Using the WADE model to investigate the relative costs of Distributed Generation (DG)

Executive Summary

Introduction

1. DTI and Ofgem announced their joint Review of Distributed Generation in July 2006. In order to underpin the work of that Review we have looked to gain a greater understanding of the costs and benefits to the UK of a greater penetration of distributed generation (DG).

2. We have worked with WADE[1] to model the costs and benefits, including the impact on carbon emissions, of meeting the needs for additional electricity generation capacity in the UK over the coming 20 years using distributed, instead of centralised, generation.

3. The WADE model is a spreadsheet-based model which calculates the cost of meeting the need for new generation using a given 'scenario', or mix of generating technologies, specified by the user. The model is typically used to compare the costs of a centralised generation (CG) scenario with the costs of a decentralised, or distributed, generation scenario. The model calculates both the quantity of new capacity of each technology required to meet demand, and the costs of this scenario, using the wide range of input assumptions provided by the model user. The model does not incorporate any form of 'black box' optimisation – it simply calculates the costs of using a specified scenario, given the assumed data inputs.

4. DTI has worked to develop both a DG and a CG 'scenario', and a set of input assumptions for use within the WADE model. Many of the data inputs have been drawn from other modelling work used within the Energy White Paper, and from published sources. However, in some cases the model requires the input of data in formats which are not available.

Modelling Approach

5. The model describes the electricity generation sector, and also attempts to capture the full efficiency benefits associated with combined heat and power (CHP), an important technology within any DG scenario. The user is required to input an 'up-rated' electrical efficiency of the CHP installation to account for the heat benefit offered by the CHP. This is not a robust approach to modelling CHP, and arises because heat is not explicitly treated within the model.

6. In addition, the model requires the user to define the transmission and distribution (T&D) costs associated with the build and operation of new

[1] World Alliance for Decentralized Energy: www.localpower.org/

generating capacity on a cost per kilowatt of capacity added basis. Data cannot be collected on this basis, because the T&D costs associated with new capacity are heavily dependent upon the geographic location in which this capacity is connected to the T&D infrastructure.

7. In these areas where data was not available on the required basis we have taken steps to provide the best available information, given the constraints. This adds uncertainty to the results, but reflects the genuine uncertainties and complexities involved in modelling DG.

8. In undertaking modelling runs we used the previous application of the WADE model to the UK by Greenpeace as a starting point. We worked with WADE to develop a new measure of outputs: net present value (NPV) of the costs to the UK, including carbon emissions, of using a given scenario to meet our needs for new generation capacity. This is in line with the approach taken in all policy evaluation and analysis by government.

Modelling results

9. We found that the conclusions as to the relative cost-effectiveness of a DG scenario are crucially dependent upon both the specific 'scenario' chosen for investigation and the input assumptions used.

10. Under a DG scenario, fuel costs and the associated carbon emissions are reduced. T&D investment costs may also be lower, though further work is required to reach a firm conclusion on this. On the other hand, plant capital costs are lower in a CG scenario. The balance of these factors in alternative scenarios, and under alternative sets of input assumptions, determines the relative costs of these CG and DG scenarios.

11. Applying the Greenpeace scenarios and input assumptions, the DG scenario is cheaper (including a financial valuation of emissions costs) than the CG scenario. If instead the DTI input assumptions are applied to the Greenpeace scenarios, the DG and CG scenarios are very similar in cost.

12. Applying the full DTI assumptions to the DTI scenarios, the CG scenario is cheaper than the DG alternative. This difference in conclusion compared to when the DTI assumptions are applied to the Greenpeace scenario is driven by the more cost-effective mix of plant in the DTI centralised scenario.

Conclusions

13. Given the wide range of uncertainties associated with modelling the costs of DG, large differences in costs between alternative scenarios would be required for us to conclude that these differences were meaningful, or

statistically significant. Hence there is not sufficient evidence in any of these model runs to conclude effectively at this stage that DG or CG offers a cheaper approach for the UK.

14. Furthermore, the limitations of the modelling approach relating to the treatment of heat and transmission and distribution infrastructure costs mean that this model cannot be used to draw robust conclusions about the relative costs of alternative scenarios. Modelling results can provide at best a starting point.

15. On the basis of this work, we do not have the evidence to reach a conclusion as to whether a distributed or centralised approach to meeting future needs for new generation capacity offers a cheaper alternative for the UK. Further work is required to reach such a conclusion, in particular to explicitly model the heat sector.

16. In a well-functioning market the cheapest technology will prevail, as long as the right frameworks are in place. The market will therefore invest in DG technologies where they prove to be cost-effective, as long as there are no barriers to take up. As part of the DG Review, DTI and Ofgem gathered evidence of such barriers and are bringing forward measures to address them in Chapter 3 of the Energy White Paper.

1. Background

17. In the light of the growing belief that a more decentralised approach to meeting the UK's energy needs may offer benefits relative to the established, centralised system, the Energy Review Report[2] announced the joint DTI/ Ofgem Review of Distributed Generation[3]. The Review considers the barriers and incentives to distributed generation, including combined heat and power at any scale.

18. In order to support this Review we have looked to gain a greater understanding of the costs and benefits, and therefore the relative merits for the UK, of an increased penetration of distributed generation (DG) technologies.

19. Modelling of the costs of an increased penetration of DG is complicated by the fact that DG is not a single, homogenous technology. Instead it incorporates a range of technologies including wind, solar photovoltaic and combined heat and power (CHP) generation at scales ranging from microgeneration in a single home to community projects such as the Woking Borough Council scheme. Equally, in comparing the costs of developing a DG system with the costs associated with a centralised system it is necessary to consider a wide range of aspects including relative transmission and distribution infrastructure costs.

20. There is very little pre-existing work that brings together all of the aspects of the electricity system to allow for a comparison of the total costs, of adopting a DG or centralised (CG) generation system[4]. The only study that we are aware of for the UK was undertaken by the World Alliance for Decentralized Energy, WADE, on behalf of Greenpeace[5]. We have worked with WADE to further our understanding of the costs and benefits of a greater penetration of DG, including the impact on carbon emissions.

21. The WADE model is a model of the electricity generation sector. It does not cover the heat sector, though it does attempt to account for the heat component of combined heat and power (CHP) in order to reflect the full efficiency of CHP. The approach taken to modelling this heat output is not robust and is a limitation of the model.

22. The overall conclusion from this work is that the WADE model is a useful starting point, but due to the limitations in the approach to modelling heat it is not able to give definitive conclusions about the relative costs of DG. Moreover, given the inevitable uncertainties associated with the future costs, technical feasibility and speed of penetration of DG applications, even a more comprehensive model would still only provide an estimate highly dependent on the respective input assumptions. Large differences

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[2] DTI *The Energy Challenge* 2006
[3] DTI/ Ofgem *Review of Distributed Generation* 2007
[4] 'Centralised' capacity is large-scale electricity-only generating capacity, generally connected to the national transmission network.
[5] http://www.greenpeace.org.uk/files/pdfs/migrated/MultimediaFiles/Live/FullReport/7441.pdf

in costs between alternative modelled scenarios would be required in order for a conclusion that the values were different would be required. The work that we have done, and the reasons for this conclusion, is discussed in detail in the paper.

2. Introduction to WADE and the WADE model

23. WADE exists to accelerate the worldwide deployment of decentralised energy systems. The WADE model was designed to compare the costs of meeting the need for new generating capacity over a 20-year period using alternative mixes of new 'centralised' and 'decentralised', or distributed, generating capacity, and has been applied to a range of countries and regions throughout the world.

24. The model is a series of spreadsheets, into which the user inputs their own assumptions and cost data. These data cover a wide range of aspects of costs and performance, from the capital costs of individual plants to assumptions about the extent of losses in transmission and distribution from different types of plant and the fuel efficiencies, and therefore carbon emissions, of alternative plant types. There is no 'black box' optimisation used by the model to determine the optimal capacity mix across technologies; instead, the model provides a framework within which to examine the cost of alternative 'scenarios' put forward by the user.

25. Given the scenario and input assumptions specified by the user, the model calculates the quantity of each type of capacity built, and the associated costs and carbon emissions. Detailed discussion of how the model works is provided in annex 1.

Key Inputs

26. The WADE model is an input-output model, rather than an optimisation model - it simply takes the input data provided by the user and calculates total cost accordingly. The values of the inputs are therefore crucial in determining the relative costs of alternative scenarios. The following aspects are likely to be the most critical in determining the costs of alternative scenarios:

- Demand growth – the higher the assumed demand growth over time, the greater the quantity of new generation, and so the greater the quantity of capacity required to meet this demand.

- Scenario – the mix of technologies specified to meet any requirement for new generation, and therefore new capacity, drives the total costs of the scenario. This reflects the cost and emissions differences between alternative technologies.

