FAILURE TO MEET LONG-TERM UK CARBON REDUCTION TARGETS – A SYSTEMATIC ASSESSMENT

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1. INTRODUCTION

Long term decarbonisation of the energy system is an integral part of the UK Government's strategy for the environment, energy and economy. The UK was the first G20 country to legislate [1] a greenhouse gas (GHG) reduction targets (of at least -34% by 2020 and -80% by 2050, relative to a 1990 baseline). A range of policy mechanisms [2] are now in place to put the UK on a path to meeting this target – an immense challenge that requires at least a fifteen fold reduction in emissions per unit of GDP. Figure 1 illustrates this challenge assuming a illustrative domestic UK carbon dioxide (CO_2) emissions target of -80% and a projected GDP annual growth rate of 2.2%.

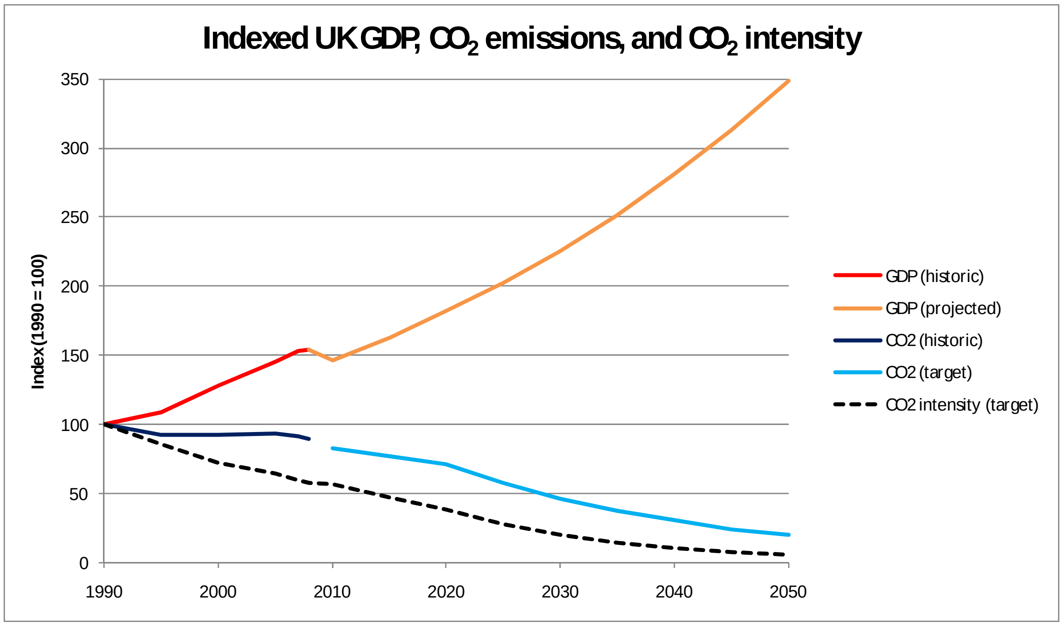

Figure 1: Indexed UK GP, CO_2 and CO_2 intensity growth rates

However, as the rhetoric on long-term CO_2 targets becomes ever tougher, there is widespread concern that these targets will be achieved. Although the UK is one of the few countries on track to meet its Kyoto GHG target of -12.5% (relative to 1990), and now may achieve a domestic target of -20% of CO_2 (again to relative to 1990), this has only been achieved by long term structural reform (the move from coal to natural gas fired power generation) and the recent financial crisis and recession, rather than the remit of UK energy and environmental policy.

Looking forward to the stringent 2050 targets, there is widespread scepticism of achieving this target. For example a recent poll of UK energy experts [3], they were asked them firstly what was technically and economically feasible in terms of UK CO2 reductions by 2050 and secondly what their prediction that these reductions would be. Although 56% though that an 80% CO_2 reduction was feasible by 2050, only 9% through this would happen. Of even more concern, following a set of presentations outlining the key findings of the UKERC Energy 2050 multi-disciplinary study [4] of UK energy futures [4] these ratios fell to 43% and 7% respectively.

