Not locked-in? The overlooked impact of new gas-fired generation investment on long-term decarbonisation - A case study of lock-in to new CCGT in the UK

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Introduction

Do investment decisions taken now impact on long-term policy goals? Gas-fired power generation is often seen as the 'medium-term' solution to power sector decarbonisation (Helm, 2011a) and natural gas has been described as a 'transition fuel' in the power sector (Hoggett et al., 2011). It is argued that gas-fired generation investment in the short-term is aligned to longer-term decarbonisation efforts (Poyry, 2010). For this to truly be the case, gas-fired generation investments need to be free of any inertia that would hinder power sector decarbonisation at a future point in time. Before embarking on such investments, it makes sense to consider how much inertia may be created by the construction of new gas-fired generation capacity and what this may imply for future decarbonisation trajectories.

The UK is an excellent place to study this topic. There is an expectation that natural gas generation will increase as a proportion of electricity produced in the coming years across the industrialised world. However, Britain is set to close a substantial (and unusually large) number of older coal and nuclear power stations in the coming decade, with gas expected to fill much of the 'gap' (Gross et al, 2008). Further, through enacting a series of carbon budgets the UK government appears to show ambition in decarbonisation beyond that of other large industrial economies. These budgets include the implication that the power sector needs to be largely decarbonised by 2030 (CCC, 2010). Taken in the context of legally-binding 2050 targets of an 80% reduction in greenhouse gas emissions on 1990 levels, decarbonisation can be seen as a primary long-term goal of policy-makers. This is the perspective taken in this paper.

Studying the UK power sector therefore represents an opportunity to understand if short term investment in gas-fired generation could endanger long-term decarbonisation objectives. While focused on the UK, the discussion presented in this paper is relevant for policy-makers in all countries with ambitions to reduce emissions whilst simultaneously investing in long-life carbon-emitting power assets.

CCGT and lock-in

Gas-fired Combined Cycle Gas Turbine (CCGT) capacity has been the 'default' generation technology choice for investors in the UK generation market since the early 1990s. Reasons include relatively low capital cost, operational flexibility, high efficiency and the expectation that gas and electricity prices are linked (gas is a 'price maker'), which creates an inherent gas price 'hedge' for CCGT operators (Gross, et al 2010).This is likely to continue for the coming decade as a the need for capacity to ensure security of supply (DECC,2011) is coupled with lower expectations on gas prices (CCC, 2010). In particular, the mandatory closure of more-polluting coal and oil-fired plant under the EU Large Combustion Plant Directive in 2016 is expected to create a need for new capacity in the second half of this decade that gas-fired generation is likely to meet (Becker, 2010, Chignell, 2011).

Gas-fired CCGT capacity, where replacing older coal-fired plant in the UK, would reduce power system emissions intensity. However, the carbon emissions of gas CCGT capacity (350-400 grams per kWh) can be contrasted with an indicative target of 50 grams of CO_2 per kWh of electricity produced by 2030 (CCC, 2010). Investment in such capacity would have implications for long-term decarbonisation objectives if an inertia exists that makes it more difficult to stop generating from these assets once they are in place.

The prevalent opinion from a series of interviews conducted as part of a research project undertaken at Imperial College during 2011 was that no lock-in exists to CCGT generation once any capital commitment associated with the plant is paid off (Chignell, 2011). This paper posits the contrasting view that there is in fact additional inertia associated with investment and this inertia may hinder future attempts at decarbonisation of the power sector in the UK. This inertia is framed as 'investment lock-in' for the purposes of this paper. Use of the 'lock-in' term is an attempt to recognise this form of inertia within a holistic framework which captures the different sources of inertia in relation to technological change (see also Unruh, 2000, David, 1985 and Foxon, 2002). This version of 'lock-in' is applied to gas-fired CCGT investment in the UK to assess whether such investment will make achievement of long-term decarbonisation more difficult and create additional issues for policy during the 2020s.

Section 2 discusses the orthodox view that capital repayment alone is relevant to the 'lock-in' associated with gas-fired generation investments. This draws upon existing literature and a series of semi-structured interviews conducted as part of the research that informs this paper.