- T&D infrastructure costs – the need to maintain and upgrade transmission and distribution (T&D) networks is a key aspect of the costs incurred in any scenario. In 2006, transmission costs accounted for 4% and distribution costs for 17% of the average annual electricity bill[6].

[6] Source: Ofgem.

- Efficiencies – these determine the amount of fuel that is required to generate electricity using a given technology, as well as the resulting carbon emissions (given the emissions factors associated with burning the relevant fuel).

- Load factors[7] – the WADE model calculates total quantities of generation to be delivered by each technology to meet electricity demand. The translation of this total generation into a capacity figure depends upon the load factor that the plant is assumed to achieve: a higher load factor means fewer plants need to be built, and hence a lower cost.

- T&D losses – the higher the losses that electrical output from a given plant is assumed to incur in transmission and distribution to the customer, the greater the total quantity of plant that must be built to meet a given level of demand.

[7] The model does not explicitly model 'despatch' within the generation system. Instead it accounts for the difference between baseload and peaking plant by applying 'load factors' to each individual generation technology reflecting the average use of the technology over the year.

3. DTI and the WADE model

27. This section discusses the approach taken by the DTI in working with the WADE model. Issues such as the source of input assumptions, the approach to developing scenarios to model and the approaches taken to minimise the impact of the limitations highlighted above are set out in detail below, under the following headings:

- Scenario building
- Input assumptions
  - i) Modelling transmission and distribution (T&D) costs
  - ii) Accounting for the heat output of CHP
- Presentation of results

Box 1: LIMITATIONS AND DIFFICULTIES IN THE MODELLING WORK

As with any model, the WADE model is necessarily an abstraction of reality and has limitations. In order to work effectively with the model it is essential to understand these limitations, so as to deliver the best possible outputs from the model, and to ensure that appropriate caveats and robust interpretation can be applied to the results.

There are two key limitations associated with the model:

- The model has a **simplistic treatment of CHP** – but in the DG scenarios modelled this accounts for over 50% of new capacity, so the treatment of CHP is crucial to the outcomes for the DG scenario. The model does not explicitly take account of heat, but instead uses a 'rule of thumb' approach to capture the benefits of the greater fuel efficiencies offered by CHP.
- The modelling work incorporates a single 'transmission and distribution' cost figure reflecting the T&D infrastructure costs associated with additional build of both CG and DG capacity. It is not feasible to generate such a figure except for a single, specified scenario, because these costs depend upon the location of any new capacity.

Other issues also affect our ability to draw robust conclusions from the modelling work:

- **Plant lifetimes** are not explicitly taken into account within the WADE model and in order to reflect these it is necessary to change the financing period applied to investments in new plants. The financing period will typically be shorter than the lifetime of a plant, so this will make any scenario involving larger volumes of long-lived plant appear more expensive.
- It is impossible to predict what the spread of generating capacity would be if there were to be no new build of centralised generation capacity. It is only feasible to compare alternative **'what if'** views of what a DG world could look like, and so outputs from the model cannot be seen as definitive predictions of the cost of a system in which all new capacity built were DG.
- The model is input-output based, so **outputs are only as good as the inputs**. Yet there is great uncertainty about the values of many of the inputs such as fuel prices and technology costs for the emerging technologies. This uncertainty is particularly important looking 20 years into the future.
- Notwithstanding the significant cost and technology uncertainties over time, **20 years into the future is a very short period of time in the context of electricity infrastructure** – especially as for the first 4 years of this 20 year period plant is pre-committed and so should be identical in any 'scenario'. The WADE model predicts that only around half of generation capacity will be replaced over the 20 year period, and the costs of maintaining the existing networks will not reduce significantly over this period of time even if only DG capacity were to be built from tomorrow.

Scenario building

28. The scenarios chosen for investigation are crucial in determining the outputs of the WADE model. Because each scenario involves different shares of alternative technologies, all of which have different associated costs, final costs depend heavily upon the scenario used.

29. In each scenario the user specifies the proportion of generation to be delivered from each technology. New capacity is built by the model in order to deliver a generation mix in accordance with the specified ratio. For example, a CG scenario may incorporate 50% CCGT (gas) generation, 30% coal and 20% large-scale renewables[8].

30. We developed two scenarios for comparison: a DG scenario, and a counterfactual CG scenario. The CG scenario is much simpler to build on the basis of existing DTI modelling work and is discussed first.

CG scenario

31. Ongoing DTI modelling work projects the capacity mix going forward. This UEP[9] data forms the basis of our CG scenario. The UEP projections to 2020 show the vast majority of capacity until the end of its modelling period being CG. These projections were extrapolated out to 2025 for this project. There was a small shortfall between new capacity required by the model to meet demand and projected build of new CG plant within the UEP, because the UK 'business as usual' scenario projected by the UEP includes some DG capacity. For the purposes of the WADE modelling work we simplified this scenario to be 100% CG by assuming that any DG plant built under the UEP projections was instead replaced by additional CCGT plant[10].

DG scenario

32. Given the current policy mix and relative costs of producing electricity from alternative technologies, the majority of projected capacity coming forward is CG. This leaves us with little guide from our existing modelling work as to the likely composition of new capacity if only DG technologies were to be taken forward. Hence, it is necessary to take a 'what if' approach, considering the cost of a scenario composed of an indicative mix of DG technologies.

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[8] The scenario contains separate information for each of the 20 years, so the user has the option to change the split of new generation provided by alternative technologies over time.
[9] *Updated Energy and CO_2 Emissions Projections*, May 2007; www.dti.gov.uk/energy/whitepaper
[10] This is consistent with the fuel price and cost assumptions in this and other Energy White Paper modelling. The economics and relative ease of building CCGTs tend to make them the technology of choice for incremental new build.

33. In building the DG scenario, we took two aspects as fixed:
    - Pre-committed plant: Any plant projected to become operational before the end of 2009 is thought to be under construction and is therefore assumed to be pre-committed. Hence the DG scenario is treated as identical to the CG scenario until the end of 2009. This limits the extent of any variation in outputs across the different scenarios, but reflects realities in the electricity generation market.

    - Large-scale renewables: In order to capture the anticipated build of large-scale, centralised renewables, 25% of any new generation requirement within the DG scenario is met by centralised generation from 2010 onwards[11]. This reflects government's ongoing commitment to the Renewables Obligation (RO) and the projected impact that the RO have on the construction of new renewables capacity. Where projected uptake of centralised renewables was insufficient to meet 25% of required plant build in a given year any remaining plant was assumed to be CCGT, as the technology most likely to meet the need for incremental new-build.

34. Taking into account these two fixed parameters, the remaining 75% of the DG scenario was constructed. Given the difficulties in determining a 'reasonable' mix of technologies within such a scenario we used the Greenpeace DE scenario as the starting point. However, we made some changes to the classification of CHP within the scenario, retaining only the total percentage of new generation comprised of CHP of alternative types. This enabled us to explicitly recognise the different costs and efficiencies associated with CHP of different types, including district heating and large-scale industrial CHP. We used data[12] on the potential for take-up of CHP of alternative sizes and fuels to generate a split of CHP by fuel and type of scheme.

35. In particular, for the purposes of developing the scenario we concluded:
    - that additional coal-fired CHP was unlikely to be built, given its cost relative to gas-fired CHP (including the costs of developing infrastructure for the delivery of the coal to the new plant) and higher emissions relative to alternatives;

    - that gas-fired CHP should be considered as three separate size bands: 'major power producers' (>50 MWe), 'industrial' (3-50 MWe) and 'district heating' (<3 MWe);

    - that these three types of CHP are declining in both size and cost-effectiveness. We assumed that the most cost-effective opportunities would be taken up first, with more expensive categories of CHP only

[11] A share of 25% of new build is sufficient to ensure that projected new build of renewables, as detailed in UEP, can be captured. A similar approach was taken in the main 'DE and renewables' scenario considered in the Greenpeace study, where 25% of all new-build was assumed to be large-scale renewables.
[12] FES studies on the potential for CHP in the UK.

taken up once the technical potential for cheaper options, as identified by the available evidence, was exhausted;

- that biomass CHP would take up some of the opportunities for industrial CHP, displacing gas.

36. The total spread of capacity across DG technologies in the DTI and Greenpeace DG scenarios is given in Table 1[13] (this excludes the centralised components of the scenarios):

Table 1 – The DG scenario

	DTI	Greenpeace
Gas CHP - Major Power Producers	5%	0%
Gas CHP - Industrial	48%	38%
Gas CHP - District Heating	1%	0%
Gas micro-CHP	15%	19%
Coal CHP	0%	6%
Biomass CHP	12%	13%
Hydro - Small	3%	3%
Wind (Local)	9%	9%
Solar (Local)	7%	11%

Input Data

37. In addition to the scenario, which is 'chosen' by the model user for investigation, the user of the WADE model must specify the values to be taken by a broad range of input variables. These values are vital in determining the total costs of any given scenario.