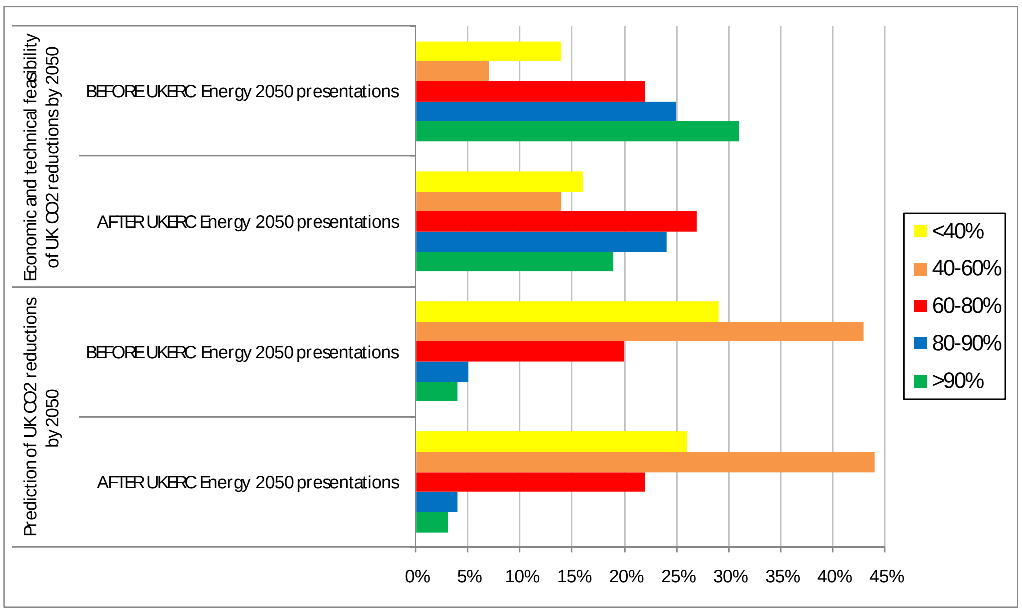

Figure 2: Expert opinions (2009) on possible and predicted reductions in 2050 UK CO_2 emissions

This paper investigates this dichotomy between the UK policy priority in reducing energy-related CO_2 emissions, and concerns over the feasibility, costs and achievability in meeting this unprecedented change in energy production and use. Section 2 reviews the literature on long term energy modelling and scenarios, noting the sparse nature of investigation of failure to meeting emissions targets. Section 3 outlines a set of failure scenarios and their implementation in variants of the UK MARKAL model. Section 4 presents preliminary results and section 5 discusses conclusions and ongoing work.

2. LITERATURE REVIEW

Few energy economists and modellers like investigating failure. Firstly there are comparatively very few energy-economic studies of very deep long term emission reductions [5], with the majority of studies being shorter term with less stringent targets. Secondly, most modelling and studies that do investigate such futures [e.g., 6,7,8] assume that this extreme exogenous constraint is met and then investigate technological pathways, behavioural measures, costs, and uncertainties in meeting this target. A final exemplar is in the long term MARKAL modelling – under conditions of optimality, rational behaviour, competitive markets and information provision – that has underpinned UK government policy analysis of stringent CO_2 reduction targets [e.g., 9,10].

Scenario analysis of catastrophic failure is also not generally a popular subject choice, often viewed as defeatist or pessimistic [11]. In a meta analysis of UK and international scenarios [12], a common element was the imposition of an exogenous CO_2 constraint and the use of a "back-casting" process to investigate technological pathways, behavioural measures, costs, and uncertainties in meeting this target. This assumes that the CO_2 target will be met, notwithstanding the unprecedented scale of largely decarbonising the entire UK energy system. In scenario typologies, such back-casting studies that assume goals are met and that do not consider failure are categorised as normative transformational [13].

