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Rapid 'low regrets' decision making for net zero policy

Executive summary

The UK government has the ambitious target to **reduce UK carbon emissions by at least 78% by 2035**, compared to 1990 levels.[1] This target **commits the UK to cutting emissions at a faster rate than any other major world economy**. This is the latest commitment to meeting the government's target to reduce the UK's net emissions by 100%, relative to 1990 levels by 2050.[2]

Achieving net zero is an unprecedented challenge[3] – in the scale and pace of policy change and action that is required. Meeting the target is not possible without sweeping energy efficiency measures, and a structured program of transition from a dependency on fossil fuels towards a new system in which net zero emissions is achieved across all sectors of the UK economy. Progress is being made. As of 2019, net territorial emissions in the UK were estimated to be 454.8 million tonnes carbon dioxide equivalent ($MtCO_2e$), a decrease of 44% compared to 1990 levels.[4] However, despite this progress, widespread decarbonisation must still accelerate rapidly across all sectors of the UK economy if the country is to meet its commitment of net zero by 2050.

The UK's ability to decarbonise at sufficient speed and scale, is dependent on key decisions made by the government now, and in the years that immediately follow. With less than 30 years until the UK must meet its target of net zero carbon emissions, it is vital that policymakers are able to make confident decisions in the face of uncertainty, identifying priority actions that can be taken today to put the UK on the path to net zero by 2050. These decisions must be made across multiple policy areas that need to work together as a system to achieve net zero in the most efficient and effective way.[5] Given the short timescales available, decisions need to be made before uncertainties are fully resolved.

Executive summary

Recognising the need for urgent action, the low regrets framework presented in this report has been developed to help policy makers identify and build confidence in the decisions that can be taken now to decarbonise the UK economy. Such 'low regrets decisions' (see **Box 1**) are an important component of the net zero policies that are urgently needed to meet our target of net zero by 2050. Such low regrets decisions should constitute the first steps for early action alongside a more comprehensive, far-reaching and adaptive transition plan which must extend beyond the immediate scope of this low regrets framework and include the tougher, higher risk, medium- and long-term decisions which will have to be made.

Low regrets decisions, including the examples presented in this report, are actions we can take now, which will position the UK to meet the challenge of achieving net zero. Examples of some important low regrets decisions that can be taken now include:

- **Reducing energy demand such as providing incentives for changes in consumer behaviour**.
- **Improving efficiencies in resource and energy use across domestic, transport and the built environment including retrofit (see Case study 1)**.
- **Scaling up deployment of proven technologies, such as scaling up of a battery electric vehicle (BEV) charging network (see Case study 2)**.
- **Demonstrating the effectiveness of unproven yet critical technologies including hydrogen and carbon capture and storage (see Case study 3)**.

A series of case studies illustrating different types of low regrets options across a range of sectors is presented. These are drawn from evidence and insights from the National Engineering Policy Centre (NEPC) Net Zero Working Group.

Box 1
Definition of low regrets decisions

Low regrets decisions are introduced in the UK Government Net Zero Strategy[6] and defined as 'actions that are cost-effective now and will continue to prove beneficial in the future'. This paper builds on this, providing more detail on the factors that must be considered to ensure a decision is low regrets. As such, we define low regrets decisions as urgent decisions that must and can be made now to have a significant impact on decarbonisation. Low regrets decisions typically unlock pathways towards the net zero target, providing options and flexibility rather than blocking off options. They can build flexibility, reduce costs for the future, can have social, economic and environmental co-benefits, and make best use of limited resources. These properties of low-regrets decisions are formalised into a set of criteria in this report (see **Table 1**).

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Box 2
Purpose

The purpose of this report is to introduce a qualitative tool for identifying low regrets decisions (defined in **Box 1**) in the face of uncertainty. This report proposes a framework that can guide decision making to identify policy decisions that can be taken now to decarbonise the UK economy. It will be necessary to develop a far-reaching, comprehensive and adaptive transition plan which must extend beyond the scope of this low regrets framework. This report focuses on providing a framework for the confident identification of 'low regrets decisions' where government can take immediate action while also developing a comprehensive and adaptive transition plan. The framework can be used to guide decision-making.

This report has been produced by the NEPC Net Zero Working Group which includes experts in engineering, systems science and social science from academia and industry.

The urgency of achieving net zero poses a major cross-sector challenge. The UK's path to net zero, and its ability to decarbonise at sufficient speed and scale, is contingent on key decisions made by the government now, and in the years that immediately follow. Decisions need to be made across multiple policy areas that must work together as a coordinated system to achieve net zero in the most efficient and effective way. These measures must not only seek to rapidly decarbonise the UK economy but also seek to support UK job creation and competitiveness, secure other environmental benefits (e.g. in respect of local air pollution and human health) while avoiding adverse environmental and social impacts, for example ensuring that low income and disadvantaged households are not disproportionally negatively affected.

Multiple options and scenarios for reaching net zero exist leading to uncertainty about how the goal will be reached. As industrial, energy and transport systems begin to decarbonise, there is uncertainty as to what set of technologies will predominate and it is still unclear how the technologies used in these systems will vary regionally and locally across the country. Given the scale and pace of change required and the short timescales for delivery, important decisions need to be made before these uncertainties can be fully resolved. However, we need to be careful not to lock ourselves into high-carbon pathways that will limit our future ability to achieve net zero.

