The National Materials Datahub Can Improve Governance for Better Material Use by Industry: An Evidence Briefing from the Resource Recovery from Waste Programme

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Summary: Decision-making and investment for improved material use, as envisioned in a circular economy, is held back by a lack of adequate data infrastructure. Governance of material use involves diverse economic, social and environmental aspects and is highly fragmented across (devolved) government bodies. Acting upon government and industry ambitions to optimise material use requires change from across society. Industry needs government to correct market failures and create an enabling context. Government has to adopt a whole-system approach and continue to develop and implement a coherent set of strategies, plans, policies, regulations and legislation. To achieve this, a better infrastructure must be developed for data collection, storage, exchange, analysis, and use in decision-making. Data has to be brought together on stocks and flows of materials and products; throughout their lifecycles from extraction to manufacturing, consumption, and end-of-use management incl. reuse, repair, remanufacturing, recycling, controlled storage, and energy recovery; on volumes, technical qualities, location and timing; and economic, social and environmental costs and benefits at each lifecycle stage. The National Materials Data hub (NMDhub) could offer essential functionalities for government both during its development and commissioning. It is important to engage the community of stakeholders and have detailed conversations about the materials and functionalities that should be prioritised in the hub's development. Building the NMDhub represents a sizeable investment and an initial assessment presented herein suggests that this would be far outstripped by significant benefits for economic growth, business opportunities, job creation, low-carbon targets, natural capital, resource productivity, and material supply security.

Paper outline: This briefing paper was written as part of the preparations of a business case and strategy for the development of the NMDhub. Here, evidence from the Resource Recovery from Waste programme will be shared: Section 1) Insight into the governance landscape for materials; Section 2) Role of government in supporting industry to capitalise on opportunities around better material use; Section 3) Challenges in creating an enabling governance context; and Section 4) Added value of the emerging NMDhub for the evolving governance of materials.

Resource Recovery from Waste: The Resource Recovery from Waste programme is a £7M strategic investment by the Natural Environmental Research Council, Economic and Social Research Council, and the Department for Environment, Food and Rural Affairs [1]. Running from 2014 to 2019, the programme brought together hundreds of partners from academia, government and industry to provide evidence and tools for a radical change in resource and waste management. Seeking to make better use of materials, Resource Recovery from Waste envisioned a circular economy in which resources and wastes contribute to a resilient environment, human well-being, and clean growth.

Materials and circular economy: The global rise of material use has brought economic growth and welfare around the world. However, resource overexploitation and the generation

of wastes following the linear economic model of take-make-use-dispose has also been linked to environmental degradation, infringing on basic human rights of people in the UK and abroad [2]. Material use is forecasted to accelerate over the next decades and it is of critical importance that we do so in support of thriving economies while generating net-gains for society and environment. Circular economy approaches could optimise economic, social and environmental values throughout the lifecycle of materials and products [3].

1. Overview of the governance landscape

Governance areas and organisations: Circular economy, and material use therein, stretches across a wide range of governance areas that are economic, environmentally or socially focused, or a mix thereof (Figure 1). As a result, a broad range of government bodies active at regional, national and international scales are involved in realising a circular economy [3,4,11,12]; see Figure 1, please note that the figure covers departments for UK and England but includes all bodies in devolved administrations where relevant [3].

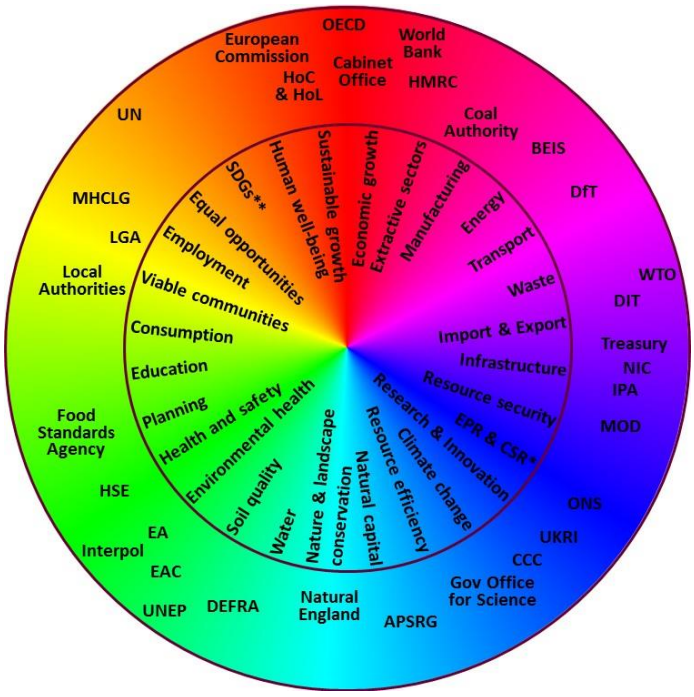


Figure 1: Government areas and organisations associated with circular economy; UK and English bodies and devolved colleagues; *Extended Producer Responsibility and Corporate Social Responsibility; **UN Sustainable Development Goals; (based on [3,4,11,12]).

Cross-societal actors: This complex government picture should be placed in the context of further stakeholders from across society that are important for implementing a circular economy. This includes companies from across supply chains as well as trade organisations, investors, product standard bodies, technology providers, and consultancies and research institutes; academia and other organisations involved in research, innovation and education; traditional and social media; and civil society [4].

