Summary Report

# Options | Choices | Actions

## UK scenarios for a low carbon energy system transition

# WELCOME
# TO THE FUTURE OF LOW CARBON ENERGY IN THE UK

## EXECUTIVE SUMMARY

**1**

The UK can achieve an affordable transition to a low carbon energy system over the next 35 years. Our modelling shows abatement costs ranging from 1-2% of GDP by 2050, with potential to achieve the lower end of this range through effective planning

**2**

The UK must focus on developing and proving a basket of the most promising supply and demand technology options. Developing a basket of options (rather than a single system blueprint) will help to limit inevitable implementation risks

**3**

Key technology priorities for the UK energy system include: bioenergy, carbon capture and storage, new nuclear, offshore wind, gaseous systems, efficiency of vehicles and efficiency/heat provision for buildings

**4**

It is critical to focus resources in the next decade on preparing these options for wide-scale deployment. By the mid-2020s crucial decisions must be made regarding infrastructure design for the long-term

**5**

CCS and bioenergy are especially valuable. The most cost-effective system designs require zero or even “negative” emissions in sectors where decarbonisation is easiest, alleviating pressure in more difficult sectors

**6**

High levels of intermittent renewables in the power sector and large swings in energy demand can be accommodated at a cost, but this requires a systems level approach to storage technologies, including heat, hydrogen and natural gas in addition to electricity



# FOREWORD

## A MESSAGE FROM THE CHIEF EXECUTIVE
## DR DAVID CLARKE

The work we have undertaken at the ETI has shown the importance of a systems approach to energy planning – sectors and their infrastructure cannot be developed in isolation. Therefore one of the first acts of the ETI was to establish ESME our Energy System Modelling Environment, which is an internationally peer-reviewed national energy system design and planning tool.

The UK energy environment comprises a complex set of needs, technologies and choices. We first conceived ESME for our own technology investment purposes, but over the years it has developed into a powerful energy system model for the UK.

Our refinement and development of the model with input from our private and public sector membership has allowed us to develop illustrative scenarios for the UK’s energy transition out to 2050. We present here two representative scenarios of the future which each show pathways the UK can follow, but importantly highlight the changes the UK needs to consider and make to its energy infrastructure – this is unavoidable.

We hope the scenarios inform and provoke debate, and progress thinking about how we power the UK in the future.

**“ WE HOPE THE SCENARIOS INFORM AND PROVOKE DEBATE, AND PROGRESS THINKING ABOUT HOW WE POWER THE UK IN THE FUTURE ”**

Download
This is a Summary Report, for the full report ‘Options, Choices, Actions – UK scenarios for a low carbon energy transition’ see:
www.eti.co.uk/programme/strategy

# ETI ENERGY SYSTEM MODELLING

## Strategic Analysis

The ETI has worked closely with its members and with project partners to develop and refine its strategic thinking. This has been supported by analysis and research activities evidenced against large scale development and demonstration projects and field trials undertaken in ETI projects.

This accumulating evidence base has been incorporated into the ETI's modelling framework.

ESME
Energy System Modelling Environment

## Modelling Approach

The ETI has developed its Energy System Modelling Environment (ESME) – an internationally peer-reviewed national energy system design and planning capability – to identify the lowest-cost decarbonisation pathways for the UK energy system. This involves running hundreds, even thousands of simulations, exploring the variation on cost-optimal designs within a range of assumptions and constraints in order to identify robust strategies against a broad range of uncertainties.

ESME covers the whole energy system for the UK, meaning the ETI can look in detail at possible designs for infrastructure, supply and end-use technologies for heat, electricity, personal transport, freight, industry and so on.

We have tested the designs by removing and adding certain technologies and adjusting their cost and performance characteristics.

The runs allow us to understand which are the most valuable (combinations of) technologies under different conditions, which are the most robust, and which technologies act as effective insurance options in case a first choice technology fails to deliver.

The system designs produced by ESME are then stress tested by other means, for example we test the power sector designs through a 'dispatch model' that can simulate electricity supply and demand on a minute-by-minute basis.

We recognise that techno-economic optimisations are imperfect. Many low carbon solutions have benefits and drawbacks that cannot be easily represented in this fashion. That is why ETI analysis is supported by detailed research around consumer needs, environmental impacts, business models and more across our entire portfolio.