Despite this, policymakers face a profound challenge and must still make urgent decisions and identify immediate priority actions if we are to move at the pace required to reach net zero by 2050. The financial and political viability of these low regrets, near-term decisions will be much greater if they can achieve 'quick wins' while also supporting the realisation of medium- and long-term opportunities and further decision making.[7,8] The concept of low regrets decisions could help to provide the basis for making these urgent decisions and can be used in combination with other approaches such as scenario planning.[9] However, it is important to recognise that low regrets decisions alone will not achieve net zero. Policymakers will also have to make bigger, higher stakes decisions if the UK is to achieve net zero, meaning many necessary decisions will be beyond the scope of the low regrets framework presented in this report.

Recent government announcements including the Ten Point Plan for a Green Industrial Revolution[10] and the Energy White Paper[11] contain policy interventions that can be considered low regrets and are important next steps on the UK's path to net zero. As the government continues to develop its strategy for net zero, policymakers will need to be clear about the sequencing of major decisions. They will need to consider interdependencies between diverse policy interventions – from space planning to carbon pricing and consumer regulation – and how they will work together toward the net zero goal. They will also need to maintain a focus on broader outcomes and on practical policy delivery.

This report introduces the following:

The nature of low regrets decisions: definition and systems thinking.

Making low regrets decisions: framework and examples.

Case studies.
The case studies have been written by members of the NEPC Net Zero Working Group to illustrate different types of low regrets option across different sectors, highlighting the scale of the challenge and why low regrets decisions are needed.

The nature of low regrets decisions: definition and systems thinking

Box 3
Audience

This report is aimed at policymakers that play a central role in setting policies on decarbonisation and achieving net zero: including central, local and devolved governments, and the diverse communities, including engineers, who will need to research, develop, implement and scale up the solutions needed to tackle the net zero challenge. The discussion and case studies in this report are written from the UK perspective, however, the framework of criteria should be transferable to other national contexts.

Box 4
Why this framework is useful to decision makers

With less than 30 years until the UK must legally meet its net zero emissions target, the UK must identify technologies and interventions that can be effectively scaled up to reduce greenhouse gas emissions. Many of these technologies and interventions already exist and, through judicious policy interventions, can be implemented and scaled up quickly to accelerate decarbonisation of the UK economy. The framework presented in this report can be used to build confidence in implementing low regrets decisions. However, it is important to recognise that low regrets decisions alone will not achieve net zero. Policymakers will have to make bigger, higher stakes decisions in the future if the UK is to achieve net zero. Successful implementation of low regrets decisions may, however, build experience and confidence for tackling higher stakes decisions.

A working definition of low regrets decisions is given in **Box 1**.[12] Low regrets decisions do not mean that no-one will have any regrets about having to do things differently in a net zero future compared to the fossil fuel age. Instead, it means that there are immediate actions that can be taken and available technological solutions that can be implemented now and at pace by decision makers to position the UK to meet the net zero challenge. Wisely chosen low regrets decisions:

- Play a significant role in reducing UK carbon emissions
- Avoid technological lock-in to high carbon technologies, instead unlocking low-carbon pathways and providing flexibility for further low-carbon interventions in the future
- Be capable of progressive upscaling so that costs will reduce in the future
- Makes the best use of a limited resources
- Provide co-benefits or synergies with other policy objectives.

As engineers involved in designing systems, we can apply systems thinking to complex challenges such as decarbonisation. Our experience in bringing together technological, financial, regulatory, legal, ethical, workforce and public-facing elements in practical solutions can be brought to bear on policymaking and decarbonisation. By taking a systems approach to net zero decision-making in government, policymakers will be better placed to assess effectiveness, monitor unforeseen consequences, provide feedback and enable future performance improvement.

To assess whether options constitute a low regrets decision, elements of a systems approach will be necessary. These are:

- **Interdependencies between different elements of the net zero system**: The choice of low regrets decisions in each sector will need to be informed by a detailed assessment of the interdependencies which exist across different sectors between options. This will be key to assessing potential for high-carbon technological lock-in and identifying co-benefits.
- **Timescales and time-dependency**: The assessment of options will need to factor in the timescales for their implementation – what decisions are needed now and what decisions are needed at different points in the future? This assessment will be key to understanding the pace of upscaling required and when benefits can be expected to be realised.

The assessment of interdependencies, timescales and time-dependency must be flexible and ongoing; it will require maintenance, review and updates over time as new evidence emerges and interventions are made.

Making low regrets decisions: framework and examples

This section presents a framework of criteria that must be met to classify as a low regrets decision.

