologies with worldwide markets and NPL's innovation-related activities help the UK take advantage of such potential for growth (3).

It does this by constantly monitoring the scientific and technical environment and providing intelligence related to the systems and infrastructures that depend on accurate measurement capacity and capability (underpinned by world-class metrology) (4). The research and development carried out at NPL provides a fundamental source of knowledge about the potential scale and impact of threats and their relative importance. As not all risks can be accurately forecasted, all stakeholders must sometimes respond quickly to unexpected events which are a characteristic of this domain (5).

Industry also seeks to understand threats and opportunities, although their drivers are largely commercial and competitive rather than concerned with national capabilities. It develops its own responses (6) but is also dependent on success on a collective understanding of likely threats and opportunities which leads to consensus on priorities (7). NPL contributes to this consensus building through its participation in policy-related initiatives and forums and its regular communications with the government (4, 8). However, it is not possible to address all threats and opportunities with equal attention and decisions need to be taken where resources should be directed. Such choices are reflected in policy and manifest through regulation and funding decisions (9). Industry also makes investment decisions (not least in research and development) and NPL also must respond to their metrology-related needs to contribute to the viability and sustainability of enterprises which are essential (because of their commercial focus and scaling potential) to achieve the desired long-term impacts for the country.

NPL responds to such investment choices (public and private) by bidding for funding to support its research, development, and innovation services (11). However, before doing this, it must make some difficult decisions regarding which technology domains to operate in (10). NPL’s deep understanding of which systems depend on accurate measurement both now and in the future determines where it directs its resources to conduct primary research and innovation support activity, however, because resources are constrained, it is not able to operate in all areas.

The logic model highlights the technology domains that NPL has determined are most relevant today for achieving the required outcomes and impacts in this challenge area. However, decisions not to invest (12), whether at the country, industry, or NMS level, can have unintended consequences and inevitably there is always an opportunity cost (13). Examples exist whereby arguably taking a follower position has led to national vulnerability and missed opportunities (13). By sitting at the vanguard of the standards creation process, which is a vital mechanism to opening new markets where the UK can make and take a significant share, NPL is helping to ensure the UK does not miss out, nor is put at risk. This work also provides a measure of protection for safeguarding the value of the assets the country has already invested in.

Once investment decisions and technology domain choices have been made, NPL undertakes a formulation process and designs work programmes that embrace a mix of impact mechanisms (or pathways). In this domain, NPL delivers outputs and achieves outcomes mainly through the knowledge, skills, standards, supply chain, and informed policy pathways. NPL delivers meaningful outcomes and contributes to the impacts depicted in the logic model because its work creates confidence in other actors and the system in general. This enables them to make their own investment decisions and build the infrastructures, products, and services on which security and resilience depend.

Confidence is created at several points in the technology maturity cycle. Confidence in the science leads to the creation and acceptance of standards. When adopted by industry, this delivers confidence in the infrastructures, technologies, products, and services that are created. Traceability back to national standards is a vital building block of any innovation.

Furthermore, for any innovations to be successful, the organisations involved in implementation need to be able to depend on effective supply chains. The resilience of these supply chains is dependent on confidence in solutions which in turn is dependent on good measurement practice supported by an independent and impartial authority such as NPL.

The confidence delivered through NPL's activities both unlocks and enables barriers that prevent other organisations (and the country in general) from making progress in this challenge area. The improvements in confidence lead to changes in understanding and behaviour (14) which in turn lead to further activity and investments that, when combined, ultimately deliver the expected long-term impacts required by stakeholders (15). The understanding of these impacts in turn leads to a revised assessment of threats and opportunities (16) in a continuous process, as long as momentum is maintained.