Government's circular economy ambitions: With circular economy branching from the devolved governance of the waste sector, differences in approaches for and degree of implementation of circular economy is diverging between the devolved administrations in the UK [3]. Nevertheless, circular economy ambitions have taken hold across government [3,5]:

- The Industrial Strategy (2017) states that the government is *"committed to moving towards a more circular economy – to raising productivity by using resources more efficiently, to increasing resilience by contributing to a healthier environment, and to supporting long-term growth by regenerating our natural capital"* (p148).
- The Clean Growth Strategy aims to achieve decarbonisation objectives (enshrined in the Climate Change Act) at low cost to UK taxpayers, consumers and businesses while maximising social and economic benefits for the UK, and as such is championing a circular economy in which renewable energy fuels economic growth.

- The Bioeconomy Strategy (2018) speaks of *"unprecedented demand for global resources"* and, in an effort to reduce dependency on fossil resources and contribute to clean growth, aims to double the bioeconomy in the UK from £220Bn (13.6% GVA and 5.2M jobs) to £440Bn by 2030 – boosting products, processes and services with renewable biological resources, in line with circular economy principles.
- The 25 Year Environment Plan (2018) aims to improve the environment, to be enshrined in law via the Environment Bill. Amongst other objectives, the plan strives to use natural resources more sustainably and efficiently, minimise waste and pollution, and mitigate and adapt to climate change (aligned with the Clean Growth Strategy). The plan requires reliable, comprehensive data.
- The Resources and Waste Strategy (2018) states that *"A more circular economy will see us keeping resources in use as long as possible, so we extract maximum value from them"* (p7). The government aims to preserve materials by minimising waste, promoting resource efficiency and moving towards a circular economy; complementing the Industrial and Clean Growth Strategies to double resource productivity and eliminate avoidable waste by 2050. The strategy states that *"high quality data, information and insights are essential for effective policy making"* (p134).
- Major public works projects committing to circular economy, as expressed by the UK National Infrastructure Delivery Plan (2016) aiming to: "*have the right infrastructure in place to deal with waste as efficiently as possible, with an ambition to move towards a 'circular economy' where material resources are valued and kept in circulation*".

Benefits of a circular economy: An increasingly circular economy is expected to deliver a number of benefits. Here we summarise benefits that are mentioned often [5]:

- Economic benefits: innovative services, technologies and processes increase global competitiveness and offer business opportunities; new business models and access to customer segments; cost savings (waste management, material inputs); derisking resource supply and impact of raw material price volatility; and sustainable growth.
- Social benefits: create up to half a million jobs in the UK[1].
- Environmental benefits: reduce carbon emissions through increased resource efficiency and renewable energy – UK emissions from primary material production is ca. 200 Mt eCO_2 p.a. and equivalent emissions avoided by current limited recycling is ca. 60 Mt eCO_2 p.a. i.e. considerably more than avoided by e.g. windfarms.

Types of circular economy: There appears to be a growing consensus in government in favour of a circular economy. There are different types of circular economy that can be realised, and Resource Recovery from Waste broadly identified three scenarios (Figure 2):

- Energy-from-waste: the current emerging circular economy that primarily relies on energy recovery.
- Material recovery: increased deployment of recycling which will remain necessary into the future for unavoidable waste.
- Circular by design: maximum waste prevention, extended durability, and recyclability of products and materials.

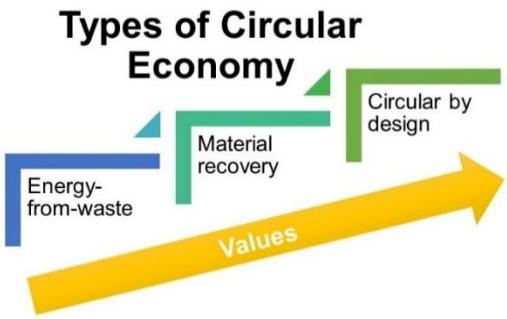


Figure 2: Different scenarios for a circular economy that could be realised in the UK.

[1] http://www.wrap.org.uk/content/employment-and-circular-economy

These circular economy scenarios have different potentials attached for the generation of economic, social and environmental values throughout the lifecycles of materials and products. The costs and benefits, and their importance as perceived by diverse government bodies as well as other stakeholders throughout society, should be transparently explored to select and realise a preferred circular economy.

2. A government supporting industry to capitalise on circular economy opportunities

Role of government: Realising a circular economy will require concerted action from actors across society including producers, consumers, governments, and knowledge- and technology providers [2]. The role of government in the transition towards a circular economy is critical according to academic literature and empirical evidence from Resource Recovery from Waste [6]. Government's main tasks were perceived as: Develop strategies and policies for circular economy; Regulation, guidance and enforcement; Enable innovation via funding, collaboration, and exploring solutions; Collaborate across government bodies; Promote circular economy; Gather evidence in support of policies; Impact on circular economy via procurement; and, Directly play a role via waste management [4].

Business drivers circular economy: Companies are increasingly committed to adopt circular economy practices, driven by material supply benefits such as: Reduced risk and cost increasing resource security including for water, energy, food and associated infrastructure; Environmental benefits; Tax reliefs and policy incentives; Changing consumer attitudes and demand; and Growing availability of new economic and business models [6,7].