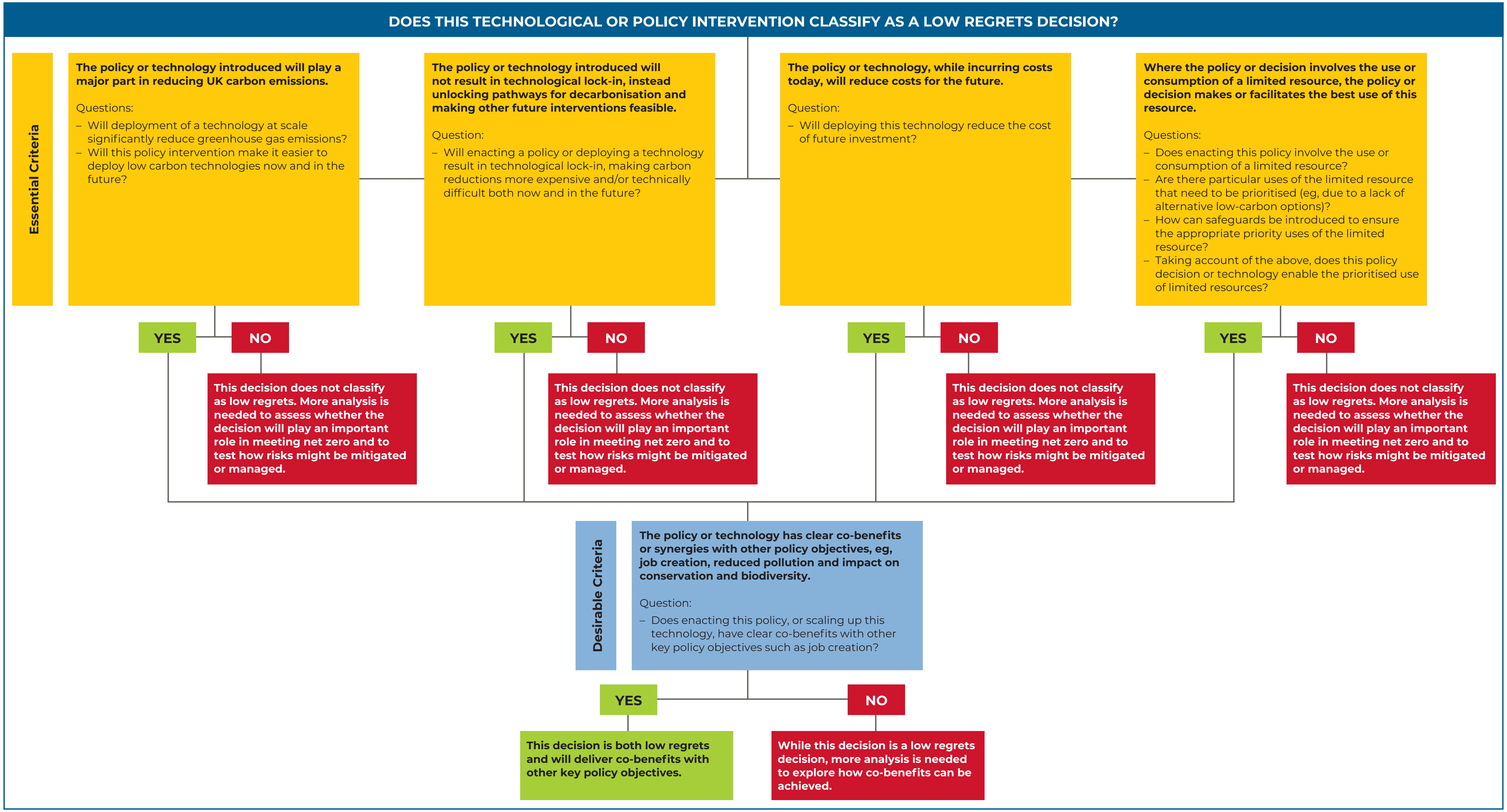
Table 1 captures the framework and rationale for each of the criteria, via an example. Any low regrets decision under serious consideration should demonstrate how it fulfils the criteria in this framework. In some cases, this is straightforward, while in other cases it is more nuanced. To ensure that decisions and technologies are not considered in isolation from the conditions in which they are deployed, there will be other salient social, economic and political considerations. As such satisfaction of the criteria outlined in this framework should be considered necessary but not sufficient to ensure a decision is low regrets. However, as a check on some of the key necessary criteria, this framework should be taken as a good first indication that a decision may constitute a low regrets decision and, on that basis, the framework should be a useful aid to decision-making.

Table 1: Framework for low regrets options

CRITERIA	EXAMPLE
Essential Criteria	
The policy or technology introduced will play a major part in reducing UK carbon emissions.	There is no credible route to a net zero UK which does not require a smart grid.[13] Therefore, decisions which enable the development of a smart grid would meet this criterion. The same can be said for energy demand reduction and energy efficiency, which are included in all credible paths to net zero.
The policy or technology introduced will not result in technological lock-in to high-carbon technologies, instead unlocking low-carbon pathways and making other low-carbon interventions feasible in the future:	Decisions on locations for housing developments can lock in dependence on private transport for decades.[14] Therefore, making decisions that enables housebuilding in locations that are already served by multiple forms of mobility would meet this criterion.
The policy or technology, while incurring costs today, will reduce costs for the future. Note: It is important here to account for the costs associated with a failure to decarbonise as well as any identifiable positive co-benefits.	Modular infrastructure which may be more expensive in the short term but that can be more easily retrofitted, adapted or disassembled in the future (including for re-use of constituent parts and components) can provide carbon and cost savings over the whole life-cycle of the infrastructure asset for marginal additional up-front expense. Decisions that enable the building of such infrastructure and consequently enable reduced carbon and economic costs over the longer term, would meet this criterion.
Where the policy or decision involves the use or consumption of a limited resource, the policy or decision makes or facilitates the best use of this resource. For example, prioritising uses where no other low-carbon option feasibly exists.	Hydrogen has been suggested to have a wide range of applications. However, there are certain applications, such as industrial processes, where there are fewer low-carbon alternatives to hydrogen. To classify as low regrets, policy decisions would need to ensure that hydrogen (which is likely to be of limited availability for the short- to medium-term) is available to those areas lacking other low-carbon alternatives.
Desirable Criteria	
The policy or technology has clear co-benefits or synergies with other policy objectives, for example, job creation, reduced pollution and impact on conservation and biodiversity.	An early switch away from fossil fuels for urban transport has strong co-benefits in terms of air quality and health.[15] Therefore, decisions that enable a switch to low-carbon transport and as result reduce air pollution would meet this criterion.