Section 3 considers a definition of 'investment lock-in' unrelated to capital repayment, but instead associated with the sunkness of the invested assets.

Section 4 identifies the relevant investment lock-in effects that might be expected to emerge from significant investment in CCGT capacity and how this effect may interact with other lock-in effects.

Section 5 concludes by discussing the implications for UK energy policy of investment lock-in to CCGT, and identifies that the effect is rather more significant than policymakers appear to recognise.

Section 2 – The 'orthodox' view of gas-fired generation investments

When questioned on the idea of an 'investment lock-in' in the context of CCGT investment, many of the experts consulted by the authors used the low capital intensity of such plant to argue that any investment lock-in to CCGT would not be significant (Chignell, 2011). One of the messages from the semi-structured interview process used to elicit views in the preceding research was that capital costs were the determining factor in deciding the level of lock-in. Many respondents argued that the characteristics of CCGT and the speed at which capital could be paid off would mean that the lock-in from investing in CCGT in the next decade would not be a significant barrier to 2030 decarbonisation goals in the UK. This argument runs broadly as follows:

Whilst representing a significant potential outlay, the capital costs of CCGT investment are lower than most other forms of generation both on an absolute basis and as a proportion of total levelised costs, as can be seen in Table 1 below.

Table 1 - Capital intensity of various power generation sources applicable in the UK

Generation source	Levelised capital costs (£/MWh)	Total levelised costs (£/MWh)	Levelised capital cost (percentage of total)
Gas CCGT	9.6	80.4	11.9%
ASC coal	24.9	104.4	23.9%
ASC coal CCS*	54.8	124.0	44.2%
Onshore wind	63.2	77.8	81.2%
Offshore wind*	100.1	136.8	73.2%
Nuclear PWR*	54.5	76.1	71.6%

*Source: (Mott MacDonald, 2010); All figures produced using 7.5% discount rate at 2010 prices. *first-of-a-kind costs.*

In a project-financing model of generation investment - where capital financing obligations are tied to individual plant - financing obligations are paid off within a given period of time provided expected revenues are realised. These revenues are generally determined by market prices for output and plant load factor. Interview respondents indicated that this period of time could be expected to be between 10 and 20 years.

Firms investing in CCGT would expect, whilst capital is being repaid, that the plant would operate at a load factor appropriate to meet these repayments. Revenue needs to be maximised so capital charges can be serviced. Historically, for new CCGT this has also tended to mean maximised utilisation, or 'baseload' operation (Peña-Torres & Pearson, 2000). However, the argument is that after capital is repaid, the requirement from the plant to generate a certain level of revenue and therefore pursue a particular operational regime is greatly reduced. After the capital repayment period, it is argued, there is therefore little or no lock-in or inertia intrinsic to the investment that would affect a movement away from such generation, whether through closure, mothballing or operation at very low load factors (Chignell, 2011).

This model, where capital repayment matters to the 'lock-in', is a simplification that relies upon the idea of capital commitments being tied to the individual plant. This could be the case in a project financing structure or for a single merchant generator, where the project or firm would suffer losses and potentially bankruptcy should a particular CCGT investment not deliver the revenues (hence load factor and power prices) anticipated. In the period to 2020 a significant portion of new investment in CCGT is expected to come from vertically integrated utilities (National Grid, 2011), and capital utilised in investment would not be tied to individual plants quite so directly (the utility could maximise overall revenue and profitability by optimising the use of its *portfolio* of plants not individual power stations). Nevertheless, in aggregate it is reasonable to expect investment and operation to approximate to the merchant model – high utilisation during the earlier years of a plant, during which capital is paid down, then greater flexibility over operation and indeed whether plant is retained or retired.

In policy terms, the 'lock-in' of this 'capital repayment' form seems reassuringly short lived. Creating the lock-in is the principle that effective 'stranding' of CCGT generation in the period where capital is still being repaid could lead to a forceful case by asset owners for recompense. This capital cost 'lock-in' effect would make it more difficult for policy to move against CCGT in the period of capital repayment. However, once the capital is paid down, there appears to be little impediment to plant closure or much reduced utilisation.

