THE ENERGY HIERARCHY:
SUPPORTING POLICY MAKING FOR 'NET ZERO'

Institution of
MECHANICAL
ENGINEERS

The original core message of this document was first published by the Institution of Mechanical Engineers in 2009, in response to the UK Government's Energy and Climate Change Acts of the previous year. History now shows that had the Institution's message of an Energy Hierarchy been followed over the intervening decade, UK energy policy could have been more effective. The UK would now have a more clearly-defined and sustainable future as it faces highly ambitious 'zero net emissions' targets for 2050. For these reasons, the Institution of Mechanical Engineers' Energy, Environment and Sustainability Group is updating and republishing the Energy Hierarchy, to mark its 10th anniversary.

In summary, if the 2050 'net zero greenhouse gas (GHG) emissions' targets are to be met, then the present Government policy needs to be rebalanced and should:

1. **Be re-developed with the Energy Hierarchy as its framework**, in keeping with the principles of sustainable development. There is a clear need for much more demand-side energy conservation and efficiency measures, alongside the more rapid development of a wide range of renewable and low-GHG-emitting energy sources for heat and transport, not just for electricity.
2. **Include statutory targets on energy demand reduction.** These should achieve genuine reductions, not those achieved by industry outsourcing its emissions' problems to developing countries, while reaping the benefit from lower cost of production.
3. **Urgently provide a long-term framework** giving investment signals for businesses to deliver major energy system change. This must go well beyond the current economic and technical assessments and make it possible for the private sector to make real business cases, which can avoid the boom and bust created by the Feed-in Tariff (FiT) and to some extent, the Renewable Heat Incentive (RHI). Any economic case analysis must also fully consider all external factors.

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The Energy Hierarchy (**Figure 1**) offers an effective framework to guide sustainable energy policy and decision-making. By prioritising demand-side activities to reduce consumption and wastage and improve efficiency, the Hierarchy links closely to the principles of sustainable development and offers an integrated, easy to use, approach to energy system design and the management of energy demand and supply. Put simply, it offers a common-sense, cost-effective, sustainable energy policy that aims to reduce energy use before seeking to meet remaining demand by the cleanest means possible.

THE RELEVANCE OF SUSTAINABILITY TO ENERGY

Sustainability embraces simultaneously economic, social, and environmental objectives and impacts. Sustainable development policy therefore involves a very wide range of issues, including food and water availability, resource use and depletion, poverty, economic growth, social cohesion, community engagement, production and consumption, climate change, population growth and international security. Growth in global demand for energy, triggered by a rapidly-rising population, is a major factor in many of these issues – especially in resource depletion, economic growth, climate change and international security.

Figure 2 provides a reminder of two well-established definitions of sustainability and are the foundation of this statement[1,2].

Figure 1: The IMechE Energy Hierarchy

MOST SUSTAINABLE

Tier 1: Energy Demand Reduction

Tier 2: Energy Efficiency

Tier 3: Utilisation of Renewable, Sustainable Resources

Tier 4: Utilisation of Other, Low-GHG-Emitting Resources

Tier 5: Utilisation of Conventional Resources as we do now

LEAST SUSTAINABLE

This policy statement focuses on the UK's energy policy, but it is important to place this in the global context, as we do in the following section.

ENERGY ≠ ELECTRICITY

For the Energy Hierarchy to be truly effective, it must be applied to all types of energy demand and energy supply. Until the publication of the Government's Renewable Energy Strategy[3] in 2009 and subsequent legislation, there had been little recognition in the UK of the significance of the amount of energy consumed in the heating and transport sectors, even though these are each far greater markets than those, then or now, supplied by electricity. In 2009 only about a quarter of the UK's energy demand was supplied by electricity, a figure which is little changed today, despite the recent emphasis on the need to 'electrify' the heat and transport sectors. The need to focus on the wider energy system is better recognised in Government today but legislation still needs to be more proportionately focussed on the heat and transport sectors and this must be followed through with action.