38. The key input information can be split into two broad categories:

- Key assumptions determining the total volume of plant, and quantity of each type of plant, built to satisfy the chosen scenario:
    a. Annual growth in demand for electricity
    b. Year of retirement for existing capacity
    c. Load factors for existing and future plants
    d. Losses incurred in T&D by centralised and distributed generators

- Key assumptions determining the costs, including carbon emissions, associated with this new-build capacity:
    a. Fuel price projections
    b. Plant capital costs

[13] WADE developed a DTI scenario retaining the same total portion of CHP as used by Greenpeace. However, the percentages do not sum exactly.

c. Costs of upgrading the T&D infrastructure as a result of additional capacity of each type being connected
d. ‘Heat rates’, or efficiencies, of plant

Data sources

39. The model uses a huge range of data. Many of these are relatively easy to source (based on DUKES[14], internal modelling such as UEP and financial cost assumptions made in the context of the Energy Review and applied throughout the White Paper modelling work), but others have been more difficult and have required us to make assumptions. These have been best estimates, but clearly add uncertainty to the results. The sources of all data used are listed at annex 5.

40. We used the Greenpeace data inputs as a starting point. In the few areas where it was not possible to specify a justifiable alternative to the pre-existing inputs, these were left unchanged[15].

41. In two areas, T&D infrastructure costs and CHP efficiencies, it was difficult to determine the best data to use in the modelling work. This is because the model uses input data in a format which cannot be observed or calculated – it assumes the input of data which cannot be robustly generated. These areas are discussed in detail below.

1. Transmission and distribution infrastructure costs

The WADE approach

42. The WADE model requires the user to input the total T&D costs associated with the connection and operation of new generation capacity, on a cost per kW basis. This cost per kW must incorporate the costs of physical connection of the generator to the network, including necessary reinforcement, as well as reflecting any additional investment required in the overall network as a result of this growth in the quantity of electricity being transported on the network.

43. This is a weakness of the model: it is not possible to estimate these costs on this basis. It is crucial to know the location of new plant in order to estimate the costs it imposes on the system – and so a further dimension of uncertainty is introduced which compounds the impact of the uncertainties surrounding the plant mix.

44. In order to take forward meaningful work comparing the total costs arising under alternative scenarios it would be necessary to develop a view as to

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[14] Digest of UK Energy Statistics
[15] Examples include the efficiencies of those CG plants not covered by the Energy Review financial modelling, and the ‘coincident peak’ (the extent to which the periods of peak demand are aligned throughout the country).

where the capacity projected in the specified CG and DG scenarios would be located. In reality, this would have to be done on a 'what if' basis, as we do not have a good understanding of where additional capacity is likely to locate in the future. This would add an additional layer of complexity, assumption and uncertainty to the modelling work, but this simply reflects the genuine uncertainties that must be addressed in order to generate a meaningful outcome.

45. The locational aspects of T&D costs, and the difficulties with using the results of existing scenario work to determine an average T&D cost associated with new capacity, are discussed in Annex 3.

Approach taken in this study

46. In the light of these concerns, we have not been able to generate a figure representing the total T&D costs associated with alternative scenarios. We believe that it is better to consider only those aspects of costs which we can project with some degree of confidence than to use an 'overall' figure which is not robust.

47. However, capturing adequate data for T&D costs is crucial if the WADE model is to deliver a robust comparison of the costs of a DG and a CG scenario.

48. Instead of attempting to model the total T&D costs associated with different scenarios we have focussed on the differential between the costs of a DG and a CG scenario. In order to develop this approach we considered which aspects of transmission and distribution costs were likely to differ under alternative scenarios, to a first approximation. This is represented in Table 2.

Table 2: Components on T&D costs

	Centralised generation		**Distributed generation**	
Costs	Transmission	Distribution	Transmission	Distribution
Connection and reinforcement	√	X	X	√
Demand growth	√	√	X	√
Asset renewal and O&M costs	√	√	√	√

49. Over the coming 20 years, not least because both the DTI and Greenpeace DG scenarios contain a substantial role for centralised renewables, there will continue to be an essential role for the existing transmission and distribution network in delivering electricity to customers. The costs of maintaining these existing networks will be broadly similar under either scenario, and so broadly cancel out across the two scenarios.

50. In estimating the differential between the DG and CG scenarios, we have therefore focussed on two aspects of costs which can be clearly identified and differentiated:

- Connection costs – the costs of undertaking reinforcement of the grid specifically required to attach the new generator to the existing network. In the case where there is sufficient local capacity on the networks to attach additional generators, this cost is simply the cost of physically connecting the generator to the existing infrastructure. In the case, such as offshore wind, where additional investment in the existing infrastructure is required because networks are already operating at capacity, this 'deep connection cost' is also included.

- Demand-growth related costs – we assume that the costs associated with reinforcing the transmission network simply as a result of the annual growth in demand (as opposed to issues related to the specific locations of new generators) apply only in a CG scenario. Under a DG scenario, if the additional capacity is located close to the sources of demand, the general increase in demand for electricity would not drive a need for increased transmission infrastructure, as this additional power would be generated closer to the point of use. We have used estimates of the costs of meeting the costs of generalised demand growth in the CG scenario, but not in the DG scenario[16].

51. This approach only considers the infrastructure costs associated with growth in demand. It does not consider whether increased investment in T&D would be required, even if demand did not increase further, because new capacity did not locate in the same location as retiring capacity. These issues affect both CG and DG. Whilst not explicitly modelling such costs will understate the transmission costs associated with new centralised generation capacity, it will also underestimate the distribution costs associated which much increased penetration of DG. This is because, beyond a certain penetration of DG on local networks, 'active management' of the two-way flows of electricity is required. It is not clear whether on balance the assumption that these aspects of costs cancel out favours DG or CG.

52. The development of a cost differential between the T&D costs imposed by new generators of different types permits a comparison between alternative scenarios using full DTI input assumptions. However, because a differential rather than a total cost figure has been used, it is not possible to draw comparisons with scenarios costed using alternative input assumptions with an absolute figure for T&D costs.

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[16] An error in the modelling work has included the demand-related costs in the DG scenario also. As a result, the T&D costs in the DG scenario are 8% higher than they should be. This difference is not crucial to any results.

2. Efficiencies of gas-fired CHP

53. CHP has a crucial role to play in the DG scenario investigated in this work (which is heavily based on the DG scenario used in the Greenpeace study). Given this importance, any issues relating to the data applied to, and the modelling of, CHP will have a significant impact on the overall output results. However the WADE model only explicitly models the generation sector. A simplified approach is taken to capture the heat aspects of CHP.

54. Efficiency is crucial to determining the relative merits of a scenario incorporating heavy use of CHP. The true fuel efficiency of a CHP installation is dependent upon whether the heat is all effectively used – if for example some of the plant's heat is wasted at the weekend because the offices which it heats and cools are not in use, the real fuel efficiency achieved by the plant is reduced. We have used the *technical efficiency* of plants of different sizes, so efficiency figures will be an upper bound of potential performance.

55. The WADE model overall compares the fuel and other costs associated with generating a given quantity of electricity using alternative generating technologies. In the case of CHP, the inputs and costs do not only generate this electricity, but also a heat output which can be productively used.

56. To capture the efficiency benefits of CHP relative to the appropriate counterfactual, it is necessary to compare the cogeneration of heat and electricity with the alternative of separate generation of electricity in centralised power stations and heat using a gas boiler. This is not possible within the WADE model, which only models the electricity generation sector and does not explicitly model heat. But unless the heat output of the CHP installation is captured, the full efficiency benefit of CHP is not identifiable.

57. To address this issue the WADE model uprates the input electrical efficiency data for the CHP installation to proxy for the heat output that the installation also generates. We do not believe this to be a robust approach, but have up-rated our electrical efficiencies as required in order to be able to use our CHP data within the WADE model.

58. To deliver the input data required we worked with the efficiency savings of different size tranches of CHP provided by FES, which compare the performance of a range of CHP installations to a 58% efficient CCGT. We then up-rated the efficiency of each tranche of CHP by the appropriate factor. For example, where the efficiency of a given size of CHP had been found by FES to be 15.5% higher than the CCGT/ boiler counterfactual, the efficiency of the CHP installation we assumed to be that of CCGT, multiplied by 1.155.

59. This is a substantial simplifying assumption. The efficiency performance of CHP is crucial to determining outputs of the model. This limitation of the modelling approach is added to already substantial uncertainties surrounding the performance of CHP, including the reduction of technical efficiency of a plant where not all heat is effectively captured and used. In the light of these issues it is not feasible to draw strong conclusions based on the outputs of the WADE model.