The fundamental implication of the capital cost lock-in argument appears to be that *if ex-ante capital costs are paid down (and therefore the capital cost lock-in is no longer there), then the owning firm would be willing to surrender the remaining value in the plant with little or no compensation*. Having identified this implication, it is worth examining whether this capital cost lock-in argument is realistic.

Section 3 – Redefining investment lock-in

The notion that investment is only 'locked in' until capital charges are paid down is superficially attractive, but a little further thought suggests that taken to its logical conclusion it is also a rather strange notion. Assuming that an asset is in good physical condition, functioning and delivering profit then why would an economically rational agent shut it down? The *value* of the asset to its owner clearly transcends the need to service debt or satisfy investors. The presence or absence of creditors for the asset clearly has *some* bearing, but is far from the only factor relevant to the decision of how to operate, or whether to close a power station. This section draws upon the economic literature around options and sunk costs in an attempt to find a more satisfactory formulation of 'investment lock-in'.

The idea of a 'lock-in' related to investment has not received a great deal of academic attention but within the past 30 years there have been concerted attempts within the economic literature to capture the idea that capital expenditure represents some kind of commitment (Bertola, 1998, Bernanke, 1983, Dixit & Pindyck, 1994, Göcke, 2002).

The expressions of this commitment most applicable to technological change relate to option values. Whereas option theory has been primarily used to explain why investment decisions do not respond simultaneously to market conditions, the same theory can be applied to *disinvestment* or abandonment of a project. As identified by Dixit, when there is uncertainty about future economic conditions, when the investment entails some sunk cost, and when the option to abandon or disinvest does not disappear if not immediately exercised, then delaying the decision to abandon the investment will have a positive value (Dixit, 1992). Indeed it is perfectly feasible to envisage conditions when companies are prepared to *pay* to retain plant in anticipation of changing conditions, even if current profitability is limited. Plant can be mothballed in anticipation of changing conditions in future for example (Roques et al., 2006).

When the option value associated with the future is 'large', for example when there is a high level of sunk cost or when the uncertainty surrounding the future economic state is considerable (O'Brien & Folta, 2009), then this option to delay the abandonment decision and continue operating the plant can be interpreted as contributing to the inertia related to the current technological system. This phenomenon is described as sunk cost hysteresis (Dixit, 1992). Returns associated with the investment may have reduced substantially from the level at which investment was induced, but due to the presence of sunk costs, this reduction is not sufficient to justify abandonment by the firm of the project (Dixit, 1992, O'Brien & Folta, 2009). In the power sector, the impact of option values has been empirically noted in relation to the continuing operation of unprofitable nuclear plant (McAfee et al., 2007).

Beyond the micro-effects of option values, the hysteretic effects of such 'investment lock-in' may also be aggregated to the industry level, particularly where the number of firms in an industry is limited, as is often the case in an industry with high exogenous sunk costs and homogenous products (Sutton, 1991), and clearly is the case in the UK power sector. This impacts on the system-wide utilisation of CCGT plants, since price formation and plant utilisation in the electricity industry is not independent of plant mix (Gross et al, 2010). The existing set of assets will impact market prices for the duration of asset lifetimes and may further the lock-in to existing technologies. This represents a 'network and co-ordination effect', identified as contributing to lock-in (Arthur, 1989). Put another way, having a lot of CCGT on the system tends to make the system, in this case the market, favour investment in and utilisation of CCGT.

The permanence of the lock-in to this particular capital stock will depend upon the level of irreversibility of the investment, such as the industry specificity of the plant, or the level of adjustment costs. In the power sector, with highly-specialised plant for generation, and high adjustment costs in the form of CCS-retrofit (UKERC, 2012), the lock-in to a particular capital stock is likely to be strong.