However, challenging the existing and prescriptive world view can be extremely constructive [14]. Scenarios (and modelling) that break the assumption of meeting CO_2 targets can firstly challenge the consensus that implicitly exists around meeting targets, and secondly, identify protective and proactive strategies to anticipate failure to meet CO_2 targets from external and internal actors and drivers respectively. This is particularly important for the UK, as a moderate sized economy it is a price takes for a range of international drivers on its energy system which are set by a range of external actors.

3. METHODS

3.1. Model overview

To systematically investigate failure to achieve long-term CO_2 targets, this paper utilises the UK MARKAL model – the same model that has underpinned the UK evidence base on long-term technology pathways, energy demands changes and costs [9]. This partial equilibrium optimisation model maximises discounted economic welfare, taking into account evolving costs and characteristics of resources, infrastructures, technologies, energy service demands, behavioural price response and a range of taxes and policy mechanisms.

UK MARKAL is calibrated in its base year (2000) to data within 1% of actual resource supplies, energy consumption, electricity output, installed technology capacity and CO_2 emissions. The model then solves from year 2000-2050 in 5-year increments. All prices are in £(2000). Table 1 details key assumptions for this study

Key parameter	**Description**									
Conversion factors	GDP deflators: (2000 = 100), 2005 = 116.9, 2008 = 123.9 (Source: www.berr.gov.uk/files/file41491.pdf) Exchange rates: $/£ = 1.8, €/£ = 1.4 (Source: www.hmrc.gov.uk/exrate/usa.htm) Physical: 1 MTOE = 11.6 TWhr = 48.9 PJ									
Discount and hurdle rates	Global discount rate of 3.5% (www.hm-treasury.gov.uk/data_greenbook_index.htm) Hurdle rates are implemented on conservation in residential and commercial sectors (12.5%); and transport technologies (10% for public transport, 10% for hydrogen private transport, 7.5% for battery and methanol private transport)									
Carbon Target	2050 target of -90% (59.3MtCO_2) relative to 1990 emissions of 592.4MtCO_2. Equal annual reduction from 2020 target of 380.2MtCO_2 (35.8% reduction from 1990 levels)									
Fossil Fuel Price 2000-2050 (2000£/GJ)	Central case	Oil	4.12	9.35	6.41	6.87	7.33	7.79	8.25	8.25
		Gas	1.93	4.47	4.47	4.85	5.16	5.47	5.70	5.70
		Coal	0.91	2.97	2.23	1.62	1.62	1.62	1.62	1.62
Fossil Fuel Price 2000-2050 (2000£/GJ)	Low case	Oil	4.12	9.35	4.58	5.31	5.50	5.50	5.50	5.50
		Gas	1.93	4.47	2.62	2.70	2.70	2.77	2.77	2.77
		Coal	0.91	2.97	1.62	1.01	1.01	1.01	1.01	1.01
Biomass Imports	Import constraint (increasing geometrically to 1260PJ by 2050)									
Energy service demand elasticities	25% maximum reduction. Own price elasticity range from 0.25 to 0.61 dependent on specific ESD									
Policy variables and energy taxes	As of 2008 Energy Bill [20]. Note, no EU-ETS price in reference case									
Technologies	As in [16,19] with additions including biomass CCS, infrastructure costs by scale and distance, additional district heat/CHP options, increased CCS costs and efficiencies, restricted capacity (30%) of residential heat pumps and night storage									

Table 1: Key study model assumptions

For further detail, a comprehensive description of the UK model, its assumptions, applications and core insights can be found in the model documentation [16] as peer reviewed papers [17, 18, 19].

As a perfect foresight model that assumes optimal behaviour, complete information, no market barriers and competitive energy markets, UK MARKAL represents a 'best-case' for the achievability and a lower bound for the costs of long-term energy policies. Systematically relaxing these assumptions explores the space between optimal solutions and the achievable pathways for such stringent CO_2 targets.