Download

This booklet will be followed by a more in-depth guide to the modelling work behind the scenarios presented. In the meantime, for more detail on ESME and how we use it in our strategic thinking, see: www.eti.co.uk/project/esme



# OUR SCENARIOS APPROACH

## ETI Scenarios

We have used ESME and its outputs to produce scenarios for use internally, by our membership and with wider stakeholders. This is to facilitate a conversation around the potential pathways for UK decarbonisation.

In developing these scenarios we have engaged frequently with our members and stakeholders, so the outputs have been crafted in collaboration with private companies, public sector bodies, academics and other experts in energy strategy.

A variety of energy system pathways are possible to meet the UK's 2050 emissions targets. We cannot represent every possible evolution of the UK energy system in two scenarios, but the other possible outcomes that are similar to the highlighted Clockwork and Patchwork scenarios in this analysis represent a significant part of the cost effective design space.

Recent experience has shown how hard it is to forecast what will happen even over the short term, let alone out to 2050. The two scenarios described in this book should not be read as predictions or forecasts of the most probable outcomes. They are both plausible and affordable but require considerable co-ordination and planning as well as consumer and social engagement.

The two scenarios we have selected illustrate key lessons we have learned. Within the two scenarios we have captured the technologies that are likely to be important in cost effective UK system designs, as well as some that are more expensive but may have popular support.

We intend for these scenarios to stimulate debate about the choices the UK must make and the actions the country needs to take. This is not to imply that the options for the UK are restricted to a simple two-way choice. However, technologies that consistently appear across a broad range of scenarios and are resilient to sensitivity analysis warrant prioritisation in preparing for transition.

**“WE HAVE USED ESME AND ITS OUTPUTS TO PRODUCE SCENARIOS FOR USE INTERNALLY, BY OUR MEMBERSHIP AND WITH WIDER STAKEHOLDERS”**

# RISKS AND UNCERTAINTIES

There are two key dimensions in developing a strategy to mitigate climate change:

» In a global context, will mitigation action progress steadily, or will a more limited initial response necessitate a rapid transition to a major commitment of resources later?

» Domestically, what is the right balance between solutions which capture popular support and those which can be combined into the most cost-effective plan?

## Mitigation Progress

Our view at the ETI is that international action will accelerate as extreme climate events become more commonplace and successful lawsuits are brought for damages. Societies that have prepared for integrated, whole-system solutions will enjoy an advantage. Those that have not will likely suffer from unfavourable terms of trade and lawsuits against their major companies.

We discuss the risks of delayed action, while our scenarios both adopt a timely and steady approach to decarbonisation.

## Technology Choices

Societal values are central to the choices that national decision-makers can legitimately make between alternative low carbon pathways. Developing an evidence base for the relative costs and benefits of different solutions can help inform societal acceptance, but ultimately where social values and perceptions clash with economic assessment, a balance will have to be struck and choices made.

Our two scenarios explore this dimension through the emergence of distinct social and political landscapes and the technology choices that might be associated with those.




# THE COST OF STANDING STILL

## Falling behind

Abandoning or weakening climate targets in the near term would represent a lost opportunity for the UK to position itself as a market leader for low carbon technology. Delays produce a very bleak outcome where the UK is trying to play catch-up without effective preparation, suffering from unattractive terms of trade through carbon price penalties and over-reliant on the skills and products of other nations to meet its needs.

In our modelling work we have explored a number of pathways in which the UK slips from its carbon budget trajectory, meaning we are producing an excess of emissions by the mid-2020s. Getting back on track after losing momentum would require a rapid reduction in energy demand, coupled with a radical transformation of the entire energy infrastructure in as little as 15 years (around the life of an average family car).

Even with highly optimistic rate-of-change assumptions, our techno-economic model fails to meet the 2050 targets under these conditions.

## Lack of ambition

Missing the carbon budgets outright is not the only risk the country could face. It is quite possible to imagine a future where the UK meets the interim targets out to 2027, but fails to establish a proven, demonstrated plan for how deeper cuts are to be achieved in the long term.