3. Presentation of results

60. The primary outputs of the WADE model are figures for the 'retail cost' of electricity in year 20 (in the case of our work, 2025), and total (non-discounted) capital investment costs and CO_2 emissions over the twenty-year period resulting from the operation of the new capacity. However, these measures do not provide an effective means of comparing the cost to the UK of meeting the need for additional generating capacity over the coming 20 years using each mix of new generation. The net present value (NPV) of costs and benefits to the UK is the approach used for all policy analysis[17], and we have worked with WADE to develop such an approach for presenting the results of this modelling work. We present all results as an NPV of the costs of the scenario over the full 20 year period, incorporating all capital, fuel, O&M and emissions costs. In line with Green Book approach, all costs are discounted at the 3.5% social discount rate.

61. Emissions are translated into 'costs' using the social cost of carbon. This is a value which looks to incorporate all of the costs to society of additional carbon emissions into the atmosphere. The value of the social cost of carbon, and its increase over time, is standard across all government modelling of carbon costs[18].

62. In this NPV of costs an annuity, or 'capital charge', is included, rather than the total value of capital investment during the 20-year period. This approach is necessary in order to make meaningful comparisons between scenarios. If instead the total capital investment figure were included for each year, the relative NPV of costs of alternative scenarios would be heavily influenced by the plant mix chosen. A plant with higher up-front capital costs would substantially increase the NPV of costs, though may be equally as cost-effective over the course of its operational life as a plant with lower capital costs but a shorter operational life.

63. In addition, if total capital costs were included the overall NPV of costs would be much more sensitive to when additional capacity was built, in particular at the end of the period. A new, large plant built in year 20 would substantially increase the calculated costs of meeting the UK's needs for electricity over the coming 20 years. If alternatively this plant

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[17] http://greenbook.treasury.gov.uk/

[18] http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/greengas-policyevaluation.pdf

wasn't built until year 21, this would be outside the modelling period and would not be captured. But the real costs to the UK over time would be very similar, with only a marginal difference in total costs and benefits to the UK between construction of this plant in one year or the next. The NPV of total costs figures should represent as far as possible the costs to the UK of taking a given approach, and should not be affected heavily by small changes in actual investments.

64. There is a weakness in using such a metric because all plants have been implicitly assumed to have a 20-year plant life[19]. This tends to disadvantage longer-lived plants, as in reality the capital costs of their investment will be spread over a longer period. This means that our modelling work disadvantages those scenarios that have a higher percentage of longer-lived plants.

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[19] This is because all technologies have been assumed to have a 20-year financing period, in line with the Greenpeace input assumption. But there is no separate opportunity to input the life of a plant.

4. The Modelling Work and Results

Reminder of vocabulary in the WADE model:
The scenario is the chosen mix of new build generation capacity across different technologies. For example a CG scenario may incorporate 50% CCGT, 30% coal and 20% large-scale wind.
The assumptions are the values placed on input data: costs, losses, plant load factors etc.

65. The results of the Greenpeace study indicated, on the basis of the standard WADE outputs of 'capital' and 'retail' costs, that there could be potential carbon and cost savings over the coming 20 years from choosing a DG scenario. This Greenpeace study has provided the starting point for our work, as the only pre-existing study of the costs of DG for the UK. In our modelling work we have investigated whether we reach the same conclusion as Greenpeace based on DTI input assumptions, and given the DTI scenario for centralised generation.

66. WADE undertook the following modelling work on our behalf:
    (a) Applied the DTI NPV output metric to the Greenpeace data and scenarios, to ensure that the outputs were comparable between Greenpeace and DTI runs
    (b) Next, retained the Greenpeace scenarios, but applied the DTI input assumptions to determine the impact of the input data and assumed system properties (including losses etc) on the overall results
    (c) Adopted the DTI scenarios, using full DTI input assumptions
    (d) Sensitivities around the results of 3, using alternative fuel and DG technology cost assumptions.

Table 3: Runs of the model

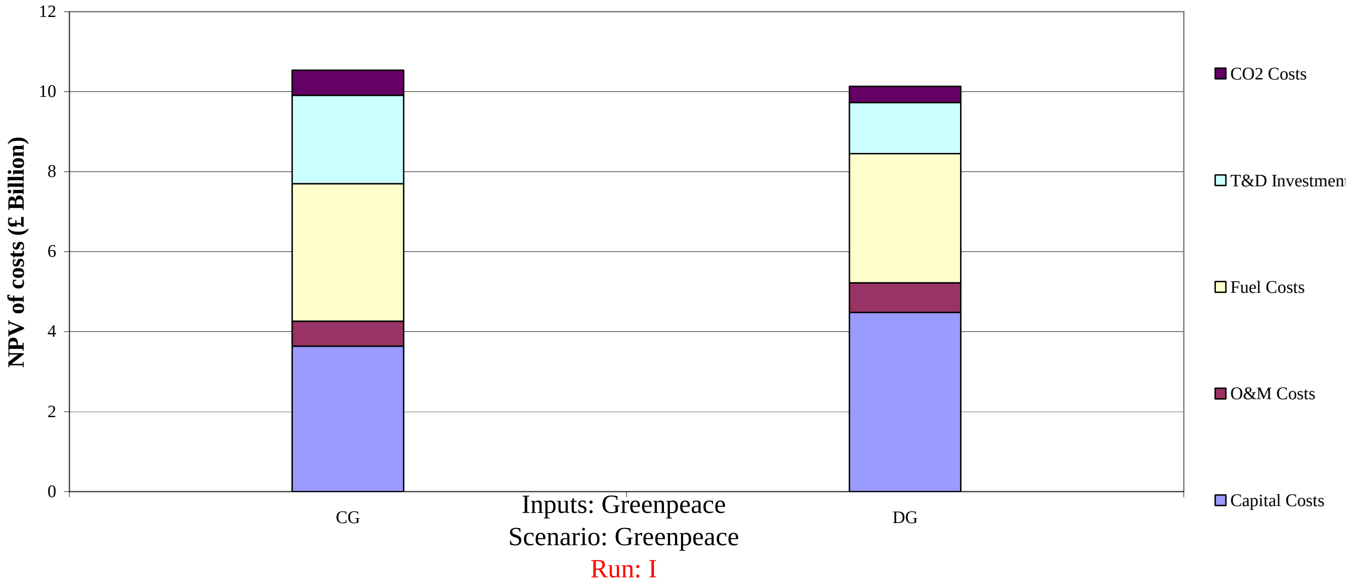
Run number	Scenario	Input assumptions
I	Greenpeace	Greenpeace
II	Greenpeace	Greenpeace, with some key inputs changed to DTI assumptions
III	Greenpeace	DTI
IV	DTI	DTI
V	DTI	DTI, high fuel price
VI	DTI	DTI, low fuel price

1. Presentation of the Greenpeace Results

67. The Greenpeace study reported the model outputs using the standard WADE outputs of 'capital costs over 20 years' and 'retail cost in year 20'. To facilitate comparison between the Greenpeace and DTI model outputs we have applied the NPV output constructed for DTI to the full Greenpeace data.

68. This is labelled as model Run I in Figure 1. This demonstrates that, applying the DTI's 'total NPV of the costs of new generation over 20 years' the general conclusion from Greenpeace's work remains unchanged: the DG scenario offers cost savings over the CG scenario.

Figure 1: Presenting the results of the Greenpeace study using the 'NPV of costs' output measure



2. Investigating the GREENPEACE results

69. In the WADE model both the scenario chosen for investigation and the input assumptions used are crucial in determining the model outputs. By investigating first the impact of changing the input assumptions, and later changing scenarios within which these assumptions are applied, we are able to understand more about the factors driving the results in the Greenpeace study.

70. First, we investigated the extent to which it was the specific input assumptions applied by Greenpeace that drove the results in Figure 1. As discussed earlier, there are some key input assumptions used within the Greenpeace modelling work on which DTI takes a different view.

<u>Key differences between the Greenpeace and DTI input assumptions</u>

Key differences include:

71. **Demand growth** The Greenpeace and DTI runs of the WADE model have both used UEP as the source for demand growth estimates, but the

estimate has been updated, and increased, since the Greenpeace study. As a result more capacity must be built under DTI assumptions to meet future demand.

72. **Fuel prices** Greenpeace ran the WADE model for the UK at a time when fuel prices were increasing rapidly, and applied fuel price data anticipating substantial annual price increases. The current DTI (UEP) fuel price projections anticipate much less rapid growth in fuel prices. Greenpeace assumed a 5% annual increase in gas prices over the period; current UEP projections anticipate annual reductions of 0.2%. A higher assumed fuel price, or fuel price increase, tends to increase the costs of the CG scenario as CG uses more fuel than DG.