This sunk cost 'hysteresis' (derived from use in physics to describe 'the permanent effects of a temporary stimulus' (Göcke, 2002, Baldwin, 1989)) allows for presence of technologies which exist at the firm or the economy level, despite not being explained by today's economic conditions. In this respect it relates to ideas of path dependence from which the idea of 'lock-in' to technological systems was first developed (David, 1985, Arthur, 1989). Hysteresis therefore refers to a dynamic process, and the impact of hysteretic effects must necessarily be considered by policy-makers when the above criteria hold.

The potential impact of hysteresis has been identified at the micro and macro levels. At the firm level, investment abandonment decisions will not be taken as immediately as a static economic analysis might suggest, as the firm will take into account the possibility of future returns from such an investment in different economic conditions (Dixit, 1992). Aggregating this phenomenon to the economy-wide or industry level allows for the presence of an existing capital stock to create an economic hysteresis, based on the technical lifetime of industry-specific assets, irrespective of the capital repayments made on those assets (Arthur, 1989, Dixit & Pindyck, 1994). .

Overall it appears that the 'sunkness' of investments - driven by their irreversibility, presence of network or co-ordination effects, technical lifetime and the size of the disinvestment option value - provides a far better indicator of 'investment lock in' than capital repayment alone. We term this 'hysteretic investment lock in'. The next section considers the implications of this version of 'lock in' for new build CCGT in the UK.

Section 4 – Lock-in related to new CCGT build

Investment lock-in

Whilst almost every investment involves some sunk cost (Dixit, 1992), it is worth understanding the nature of CCGT investments to determine the level of 'sunkness' involved. The majority of a typical CCGT investment (Mott Macdonald, 2010) can be viewed as intrinsically 'sunk', with significant cost irrevocably committed as part of the project (Wang, 2001). It could be argued that the CCGT plant is not a sunk investment for the firm due to the potential for selling the plant on to another generation investor. The possibility of selling the plant does not however affect the irreversible commitment in building a CCGT plant. In a transparent market, the value of the investment is likely to be seen similarly by all market participants (Dixit & Pindyck, 1994). Any loss associated with the sunk investment will therefore have already have crystallised for the firm. Further, intra-market trading of CCGT plants does not affect the economy-level utilisation of or emissions from such plants.

This sunk investment contributes to creating 'hysteretic investment lock-in' as identified in Section 3. At a firm level, plant operators will choose to generate wherever the price received for such generation exceeds the marginal costs of such generation. They will also value the option of being able to profitably generate in the future. In other words, as long as there is some expectation that future returns (closely linked to the discounted forward spark spread) from such a plant may be positive, plant owners may make the decision to stay operational (Bunn, 05/08/2011).

The question also arises as to how investment lock in will impact on *utilisation* of assets in the power sector. Hysteretic investment lock-in implies that CCGT investments are not merely retained, but retained and *widely used* to the extent that power sector decarbonisation is seriously undermined. As noted above, the continued operation of a fleet of CCGT investments willing to generate based on their marginal costs is likely to impact on prices within the electricity market, in turn a source of lock-in to this technological system. By affecting market prices, particularly in setting prices and sustaining a degree of price volatility linked to gas prices (Gross et al, 2010), a larger existing stock of CCGT assets may slow the adoption of alternative technologies, particularly those with low marginal costs (Ibid).

In policy terms, such effects would manifest themselves in the requirement that the incentives needed to retire or radically decrease the utilisation of CCGT plant on the system would have to be stronger than might be expected in the absence of sunk cost hysteresis, and also be expected to hold in the long-term. If these conditions are not met, the realised load factors of a CCGT fleet in a power sector attempting to decarbonise may prove higher and more resilient than expected due to hysteretic investment lock-in.

Related effects

Investment lock-in as described above has the potential to interact with other lock-in effects to reinforce the inertia created to a particular technological system. For example, in considering the wider UK gas techno-institutional complex (Unruh, 2000) there may be significant effects of investment in new CCGT capacity on gas import, transmission and storage infrastructure. Whilst estimating the magnitude of such effects is beyond the immediate scope of this paper, it is important to note that just as investment in CCGT brings with it sources of lock in to CCGT, so investment in gas infrastructure brings with it a similar set of technological, institutional and financial path dependencies.