Figure 2: Definitions of sustainability

Sustainable development and sustainability have been defined in various ways. Two well-rounded definitions of sustainable development and sustainability are:

- "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
- "Sustainability can best be defined as the capacity for continuance into the long-term future. Sustainability depends upon maintaining, and where possible increasing our stocks of certain assets, so that we manage to live off the income without depleting the capital. Sustainable development is the process by which, over time, we succeed in managing all the different capital flows in our economies on a genuinely sustainable basis."

CLIMATE CHANGE

For the past three decades (the first IPCC Report[4] was in 1990), there has been an overwhelming consensus among climate scientists that human activity is causing gaseous emissions that are gradually warming the Earth, over and above any natural climate cycles or influences. These anthropogenic emissions come from a variety of activities and sources, including agriculture, forestry, waste, and industry, but the main component consistently confirmed in the IPCC reports, is associated with the supply and use of energy from fossil fuels. The science of climate change is now broadly accepted across all disciplines, however solutions for both mitigating emissions and adapting to our changing climate remain difficult to implement.

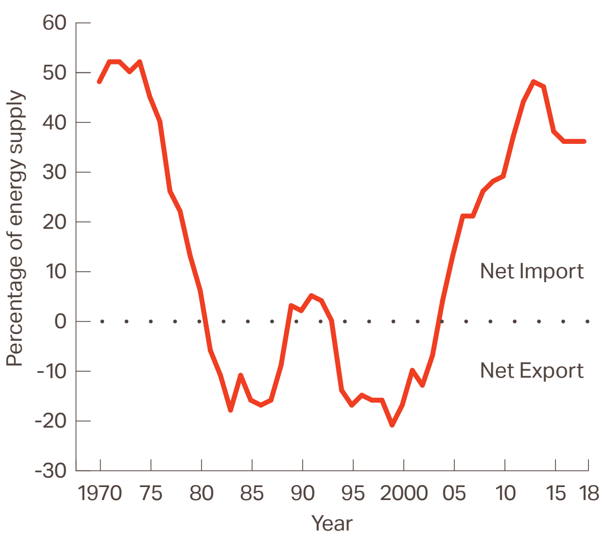
GLOBAL POPULATION GROWTH AND AN ASPIRANT MIDDLE CLASS

Dealt with more fully in the Institution's 2011 report on population[5], a rapidly rising global population, along with growing prosperity, is a major cause of ever-increasing global energy demand. World population rose from 6bn in 2000 to 7bn in 2011 and is predicted to reach 8bn in 2023 and almost 10bn by 2050[6]. At the same time, people in developing countries aspire to higher standards of living (and therefore increased per capita energy consumption), meaning that global energy demand has been projected to increase by 50% by 2050[7]. In the UK, Government estimates predict the population to rise from 65m today to 70m by 2030[8], which will inevitably work against efforts to drive down demand. There are certainly no easy or ethical answers to this growing problem, but it receives little public attention in the energy/emissions debate, which centres around 'anthropogenic' emissions. Without significant reductions in individuals' energy consumption, worldwide, any mitigation measures will be chasing increasingly difficult targets.

INTERNATIONAL SECURITY

The use of energy for heating, lighting, cooking, communications, and healthcare has clear societal benefits, but there are ever-rising societal and environmental risks associated with the transfer of energy and energy technologies between nation states. As shown in **Figure 3**, apart from the period from 1980–2004, the UK has been and remains heavily dependent on the import of energy, mostly in the form of fossil fuels; most of these imports are supplied over long distances, particularly by ocean shipping. Not only are there security risks but the considerable levels of GHG emissions, known as fugitive emissions, in shipment are not accounted for in either the UK's statistics, or anywhere else. Economically viable North Sea oil and gas reserves are being rapidly depleted, and the UK coal industry has almost disappeared. Despite its notable success in the USA, attempts at 'fracking' in the UK have met with heavy public opposition and appear unlikely to continue.

Figure 3: Historic UK net energy import/exports[9]



THE HIERARCHY IN DETAIL

To guide the development of sustainable energy policy, in 2009 the Institution created the Energy Hierarchy[10], a concept which has been adopted by many organisations in the UK, as well as by engineering institutions around the world.