Making low regrets decisions: framework and examples

Box 5: How to use the low regrets framework



Making low regrets decisions: framework and examples

As stated in the previous section and illustrated in **Box 5**, to classify as low regrets, it is essential that any technological or policy intervention results in reduced carbon emissions, avoids high-carbon technological lock in, reduces future costs and prioritises the use of any limited resource to where it is needed most. It is also desirable, but not essential that the intervention has clear co-benefits or synergies with other policy objectives. If a decision does not meet the criteria, this does not mean the decision should be rejected. Instead, further analysis is required to determine the importance of this decision in achieving net zero and to test how risks might be mitigated or managed. Examples of the application of this framework, proposed and developed by members of the NEPC Net Zero Working Group, are shown below in **case studies 1 to 3**.

Table 2: Examples of low regrets options compared against the criteria ('**X**' indicates that this options fulfils this criteria)

	ESSENTIAL CRITERIA				DESIRABLE CRITERIA
Option	Will play a major part in reducing UK carbon emissions	Will not result in technological lock-in to high-carbon technologies, instead unlocking low-carbon pathways and making other low-carbon interventions feasible in the future:	Although incurring cost today, can be progressively upscaled so that it will reduce costs for the future	Facilitates the prioritised use of a currently limited resource in an area where no other option exists	Clear co-benefits or synergies with other key policy objectives
Scaling up deployment of proven technologies as fast as possible					
Upgrading the electricity grid to deal with greater electrification and renewables	X	X	X	X	
Scaling up energy storage capabilities	X	X	X	X	
Upscaling of electricity distribution networks/electric vehicle charging infrastructure to deal with an increase in electric vehicles (**Case study 2**)	X	X	X		X
Ensuring excess renewable energy is available where hydrogen will be made by electrolysis	X	X	X	X	
Demonstration of low carbon technologies so they are ready to be deployed in the future					
Investment in research, demonstration and testing of low carbon technologies such as carbon capture and storage and hydrogen	X	X	X		X
Developing niches for hydrogen eg, green hydrogen for transport depots and blue hydrogen for industrial clusters	X		X	X	
Improving efficiencies in resource and energy use across domestic, commercial, transport and industrial applications					
Driving decarbonisation using new building standards	X	X	X		X
Retrofitting existing buildings (**Case study 1**)	X	X	X		X
Mandating hydrogen ready appliances (**Case study 3**)	X		X	X	
Demand Reduction					
Rolling out smart meters	X	X			X
Public engagement on demand reduction	X	X			X

Making low regrets decisions: framework and examples

The low regrets framework presented in this report can guide decision making to identify low-risk policy options that can be taken now to begin to steer the UK towards net zero. However, solely making low regrets decisions will not be enough to achieve net zero. Achieving the socio-technical transition required to achieve net zero will inevitably require decision makers to make bigger, higher-stakes policy decisions that will go further than the limitations of this framework.

Such higher risk decisions are those that in the long term will have a key role in decarbonising different sectors of the UK, but which do not satisfy the criteria in the framework set out above. For example, some key necessary decisions may:

- Have significant impacts, including short term increases in carbon emissions
- Depend on some technologies or processes for which there is not yet a clear low-carbon option or pathway for decarbonisation
- Involve high costs that do not decrease with time, but which are justified by costs associated with failing to decarbonise
- Not deliver co-benefits with other key policy objectives
- Make use of limited resources.

An example of such a decision that may have to be made to reach net zero by 2050 is the construction of new nuclear generation, discussed further in **Box 6**. As this example demonstrates, a decision that does not meet the low regrets criteria set out in this report should not necessarily be ruled out, but it cannot automatically be considered to be low regrets. When a decision does not meet the low regrets criteria this indicates that the underpinning analysis for the decision must go beyond the guiding questions set out in the framework. Failure to meet the low regrets criteria should not exclude options from longer term consideration, but where a decision successfully meets the criteria, this can be taken as a strong indication that it should be prioritised for action in the short-term.

Box 6

A tool for ruling in, not for ruling out: the case of new nuclear

Some studies consider nuclear power to be a low carbon alternative to fossil fuels capable of producing a large quantity of low carbon electricity during operation over a reactor lifetime of approximately 60 years.[16] Nuclear power can also play a key role in ensuring the security of electricity supply. For this reason, some studies suggest that nuclear will play a key role in decarbonising economies and achieving net zero by 2050.[17,18]

However, the construction of nuclear reactors, the processes of mining and refining uranium, and the making of nuclear reactor fuel are all carbon intensive.[19] Therefore, to produce low carbon electricity for the future, shorter term increases in greenhouse gas emissions will be required during construction phase and longer-term operational impacts would be locked in. There are also credible future scenarios in which nuclear is a relatively costly contributor to electricity generation, including when decommissioning costs are taken into account.[20] For these reasons, the construction of new nuclear reactors would not meet the criteria for a low regrets option set out in this report.