Our modelling work suggests the UK could meet existing carbon budgets out to 2027 largely through existing policies to deliver a pipeline of low carbon projects, supported by improved efficiency in the housing stock and turnover of incumbent technologies such as gas boilers and internal combustion engines.

Over the long term, these technologies will continue to deliver efficiency savings which can contribute to further emissions reduction. But these improvements will level off over time. Eventually, the residual emissions resulting from even the most efficient models of these technologies will be too high, and low carbon solutions will be required that can drive emissions down more aggressively.

It would be a mistake to think the country can wait until efficiency measures have been exhausted before we turn to alternative, low carbon solutions. If the UK waits until the mid 2020s, a lack of supply chain capacity is likely to mean that preferred solutions have to be supplemented by second-choice technologies at far greater expense. In our model, failure to prepare properly leads to a significant escalation in the cost of abatement action by 2050 (to around 3-4% of GDP).

> **“IN OUR MODEL, FAILURE TO PREPARE PROPERLY LEADS TO A SIGNIFICANT ESCALATION IN THE COST OF ABATEMENT ACTION BY 2050 (TO AROUND 3-4% OF GDP)”**

# THE NEXT DECADE

Over the course of the next decade, the UK must prepare for a comprehensive energy transition out to 2050. There should be no let-up in action to meet forthcoming emissions budgets, but incremental change will not suffice for the long term. At a certain point, decisions have to be made on a clear direction of travel so that new infrastructure can be planned and investments made in a timely fashion.

There is always a risk that some technologies will fail to deliver. Even those that are proven from a technological standpoint may fail to gain the popular support necessary to persuade policy makers to back them. A number of solutions therefore have to be explored in parallel until it is clear which ones represent genuine options for the UK.

The ETI is developing strategies for ensuring UK preparedness by 2025. By then, we need to be in a position to have assessed the available options and to allow for a series of difficult choices to be made regarding long term infrastructure needs. Any indecision would prove costly. Duplicating infrastructure or committing to one path then switching tracks will be unnecessarily expensive and wasteful – of money, time and talent.

Decisive leadership will also boost global efforts by showcasing solutions that will support decarbonisation of much larger nations with more significant emissions. Where the UK has gained a market lead in successful technologies, export opportunities offer a long term benefit to the UK economy.

Our two scenarios, Clockwork and Patchwork, follow distinct pathways as technology development and societal choices play out differently.

**“OUR TWO SCENARIOS, CLOCKWORK AND PATCHWORK, FOLLOW DISTINCT PATHWAYS AS TECHNOLOGY DEVELOPMENT AND SOCIETAL CHOICES PLAY OUT DIFFERENTLY”**

**2050**

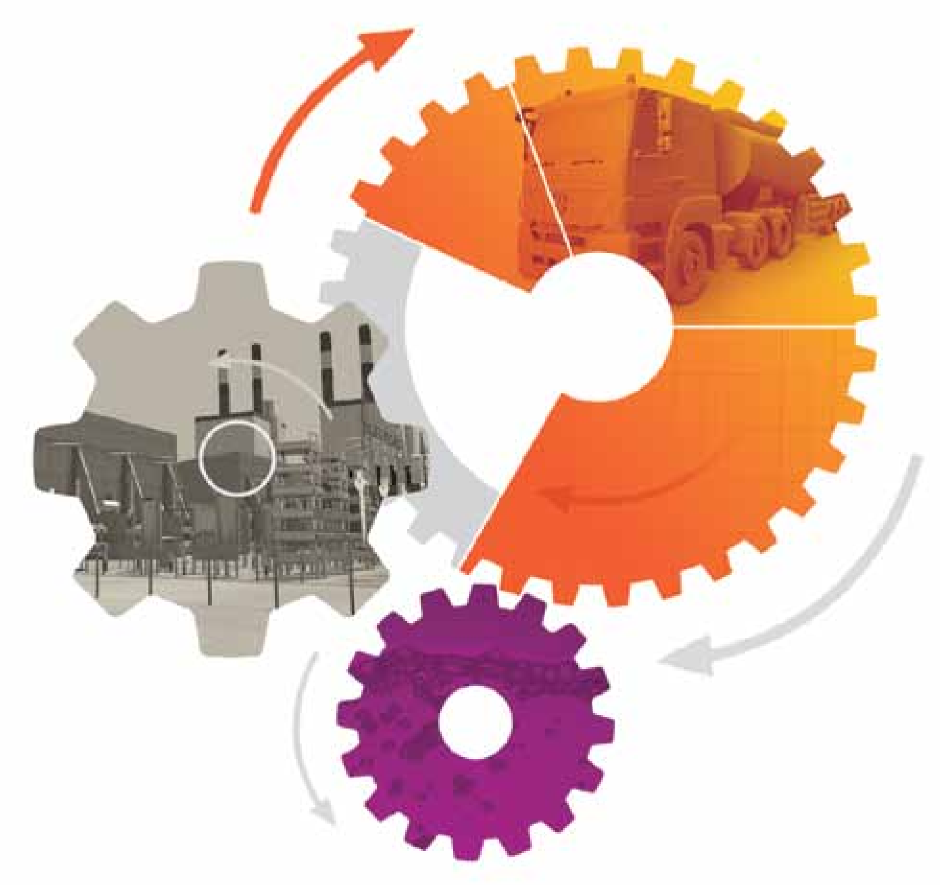
Over the course of the next decade, the UK must prepare for a comprehensive energy transition out to 2050. There should be no let-up in action to meet forthcoming emissions budgets, but incremental change will not suffice for the long term.