The concept is a simple one and could have profound implications for energy strategy or policy. The Energy Hierarchy states that a successful energy policy must start by first considering energy demand reduction and then improving energy efficiency before different types of energy supply are considered. Naturally, careful consideration needs to be given to any possible consequential whole energy system effects this might have. The Energy Hierarchy is summarised as follows:

Tier 1: Energy Demand Reduction (EDR)

Energy conservation, or demand reduction, is about eliminating the need for the energy demand in the first place. The concept is simply that a kilowatt or kilowatt-hour saved (or not used) is much more valuable than a kilowatt or kilowatt-hour supplied, no matter what the source; this concept is also sometimes known as the 'negawatt'. It is also the only tier of the Hierarchy that can guarantee zero GHG emissions. Energy demand reduction can often be achieved through behavioural changes; for example, not making a journey and conducting a meeting by virtual means instead. Nevertheless, engineering solutions such as smart meters and real-time displays also have an important role to play in energy conservation, though how much they actually influence behaviour change remains to be seen. However, genuine smart meters should be able to achieve EDR by direct intervention, rather than by merely educating the consumer.

Tier 2: Energy efficiency

Energy efficiency is defined as the ratio of the useful output of services from an appliance, vehicle, process or system to the energy input. Energy efficiency improvements are usually achieved through the application of engineering principles, eg to reduce frictional losses, improve the conversion efficiency of a thermal combustion process or reduce heat loss from a building. It can be applied on both the demand-side and supply-side of energy provision, from improving the efficiency of a domestic appliance through to that of a thermal power station. Combined heat and power (CHP) falls into this category, as it too, generally allows for more of the energy contained within a fuel to be used usefully (both as heat and electricity) than would be possible if the fuel was used for electricity generation alone. The same is true for waste heat recovery and other energy recovery systems. Nevertheless, care must be taken to avoid Jevon's Paradox[11], also known as the rebound effect, that improved efficiency merely leads to increased consumption.

Tier 3: Utilisation of renewable, sustainable resources.

Having taken all reasonable steps to minimise energy demand and improve efficiency, the next priority is to supply that demand from renewable energy sources that can be considered infinite. Effective, sustainable energy provision is not just about resource availability, it must also embrace wider issues such as affordability (although this does not necessarily equate to cheap energy), societal acceptability and environmental impact. These issues tend to drive policy makers towards actions that encourage and incentivise a broad portfolio approach. Such an approach is particularly relevant to the UK which has an abundance of different renewable energy sources available on- and off-shore, but where an over-emphasis on any one source could have unacceptable impacts on another aspect, for example, energy security, environmental, business or economic perspectives. Furthermore, a resource being considered renewable does not necessarily mean it is truly sustainable, a good example is large-scale hydro-electric schemes. Other sustainability issues also need to be addressed, for instance, in the material choices and end-of-life treatment of wind turbine blades, as well as the materials of construction of solar photovoltaics.

Tier 4: Utilisation of other low-GHG-emitting resources

Finite natural resources such as fossil fuels, in the form of oil, coal, and gas, and uranium still provide the vast majority of global and UK energy supply. The UK's transport systems, buildings, power generation and gas transmission infrastructure have been built such that they are dependent on the continued supply of these resources. This means that the transition to an energy system that is fully renewable and sustainable will take time. In the interim, it may be sensible to use and adapt these systems and processes to be not just more efficient (eg by using co-generated heat energy instead of wasting it) but also less damaging to the Earth's climate. Nuclear energy in the form of the fission of uranium is one such existing low-emissions source of electrical energy, although other sustainability issues and high costs are current challenges to overcome.

Most nuclear power plants operate with once-through fuel cycle where no effort is made to recycle spent nuclear fuel or make use of the co-generated heat. This is an inefficient use of the uranium resource. In addition, the future development of carbon capture and storage (CCS) has the potential to substantially reduce emissions from fossil-fuel combustion across various sectors, however alongside this will likely reduce the plant's overall energy efficiency in contravention of Tier 2.