73. **Transmission and distribution costs** Greenpeace has used an estimate of the total T&D costs resulting from additional capacity; DTI has used an estimate of the differential between the CG and DG cases. The issues associated with this assumption are discussed in section 3 above.

Other aspects also reflect an important difference in approach, but do not actually have a substantial impact on the modelling results. These include:

74. **Transmission and distribution losses** The format of the WADE model assumes that DG incurs zero loss in distribution, and the Greenpeace model runs took this approach. However, all DG (except microgeneration used within the generator's premises) has to travel some distance on the distribution network, and therefore will be subject to some loss in distribution. Furthermore, very large-scale industrial CHP is typically transmission-connected, so incurs losses of the same magnitude as a centralised generator. Our approach to modelling the T&D losses associated with DG is discussed in Annex 2.

75. **CHP Costs** The Greenpeace input assumptions contained no costs associated with transporting the heat output from a CHP plant to where it will be used. We assumed this cost to be zero in the case of large-scale and industrial schemes, as these plants are usually integrated into the industrial site and sized to meet the customer's demand for heat. For district heating CHP the costs of heat main installation are based on a Carbon Trust report[20] which gives an 'average' figure is £2,200 per dwelling (for retrofit)[21].

76. Collectively the application of DTI assumptions on fuel prices, T&D losses and costs of a heating main all reduce the costs of the CG scenario relative to the DG alternative. The higher assumed demand growth increases the costs of all scenarios proportionately.

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[20] Energy Saving Trust/ Carbon Trust *Community Energy Programme Indicators* May 2004

[21] The per dwelling figure has been converted to a 'per kWe' figure using an estimate of the total heat demand for the average home to identify how many homes are heated by a kWe of installed CHP capacity.

77. The Greenpeace and DTI input assumptions for plants costs and efficiencies are very similar, and in many cases the same sources have been used. Where there are substantial differences these are set out in Annex 4.

Investigating the impact of changing the input assumptions

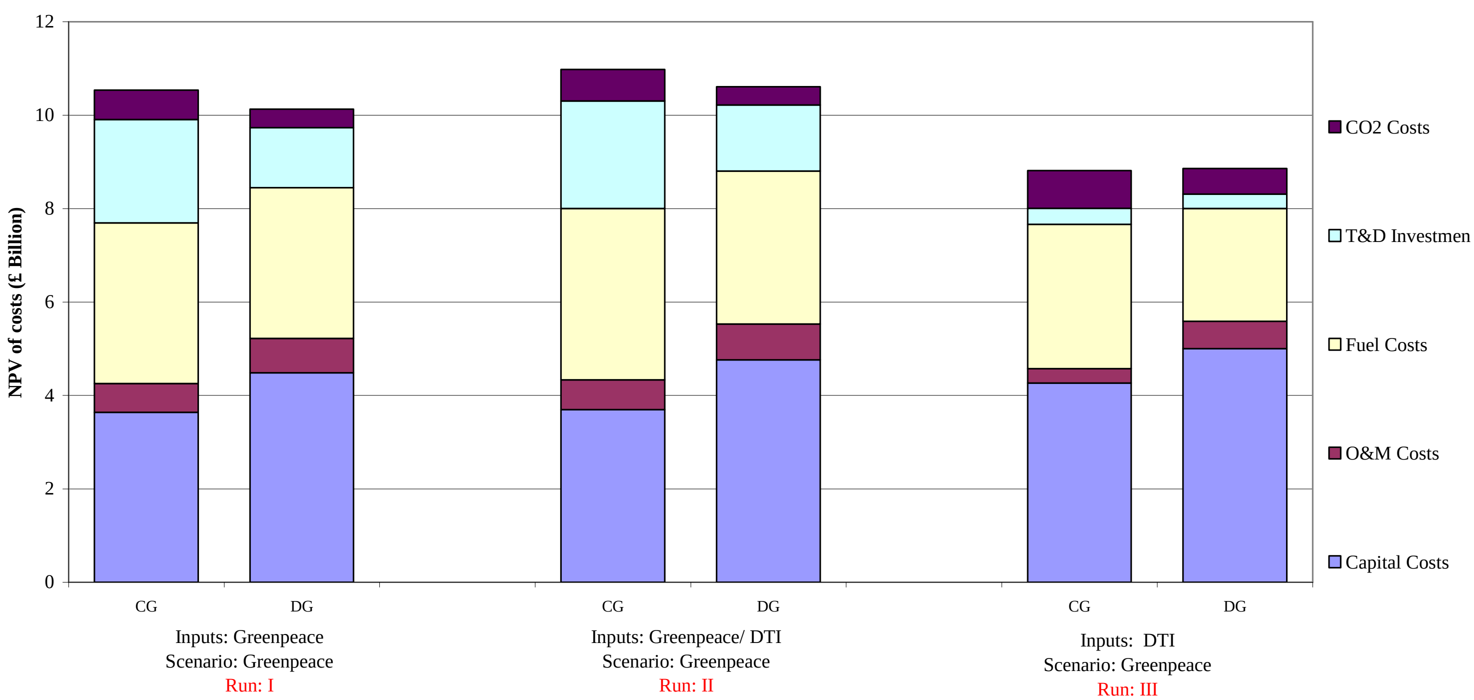
78. In order to understand the extent to which the value taken by the Greenpeace input assumptions drives the outputs of the model we used an incremental approach to adopting the DTI input assumptions in the place of the Greenpeace assumptions. This work took place in the context of the Greenpeace scenarios, starting with Run I as shown above.

79. From the starting point of using full Greenpeace input assumptions, we applied initially DTI estimates of current capacities and load factors. This made very little difference to total costs and the results are not reported separately here. Next, the DTI assumptions regarding the retirements of existing capacity and demand growth were also applied, with all remaining assumptions left unchanged. This gave the results in Run II: the relative costs of DG and CG remain the same, but the total costs of each scenario have increased relative to Run I.

80. In the next step, DTI assumptions about losses were changed, but again this had only a small impact so the results are not reported separately. Finally, all remaining inputs were changed to the DTI input assumptions. This gives the results in Run III.

81. The results of model Runs II and III are reported in Figure 2.

Figure 2: Impact of changing input assumptions within the Greenpeace scenario



82. The problems with developing T&D data mean that the runs using DTI and Greenpeace input assumptions are not directly comparable. However, it remains possible to compare the CG and DG aspects of each scenario. It is clear that where DTI assumptions about current generation capacity, retirement and growth are applied, the DG scenario remains slightly cheaper than the CG alternative. Inputting DTI assumptions about losses does not change this conclusion. However, where full DTI assumptions are applied, the cost differential between DG and CG disappears and CG is marginally cheaper (though given the huge range of data uncertainties this difference is certainly too small to be statistically significant).

83. Under DTI input assumptions (Run III), as under Greenpeace input assumptions (Run I), the summed capital and operation and maintenance (O&M) costs associated with DG technologies is higher than for CG. Under DTI assumptions the total fuel costs are lower in both the CG and DG scenarios than in Run I, in spite of seeing an increase as a result of the higher demand growth figure applied. However, the fuel costs of DG fall more than those of CG between Run I and Run III, and so this partly offsets the cost differential between DG and CG under the DTI input assumptions.