Business constraints circular economy: Companies are, however, faced with a number of challenges including [5-7]: A lack of knowledge and skills to improve their sustainability performance through altered material use and to manage radical and collaborative innovations in the transition towards a circular economy; Supply chain dependencies; Focus on short-term returns on investment; Market failures such as limited insight into the quality of recycled materials and externalised costs such as carbon emissions, and pricing of primary and secondary materials; Lack of standardised data collection on resource flows; and a raft of governance related barriers.

Lack of governance constrains business: The main constraint regarding governance, as viewed by industry, is the lack of a long-term, centralised government vision and planning for better material use [7]; this view was expressed between 2016 and 2018, the publication of the series of strategies and plans (see Section 1) incl. the Resources and Waste Strategy in 2018 have likely improved this situation [8]. This positive development must be followed through with actions to bring ambitions into practice, incl. suitable policies and regulations. Industry identified political barriers incl. poor regulation and transfer of liabilities, clashes between the motivation and action of government departments, and political inertia and dogma as the prime constraints for adopting circular economy practices [7].

Business actions: Industry can take a number actions and the following were prioritised [7]:

1. Embed extended producer responsibility into corporate social responsibility policy.
2. Contribute to policy development, especially by providing data on resource stocks and flows.
3. Design products and materials to retain economic, technical, social and environmental value.
4. Innovate for resource security, e.g. by finding valuable applications for unavoidable wastes.

5. Business model innovation embedding circular economy within companies.
6. Promote behaviour change by educating staff and consumers.

Change in government is crucial: Government plays a key enabling role for companies to make better use of materials [6]. Experts from across academia, government, industry and third party organisations, brought together at the Resource Recovery from Waste Annual Conference 2017, identified key themes, motivations and constraints for the transition towards a circular economy. The relations between themes were analysed to identify key intervention points, revealing an intricate web of dependencies between themes that should be acted upon in order to make better use of materials (Figure 3). Regulatory change and policy integration featured in the most connected themes, suggesting that government action can deliver benefits regarding nearly all themes stipulated around Figure 3 and for the associated actors. The most important intervention point was to change how materials are valued, referring to the importance of correcting market failures and to take into account the combined economic, social, environmental and technical (functional) value of materials. These values can only be assessed if the data are available. However, availability of sufficient and compatible data was identified as a major constraint for decision-making around for example government policy and public and private investment.

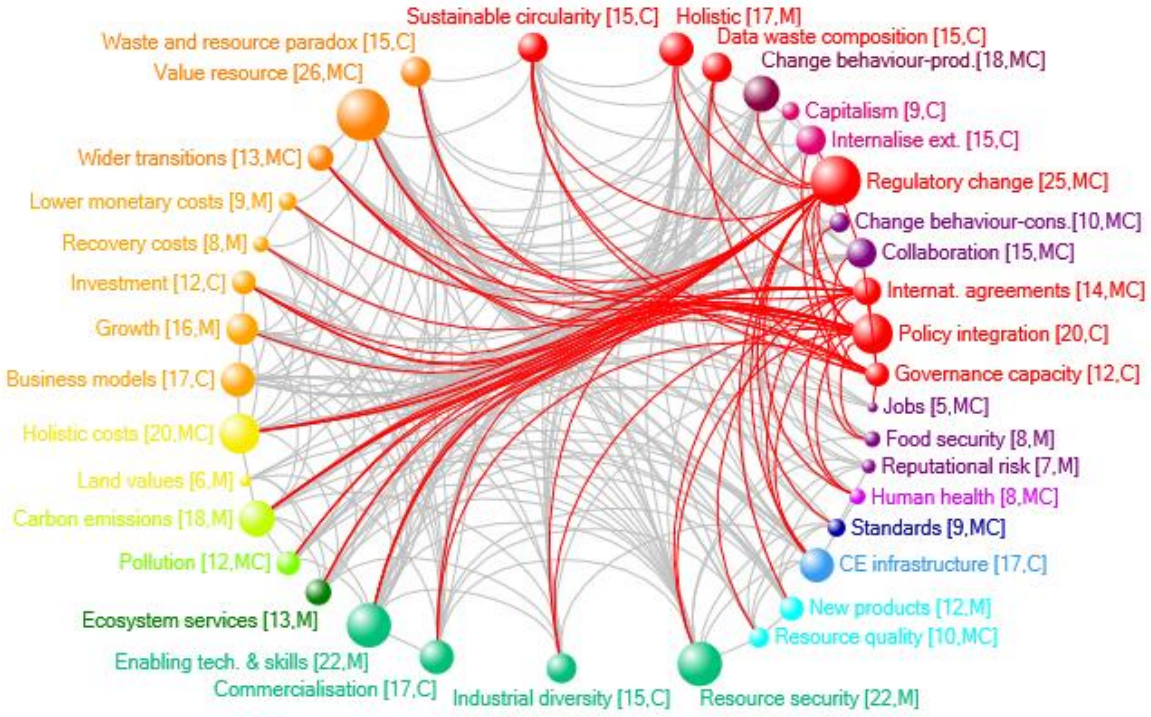


Figure 3: Relations between themes of the business case for resource recovery. Connections from nodes directly about governance highlighted red. Legend: Node sizes are relative to the number of connections. Red nodes=general; Purple=social; Aqua=technical; Light green=environmental; Light orange=economic; and transition colours thereof indicate combinations of any of these types – NB regulatory change, international agreements, policy integration and governance capacity were purple but highlighted red in this version of the figure to emphasise how government action can impact on all other themes that are important for realising a sustainable circular economy; C=challenge; MC=motivation and challenge; M=motivation [after 6, 9].