3.2. Definition of 'failure scenarios'

In the discussion on failure scenarios (sections 4 and 5), the following definitions of a "failed scenario" are utilised:

- Does not meet CO_2 reduction targets (in practice the model backstop emissions reductions option (£5,000/tCO_2) is triggered in order that the model still solves)
- Meets CO_2 target but still at excessive costs – both marginal price (price of fuels) and welfare loss
- Meets CO_2 target but with reliance on uncertain model elements with little empirical basis

In identifying the drivers of potential failure scenarios, of most interest are cross-cutting common mode failures that impact across the energy system. Table 2 lists five categories of common mode failures, the actors involved and a summary of initial model implementation. The initial results and discussion focus on the first two elements – build rates and resource imports

Cross-Cutting Issue	Principal Actor	Description	Initial model implementation
Build times	UK government; industry; society	Engineering capability for the UK to build plant. Available financing. Planning regime. Public opposition to construction/operation.	Build rates on large capital investments – coal, gas, CCS plants, wind (on- off-shore), nuclear, marine (tidal & wave), distributed generation. Build rates per technology class are: • until 2030 - 1GW pa • from 2030 - 2GW pa
Resource imports	External (global driver)	Access and cost of the UK to conventional and unconventional resource imports (fossil fuels, uranium, biomass, electricity, hydrogen)	Zero availability on biomass and hydrogen imports; lowered fossil fuel prices (see Table 1)
Innovation	External (global driver), UK government	Ability of technologies to reach commercial production and compete with existing technologies with or without support/regulatory regimes	[*Not discussed in this paper*] Cost increase and/or unavailability of key technologies
Human factors	Society	Behaviour of individuals and response to pricing, information and regulation. Alternate underlying demographics and lifestyle issues. Altered social norms.	[*Not discussed in this paper*] Removal of demand response to prices; restriction on conservation options. Alternate reference energy service demands
Carbon price	UK Government; external, society	Delay in imposition and/or ceiling in acceptable CO_2 price, based on stalled international negotiation or through fear of political cost	[*Not discussed in this paper*] Carbon prices delayed and/or limited in scope or value.

Table 2: Summary of initial set of common model failures

4. RESULTS

In an initial set of results, the focus is on a CO_2 reduction of 90% in 2050, reflecting the additional role of CO_2 emissions outside the UK energy system (e.g. bunker fuels) and the retention of non-CO_2 GHGs in agriculture and other sectors.

It is important to note there is a generic capacity for scenario failure in all models, through potentially unrealistic outputs generated by that model. For example, Figure 3 illustrates the annual investments in the UK power sector (current size 84GW) in an optimal UK MARKAL run with no build rate constraints. As new vintages of plants become available (via global R&D, global learning rates and international supply chains), and as CO2 targets tighten (leading to an expansion of zero emission power production. Peak installation rates for nuclear are 4.4GW in 2030, for cofiring CCS (negative emission) are 3.7GW in 2040 and conventional gas plant (back-up) are 3.5GW in 2045 By comparison, in the 1990s "dash-for-gas", the build rate of well understood, modular CCGT peaked at only 2.5GW. It is a very open question as to whether available finance, technical expertise, and grid management protocols will be able to deliver this level of investment in new technologies.