As with other decisions to get to net zero, just because new nuclear generation does not meet the low regrets criteria in this report does not necessarily mean that it should be ruled out. As stated, there is potentially a strong case for new nuclear capacity as part of a low-carbon energy mix and in ensuring security of supply. Not meeting the low regrets criteria simply means that this decision cannot automatically be considered a low regrets decision as defined here and the underpinning analysis for this decision must go beyond the guiding questions the framework sets out.

Case studies

This section introduces case studies aimed at illustrating the application of the framework outlined in this report to decision making in the UK context[21]. The case studies apply the criteria to examples of policy and technological interventions that can play a key role in reducing carbon emissions and provide a qualitative discussion of how well these interventions meet the criteria, for example, unlocking pathways to net zero, offering co-benefits with other key policy objectives and how they might scale up to reduce costs for the future. Crucially, where it is not clear that criteria have been met, an attempt has been made to outline the questions that need to be addressed.

These case studies have been authored by individual members of the NEPC's Net Zero Working Group and present the author's own reflections on each topic. The NEPC would like to thank the authors for their contributions.

CASE STUDY 1 | BUILDING RETROFIT

Author: Julie Godefroy, Head of Sustainability, Chartered Institution of Building Services Engineers

Why is building retrofit a low regrets option?
The net zero transition will require reduction in the consumption of energy and water within our buildings and the switching to zero-carbon heating systems (or ones which will become zero-carbon as more low-carbon electricity generation comes onto the electricity grid). Retrofitting buildings is a good example of a policy that will play a major part in reducing carbon emissions from the built environment and that can be implemented to achieve net zero. Retrofit here covers interventions on a building's fabric, building services, and equipment with the aim to reduce demand and meet the remaining demand via a low carbon technology, or facilitate the incorporation of low-carbon technology in the future. The retrofitting of existing infrastructure meets all of the key criteria of the low regrets framework presented in **Table 1**.

Will play a major part in reducing UK carbon emissions:
Decarbonising heat within buildings is a major step in all scenarios for reaching the net zero target. Given that the vast majority of buildings that will be in use in 2050 have already been built and do not have the carbon performance necessary to achieve net zero, retrofit must play a major role in reducing carbon emissions. The Climate Change Committee's 6th Carbon Budget highlights retrofitting and upgrading all buildings in the next 10–15 years as a priority. Their budget assumes a 12% reduction in heat demand from improvements in energy efficiency, which they consider conservative.[22]

Will not result in technological lock- in to high-carbon technologies, instead unlocking low-carbon pathways and making other low-carbon interventions feasible in the future:
Retrofit (as defined above) is required under any decarbonisation scenario and is an enabler for the electrification of the energy, building and transport systems.[23] "Thermal efficiency of buildings is as important for hydrogen boilers as it is for heat pumps".[24] Without reductions in demand, the transition to low-carbon heat by 2050 (whether via electrification, through hydrogen, or a mix) is unlikely given the infrastructure and investment it would require and the financial impact on consumers. At the system level, retrofit reduces the generation, storage and distribution infrastructure required and improves resilience. At the building level, it reduces the size and costs of heating systems, reduces energy costs and, at a system level, can make technologies such as heat pumps more efficient.

Although incurring cost today, can be progressively upscaled so that it will reduce costs for the future:
Retrofit is scalable. Tackling all buildings will necessarily happen gradually, which provides opportunities for developing new supply chains, learning lessons and continuously improving delivery and outcomes, including cost effectiveness.[25] "Hard to treat" properties could be tackled in later phases, benefiting from these improvements.

Innovative solutions (e.g., Energiesprong UK[26,27]) tackle a group of homes (e.g. terraced row) all at once. They use standardised approaches and are not applicable everywhere (e.g. conservation areas), but they offer significant benefits in costs, speed, and disruption. Alongside more bespoke individual building solutions, these approaches are best deployed as part of an area-based strategy.[28]

Clear co-benefits or synergies with other key policy objectives:
Retrofit offers clear co-benefits at the building and system level:

- Benefits to residents:
  - Reducing energy costs: this would help mitigate increases in energy prices due to decarbonisation.[29]
  - Improved comfort and health, in particular for households in fuel poverty.
  - Tackled as part of wider works, it can contribute to enhancing the value and lifetime of properties.
- Reducing air polluting emissions from energy use:
  - Reducing fossil fuel consumption will reduce air polluting emissions, as well as carbon emissions. This is less significant in an all-electric scenario, but with hydrogen, combustion emits nitrous oxides (NOx).
- Job retention and creation:
  - It is estimated that around 500,000 new professionals and trades will be required. They would be spread across the UK, a significant opportunity for post-pandemic recovery plans.[30]

Note that this relies on retrofit done well, from the assessment of options through to design and delivery. This is a crucial point to address in policy, to avoid detrimental unintended consequences.[31]

Makes or facilitates best use of any limited resources, for example prioritising uses where no other low-carbon option feasibly exists:
Currently, a large number of buildings perform well below what is technically feasible for energy efficiency and much can be achieved through retrofit to reduce energy demands that would otherwise need to be met across our building stock. So, energy efficiency measures (and any other demand reduction) fundamentally reduce the demand for input energy.