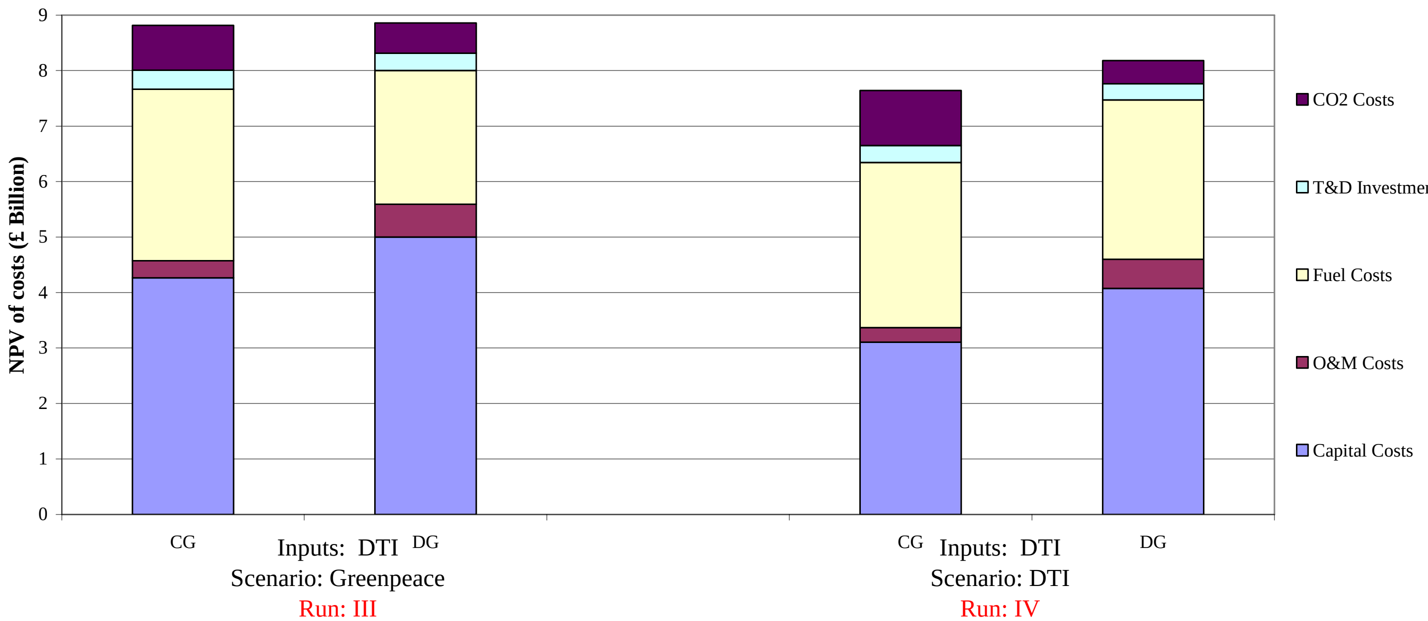
84. Under the full Greenpeace assumptions the lower T&D infrastructure costs of DG are crucial in driving the result that DG is cheaper than CG. We have not been able to generate satisfactory data to reflect the full costs of the T&D infrastructure, and so cannot discuss the total costs of T&D. However, on the basis of the information that we have been able to collect reflecting the differential in T&D costs in alternative scenarios, we do not see a big difference between the T&D costs in the CG or DG scenario. This is largely due to the importance of onshore and offshore wind in both scenarios, given the inclusion of 25% centralised renewables in the Greenpeace DG scenario. This is the most costly capacity to connect, and occurs in both the DG and CG scenarios.

3. Applying the DTI scenarios, using the DTI input assumptions

85. Thus far the modelling work has investigated the impact of applying the DTI input assumptions in the context of the Greenpeace scenario. This has enabled us to investigate the extent to which the outputs from the Greenpeace study could be driven by the input assumptions used. However, the scenario – the percentage of each generation technology within any new capacity built – is also a key driver of costs.

86. The CG and DG scenarios built by DTI have been discussed in detail in section 3. The DTI input assumptions were applied to these scenarios in Run IV, and the results are illustrated in Figure 3.

Figure 3: Comparison of the Greenpeace and DTI scenarios under DTI input assumptions



87. The results of Run IV indicate that, under the DTI scenario and applying the DTI inputs, the total cost of the CG scenario is lower than that of the DG scenario. The total plant costs, including capital costs and O&M costs, are substantially lower in the CG scenario. The DG scenario offers some fuel cost saving, and a considerable carbon emission saving. But overall, these savings are not sufficient to outweigh the technology cost advantages of the CG scenario.

88. This difference in conclusion relative to the Greenpeace scenario is, by definition, driven by the different plant mix, as the input assumptions are constant across the two runs illustrated in Figure 3. DTI uses a lower cost mix of technologies in its CG scenario than is included in the Greenpeace scenario. This is emphasised by the difficulties highlighted above in the approach to modelling plant life: the annuitisation of capital cost does not reflect the life of the plant. The Greenpeace scenario builds 7 GW of nuclear plant by 2025 as opposed to 3GW in the DTI scenario. Given the long plant life of nuclear, but high capital costs, a higher proportion of nuclear will artificially increase the costs of the Greenpeace CG scenario.

89. The Greenpeace CG scenario also uses more bioenergies capacity than the DTI CG scenario. ‘Bioenergies’ incorporates a number of alternative generation technologies, and DTI assumptions on cost are substantially above those applied by Greenpeace. This may reflect the use of data for a different type of plant, rather than any strongly conflicting views on the costs of such plants. However, under a market system where the most

cost-effective technologies come forward, the high share of bioenergies included in the Greenpeace scenario would not be expected to come forward under the costs applied to it in the DTI input assumptions. Overall, this will tend to generate relatively high costs of the Greenpeace CG scenario when the DTI input assumptions are used.

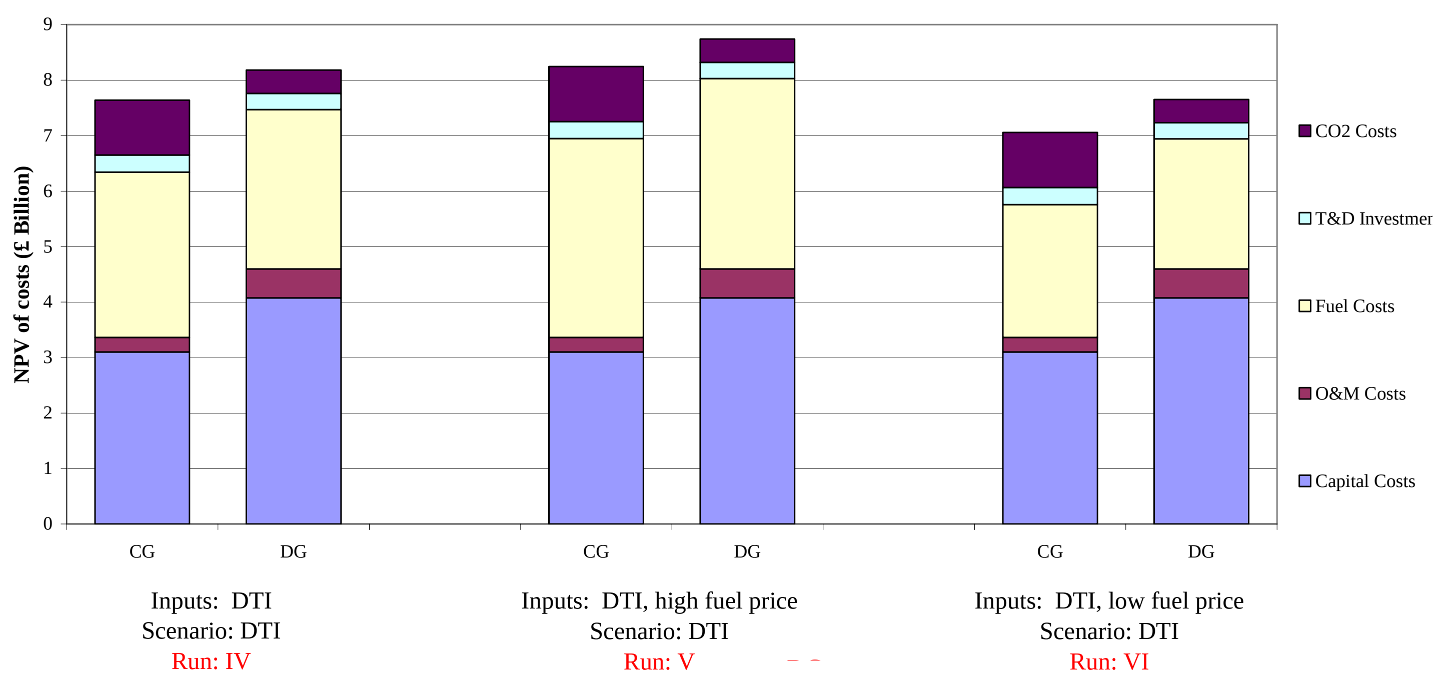
90. The greater use of gas, and in particular coal, in the DTI CG scenario is reflected in the higher emissions costs associated with this scenario. These emissions costs represent the social valuation of the emissions from the fossil-fuelled plants. Under the EU Emissions Trading Scheme (EU ETS), an increased share of fossil fuel generation, and therefore increased emissions, in the UK will be offset by the need to buy abatement credits from elsewhere in the EU.

4. Sensitivity analysis

91. In order to check the robustness of these results to alternative assumptions, sensitivity analysis was applied to the fuel cost and DG technology cost assumptions.

92. The fuel price sensitivity involved applying the ‘high’ and ‘low’ fuel price sensitivities to complement the ‘central’ projection used elsewhere. Other aspects of the scenario were left unchanged. The fuel costs increase by a marginally higher percentage in the high fuel price scenario for CG than for DG. Conversely, total fuel costs reduce by marginally more for CG than for DG in the low fuel price scenario. But these differences are only marginal and do no affect the overall conclusion that the DG scenario has

Figure 4: Impact of fuel price sensitivity under DTI scenario and input assumptions



higher total costs than the CG scenario. The results of the fuel cost sensitivity are represented in Figure 4.

93. Sensitivities were also explored around the DG input assumptions due to the large amount of uncertainty surrounding the costs and efficiency performance of DG technologies, especially CHP. The baseline data were flexed up and down by 10%, and the Delta CHP data was used as an alternative to the FES data. None of these sensitivities affected the overall results.