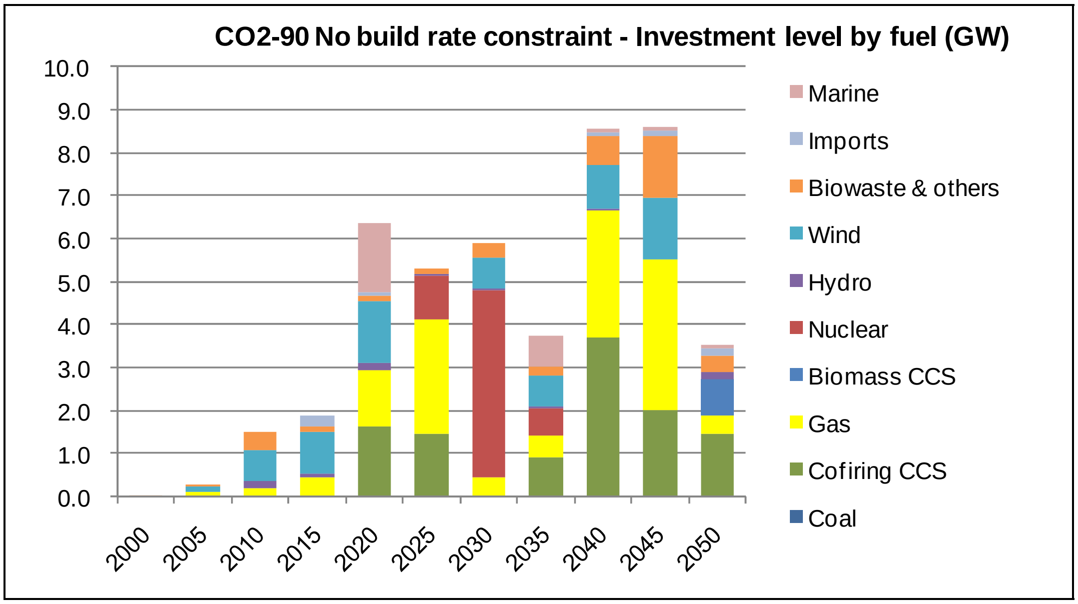

Figure 3: Unconstrained annual build rates (GW) in the power sector under a CO_2-90% case

Focusing on the cross cutting modes for failure scenarios, the remaining outputs are for combinations of imposed build rates and imported fuel restrictions. Build rates on large capital investments – coal, gas, CCS (carbon capture and storage) plants, wind (on- off-shore), nuclear, marine (tidal & wave), distributed generation. Build rates per technology class are (until 2030) 1GW pa, and (from 2030) 2GW pa. Given the role of international drivers on the UK, especially if major developing countries undertake stringent emission reduction and reduce their demand for conventional fuels whilst increasing demand on low carbon resources and fuels. Hence this is implemented as combinations of lowered fossil fuel prices (see Table 1), zero availability of sustainable biomass imports, and zero availability of hydrogen imports. Comparing to a reference case with no carbon constraint, the model runs are given in Table 3.

Scenario name	CO_2 constraint by 2050	Build rates imposed	Fossil fuel prices	Biomass imports	Hydrogen imports
REF	No	Yes	Central	Yes	Yes
C90	Yes	Yes	Central	Yes	Yes
C90-LF	Yes	Yes	Low	Yes	Yes
C90-LFB	Yes	Yes	Low	No	Yes
C90-LFBH	Yes	Yes	Low	No	No

Table 3: Build rate and import constraint combination scenarios

It is unsurprising that meeting a 90% reduction in UK CO_2 emission produces a radically different portfolio of technologies, infrastructure and behaviour change, as seen in comparing the REF to C90 scenario's primary energy (table 4). A major component of this change is the C90 scenario is the deployment of cofiring CCS and biomass CCS (table 6). This ensures that the power sector produces negative emissions to enable to UK to meet its overall CO_2 constraint, and facilitates residual emissions in industrial and transport sectors (table 5). The impact of lower fossil fuel import prices (C90-LF) further increases the role of biomass CCS to enable additional (cheaper) natural gas consumption. This dependence of the untried energy supply chain of bio-cofiring CCS and pure biomass CCS represented one potential cause of these scenarios to fail.

Without bio-imports (C90-LFB), the model cannot utilise this energy vector and adjusts accordingly. Final and primary energy are reduced further (from an already optimised and price responsive system). This finding relies on the response of consumers to prices and their willingness to pay upfront costs for energy conservation, both of which are problematic to predict over such long time scales. A range of alternate technology options include a massive growth in nuclear and wind capacity, with associated issues in public acceptance and electric grid stability. Finally esoteric options are chosen including liquid hydrogen imports, which exist in the model as a mitigation option but whose costs and practicalities are (at best) estimates derived from similar technologies and infrastructures. If one removed hydrogen imports (C90-LFBH), then the model switches to other highly uncertain options (advanced wave, solar PV, additional wind sites and additional bio and waste CHP; table 6). These scenarios, and their capacity to fail reinforces the danger in relying on an optimal deterministic scenario that is reliant on embryonic energy supply options or fundamental changes in the use of energy services.