Building retrofit to decarbonise heating by switching heating systems does, however, require ongoing scrutiny to ensure performance against this criterion. There is more than one technical option for heating buildings and the main considerations differ for each. For example, electrification via heat pumps will increase demand for low-carbon electricity where the key consideration is the management of peak demands for electricity and how these are met. For hydrogen, pilot scale projects are needed to better understand what scale of low-carbon hydrogen production and use is technically and economically feasible before a good understanding of its role in heat provision in buildings is known (see **Case Study 3**). Ultimately the most effective technology (e.g. electrification or heat networks) for decarbonising home heating will likely differ across different localities.

CASE STUDY 2 | BATTERY ELECTRIC VEHICLE (BEV) CHARGING NETWORK

Author: Professor Roger Kemp MBE FREng, Lancaster University

Why is a BEV charging network a low regrets option?
Developing a BEV charging network is a good example of a policy that can be implemented to achieve net zero which plays a major part in reducing carbon emissions from the built environment. Developing a BEV network meets three key criteria of the low regrets framework presented in **Table 1** while the criteria that are not met indicate key areas where decision-makers need to focus their attention:

Will play a major part in reducing UK carbon emissions:
Developing a BEV charging network will play a key role in reducing carbon emissions from the transport sector. The transport sector currently accounts for a third of all carbon dioxide emissions, the large majority of which are from road transport.[32] Therefore, any policy or technological intervention, including the rollout of a BEV charging network, which helps to replace of most petrol/diesel cars and vans meets this criterion.

Will not result in technological lock- in to high-carbon technologies, instead unlocking low-carbon pathways and making other low-carbon interventions feasible in the future:
Developing a BEV charging network will provide the best short- to medium-term opportunity to move away from fossil fuels. Studies have shown that the scope for replacement of fossil fuels by sustainable biofuels is limited,[33,34] and the development of a nationwide infrastructure to deliver low-carbon hydrogen is, at best, some way off (see **Case Study 3**).[35] Electric vehicles are a viable medium-term (i.e., next 20 years) solution for some road traffic applications (other solutions such as hydrogen may be required in the future). However, electricity is likely to be a major road vehicle energy source for the foreseeable future, so it is a low regrets decision to scale up a BEV charging network. Scaling up BEV charging network capabilities can allow for a move away from fossil fuel powered transport and provide flexibility for the future.

BEVs also represent a large and flexible domestic load. For many users, it is possible to charge at almost any times in the day or night, either at home, at work, or in a car park. Coupled with flexible tariffs and an effective smart grid, this would allow the Electrical System Operator (ESO) to schedule the charging load in real time. This provides the ESO to ability to reduce the peaks and 'filling in the troughs' of demands on the grid, thereby increasing the load factor on low carbon generation and improving the economic performance of the system.

Clear co-benefits or synergies with other key policy objectives:
Developing a BEV charging network will also offer clear co-benefits. As a part of the net zero transition, it is important to reduce the amount of road traffic. However, having an effective BEV charging network will stimulate a greater uptake of electric vehicles by the public and therefore reduce the number of petrol/diesel vehicles on the road. This will consequently, improve the air quality and health impacts from air pollution associated with road vehicles.

Although incurring cost today, can be progressively upscaled so that it will reduce costs for the future:
Developing a BEV charging network can also be progressively upscaled to reduce costs for the future. Firstly, increasing the scale of the UK's BEV charging network should increase consumer confidence in BEVs, increasing uptake and ownership. As a result, there would be an increased demand for charging and therefore potential economies of scale. Secondly, procuring charging infrastructure at scale should drive delivery capacity and therefore drive down costs for the future. However, it is important to acknowledge that costs from maintenance of the charging network will continue into the future.

Makes or facilitates best use of any limited resources, for example prioritising uses where no other low-carbon option feasibly exists:
The scaling up of a BEV charging network will require ongoing scrutiny to meet this criterion. The increased electrification of transport will result in an uplift in the demand for low-carbon electricity. Within this, the key consideration is the management of peak demands for electricity, and this depends on the amount of flexible demand management that can be introduced through a combination of flexible tariffs and effective smart grid technologies. The ability to control and limit the peaks in demand is a key factor in allowing BEV charging alongside other uses of electricity, such as the electrification of heating, while avoiding severe peaks in demand at key times that would reduce the utilisation factor of the grid and increases prices.

Linked within the wider system of BEV charging and use are the BEVs themselves, including the manufacturing of the batteries used in the vehicles. Ongoing assessment of the demands from increased BEV manufacture will be needed since, depending on the chemistry of the batteries, the supply chains for some materials face potential obstacles including high costs and environmental concerns associated with the extraction and processing of materials.[36] Studies have suggested that both the future supply of cobalt[37] and lithium, key components for some battery compositions, will not be able to meet demand due to limitations in mining and manufacturing. To help tackle this supply issue, the Royal Society of Chemistry is advocating the approach of 'reduce, reuse, recycle'.[38] Flexibility is available from different battery options, but it is important to maintain ongoing analysis of potential limitations, costs and environmental impacts in the supply chains for materials.

CASE STUDY 3 | DEPLOYMENT OF CRITICAL TECHNOLOGIES eg HYDROGEN AND CARBON CAPTURE

Author: Ian McCluskey, Head of Technical and Policy, Institution of Gas Engineers and Managers

Why is the deployment of critical technologies such as hydrogen and carbon capture a low regrets option?
Reaching net zero by 2050 will require the deployment of multiple critical technologies and solutions supported by coordinated programmes and new policies. Hydrogen (both so-called green and blue hydrogen, with carbon capture and storage (CCS)) is a good example of a critical technology which needs to be deployed to achieve net zero. Deployment of these technologies at pilot scale, meets four key criteria of the low regrets framework presented in **Table 1** while the criteria that are not met indicate key areas which would need to be addressed before wider scale deployment is possible. In this case, it is precisely the remaining uncertainties relating to technical and economic feasibility that pilot-scale deployment of these technologies would address and it is the criticality of these technologies to achieving net zero, as well as the potential co-benefits that could be realised, that makes pilot-scale deployment a low-regrets decision.