3. Towards a supportive governance context

Government change to improve material use: Industry indicated that they need government change and support in order to capitalise on the opportunities offered by a circular economy and, associated therewith, better use of materials [7]. Government can take a number of actions to support industry in their ambitions to make better use of materials and Resource Recovery from Waste articulated the following recommendations based on extensive stakeholder engagement [4,6,7,10-14]:

1. Continue to develop an increasingly coherent, cross-departmental, long-term government vision and strategy for a circular economy that increases coherency across the UK nations, optimises economic, technical (functional), social and environmental values of materials and products, and designs wastes out of the economy as much as possible, indicating a clear and joined up direction of travel that provides a framework for consistent policies, regulations and a stepwise delivery of a circular economy that can be flexible within the parameters of the long-term vision. This is crucial for instilling investor confidence. More coordination and leadership is required and this could be provided by a cross-departmental governmental body for circular economy that supports the development of an overarching vision and set of associated strategies, evidence-based policies, and regulations in the departments involved in circular economy and materials, and collects data and monitors progress (see below). More coordination is required to ensure that government ambitions for circular economy and improved use of materials are accompanied with sufficient funding for associated departments, regulators and local authorities that are responsible for implementation, recognising their contribution towards environmental, social and economic aims possibly set out by other government departments.
2. In line with the long-term vision and strategy, set new targets for material use and develop metrics and metric-systems to assess costs and benefits of materials and products holistically. As a minimum this should be linked to climate change, include resource efficiency targets for scarce materials and materials whose extraction has severe environmental implications, more ambitious targets aiming to preserve more functionality of materials and products through recycling, reuse and waste minimisation, and cover the full supply chain from extraction and manufacturing to end-of-use management and everything in between. Joining up targets and monitoring of delivery with the UN Sustainable Development Goals could help working towards the ambition to deliver improvements across the full range of major sustainability challenges and limit risks for displacing impacts through material use.
3. Collect data about stocks and flows of raw and recycled materials as well as products throughout their lifecycle from extractive phases to end-of-use and recovery, ideally including volumes, technical characteristics, and economic, social and environmental costs and benefits. Reporting mechanisms for all resources and waste must be streamlined and either incentivised (e.g. with tax relief) or regulated as there is little insight into material stocks and flows from e.g. extractive, manufacturing and commercial sectors; insight into stocks and flows throughout the lifecycle of materials and products is crucial for realising a circular economy.
4. Combine access to better data with the development of a new forecasting model for the integrated assessment of future material demands, for implementing ambitions around e.g. clean growth and the waste hierarchy, and estimating demand for innovation and end-of-use infrastructure requirements. This is important in order to assess the feasibility of strategies regarding criticality of materials, and impact on decarbonisation and resource efficiency.
5. Show global leadership in establishing a level playing field for valuing materials and products across borders to the benefit of companies trading internationally, by further

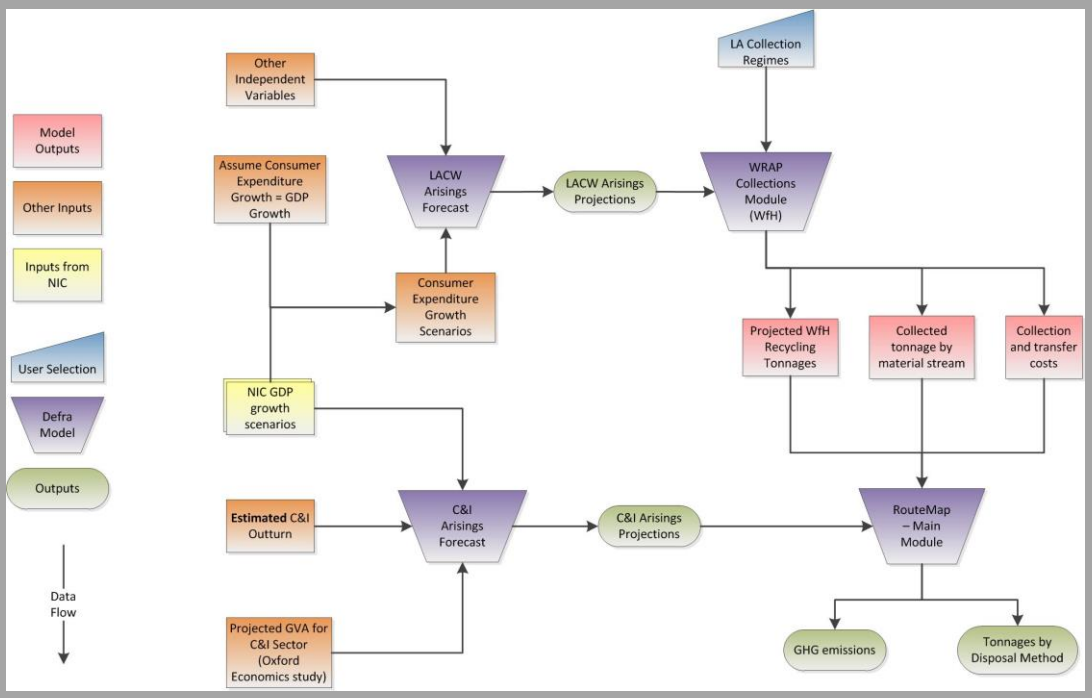
embedding resource efficiency and circular economy into global agreements, and their domestic delivery, on e.g. climate change and sustainable development.