Investment may help to entrench existing regulatory structures, even when these may not be best suited for a decarbonised power sector (Helm, 2011b). There is also the potential for new CCGT investment to lessen the requirement to find flexibility measures on the demand side of the electricity system, because of the capability of CCGT plant to provide much or all of the required flexibility. This could create a positive feedback mechanism whereby the future generation fleet is expected to continue to be flexible, thereby enhancing the lock-in to a CCGT-dominated system.

Factors influencing the strength of the lock-in

Investment lock-in and related lock-in effects are driven by the long technical lifetime of CCGT assets and the specific features of a CCGT plant. Therefore to better understand the investment lock-in arising from sunk cost hysteresis, it is necessary to discuss the technical lifetime of a new CCGT plant.

The technical lifetime of CCGT plant built today is likely to be approximately 35 years (Mott Macdonald, 2010), however there are number of technical and economic factors that will determine the actual lifetime of the plant (and subsequent investment lock-in). The expected degradation of the plant and its components is likely to affect the achievable efficiency and availability of the plant as it ages, and hence effect the economic decision of plant owners to keep it operating (PB Power, 2009a). One response is retrofit and repowering, which could extend the lifetime of a CCGT plant for approximately 15 years at around 50% of the cost of a new plant (PB Power, 2009b). Neglecting repowering, estimates of lifetime degradation suggest limited impact on the economic decision to close (Mott Macdonald, 2010), and the impact on efficiency will depend upon historical operational and design factors (Kurz, 2001).

Age-related impacts and technological improvements in newer plants coming online may reduce the utilisation of a plant as it ages and facilitate a movement down the 'merit order' (White, 2012, Brown & Edwards, 1961). It could be argued that this 'natural reduction' in load factors of CCGT plants aligns, at least partially, with the load factor reduction implied by decarbonisation objectives. The speed of decarbonisation required by the 2030 target is however likely to be beyond that caused merely by 'natural reduction' in load factors of CCGT plant from replacement plant coming online (Chignell, 2011).

There is a clear historical precedent for both coal and gas-fired plants to continue far beyond their expected technical lives at commissioning (PB Power, 2009), in contrast to the early stranding of CCGT plant potentially required for decarbonisation objectives. This empirical observation hints that the technical lifetime may actually underestimate the continued use of power generation assets and reinforces the idea that the inertia related to such investments will be significant.

One further characteristic of CCGT plants affecting the level of 'lock-in' is the ability of operators to easily mothball such plants. This is likely to strengthen the hysteresis associated with investment as a plant may be shut down for a sustained period of time before the operator chooses to generate when commercial signals improve. This ability (and the subsequent option associated with mothballing) is held to be of significant value to investors in the presence of uncertainty (Roques et al., 2006), and creates the potential for mothballed CCGT capacity to fill any generation capacity gaps that arise in the 2020s.

Summary

The different lock-in effects described above are summarised in table 2 below:

Table 2 – Summary of lock-in effects from new CCGT investment

Investment lock-in related to CCGT	Broader lock-in effects
Micro-level hysteretic effect – Only marginal costs will be relevant to owners of plant already built and they will also value the option of being able to generate during future periods of high prices. These effects combined represent a lock-in for the owner relative to an equivalent new-build plant.	**Flexibility –** in the power sector, new CCGT investment may help lock-in the need for flexibility on the supply-side of the system. **Institutional effects –** significant new gas plant may help entrench regulatory structures that are not aligned with a decarbonised power sector.
Macro-level hysteresis – aggregating the above effect, an existing capital stock of CCGT stations may affect market power prices and disincentivise replacement low-carbon investment for economic reasons alone.	**Impact on the gas infrastructure –** new gas generation assets may strengthen the need for importation and storage facilities, which may in turn make continued gas reliance in other sectors more likely.