General conclusions from the results:

94. This work has investigated the relative costs of a DG and CG scenario within the context of the WADE model. Given the concerns we have about the capacity of the WADE model to effectively model these costs, we do not believe that these results enable us to draw robust conclusions about these relative costs. Notwithstanding these concerns, we have reported the results of our modelling work. Whilst these results can only offer a preliminary view of the relative costs of a DG scenario, they do add to the existing evidence base.

95. This work does not support the thesis that a DG scenario is cheaper for the UK, even taking into account the carbon costs associated with electricity generation, though nor does it provide strong support for an argument that a DG scenario is more expensive. Given the great uncertainty surrounding many of the data inputs used in the model, very large differences in the outputs from the model would be required before any differences were meaningful (or would be likely to be statistically significant). Equally, given that we are simply comparing one specific DG scenario with a specific CG counterfactual, is it difficult to generalise from these results.

96. These results have highlighted the importance of both the input assumptions and the scenario in determining the relative costs of meeting future electricity demand using alternative mixes of capacity.

97. Under the Greenpeace scenario and input assumptions, the conclusion that DG offers a cheaper alternative than CG remained under the DTI ‘NPV of costs’ output measure. However, applying the DTI input assumptions to this Greenpeace scenario resulted in costs of the CG and DG scenarios that were very similar. This was largely driven by differences in the T&D cost assumptions: the Greenpeace inputs assume that the T&D infrastructure costs associated with new CG capacity are considerably higher than those associated with new DG capacity. It is not possible to generate robust data for total T&D costs, but the information that we have collected on the cost differential between a DG and CG scenario does not support such a substantial difference in T&D costs between the two alternatives over the coming 20 years.

98. In moving to the DTI scenarios, the CG scenario became cheaper than the DG scenario on the NPV of costs measure. This was driven by the substantially lower costs of the DTI CG scenario relative to the Greenpeace CG scenario. This implies that the DTI scenario incorporated a more cost-effective mix of CG capacity than the Greenpeace scenario.

99. This conclusion is driven in part by the failure to explicitly model plant life within the NPV of costs calculation. Because all plants are effectively treated as having the same 20 year plant life, a scenario incorporating a higher share of plant with high capital costs, but a long life-length, appears more expensive.

5. General conclusions

100. The issues discussed above relate to the application of the WADE model and the specific inputs and scenarios used. On the basis of this analysis we do not support the Greenpeace conclusion that DG can offer a cheaper means of delivering new requirements for electricity generation capacity, as well as a lower carbon option (though neither do we dispute it – we simply do not have the evidence to reach such a conclusion).

101. However, as highlighted at the start of this paper, there are broader issues surrounding our acceptance of the results derived from this model. We have demonstrated that the specific results obtained are sensitive to the inputs used. But more importantly, we have concerns about the use of this model to answer the question which is being proposed.

102. These concerns are driven by the treatment of heat within the model. This is crucial because of the importance of CHP within a DG scenario – if we do make a move to a decentralised energy system, one of the major impacts on the UK system would be in the extent to which fuel-efficient CHP was exploited. But this means that the carbon and fuel savings offered by CHP are crucial to understanding the potential benefits of the shift. With heat not treated explicitly within the model, the results of the model depend crucially on simplified changes made to electrical efficiency to proxy for the thermal output of a CHP.

103. There are also concerns which relate to the input information that the user must put into the model in order to be able to generate results. Many of these data are highly uncertain, as with any modelling work. But difficulties in determining the costs associated with T&D investment, and the treatment of plant lifetimes, are particularly important in illustrating the difficulties in using the results of this model to reach robust conclusions about the relative costs of DG.

104. In order to reach firm conclusions as to the relative cost-effectiveness of DG as a tool for delivering carbon abatement, analysis would need to be undertaken using a model which treats heat explicitly. Equally, more work would be needed to fully capture the location-specific aspects of T&D investment costs.

105. It is interesting to model the costs and benefits to the UK of meeting our need for new capacity using distributed generation as an alternative to centralised plant. However, in a well-functioning market the cheapest technology will prevail. Hence if DG technologies are cheaper than CG alternatives they will be developed, as long as the right framework is in place and there are no barriers to take-up. Government work to address any barriers to DG will help ensure that cost-effective opportunities for DG will be taken up by the market[22].

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[22] DTI/ Ofgem *Review of Distributed Generation*; www.dti.gov.uk/energy/whitepaper

Annex 1: How the WADE model works

The model determines the need for new capacity in each of the 20 years of the modelling period, depending upon assumptions input by the user including demand growth, retirement of existing plant, extent of transmission and distribution (T&D) losses, and load factors of new and existing plants. It assumes a constant capacity margin over the 20-year period.

The model then determines how this new-build capacity is spread across the range of generation technologies using the 'scenario' defined by the user. This scenario specifies the percentages of energy production from each generation technology in total new build; for example, a centralised scenario could incorporate 50% CCGT (gas) plant, 30% coal plant and 20% large-scale wind. The process of determining exactly how much capacity of each type is required is iterative, as different types of capacity have different load factors. There is therefore interdependency between the type of capacity built and the total amount of new capacity required to meet demand.

There is no explicit treatment of the need for back-up capacity to support intermittent sources such as wind power. The intermittency is only captured by the 'load factor' representing the average portion of the year for which the plant is operating.

By taking into account the full range of cost information and input assumptions put forward by the user the model then calculates the full costs of developing new capacity according to the chosen scenario, including costs such as plant capital costs, fuel and operation costs, transmission and distribution (T&D) costs and total carbon emissions.

This is a model of the electricity generation sector. However, CHP cogenerates heat and electricity. In order to determine the value of these efficiency benefits it is necessary to compare the electrical and heat output of the CHP to the counterfactual, which is electricity generated by an alternative source and heat generated from a boiler. In the context of a full model of the energy sector, this would occur automatically within the model. But the WADE model only explicitly models the electricity generation sector, and so in order to bring in the full benefits of CHP for fuel efficiency it is necessary to uprate the electrical efficiency of the CHP to proxy for the heat output which is also produced when electricity is generated in a CHP plant.

Annex 2: Transmission and distribution losses

We have undertaken internal work to estimate the average distribution loss incurred by DG[23], illustrated below. This involved:

- estimating the average loss in distribution from each DG technology by considering the location in which such capacity is located relative to demand;
- taking a weighted average of these estimated losses figures to reflect the share of each technology within the DG scenario, therefore finding an 'average' losses figure of 2.3% to apply to DG.

Technology	Distribution losses %	Average % of technology in Greenpeace DG	Connection Voltage	Comment
Gas CHP	2%	63%		Could be connected at 11kV or 33kV but close to demand in all cases.
Gas micro-CHP	0%	7%	LV	Assumed devices connected on the customer's side of the meter. Exports are likely to 'back-off' local flows so losses could actually be -ve in some situations.
Coal CHP	4.50%	10%		Assumed connected at 132kV.
Biomass CHP	3.50%	15%		Assumed connected at 33kV but remote from demand.
Hydro - Small	3.00%	3%		Assumed connected at 11kV but remote from demand.
Wind (Local)	0%	2%	LV	Assumed devices connected on the customer's side of the meter. Exports are likely to 'back-off' local flows so losses could actually be -ve in some situations.
Solar (Local)	0%	1%	LV	Assumed devices connected on the customer's side of the meter. Exports are likely to 'back-off' local flows so losses could actually be -ve in some situations.
Weighted Average	**2.3%**			

[23] This excludes transmission-connected CHP, which is assumed to face the same losses as other transmission-connected generation.

Annex 3: Location-specific aspects of T&D costs

This location-specific aspect of costs is explicitly recognised in the transmission charging methodology used to charge generators for the costs they impose on the system. Generators in the South East, where there is insufficient generating capacity to meet demand, 'pay' a negative locational component of total charges, recognising their impact in reducing investment below the level that would otherwise have been required.

A 'locational' element is also being introduced into distribution charging methodologies, reflecting the differential impact that distributed generators have on distribution network costs, depending upon the specific point at which they connect to the distribution infrastructure. In cases where the infrastructure is already congested they may actually trigger substantial need for re-investment, perhaps including a move towards more 'active management' of the distribution infrastructure. In other cases the distributed generator reduces the costs of balancing demands and supplies in the local area.

This issue of location-specific costs means that the T&D costs associated with different mixes of new build capacity must be treated in a similar manner to the development of a DG scenario – this can be done only on a 'what if', scenario-based approach.

Some such studies have previously been undertaken, evaluating the total network costs associated with absorbing a given quantity of additional capacity onto the system. However, it is spurious to take the total costs in such a scenario, and divide by the number of kW connected to deliver a generic 'cost per kW'. This cost applies only in the specific scenario under discussion.