6. Support secondary material markets by correcting market failures around raw and recycled material pricing, such as with a differential tax to price in social and environmental costs of materials. This could start with a carbon tax depending on recycled content and government procurement favouring products with recycled content. Implementation of tax interventions will require better data on stocks and flows of materials and products, and costs and benefits associated with these.
7. Initiate a “Circular Economy Network” offering a comprehensive business support programme that: disseminates essential circular economy knowledge and skills to companies throughout the UK; helps companies to address risks and opportunities associated with sustainability and material use, increasing resilience to benefit from emerging technologies, and changing material stocks and flows; embeds circular supply chains into regional economies via local industrial strategies (taking into account detailed insights into stocks and flows of materials within and between regional industries); supports design for durability, reuse and recyclability through innovation support, investment, and collaboration with regulators; support research, innovation and multi-stakeholder collaboration through investment; and facilitates business model innovations that improve material use via practices such as waste minimisation and industrial symbiosis, establishing flows of recovered materials across sectors.
8. Improve regulation and implementation thereof: Increase regulatory capacity in terms of technical advice regarding resource and wider environmental management and enforcement to raise standards in industry; Introduce more ambitious regulatory targets and streamline end-of-waste procedures to unlock potential for organisational, social, and technological innovation; Drive culture change from singular focus in environmental protection to a whole-system approach that recognises economic potential of resource recovery, via more ambitious and harmonised regulations and by facilitating dialogue between regulators, policy makers, businesses and research.
9. Influence behaviour of the general public through education about circular economy including reuse and recycling aiming to normalise resource recovery practices, and enforcement of measures around consumer responsibility such as fines for littering.
10. Diversify investment into infrastructure for a circular economy which currently is heavily skewed towards energy-from-waste; the overall end-of-use sector would become more resilient and increase sustainability performance if investment was balanced with the establishment of more infrastructure for reuse, repair, remanufacturing and recycling.

Barriers to government change: Making radically better use of materials will require a significant number of changes in government structure, strategy, policy, regulation, and governance delivery (as indicated above). However, government itself is equally held back by the challenges implied in the recommendations above. The most important constraints include the combination of a highly complex government environment (Figure 1) together with a lack of formal government structure offering leadership for circular economy and sufficient capacity for cross-departmental collaboration (recommendation 1, above) to effectively act upon otherwise shared ambitions (overview in Section 1). Government needs a better infrastructure for the development and delivery of evidence-based strategies, plans, policies and regulations [5]. This includes better systems to store, exchange, analyse and use data in decision-making (see recommendations 2-4 above) populated with better data on materials and products.

Case study: Modelling impacts and benefits of new waste policy

Outline: DEFRA generally uses two models, about waste flows (image below) and household waste collection systems, to analyse environmental impacts and benefits of a policy change in the waste sector. The models cover a part of the production-consumption cycle, from the point of waste generation through to collection, sorting and further downstream processes such as recycling and reprocessing; and only include Municipal Solid Waste. The models use either GDP growth scenarios or consumer spending forecasts to predict the volume of future waste flows.



Challenges: Current models do not account for stocks of materials and for what happens with materials after reprocessing, and thus cannot assess impacts and benefits of new policies on the whole production-consumption system. This is especially limiting the ability to assess measures upstream from the point of waste generation that are important to slow down and reduce material use, such as servitisation and dematerialisation. The models are further constrained by the limited data availability on different types of stocks and flows of materials such as from extractive, construction, and manufacturing sectors, known to be both resource intensive and among the largest waste producers, and from imports and exports.

Functionalities required: Modelling and subsequent decision-making would benefit from: Data with a higher granularity on the size and composition of stocks and flows, e.g. covering the types of plastics, metals etc. used; Insight into products in which raw and reprocessed materials have been used and how much materials is present in a product type, e.g. how much of a specific metal is present in cars in the UK; Form of materials, e.g. mixed/ segregated in controlled storage or landfills or part of natural reserves; Geographic location of materials and products from origin to current and likely next destination; and Insight into a wider range of aspects such as embodied carbon of materials and products.

Solutions pursued: Data on stocks of materials are occasionally supplemented, resulting in patchy results. New interactive waste tracking solutions are under development which could potentially improve data on waste flows. A data hub on materials could be a valuable source of missing data on material stocks and flows outside the waste sector and provide a platform to exchange data on waste flows with other departments. Decisions that affect material use are made across government by diverse departments, e.g. DEFRA, BEIS, Treasury, MHCLG and Transport; yet due to limited cross-departmental collaboration and data exchange these decisions are insufficiently supported by evidence on material availability and wider implications of material use e.g. for resource security, climate change, quality of life and the economy.