# INTRODUCING THE SCENARIOS

## CLOCKWORK

Well-coordinated, long term investments allow new energy infrastructure to be installed like clockwork. The regular build of new nuclear, CCS plants and renewables ensures a steady decarbonisation of the power sector. National-level planning enables the deployment of large-scale district heating networks, with the local gas distribution network retiring incrementally from 2040 onwards. By contrast, due to a strong role for emissions offsetting, the transportation system remains in the earlier stages of a transition and people and companies continue to buy and use vehicles in a similar way to today, albeit with regulation and innovation continuing to improve their efficiency.



## PATCHWORK

With central government taking less of a leading role, a patchwork of distinct energy strategies develops at a regional level. Society becomes more actively engaged in decarbonisation, partly by choice and partly in response to higher costs. Popular attention is paid to other social and environmental values, influencing decision-making. There is a more limited role for emissions offsetting, meaning more extensive decarbonisation across all sectors, including transport. Cities and regions compete for central support to meet energy needs which is tailored to local preferences and resources. Over time central government begins to integrate the patchwork of networks to provide national solutions.

# CLOCKWORK

## KEY CHARACTERISTICS

### POWER

- The policy framework supports large scale investments in CCS and nuclear. Clarity over the role of CCS enables early investment in “outsized” infrastructure and investor support for follow-on CCS projects
- The current pipeline of renewables projects are delivered out to 2020 and capacity is maintained on a replacement basis until new capacity is added in the 2040s
- Hydrogen for peaking plants is produced from biomass with CCS, providing system benefits including negative emissions
- The capacity of nuclear, CCS and renewables is evenly balanced by 2050

### HEAT

- A national framework for large scale district heating is introduced, enabled in part by waste heat from thermal power plants
- A phased shutdown of the local gas distribution network from the 2040s encourages the uptake of district heating schemes
- Subsidies are provided for heat pumps and efficiency improvements to speed up rural and suburban decarbonisation

### TRANSPORT

- A steady tightening of EU vehicle efficiency targets for new cars is met through the uptake of hybrid and plug-in hybrid vehicles
- The introduction of “soft” incentives such as road tax or congestion charge concessions for low-carbon vehicles
- Emissions reduction of freight is market-led, driven by cost of liquid fuels

**Institutional Mandate**
A national planning approach establishes a framework for energy system decision-making. There is societal acceptance of chosen solutions.

**National Scale Infrastructure**
A focus is placed on national co-ordination of supply-side generation and shared infrastructure.

**Carbon Offsetting**
Realising the system-wide value of CCS and biomass in generating negative emissions, provides headroom for other sectors to postpone expensive decarbonisation decisions.

**Phased Decarbonisation**
Emissions reduction is led by action in the power sector, followed by buildings and finally transport, where regulation drives incremental efficiency improvements in vehicles, including through adoption of plug-in hybrids.