A scenario-based approach could be used to estimate costs per kW of new T&D infrastructure. This would require careful estimation of alternative scenarios, including where the new capacity might be expected to connect in each of these scenarios, and some reasonable sensitivities around these data.

Annex 4: Some input differences between DTI and Greenpeace

	Installed Capacity Costs (£/kW)		Average Yearly Increase / Decrease (%)		2025 Capacity Costs (£/kW)	
CG	GP	DTI	GP	DTI	GP	DTI
Bioenergies	1200	1600	-2.0%	-0.8%	801	1353
Nuclear	1500	2107 *	1.0%	-0.2%	1830	1492
DE	GP	DTI	GP	DTI	GP	DTI
Gas CHP - Major Power Producers	670	550	0.0%	-0.2%	671	480
Gas CHP - Industrial	670	550	0.0%	0.0%	671	550
Biomass CHP	1300	2550	-2.0%	-0.8%	868	2156

* comprises; capital cost 1557, interst during contruction 493, fixed O&M 57

	Current Plant Variable O&M Costs (tenths of pence / kWh)		2025 Variable O&M Costs (tenths of pence / kWh)	
CG	GP	DTI	GP	DTI
Bioenergies	5.3	5.3	4.7	4.7
Nuclear	3.5	0.0	3.5	0.0
DE	GP	DTI	GP	DTI
Gas CHP - MPP	5.3	5.0	4.0	5.0
Gas CHP - Industrial	5.3	5.0	4.0	5.0
Biomass CHP	4.3	0.0	4.3	0.0

	Average Yearly Increase / Decrease (%)	
Fuel Prices	GP	DTI
Gas	5%	-0.1%

Annex 5: Input data sources

Existing Capacity	
CG	
All centralised capacity except solar	Dukes 2006
DG	
Gas CHP - Major Power Producer (MPP), Gas CHP Industrial	Dukes 2006; split by categories a DTI estimate
Gas micro-CHP, Gas CHP - District Heating	Assumed zero
Coal CHP, Biomass CHP, Hydro (small), Solar (including CG) Wind (local)	DTI estimate using data from the Ernst and Young and Oxera reports

Generation and Load Factors	
CG	
Coal Steam Turbine (ST), Oil ST, Gas CCGT, Nuclear, Bioenergy, HEP/Pump Storage, Tidal/Ocean/Wave, Wind Onshore, Wind Offshore	Dukes 2006
Mixed ST, Gas T & Oil Engine, Interconnector,	DTI estimates based on current data
Solar	DTI estimate using data from the Ernst and Young and Oxera reports
DG	
Gas CHP - MPP, Gas CHP Industrial, Gas CHP - District Heating	Future Energy Solutions (FES) - CHP Assurance Scheme data, Dukes 2006
Gas micro-CHP, Wind (local)	DTI estimate using data from the Ernst and Young and Oxera reports
Coal CHP	Dukes 2006
Biomass CHP	Analysis to support the forthcoming Biomass Strategy paper, Dukes 2006
Hydro (small), Solar (local)	Dukes 2006

Future Load Factors	
CG	
Mixed ST, Gas T & Oil Engine, Bioenergy, Gas CCGT, Interconnector, Tidal/Ocean/Wave	DTI estimates based on current data
Coal ST, Wind Onshore, Wind Offshore, Nuclear	Energy Review Assumption
Oil ST, HEP/Pump Storage	UEP
Solar	Assumed unchanged from 2005 load factor
DG	
Gas CHP - MPP, Gas CHP Industrial, Gas CHP - District Heating	Future Energy Solutions (FES) - CHP Assurance Scheme data
Gas micro-CHP, Hydro (small), Solar (local)	DTI estimate using data from the Ernst and Young and Oxera reports
Coal CHP, Biomass CHP	DTI estimates based on current data
Wind (local)	Assumed unchanged from 2005 load factor

Retirement Rates	
All technologies	UEP

Capital Costs	
CG	
Coal ST, Bioenergy, Gas CCGT, Nuclear, Wind Onshore, Wind Offshore	Energy Review Assumption
Tidal/Ocean/Wave, Solar	DTI estimate using data from the Ernst and Young and Oxera reports
Oil ST, Mixed ST, Gas T & Oil Engine, Interconnector, HEP/Pump Storage	Unchanged from application of WADE model to UK by Greenpeace
DG	
Gas CHP - MPP, Gas CHP Industrial, Gas CHP - District Heating	Future Energy Solutions (FES) - CHP Assurance Scheme data
Coal CHP	MARKAL assumption for White Paper modelling
Biomass CHP	Analysis to support the forthcoming Biomass Strategy paper
Hydro (small), Solar (local), Wind (local)	DTI estimate using data from the Ernst and Young and Oxera reports

Changes in Future Capital Costs	
CG	
Coal ST, Gas CCGT, Bioenergy, Nuclear	Redpoint Energy study
Oil ST, Mixed ST, Gas T & Oil Engine, Interconnector, HEP/Pump Storage	Unchanged from application of WADE model to UK by Greenpeace
Tidal/Ocean/Wave, Solar	DTI estimate using data from the Ernst and Young and Oxera reports
DG	
Gas CHP - MPP	Energy Review Assumption
Gas CHP Industrial, Coal CHP, Gas CHP - District Heating	Assumed unchanged from 2005 cost
Hydro (small), Solar (local)	DTI estimate using data from the Ernst and Young and Oxera reports

Financing Term	
All Technologies	Unchanged from application of WADE model to UK by Greenpeace

Return on Capital	
All Technologies	Energy Review Assumption

O&M Costs	
CG	
Coal ST, Gas CCGT, Nuclear, Wind Onshore	Energy Review Assumption
Oil ST, Mixed ST, Gas T & Oil Engine, Bioenergy, HEP/Pump Storage, Tidal/Ocean/Wave, Interconnector, Solar	Unchanged from application of WADE model to UK by Greenpeace
DG	
Gas CHP - MPP, Gas CHP Industrial, Gas CHP - District Heating	Future Energy Solutions (FES) - CHP Assurance Scheme data, Dukes 2006

Coal ST	MARKAL assumption for White Paper modelling
Gas micro-CHP, Hydro (small), Wind (local), Solar (local)	Unchanged from application of WADE model to UK by Greenpeace

Fuel Costs	
CG	
Coal ST, Oil ST, Gas CCGT	UEP
Mixed ST, Gas T & Oil Engine, Bioenergy	Unchanged from application of WADE model to UK by Greenpeace
Nuclear	Energy Review Assumption
DG	
Gas CHP - MPP, Gas CHP Industrial, Gas micro-CHP, Coal CHP, Gas CHP - District Heating	UEP

Transmission and Distribution, including costs for network upgrade	
All Technologies	DTI assumption based on "Total cost estimates for large-scale wind scenarios in UK", Power UK, March 2003 and information provided by National Grid

Heat Rates	
CG	
Coal ST, Gas CCGT, Nuclear, Gas CHP - MPP	Energy Review Assumption
Oil ST, Mixed ST, Gas T & Oil Engine, Bioenergy	Unchanged from application of WADE model to UK by Greenpeace
DG	
Gas CHP Industrial, Gas micro-CHP, Coal CHP, Biomass CHP, Gas CHP - District Heating	Energy Review Assumption

NO_x, SO_2 and PM10 Emission Factors	
All technologies	Unchanged from application of WADE model to UK by Greenpeace

CO_2 Emission Factors	
CG	
Coal ST, Gas CCGT	Energy Review Assumption
Other CG technologies	Unchanged from application of WADE model to UK by Greenpeace
DG	
All DG technologies	Unchanged from application of WADE model to UK by Greenpeace

System Growth Properties	
Average T&D losses	Dukes 2006
Peak T&D losses, Coincident peak, CG safety margin, T&D safety margin, DE safety margin	Unchanged from application of WADE model to UK by Greenpeace
Annualised demand growth,	UEP

Annualised peak growth

References

Dukes 2006	Available at: www.dti.gov.uk/energy/statistics/publications/dukes/page29812.html
Ernst and Young Report	Impact of Banding the Renewables Obligation: Cost of Electricity Production 2007, available at: www.dti.gov.uk/energy/whitepaper
Oxera Consulting Ltd Report	Reform of the Renewables Obligation - What is the likely impact of changes? 2007, available at: www.dti.gov.uk/energy/whitepaper
Energy Review Assumption	Available at: www.dti.gov.uk/energy/whitepaper
UEP (Updated Energy and CO2 Emissions Projections)	Available at: www.dti.gov.uk/energy/whitepaper
Application of WADE model to UK by Greenpeace	Available at: www.greenpeace.org.uk/media/reports/decentralising-uk-energy
Redpoint Energy Study	Dynamics of GB Electricity Generation Investment, available at: www.dti.gov.uk/energy/whitepaper