Limited data available on materials and products: Lack of sufficient and compatible data constrains government in the preparation of measures in support of better material use [6] – see recommendation 3 above. Data is needed from raw material extraction through to production, consumption and end-of-use management, about mass flows, material characteristics and materials used in products, the economic, social and environmental values attached to them, current time and place and next fate/ destination, and (potential) waste arisings (as also expressed in the case study above). With such data, forecasting capabilities could be developed which is important in order to support government in the preparation of evidence-based strategies, plans, policies and regulations as well as for decision-making for the required public investment into e.g. diversifying infrastructure for circular economy that is estimated at £5-25 Bn with high returns on investment [10]. Similarly, industry requires access to better data to underpin decisions regarding for example business model innovation and investment into new technologies and infrastructure.

Improving data collection: Current data available are primarily about wastes and collected in response to legal obligations [6, and see case study above]. To get a more complete picture of stocks and flows of materials and products throughout their lifecycle, as outlined in recommendation 3 above, a combination of digital technologies, standards, additional legal obligations, and reporting requirements could aid data collection: New digital technologies/ internet of things can help to capture data; Standards can help to harmonise data collection and this will help to get a better insight into infrastructure requirements; Reporting requirements for operators exempt from legal obligations (i.e. those falling outside of environmental permitting regulations, and including the most resource intensive sectors in the UK economy) must be enhanced or incentivised. Confidentiality issues around commercially sensitive data on material flows must be addressed. Ideally data would be transparent and available open access, or at least externally searchable.

4. The added value of the National Materials Datahub in an evolving governance landscape

Based on engagement of experts in government, Resource Recovery from Waste anticipates that six areas in the governance landscape will continue to evolve and additional dynamics are likely to occur [3]:

Short-term – within 5 years:

- **BREXIT:** Expected to result in anticipated and unanticipated material shortages in the short-term, and possibly disruption to waste export. Better material use could be embedded more into government procurement outside of EU rules. The UK is expected to transpose the EU circular economy package into UK legislation and in the medium- to long-term more effort will be required from the UK itself to develop legislation that guides sustainable material use.
- **Industry 4.0:** Digitisation offers opportunities to improve data collection, transfer, analysis and communication around material use. Advanced tracking systems are under development, enabling better insights into material and product stocks and flows. Technically it is increasingly feasible to introduce material and product passports, such as with distributed ledger technologies, that should include compositional analysis and end-of-use plans covering the energy cost of the recovery process; and in the absence of passports the periodic assaying of materials and products in government laboratories (such as already customary for some materials entering the UK) should be introduced more widely, prioritising (products containing) critical raw materials and materials and products with a high environmental impact.

Digitisation of information flows will enable communication of impacts of materials and products to consumers and, in return, government should prepare to become more responsive to the wishes of the general public to drive sustainability.

- **Growing demand for (near) critical materials:** The on-going digitisation and clean growth ambitions will add to a growing demand for (near) critical materials globally and in the UK. Supply will be affected by political instability and dependence on new trade deals. At end-of-use, products and materials that are difficult to recover will emerge that are unfamiliar to the waste sector, likely requiring new or updated regulation. Stricter extended producer regulation, designing durability, reparability, and recyclability into products and the materials they contain, is expected to be introduced and enforced better.

Medium-term – within 5-15 years:

- **Integration of low-carbon, resource efficiency and natural capital agendas:** Evidence regarding the potential for decarbonisation via greater resource efficiency is mounting up and government is increasingly taking notice, recognising the embodied carbon accumulating from raw material extraction, processing and manufacturing into products – all of which could be limited through dematerialisation, greater durability, shared consumption, reuse, repair, remanufacturing, and recycling. This coincides with decreasing access to stocks of natural capital globally, particularly those required for clean technologies. A continued change in government culture is expected, with on the one hand increasingly integrating the recognition of economic potential of recycled materials with the management of environmental and health risks, and on the other hand the integration of environmental and social costs and benefits into the market value to create a level playing field for raw and recycled materials. Government measures introduced may include a carbon tax on materials, bans on raw materials if recycled materials are available, more levies to incentivise recycled material use, better information and control on recyclates quality, and green procurement by government.
- **Towards integrated economic, social and environmental progress:** Parts of the UK have integrated better use of materials into sustainable development, and defined progress in economic, social and environmental terms. Government guidance on assessing potential returns on investment already include monetised and non-monetised values on economic, environmental and social aspects. The obligation to deliver net-environmental gains is about to become law in England and for some matters for the whole UK. On-going decarbonisation is closely aligned with industrial strategy and economic growth. This movement towards integrated economic, social and environmental progress is expected to continue to gain momentum. This development will be accompanied with development of multi-criteria decision analysis tools and holistic indicators and metrics, and systems to gather compatible data on quantities, qualities and location in time and space of material stocks and flows.

Long-term – within 15-25 years:

- **Decreasing material use and waste:** Government officials consulted by Resource Recovery from Waste unanimously envisioned a long-term future for material use moving away from end-of-pipe approaches and towards the maximising of values created from materials whilst keeping them in the economy for as long as possible. This will involve better design that considers how materials are transformed during each stage of the lifecycle, and aims for dematerialisation (particularly for the energy intensive industries), waste prevention (for example by banning single-use products),

and increased options for reuse, dismantling, and recycling (including bulk recovery of aggregates). Changing consumer behaviour is an essential part of decreasing material use and waste, and government is expected to take measures to inform the general public about the impacts of consumption choices, promote waste prevention and regulate how producers place products onto the market for consumers (e.g. preventing designed obsolescence and supporting innovative business models such as products-as-service), and to develop better models to forecast consumption and anticipate consequences such as for end-of-use infrastructure. While this development is expected to unfold over a longer period, government has already started to work towards it.