	REF	C90	C90-LF	C90-LFB	C90-LFBH
Renewable electricity	216	393	347	672	911
Biomass and waste	195	1,660	1,645	735	735
Natural Gas	1,853	499	738	442	442
Oil	1,029	558	562	441	441
Refined oil	238	238	238	190	190
Coal	4,379	2,603	2,537	91	477
Nuclear electricity	184	2,807	2,737	4,517	4,517
Imported electricity	8	45	44	96	97
Hydrogen	-	-	-	382	-
Total	**8,101**	**8,803**	**8,848**	**7,566**	**7,810**

Table 4: Primary energy in 2050 (PJ)

	REF	C90	C90-LF	C90-LFB	C90-LFBH
Upstream	6.3	2.8	3.1	2.3	2.3
Agriculture	3.4	2.5	2.5	2.5	2.5
Electricity	326.4	- 26.2	- 28.8	- 10.6	- 9.9
Hydrogen	34.6	0.2	2.0	0	0
Industry	83.0	23.6	23.8	21.1	21.1
Residential	44.2	1.6	1.6	1.2	1.2
Services	20.6	1.4	1.4	1.2	1.2
Transport	33.1	18.1	18.3	12.8	12.8
Other Emissions	40.9	35.4	35.4	28.7	28.0
Total	**592.5**	**59.3**	**59.3**	**59.3**	**59.3**

Table 5: Sectoral CO_2 emissions in 2050 ($MtCO_2$)

	REF	C90	C90-LF	C90-LFB	C90-LFBH
Coal	1,198.1	0.0	0.0	0.0	0.0
Cofiring	0.0	0.0	0.0	0.0	0.0
Cofiring CCS	0.0	1,317.7	1,284.1	43.7	239.7
Coal CCS	0.0	0.0	0.0	0.0	0.0
Gas	13.4	0.0	0.0	0.0	0.0
Gas CCS	0.0	0.0	0.4	0.0	0.0
Biomass CCS	0.0	128.6	162.2	114.2	81.4
Nuclear	58.8	898.3	876.0	1,445.3	1,445.3
Oil	0.0	0.0	0.0	0.0	0.0
Hydro	14.8	31.2	31.2	40.6	40.6
Wind	137.5	239.8	194.5	510.0	554.5
Bio and waste (CHP)	210.8	136.0	120.7	128.2	168.0
Imports	7.8	45.3	44.2	96.4	97.1
Marine	63.7	121.7	121.7	121.7	238.2
Solar PV	0.0	0.0	0.0	0.0	77.7
Storage	0.0	0.0	0.0	4.6	4.6
Total	**1,705**	**2,919**	**2,835**	**2,505**	**2,947**
Share of renewable	25%	23%	22%	37%	39%

Table 6: Electricity generation in 2050 (PJ)

In terms of costs, the most restrictive scenarios (C90-LFB, C90-LFBH) essentially fail, and would not solve without the existence of a placeholder backstop technology at the very high price of £5000/tCO_2 (Table 7). This suggest that the role of imported sustainable biomass for the UK is critical if it is to meet stringent CO_2 targets. Without access to this energy resource, the UK requires technology, price or behavioural options that are currently not in this model formulation, for example access to emission credit purchases or a step change in energy service demands.

Some scenario assumptions can benefit the UK, such as lowered global fossil fuel prices (due to declining global demand) that in the medium term at least outweigh the welfare costs of decarbonisation (Figure 4). However this effect is short-lived and by 2050 UK welfare losses range from £23.8 billion to £58.7 billion. Although these annual amounts should be taken in context of an overall UK economy that should be three times larger than its current size (to around £3 trillion), this is still a very significant cost and could cause this scenario to fail due to societal and business opposition.