Will play a major part in reducing UK carbon emissions:
In every net zero pathway, hydrogen and CCS play a significant role. The National Grid Future Energy Scenarios 2020 report[39] states "Hydrogen and carbon capture and storage must be deployed for net zero. Industrial scale demonstration projects need to be operational this decade." The Carbon Trust report, Flexibility in Great Britain[40] used the advanced integrated whole energy system (IWES) model to analyse the role and value of flexibility in various energy scenarios through to 2050. One of the key findings describes how "the use of hydrogen across the energy system brings carbon and cost benefits and requires a portfolio of production methods and availability of CCS infrastructure" if the system is coordinated effectively. In addition, the National Infrastructure Commission (NIC) has argued in a recent report that engineered greenhouse gas removal and storage, involving CCS, will need to become a major new UK infrastructure sector in order to meet carbon targets and has recommended the government must commit to deploying these technologies at scale no later than 2030.[41]

Will not result in technological lock- in to high-carbon technologies, instead unlocking low-carbon pathways and making other low-carbon interventions feasible in the future:
Every net-zero carbon society around the world will need at least four net-zero carbon energy storage and transmission vectors in different proportions relating to their local circumstances and endowments: electricity, hydrogen, synthetic fuels and biofuels. The main issue that will play out over time is the relative proportions and the roles where each vector is most suitable. These proportions may also vary according to changes in technology opportunity and customer adaption and acceptance, so agility across the vectors and the ability to respond quickly will prove valuable.

The Climate Change Committee's (CCC) Sixth Carbon Budget's balanced net zero pathway envisions more than three quarters of hydrogen produced in 2050 will be blue and green hydrogen,[42] meaning that a balanced hydrogen strategy will be needed involving the scale up of both blue and green hydrogen. The development of hydrogen from fossil fuels, namely natural gas (blue hydrogen), is contingent on the successful roll out of CCS technologies. It is therefore a low regrets decision to incentivise and promote developments in CCS not just to facilitate the range of engineered greenhouse gas removals outlined by the NIC[43] but to unlock the capability for hydrogen production and use, alongside localised synergies across the industrial sectors where such facilities arise, thereby easing concerns over supply shortfall in the short to medium terms.

The development of technologies that can produce green hydrogen at the required scale and resilience is also of primary concern for any net zero society. There are a number of technologies, each at different stages of maturity. Some of these technologies are dependent upon major growth in renewable electricity and again this must be encouraged, from a whole energy systems perspective, rather than that of a singular energy vector, to put the UK on an accelerated timeline to net zero. Across this range of technologies there is a need to build up UK capability, knowledge and skills discussed further in the criterion relating to co-benefits.

Although incurring cost today, can be progressively upscaled so that it will reduce costs for the future:
The rollout at scale of hydrogen will require deployment of new critical technologies which have yet to be tried and tested. While investment will be required for demonstration and scale up, in parallel with ongoing research and innovation, and more thought will be required to determine whether and how to prioritise certain end-uses that are hard to decarbonise, early deployment will reduce costs for the future. Underpinned by targeted scientific and engineering research, "learning by doing" is needed to ensure uncertainties can be evaluated and the risks are minimised.[44] This will reduce costs for any future deployment, provide certainty for supply chains and skills providers, thereby having the benefit of minimising the impact on the consumer and, as such, accelerate adoption.

The UK does not necessarily have to adopt a 'first mover' position on hydrogen technology, and could wait for other countries to develop, demonstrate and deploy these technologies. While this may result in reduced short-term risks and costs to the UK, as has been witnessed through the evolution of wind technologies, it also risks missing the opportunity of significant co-benefits to the UK from the early development of the intellectual property, UK based manufacturing, and the skills needed in this new sector, as well as the opportunity to drive the standards to which low-carbon hydrogen technologies perform.

Clear co-benefits or synergies with other key policy objectives:
Hydrogen has the potential to play a valuable role as a viable, affordable and secure energy vector for decarbonisation of industry, such as substituting fossil fuel in heat provision in, for example, high-heat industries for which there are limited alternatives to fossil fuels.[45]

However, the role of hydrogen needs to be further tested through medium and large-scale demonstration projects which, under scenarios that deploy blue hydrogen, will need to include demonstration of CCS at the required scale and suitably scaled hydrogen storage systems to balance production against demand. The growth of hydrogen and CCS provides potential economic growth areas with co-benefits and opportunities around new markets and exports, supply chains and services and jobs, potentially at scale, if hydrogen production and supply can be achieved in a low carbon way. Demonstration projects will help to test and understand the skills, competencies, markets, regulations, supply chains and services required to scale up the role of hydrogen and CCS. The UK has the opportunity to become a lead innovator, developer and first adopter of new technologies, a principal adopter of a wide range of low carbon solutions, bolstering internal manufacturing and product development capability, leading to new jobs and skills, enhancing our export potential for skills, capability and goods.