NMDhub development timeline and government benefits: The NMDhub is proposed to be developed in four stages over the next 10-12 years. During this development time the hub could already deliver benefits for the evolving governance landscape outlined above and to the government ambitions outlined in Section 1 (Table 1).

Table 1: Benefits for government delivered during the NMDhub development (co-produced with representatives from ONS, BEIS, Defra and University of Leeds).

Development stage	*Added value for government over time*
Stage 1: Discovery – data sharing and policy, legislative and incentive schemes [2020-2022] *Feasibility programme preparing a plan to enable hub through policy and legislation and gain clarity on data availability.*	**General benefits:** Build closer partnerships between industry and government through the convening of a community of people actively working on data and circular economy. Thereby promoting a joined-up approach and preventing unintended negative impacts of changes in material use, and working towards synergies instead. Design compatible data collection and storage systems with stakeholders from across industry, government and other stakeholders. Estimate how much data could be sufficient for models to learn from and to forecast material stocks and flows. **Benefits for identified governance trends [trend in brackets]:** Possibly have better data about material availability and potential shortages. The hub should prioritise data inventory for materials that are essential for UK society. Even in absence of better data, the closer community of people working on materials can help to become aware sooner of any issues in material supply [Brexit]. Proactively contribute to the introduction of material and product passports, ensuring that the NMDhub can eventually provide evidence e.g. to inform consumers about impacts of consumption choices and to increase producer confidence to use recycled materials [Industry 4.0, and part of Resources and Waste Strategy]. **Benefits related to government ambitions:** Directly contribute to the Industrial Strategy ambition to be innovative in data collection and analysis, in order to strengthen the evidence-base and improve decision-making quality. This will add value to existing initiatives with ONS and other stakeholders to identify gaps in the evidence base and contribute to the strategy's aim to improve living standards and grow a clean, circular economy throughout the UK with the use of data. Contribute to two Industrial Strategy grand challenges: 1) Embed AI, machine learning and big-data into the economy to create skilled jobs (total estimated up to 80,000) and promote economic growth (up to £232Bn by 2030). 2) Support better use of materials and energy with AI and data analytics technologies, in line with clean growth ambitions such as developing a network of resource efficiency clusters led by LEPs and funding a big-data centre of excellence to build a more

	productive, sustainable and efficient food system. Clean growth is estimated to grow at four times the rate of GDP. Capitalise on the opportunities of strong growth markets in the bioeconomy such as biorefineries, bioplastics and global biotechnology, forecasted to double-treble by 2021-22 with a global opportunity cost/ benefit of £240Bn; Funding and investment is a challenge, a known risk factor holding back investment is limited data on resource availability (volumes, quality, time, location and price). Contribute to digital waste tracking innovations envisioned in the Resources and Waste Strategy, starting in 2019 and to be rolled out further over time.
Stage 2: Early adopters [2022-2024] *Using test environments to pilot and adjust concept development with industry and government stakeholders for 5-6 materials.*	**General benefits:** Start to give insight into alternative materials such as innovative materials introduced to the market, and decarbonisation and resource efficiency potential if one materials is incentivised over another. **Benefits for identified governance trends [trend in brackets]:** Capitalise on the new technical abilities to collect better data on material stocks and flows [Industry 4.0]. Prioritise critical raw materials crucial for clean and information technologies [Growing demand for (near) critical materials]. Facilitate collaboration between designers of clean technologies and the waste sector [Growing demand for (near) critical materials]. Provide essential insights into embodied carbon of materials and products, to support introduction of carbon tax and other measures to limit carbon emissions through greater resource efficiency [Integration of low-carbon, resource efficiency and natural capital agendas]. Bring together data on economic, social and environmental costs and benefits of materials and products, supporting the use of new indicators and metrics that are currently not feasible due to data limitations [Towards integrated economic, social and environmental progress]. **Benefits related to government ambitions:** Provide intelligence on material availability required to keep clean growth ambitions on track. Prioritise plastics as test environment, to contribute to Resources and Waste Strategy targets to ensure that all plastic packaging placed on the market will be recyclable, reusable or compostable by 2025, and to reach zero avoidable plastic waste by 2042. Give insight into the evidence-base that has become and will be available, to review and support the continued development of approaches to measure progress, including systems for data, monitoring and evaluation when the Resource and Waste Strategy will be updated ca. 5 years after being launched.
Stage 3: Rollout and build [2024-2029] *Incremental expansion to test development across industries and government departments for all materials.*	**Benefits for identified governance trends [trend in brackets]:** Offer a unique overview of natural capital combined with a growing insight into stocks and flows of materials in later lifecycle stages; enabling the identification of stocks and flows with the largest volume/ that have the biggest impacts and potential benefits, which could be prioritised for governance measures to steer the production-consumption systems towards greater circularity in the most efficient and effective manner [Integration of low-carbon, resource efficiency and natural capital agendas, Decreasing material use and waste]. **Benefits related to government ambitions:** Support the implementation of the natural capital approach with *"comprehensive, reliable data; strong governance and accountability; a robust delivery framework, and everyone to play a role"* proposed in the 25 Year Environment Plan (p11). Provide evidence on circular economy potential in the preparation of the Chemicals Strategy, announced in the Resources and Waste Strategy. Help delivery of food waste reduction targets articulated in the Resources and Waste Strategy, decreasing the estimated 10M tonnes currently wasted each