Overall, the above analysis suggests that the potential need to strand CCGT capacity to achieve decarbonisation in the 2020s would require either strong market-based signals that are viewed as permanent, or regulation to put a fixed limit the total emissions associated with such plant. Section 5 considers policy implications in more detail.

Section 5 – Conclusions

Implications of lock-in to CCGT

This paper has sought to identify and apply an important form of lock-in, one that appears to be overlooked in the UK energy policy discourse as well as in the literature related to technological change. This 'hysteretic investment lock-in', linked to the idea of sunk cost hysteresis, has the potential to interact with and reinforce other lock-in effects to significantly inhibit technological change. This form of lock-in holds at a micro and macro-economic level in situations where investments are particularly sunk or irreversible and the lifetime of the related assets is long.

At a practical level, such lock-in effects suggest that owners of CCGT plant will not choose to retire such plant early, and that in the absence of policies explicitly designed to make CCGT owners to operate at very low load factors, there are likely to be strong incentives to continue to utilise them. Overcoming this effect is likely to require more aggressive intervention than a static comparison of levelised costs and carbon prices might suggest (CCC, 2010; Mott MacDonald, 2010).

The large amounts of gas-fired generation potentially on the system in the 2020s, and the ability of such plant to be mothballed, will increase the opportunity cost associated with building new low-carbon plant. In effect, rather than low-carbon generation being built to meet demand, it would be built purely to displace mid-life CCGT plant in order to achieve decarbonisation goals. This would involve stranding assets with significant economic value. Whilst policymakers obviously *could* use a range of measures to strand these assets, the lock-in engendered by CCGT investments made in the 2010s will create strong incentives for them *not to do so*. The more directed approach to policymaking brought into being by the government's proposals to reform the power market will provide new levers for government, but won't change the underlying dynamics in play. The key issue is that the greater the lock-in to CCGT, the more robust (and potentially costly) the policy requirements to overcome it become.

Policy responses

Government will therefore need to be careful to limit the volume of investment in new CCGT capacity if long-term decarbonisation objectives are to be achieved. While gas-fired generation has a clear role to play in the generation mix in the period to 2030, over-investment in new capacity in the coming decade, and related investment lock-in, could make 2020s decarbonisation difficult, if not impossible, to achieve.

Policy-makers appear at present to be neglecting or underestimating the hysteretic effects of new investment in plant with asset lives of 30 to 40 years, and it is important to ensure that all alternatives, including life-extensions of ageing 'dirtier' coal or oil plant or repowering of 1990s-build CCGT, are fully considered. These shorter-term investments or delays to decommissioning may provide a much better fit with the power sector decarbonisation 'pathway' to 2030. They buy time, during which the volume of CCGT, or other forms of generation (including open cycle gas turbines, demand response and storage) needed to balance wind power in the 2020s will become clearer.

Assuming a large volume of CCGT is in-place in the 2020s it is important to consider the type of policies likely to be needed to protect decarbonisation goals. The value of command-and-control regulation where technological and institutional constraints are substantial is well documented (Cole, 1999). A well-signalled command and control framework of regulation in relation to all carbon-emitting plant could be an effective means of setting expectations and achieving the decarbonisation of power generation necessary in the 2020s.

The Emissions Performance Standard (EPS), introduced within the Electricity Market Reform (EMR) proposals intends to provide a framework for carbon emissions reduction regulation (DECC, 2011a, DECC, 2011b), but in its proposed form does not provide a signal to CCGT investors that use of such plant will need to be compatible with power sector decarbonisation in future, and may (through grandfathering provisions) actually induce gas-fired generation investment in quantities that make power sector carbon intensity of 50gCO_2 per kWh in 2030 less likely.

A key implication of the lock-in effects described above is that government risks being too complacent about the potential for investments in CCGT, however benign in the short term, to undermine longer term decarbonisation. One response would be to provide a clear, long term regulatory regime prescribing a set time by which carbon emitting plant needs to adapt, close or be have its use constrained. Unfortunately the UK government appears at present to be both underestimating the risk of lock in to CCGT and neglecting the development of the policy framework needed to overcome it.

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