The recent commitment in the Prime Minister's Ten Point Plan for a Green Industrial Revolution set out key milestones for a programme of trials. It committed to support industry to begin a Hydrogen Neighbourhood trial by 2023, a large Hydrogen Village trial by 2025 and how government will help deliver the UK's first 'Hydrogen Town' by 2030.[46]

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Case studies

Case studies

Makes or facilitates best use of any limited resources, for example prioritising uses where no other low-carbon option feasibly exists:
As described in the CCC's Sixth Carbon Budget, hydrogen will be essential in every pathway to net zero.[42] However, it is important that within the scale up of hydrogen production, storage and use, the sectors that are most difficult to decarbonise without hydrogen are prepared to transition to hydrogen, have the policies and incentives necessary to accelerate adoption, invest in R&D and skills and receive the hydrogen supply they need to decarbonise.

This means including these sectors in the pilot projects aimed at scaling up hydrogen production, storage and end-uses, and increasing the products, markets, skills and knowledge base needed to do so. Pilot projects and any further roll out of hydrogen technologies should be partnered with public engagement aimed at developing people's understanding of this new energy vector and its use in the sectors where it is adopted. This will allow these otherwise hard-to-decarbonise sectors to take advantage of the increasing availability of hydrogen, achieve immediate emission reduction and be a successful part of the net zero transition.

Pilot scale hydrogen production project in Hastings, Victoria, Australia

Conclusion

Given the limited timescales available to policymakers to meet the target of net zero carbon emissions, it is important that decision makers can rapidly identify low regrets decisions that will result in reduced carbon emissions, no high-carbon technological lock in, scaling up to meet demand, clear co-benefits with other key policy objectives and the best use of resources where they are limited.

The low regrets framework (**Table 1**), the low regrets examples (**Table 2**) and case studies outlined in this report can help policymakers to identify low regrets decisions, including what technologies are available now and can be effectively scaled up to decarbonise the UK and achieve net zero by 2050. However, solely making low regrets decisions will not be enough to achieve net zero. Achieving the socio-technical transition required to achieve net zero will inevitably require decision makers to make bigger, higher-stakes policy decisions that will go further than the limitations of this framework.

Many necessary decisions may well contravene the criteria set out in the low regrets framework, perhaps involving short term increases in carbon emissions, introducing high costs that do not decrease over time or lacking co-benefits with other key policy objectives. The greater degree to which options satisfy the criteria in the framework presented in this report, the more likely they are to be low regrets and, as such, the framework can be used to aid swift action. Failure to meet the criteria in this framework should not rule out options but should instead guide decision makers toward the questions or uncertainties that need first to be addressed.

Identifying low regrets decisions must be done in tandem with taking a systems approach to ensure the various options are joined up. Achieving net zero is a unique policy goal, not only due to the scale of ambition in the limited timescale, but also the breadth of policy areas and stakeholders that must work together towards this shared and uncertain goal. This immense task is achievable if the right approach is taken. Taking a systems approach can improve the ability of policymakers to assess the interconnectedness between different sectors and identify the interdependencies, highlighting the unknowns and the uncertainties associated with making decisions, and monitoring for unforeseen consequences.

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Reviewers:

Professor Jillian Anable
Professor of Transport and Energy, Institute for Transport Studies, University of Leeds.

Professor Paul Ekins OBE
Professor of Resources and Environment Policy, Bartlett School of Environment, Energy and Resources, University College London.

Contributors:

Professor Roger Kemp MBE FREng
Lancaster University

Dr Julie Godefroy
Head of Sustainability Chartered Institution of Building Services Engineers

Ian McCluskey
Head of Technical and Policy Institution of Gas Engineers and Managers

Ian Gardner
Global Energy Leader, Arup

Dr Simon Harrison
Institution of Engineering and Technology, and Group Head of Strategy, Mott MacDonald

Members of the NEPC Net Zero Working Group:

Dervilla Mitchell CBE FREng
Chair

Professor Nilay Shah OBE FREng
Vice-Chair

Mark Apsey MBE
Chair, Institution of IChemE Energy Community of Practice

Dr Jenifer Baxter
Chief Engineer, Institution of Mechanical Engineers

Professor Harriet Bulkeley FBA
Durham University

Dr Mike Cook FREng
Director Buro Happold; Adjunct Professor, Imperial College: IStructE Head of Climate Emergency Task Group

Ian Gardner
Global Energy Leader, Arup

Dr Julie Godefroy
Head of Sustainability Chartered Institution of Building Services Engineers

Professor Jim Hall FREng
University of Oxford; Vice President of the Institution of Civil Engineers

Dr Simon Harrison
Institution of Engineering and Technology, and Group Head of Strategy, Mott MacDonald

Steve Holliday FREng
President, Energy Institute

Professor Roger Kemp MBE FREng
Lancaster University

Professor Rebecca Lunn MBE FREng FRSE
University of Strathclyde

Ian McCluskey
Head of Technical and Policy Institution of Gas Engineers and Managers

Emeritus Professor Susan Owens OBE FBA
University of Cambridge

Dr Sophie Parsons
National Composites Centre; Strategic Advisor Institute of Materials, Minerals and Mining

Nick Winser CBE FREng
Chair, Energy Systems Catapult

Contact information
If you are interested in finding out more about this project or want to get involved, please contact: **nepc@raeng.org.uk**

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Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel 020 7766 0600
www.raeng.org.uk
@RAEngNews

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