- The combination of CCS and biomass creates “negative emissions” which provides headroom for other sectors and produces hydrogen for use in industry and electricity peaking plant
- There is a phase out of local gas distribution networks in the long-term
- Decarbonisation has to be balanced against two other priorities: minimising disruption to lifestyles and facilitating economic growth – creating a focus on solutions that are likely to be cheaper from an overall systems perspective
- By 2050 the capacity from nuclear, CCS and renewables is evenly balanced
- Nuclear capacity would require the development of two or three operating plants by 2025
- Aggregate power sector build rates of 2.5GW/yr to 2030, 4.5GW/yr to 2050
- Strong investment required in the electricity transmission grid to move energy from production to demand centres
- Renewables growth is scaled back
- Switching from gas boilers may impact on the welfare of some households
- Upfront investment is needed including piping for heat networks and potential reconfiguring of power plants to supply waste heat
- Mind-set change is required around public attitudes towards district heating
- Early notification and engagement necessary if switching from a local gas distribution grid
- A decline in liquid fuel sales puts the viability of current petrol infrastructure in jeopardy
- Cost of the Clockwork scenario is smaller – due to the stronger role for negative emissions relative to Patchwork

# PATCHWORK

## KEY CHARACTERISTICS

### POWER

- Renewables find support at all levels of society: central government backs large scale projects such as offshore wind, while local authorities and communities support combined heat and power, onshore wind and solar
- Initially, there is uncertainty over the role of nuclear and CCS due to a growing focus on renewables. This dampens investor appetite and limits the co-ordination of infrastructure planning
- Later on, CCS deployment picks up, enabling clean hydrogen production from a mixture of biomass and coal, although biomass uptake is limited by societal concerns about land-use change and biodiversity as well as by market failures

### HEAT

- There is “grassroots” support for small and medium scale district heating projects, coupled with private sector and local authority investment
- A mixture of changing attitudes and high energy costs cause the growth in average indoor temperature to level off from 2030
- There is improved efficiency of housing stock through selective the retrofit of existing homes, and with apartments increasingly dominating the market for new builds

### TRANSPORT

- Greater urbanisation and modal shift means slower growth in new car sales, particularly for large cars
- Some cities set more aggressive vehicle efficiency targets as part of their measures to improve urban air quality
- Freight transport experiences a market-led reduction in emissions due to liquid fuel costs
- Market-led emissions reduction of freight

**Societal Engagement**
Alongside decarbonisation, popular concerns over other social and environmental values (including land use and air quality) influence decisions taken on energy system planning at a local level.

**Multi-Scale Infrastructure**
A mixture of national, regional and local approaches continue to deliver a patchwork of low carbon energy infrastructure and supply, with active societal engagement.

**Extensive Renewables**
A renewables-heavy solution to energy supply is dominated by offshore wind and supported by smaller-scale technologies including the continued growth of solar.

**Parallel Decarbonisation**
Transformation of the power sector is followed by extensive, parallel abatement action across buildings and transportation, with a substantial uptake of hydrogen fuel cell vehicles and plug-in hybrids.



- Affordable carbon abatement is a priority but it is viewed through a broader lens of sustainability and social values
- Renewables grow to account for the majority of electricity generation
- Intermittency of renewables implies significant backup capacity is required
- Unprecedented build rates to keep up with increasing capacity – averages 4GW/yr to 2030 then 7.5GW/yr to 2050
- With excess of 75GW of wind capacity, there are many hours of the year when electricity supply greatly exceeds demand
- Heat pumps grow steadily to supply the majority of residential heat demand by 2050
- Electric heating becomes increasingly important as a source of back-up supply of heat by 2050
- Support for whole-house retrofits and heat storage will be needed in tandem with heat pumps
- Series of electricity network upgrades and hydrogen infrastructure installations are required
- Least affluent in society who depend on older, higher emitting cars will be most susceptible to tightening emissions standards
- UK based refineries are likely to shut as petrol usage drops

# COMMENTARY

## Conclusion

The ETI does not advocate today a single detailed blueprint for a future energy system. We do not yet have knowledge from the development and real-world scale adoption of most of the technologies discussed. Nuclear is the closest to being a tried and tested low carbon energy supply, but it is some time since we built a nuclear power plant in the UK.