Tier 5: Utilisation of conventional resources, as we do now

The 5th tier of the Hierarchy, namely the utilisation of conventional resources that represent a large proportion of the current energy system, is clearly the least sustainable option and is unlikely to form any part of a future sustainable energy strategy. The myriad of ways that fossil-fuel use is locked into current energy systems means that efforts will continue to be made by incumbent players to perpetuate 'business as usual' in order to gain increased returns on past investments. Fossil fuel companies devote much of their attention to finding and recovering new sources of oil and natural gas, both conventional and unconventional. Developing nations will naturally favour cheap, proven, reliable sources of new energy supply, which often includes coal, oil and natural gas. Whilst these approaches may be understandable from a short-term economic perspective, they have unsustainable local and global impacts, hence their lower position in the Energy Hierarchy.

UK ENERGY POLICY PROGRESS AGAINST THE ENERGY HIERARCHY

This section examines the UK's progress against the Energy Hierarchy over the decade since the original energy hierarchy policy statement was published in 2009.

Tier 1: Energy Demand Reduction (EDR)

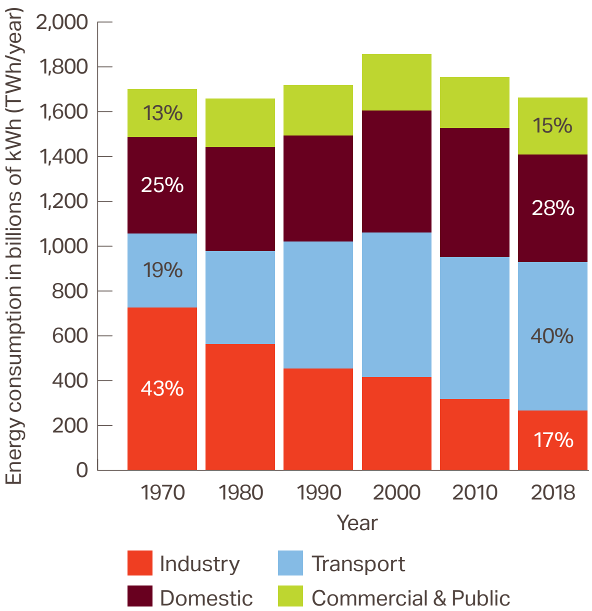
Energy demand reduction has not been a priority for the UK Government over the past decade; focus has largely been on the supply-side (Tiers 3–5), particularly for electricity. Any apparent reduction in energy demand appears to be accidental, rather than by design. **Figure 4** shows UK energy demand since 1970.

It shows that the only area of energy consumption which has significantly reduced is in industry (43% to 17%), while energy demand in transport has increased from 19% of the total to 40%; furthermore, the figures for transport do not include either international aviation or shipping, both of which have increased over the period and are now approximately 2% of global GHG emissions each. However, the most concerning figures are those for industry, where the supposed reduction in UK energy demand is largely explained by the offshoring of much of the UK's manufacturing sector, along with its related energy demand, costs and GHG emissions. This was demonstrated in a recent report from the Office National Statistics[13] that showed Britain to be the biggest net importer of CO_2 emissions in the G7. Additionally, since we pointed out the huge importance of behaviour change in our original policy statement, it is noteworthy that it was not until August 2019 that the Committee for Climate Change (CCC) admitted that the new 2050 targets could not be achieved without significant behaviour change. Had this admission been made ten years earlier, the UK might be much better positioned today to tackle these highly ambitious targets.

Tier 2: Energy efficiency

Although the UK Government has recognised energy efficiency (eg the Energy Act of 2011[14]), it has failed to recognise EDR as a separate issue and has simply lumped them together. Incentives offered in this field over the past decade, eg The Green Deal[15], have not been successful, mainly because they were not commercially viable regardless of what technical or economic analyses might have suggested. As a result, to take just one example, the standard of building insulation in the UK is still very much lower than it is in most other northern European countries. Energy efficiency in some other areas has indeed improved, eg with electric vehicles (EVs). However, it remains very difficult to make a business case for energy efficiency in the private sector in the UK and substantial Government intervention is likely to be required to improve the future viability of this sector. One major success story over the past decade has been the widespread change to using LEDs for lighting, although this again has been enabled by the ease of making a business case, rather than solely by Government intervention.