A Simplified Logic Model for Security and Resilience

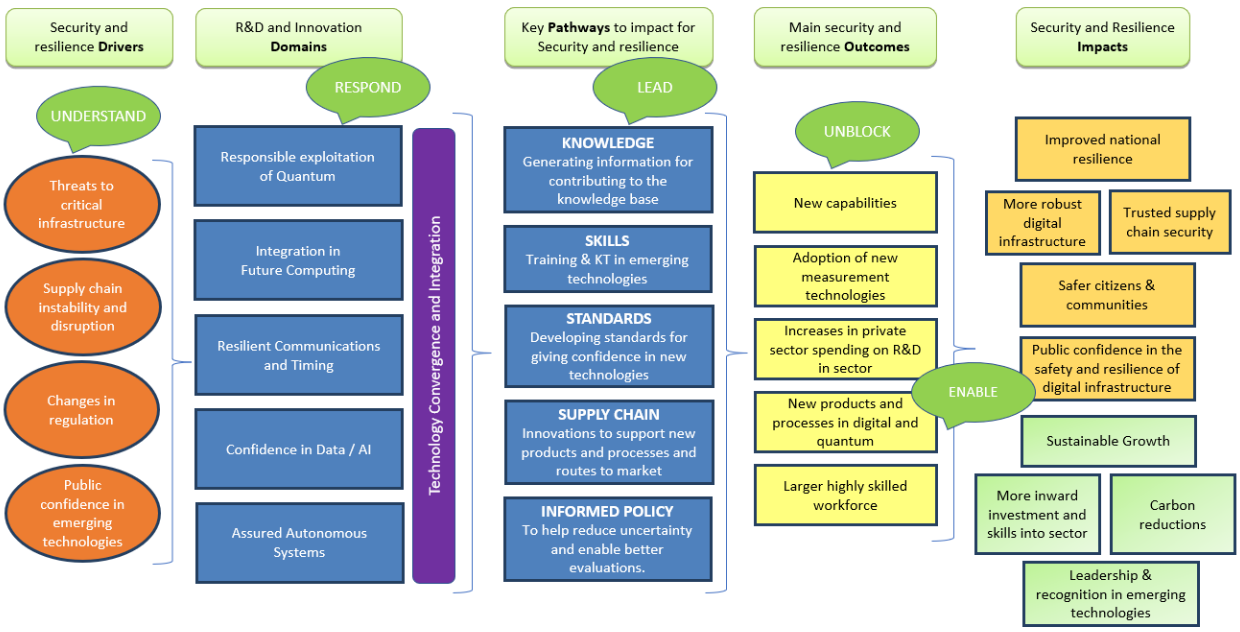

Figure 8 Logic Model for Security and Resilience

Although a left-to-right logic flow is presented in this simplified model, there are multiple linkages and flows between the main elements.

- **Drivers** represent the understood needs directed through science-based research, industry and government risks and challenges, and NPL strategic objectives that drive the design of work done in this challenge area. They are grouped as shown to draw a general distinction between drivers that prompt a reactive response and drivers that reflect a more proactive and strategic response and where the opportunities may be longer term and about market making and building.

- The model includes five technical **Domains** highlighted by the challenge area teams. These domains are overlapping and complementary and have relevance in multiple industrial sectors. The domains reflect the convergence of technologies and the move towards integrated autonomy which is driving much of defence and national security as well as the national economy.

- In this challenge area, the **Pathways** to impact (or impact mechanisms) are grouped into five categories: Knowledge, Skills, Standards, Supply chain, and Informed policy. The grouping in this model reflects the language and descriptions provided by the challenge area team as being of key importance.

- The **Outcomes** are categories of specific security and resilience-related benefits generated as a direct result of NPL/NMS activity. These have been drawn from discussions, workshops, and documentary materials such as benefit maps. Similarly, the **Impacts** are the long-term societal and economic benefits that are sought by stakeholders and to which NPL/NMS contributes. They are grouped into benefits that directly relate to the resilience of people, organisations, and systems, and those that are more about the benefits of the UK taking a leading position in these emerging markets and related opportunities.

Conclusion

This report has laid the foundation for a more nuanced and targeted approach to programme design, evaluation, and strategic alignment within NPL by developing bespoke logic models for each of the four challenge areas. The logic models presented in this report are strategic instruments that articulate the causal pathways from drivers to long-term impacts. Each model is underpinned by a theory of change that reflects the complexity of the systems in which NPL operates, the interdependencies between stakeholders, and the evolving nature of societal and technological challenges.

In the case of **Advanced Manufacturing and Materials**, the logic model captures the sector's role as a foundational enabler of innovation and productivity, linking metrology capabilities to economic growth, global competitiveness, and clean growth technologies. The model highlights how investments in digital engineering, advanced materials, and semiconductor technologies can drive Total Factor Productivity and GDP per capita, reinforcing the UK's industrial leadership.

For **Life Sciences and Health**, the logic model reflects a systems-based approach to healthcare innovation, emphasising the importance of understanding biology, predictive diagnostics, and bioeconomic transformation. It illustrates how measurement science can support early disease detection, precision medicine, and sustainable healthcare systems, while also contributing to regulatory frameworks and public health outcomes.

The **Energy and Environment** challenge area is addressed through a model that integrates environmental monitoring, policy support, and technological innovation. It demonstrates how NPL's metrology infrastructure enables the UK to respond to climate risks, support net-zero transitions, and influence international standards. The model also acknowledges the opportunity costs of investment decisions and the importance of maintaining momentum in the face of uncertainty.

The **Security and Resilience** model underscores the critical role of measurement science in safeguarding national infrastructure and enabling technological sovereignty. It captures the dual imperative of responding to immediate threats and preparing for future challenges, while also fostering economic success through leadership in emerging markets. The model reflects the convergence of technologies and the need for robust standards, resilient supply chains, and informed policymaking.

Together, these logic models provide a coherent framework for NPL to demonstrate its value proposition, guide strategic investments, and enhance its impact across multiple sectors. They offer a transparent mechanism for aligning programme activities with stakeholder expectations and national priorities, while also enabling adaptive learning and continuous improvement.

As the UK continues to navigate complex global challenges from climate change and health crises to technological disruption and geopolitical shifts, NPL's ability to deliver trusted measurement science will be pivotal. These logic models will serve as living documents, evolving in response to new evidence, stakeholder feedback, and policy developments.

Logic Models for the Challenge Areas of The National Physical Laboratory

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