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
REF	0	0	0	0	0	0	0	0	0	0	0
C90	0	0	0	48	38	105	103	130	180	248	288
C90-LF	0	0	0	48	41	112	146	168	219	286	304
C90-LFB	0	0	0	51	39	112	153	195	302	519	5000
C90-LFBH	0	0	0	50	40	109	149	193	300	579	5000

Table 7: Marginal CO_2 price (£/tCO_2)

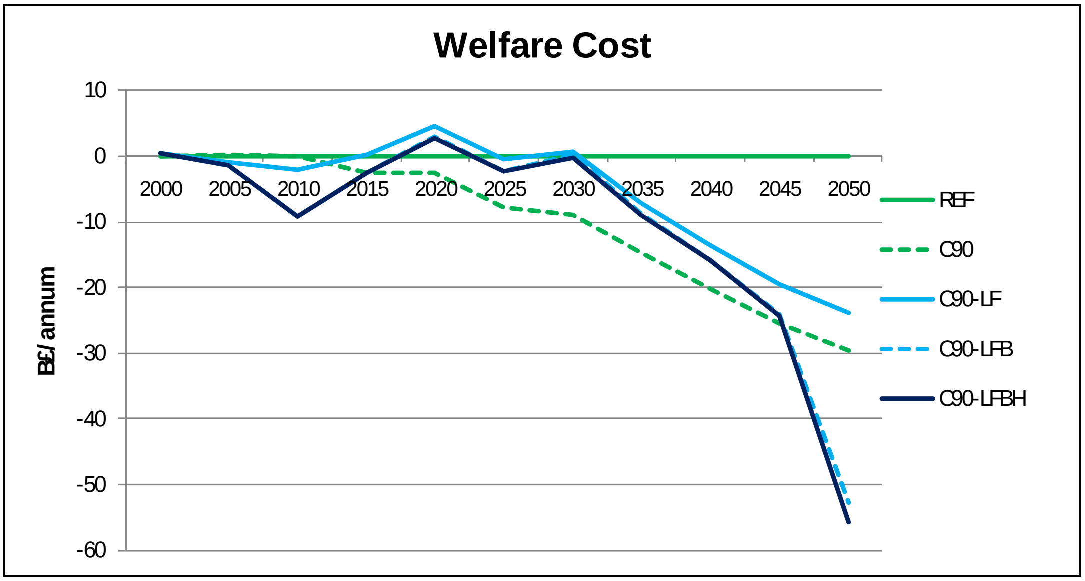

Figure 4: Annual welfare costs (£ billion)

5. CONCLUSIONS AND ONGING WORK

This exploratory analysis on the potential failure to meet long-term UK CO_2 targets highlights the dichotomy between the UK policy priority in reducing energy-related CO_2 emissions, and the concerns over the feasibility, costs and achievability in meeting this unprecedented change in energy production and use. Despite this potential contradiction, there are very few energy-economic or scenario studies of deep long term emission reductions where the target is not met.

By focusing on common mode failures and modelling the long-term impacts, it is relatively easy to trigger the failure criteria: that there is no viable solution, that the solution is deemed too expensive, or that the solution is based on one or more embryonic supply options or fundamental changes in energy service demands. In the limited number of scenarios discussed here, key uncertainties have included biomass CCS energy vectors. Further restrictions on the model solution results in a dependence on multiple uncertain energy options, including deep demand reductions that query the ability to retain energy services (e.g. home heating levels), an expanded power sector dominated by nuclear and wind, the cost-effective use of imported hydrogen in transport modes, and the maturity of advanced wave technologies. The availability of sustainable biomass imports is a key element to meet stringent CO_2 reduction targets. Even with a portfolio of these – and other esoteric options – further constrained scenarios either solve at prohibitively high costs or fail to solve at all.

Ongoing work in this area of failure to meet carbon targets will explore a wider range of interrelated common mode failures. Further efforts will develop better criteria for the definition of failure. Finally a stochastic programming variant of the UK MARKAL model will be used to relax the assumption of perfect foresight and hence further investigate intertemporal uncertainties. This will generate further insights into the causes and implications of failure to meet long-term CO_2 reduction targets and hence aid in the development of iterative policy making.

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