Meanwhile people will make their own choices and those can never be fully understood in advance. Small scale demonstrations of a few thousand alternatively fuelled vehicles and their infrastructure, or changing over heating systems in a few tens of thousands of houses, will provide greater insight into this.

## Options, choices, actions

We have approximately a decade to build up a suite of low carbon technology options for the long term. During this time, the ETI recommends that the UK focuses its resources on learning about – and developing the capacity to implement – a basket of the most attractive supply and demand technologies. This includes bioenergy, carbon capture and storage, new nuclear, offshore wind, gaseous systems, efficiency of vehicles and efficiency/heat provision for buildings. Of these, bioenergy and CCS are by far the most critical.

By 2025, choices must be made regarding infrastructure design for the long-term. Closing down our options too soon could prove unnecessarily costly for the UK, but the bigger threat is failing to build up those options at all.

Of course, near term actions are required to meet the carbon budgets, but these have more or less been identified already. When it comes to the longer and more comprehensive transition to 2050, action will be required on another scale altogether. That is why it is so important to get it right, which requires substantial preparation.

In conclusion we would emphasise once more that these are scenarios, not forecasts. Our analysis shows that there are various trajectories possible for reasonably attractive and feasible UK energy systems within a wide range of variation.

Whether people prefer the vision of Clockwork or Patchwork or elements of each, the important thing is that our energy system works to the benefit of all. To that end, we hope these scenarios will stimulate discussion of our analysis and insights so that we continue to learn together.



# ABOUT THE ETI

The Energy Technologies Institute is a partnership between global energy and engineering companies and the UK Government.

Its role is to act as a conduit between academia, industry and government to accelerate the development of low carbon technologies.

It brings together engineering projects that develop affordable, secure and sustainable technologies to help the UK address its long-term emissions reduction targets as well as delivering nearer term benefits.

It makes targeted investments in a portfolio of nine technology programmes across heat, power, transport and the infrastructure that links them.

ETI Members

bp

CATERPILLAR

EDF ENERGY

Rolls-Royce

Shell

EPSRC Pioneering research and skills

Department for Business Innovation & Skills

Department of Energy & Climate Change

Innovate UK Technology Strategy Board

ETI Programme Associate

HITACHI Inspire the Next

# GET IN TOUCH

Energy Technologies Institute
Holywell Building
Holywell Way
Loughborough
LE11 3UZ