	year in the UK, costing ca. £20Bn and damaging the environment. The UN Sustainable Development Goals aim to halve global food waste at consumer and retail levels by 2030, and the Resources strategy strives to eliminate food waste to landfill by 2030. Provide data to estimate waste infrastructure requirements for achieving targets set out in the Resources and Waste Strategy, such as 65% recycling rate of municipal solid waste by 2035.
Stage 4: Commission [2029-2030] *Commissioning of the finished NMDhub.*	**General benefits:** Better data to support higher quality and more transparent decision-making e.g. for new policy and investment. Insight into the positive and negative effects of actions on the economy, society and environment, and risks taken if a circular economy type (see Section 1) is not implemented. **Benefits for identified governance trends [trend in brackets]:** Evaluate impacts of government actions up-front to prevent unintended consequences and facilitate a joined-up approach, to realise a circular economy that delivers economic, social and environmental net-gains in collaboration with stakeholders across society (see Section 1) [Decreasing material use and waste]. Mapping resource stocks and flows and their embodied carbon within the economy enables identifying the major carbon sources and sinks, thereby revealing opportunities for clean growth through greater resource efficiency. The largest wins for carbon reductions are associated with boosting resource productivity. Plans for decarbonisation articulated around an understanding of industries in isolation can have detrimental effects on other industries and even lead to an increase in carbon emissions at a systems level. It is thus important to have a model that provides cross-sectoral insight into resource stocks and flows in support of decision-making for clean growth [Integration of low-carbon, resource efficiency and natural capital agendas]. Turning negative impacts of material use into positive contributions offers a major opportunity for realising environmental net-gains. Insight into stocks and flows of materials, and their potential for environmental gains, in the economy enables the identification of key intervention points for greater resource efficiency and environmental growth [Towards integrated economic, social and environmental progress]. Increase security of supply of materials by establishing a cross-government oversight of the natural resources and the materials in use/ stored in the UK, and offer insight into potential alternatives for materials supply [Decreasing material use and waste]. **Benefits related to government ambitions:** Bring together the data that is needed to identify pathways to achieving the commitments made in the Industrial, Clean Growth, and Resources and Waste Strategies to double resource productivity and eliminate all avoidable waste by 2050. This will involve radical change of supply chains within and between industrial sectors and the wider society. Data on materials stocks and flows will help to map and discern opportunities for supply chains with highest benefits associated with dematerialisation, reuse, repair, remanufacturing, and recycling, and provide the evidence-base on material and product quantities and qualities to enable decision-making for investors to grow a circular economy.

An NMDhub offers essential functionalities for government to support industry to make better use of materials: This briefing has presented evidence that better data is essential for decision-making to create an enabling context for a circular economy that will unlock investment in and action for improved material use, to achieve shared ambitions regarding resource productivity, elimination of avoidable waste, regenerating natural capital, and clean and environmental growth. Government needs a better infrastructure for the development and delivery of evidence-based strategies, plans, policies, regulations and

legislation. Data infrastructure is a fundamental part of this. The NMDhub is proposed to be developed in four stages over the next 10-12 years, and during this time it could facilitate improvements in data collection, storage, exchange, analysis, and use in decision-making. Data has to be brought together on:

- Stocks and flows of materials and products.
- Throughout material and product lifecycles, from extraction to manufacturing, consumption, and end-of-use management including reuse, repair, remanufacturing, recycling, controlled storage, and energy recovery.
- Volumes of stocks and flows as well as qualitative, technical characteristics, location and timing.
- Economic, social and environmental costs and benefits of materials and products at each stage in the lifecycle.

Realising the NMDhub would require input from stakeholders from across society. The preparation of the hub could function as a platform to strengthen collaboration between (devolved) government departments, taking a whole-system approach to prevent unintended consequences and create synergies between e.g. environmental and economic growth, and be a catalyst for integrating a community of stakeholders with an interest in material use and implementing a circular economy.

Detailed conversations must be held to prioritise functionalities NMDhub: The scale of the data challenge is vast and could be broken down into manageable sections for example by selecting priority materials such as (near) critical materials for clean growth, plastics, and food and bioeconomy. Early in the hub's development, it is important to have detailed conversations with all stakeholders about the necessity of functionalities for the purpose of developing strategies, plans, policies, regulations and legislation that would enable better material use by industry. The functionalities should be assessed collaboratively with a broader range of government stakeholders and informed by industry demands and limitations. For example, what level of granularity is required to get a sufficient insight into products and their material contents that are in stocks and flowing between stocks in the UK? And are real-time data on stocks and flows necessary?

Better data will unlock economic, social and environmental potential of improved material use: The NMDhub would drive the resolving of data challenges that currently constrain government and industry change in favour of realising a circular economy that optimises economic, social and environmental benefits through material use. It is broadly recognised that doing nothing about the linear material take-make-use-dispose pattern is no option. Without better data capabilities, the UK would risk high costs and miss out on global circular economy opportunities. Unlocking the potential of a high-value circular economy would significantly benefit economic growth, business opportunities, material supply security, low-carbon targets, and job creation.

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