Figure 4: Energy consumption by sector in billions of kWh, 1970–2018[12]



Tier 3: Utilisation of renewable, sustainable resources

As noted, the first two tiers of the Hierarchy have been poorly implemented in the UK over the past decade with most focus on the implementation of different types of renewables, particularly in the electricity generation sector. Although now much more buoyant, even this sector was slow to start. The 2010 target, set by the Utilities Act 2000[16] , for the UK to generate 10% of all electricity from renewable resources was missed by a large margin (only 6.8% achieved). The UK's 2020 commitments, set by The UK Renewable Energy Strategy[17] of 2009 and subsequent legislation, require 30% of electricity, 12% of heat and 10% of transport energy (with overall target of 15% of all energy demand) to be supplied from renewable resources; the heat and transport targets will, again, be missed by very considerable margins, as will the overall 15% target. Meeting the 30% renewable electricity target has been hailed as a success story but questions remain over the sustainability of part of this, particularly in relation to biomass-firing, with the biomass supply-chain requiring transatlantic shipment and little attempt being made to recover the enormous quantities of cogenerated heat energy, which is still wasted to the environment. At a smaller-scale, both the Feed-in Tariff (FiT) and the Renewable Heat Incentive (RHI) were introduced during the period and although well-intentioned, ran into problems which means it cannot be regarded as a sustainable success.

Tier 4: Utilisation of other low-GHG-emitting resources

Much attention has been given to this tier of the Hierarchy over the past decade, with a lot of debate over the sustainability of different technologies in the UK. This debate is not repeated here, although it must be noted that unless and until the cogenerated heat energy from power generation is recovered and utilised in heating systems, rather than rejected to the environment, these technologies will not meet the sustainability criteria. Another technology in this tier is CCS, a technology that has been very slow to progress in the UK for a variety of reasons, including its potential impact on the energy efficiency of power generation plant, and the difficulty in making a good business case for its use. The current renewed interest in hydrogen as a substitute for natural gas may also be considered here (since hydrogen itself is not renewable). Production of hydrogen by electrolysis is currently inefficient and production by steam-methane-reformation of fossil fuels will probably require the additional use of CCS, potentially reducing the overall energy efficiency and likelihood of presenting a viable business case in the absence of strong Government intervention or a high and stable carbon price.

Tier 5: Utilisation of conventional resources, as we do now

As the penetration of renewable electricity generation has increased, it has been possible to reduce reliance on electricity generated by fossil fuels during the period. Accordingly, the Government has pledged to close all UK coal-fired power stations by 2025. While this is commendable from an emissions point of view, it is not clear what effect this will have on the resilience of the grid system, or how this synchronous generation will be replaced. Furthermore, little impact has been made, over the period, on either oil consumption in the transport sector, or natural gas in the heat energy sector, both of which are very much larger than the market currently served by electricity.

WHAT SHOULD WE DO?

A decade ago, IMechE advocated the transition to a sustainable energy economy, based on the Energy Hierarchy. At the time, this was not taken up by Government, with the result that progress towards the emission reduction targets in the 2020s has been slow and look set to be missed. If the 2050 'net zero GHG emissions' targets are to be met, the present policies remain inadequate and we believe that the UK's energy policy should:

1. **Be re-developed with the Energy Hierarchy as its framework,** in keeping with the principles of sustainable development. There is a clear need for much more demand-side energy conservation and efficiency measures, alongside the more rapid development of a wide range of renewable and low-GHG-emitting energy sources for heat and transport, not just for electricity.
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FURTHER INFORMATION

This Policy Statement has been prepared by the Institution's Energy, Environment and Sustainability Group. More information can be found at: https://www.imeche.org/get-involved/special-interest-groups/energy-environment-and-sustainability-group

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