01509 202020

www.eti.co.uk

info@eti.co.uk

@the_ETI

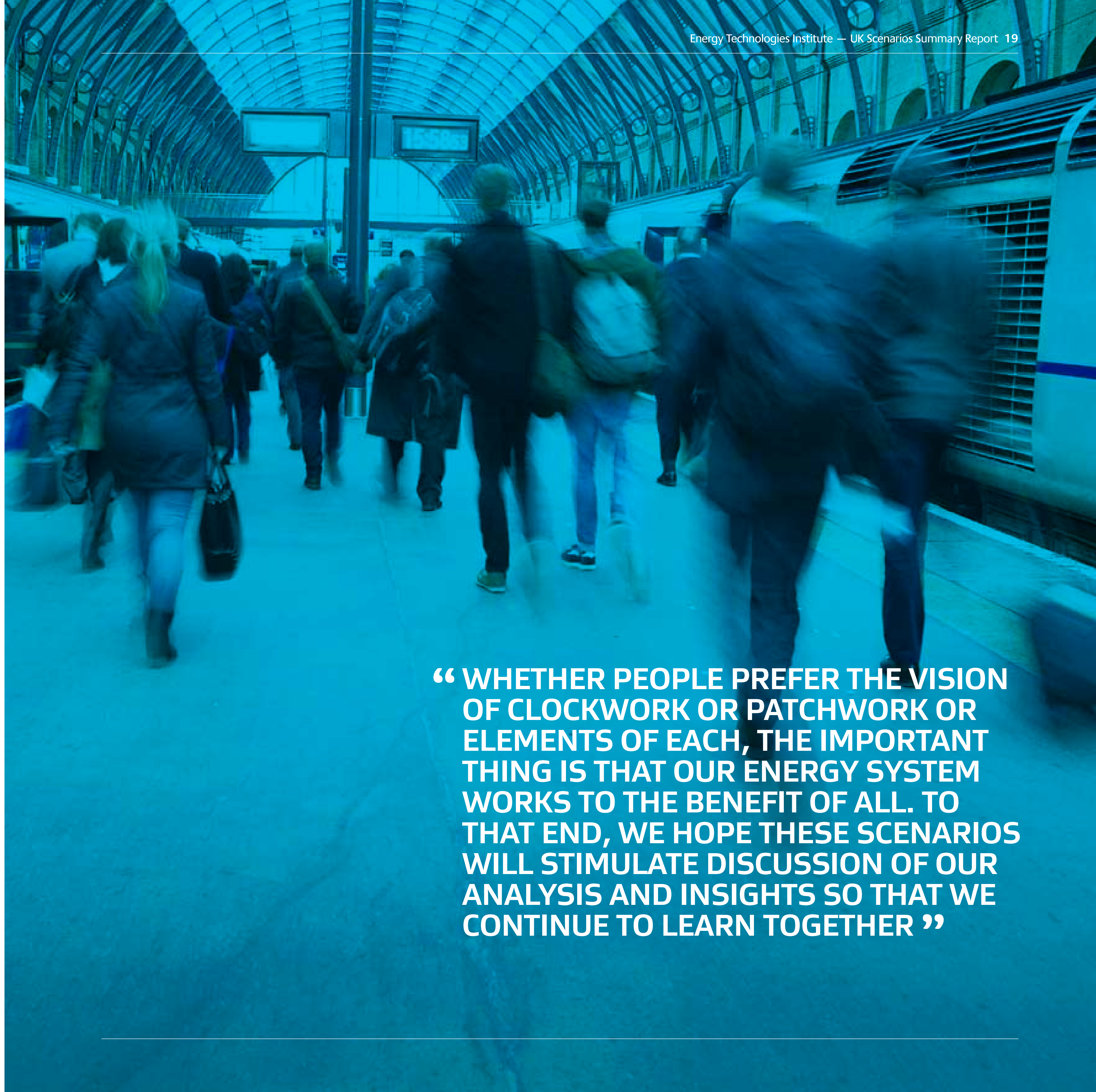
**Jo Coleman**
Director – Strategy Development
01509 202066
jo.coleman@eti.co.uk

**Dr Chris Heaton**
Strategy Manager – Modelling
01509 202051
chris.heaton@eti.co.uk

**George Day**
Head of Economic Strategy
01509 202046
george.day@eti.co.uk

**Dr Scott Milne**
Strategy Analyst and
Scenarios Project Lead
01509 202043
scott.milne@eti.co.uk





"WHETHER PEOPLE PREFER THE VISION OF CLOCKWORK OR PATCHWORK OR ELEMENTS OF EACH, THE IMPORTANT THING IS THAT OUR ENERGY SYSTEM WORKS TO THE BENEFIT OF ALL. TO THAT END, WE HOPE THESE SCENARIOS WILL STIMULATE DISCUSSION OF OUR ANALYSIS AND INSIGHTS SO THAT WE CONTINUE TO LEARN TOGETHER"

Energy Technologies Institute
Holywell Building
Holywell Way
Loughborough
LE11 3UZ

01509 202020

www.eti.co.uk

info@eti.co.uk

@the_ETI



**Acknowledgements**
Scenario analysis and narrative development supported by Marakon.

The Energy Technologies Institute LLP ("ETI") believe that the information presented in this document is reliable. However, we cannot and do not guarantee, either expressly or implicitly, and accept no liability, for the accuracy, validity, or completeness of any information or data (whether prepared by us or by any third party) for any particular purpose or use, or that the information or data will be free from error.

This information is given in good faith based upon the latest information available to the ETI. We do not take any responsibility for any reliance which is placed by any person on any statements or opinions which are expressed herein. Neither the ETI or any of their affiliates, directors, trustees or employees or any contributors to this project will be liable or have any responsibility of any kind for any loss or damage that any person may incur resulting from the use of this information.