Analysing the costs and carbon emissions of distributed wind power

The carbon and economic impacts of Active Network Management (ANM) on local energy systems

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Introduction

- ANM techniques are being developed to facilitate the accommodation higher capacities of distributed generation (DG) on constrained networks, beyond the simple 'fit-and-forget' [1].
- Evidence is needed to test the implicit assumption that this greater installed capacity of renewable generation will have a positive environmental effect .
- The output of the DG will achieve a carbon reduction by displacing supply from the transmission system. This will impact the generators operating on the margin, displacing only marginal emissions.
- The time of generation and curtailment may have an impact on emissions reductions (Figures 1 & 2).

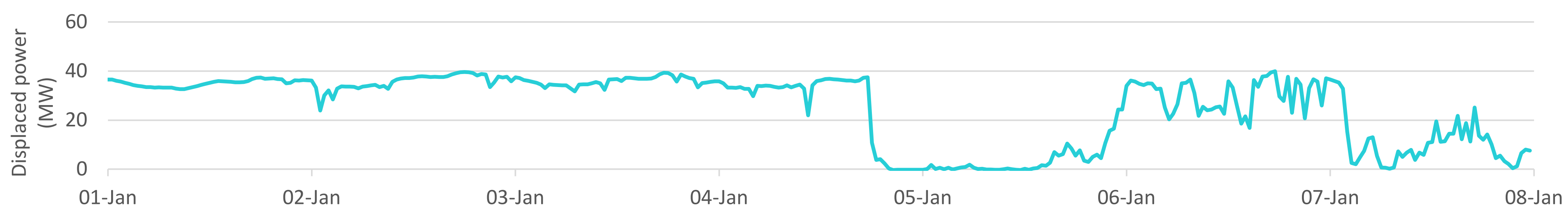

Figure 1 – Displaced power across one modelled week for scenario with full ANM (curtailment, CVC and PFC)

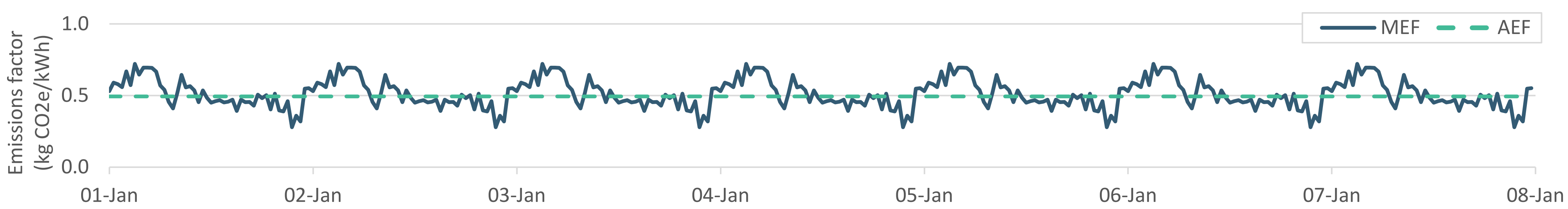

Figure 2 – Emissions factors across the same week as Figure 1 (data from 2014)

OPF with ANM

- **Basic OPF**
  - Real and reactive nodal power balance
  - Voltage level constraints
  - Voltage angle set to zero for the reference bus
  - Thermal limits (lines and transformers)
  - Constant power factor operation of DG units
- Coordinated voltage control (CVC)
- Adaptive power factor control (PFC)
- Generation curtailment (Curt.)

Method

- Power flow based on a time-sequential AC Optimal Power Flow (OPF) model of a generic UK distribution system with the DG represented by 2 wind farms [2].
- Five connection strategies are modelled (Table 1), with installed capacity from [1].
- Carbon emissions displacement for each scenario is calculated based on the difference in active power from the no DG case.
- Seasonal and diurnal time-sequential marginal carbon emissions factors are calculated from historical GB data (Figure 2) [3].
- It is assumed that all prices and emissions intensities will remain constant across the life of the project, in accordance with current practice for estimating emissions reductions.

Comparison of ANM strategies

- Generally ANM increases the displaced energy, carbon emissions displacement and economic revenues (Figure 4 and Table 1).
- Trends of revenues and carbon emissions are similar across different types of ANM, but diverge annually (Figure 4).
- Both revenues and displaced emissions decrease per unit of installed capacity as capacity factor is reduced (Figure 5).
- Time-varying effects of curtailment on emissions reductions are not found to be significant in this case study (Figure 3).
- This study is focussing on the development and testing of methodology, so the power flow model has not been fully validated and results on relative impacts of ANM strategies are not conclusive.

	No DG	Fit-and-forget	Curtailment	Curt + PFC	Curt + CVC	Curt + PFC + CVC
DG capacity (MW)	0	20.5	36.5	33.5	32	53
DG energy yield (GWh/yr)	-	70	112	106	106	157
Displaced energy (GWh/yr)	-	64	106	99	100	147
Capacity factor	-	39%	35%	36%	38%	34%
Mean carbon payback (months)	-	5.4	5.8	5.7	5.4	6.1
LCOE (2017 p/kWh)	-	4.8	5.4	5.2	5.0	5.5
Mean NPV (2017 £m)	-	29	44	42	46	57
Mean emissions reduction ROI (2017 t CO2e/£)	-	22	20	21	22	19

Table 1 – Details of key outputs for each modelled scenario

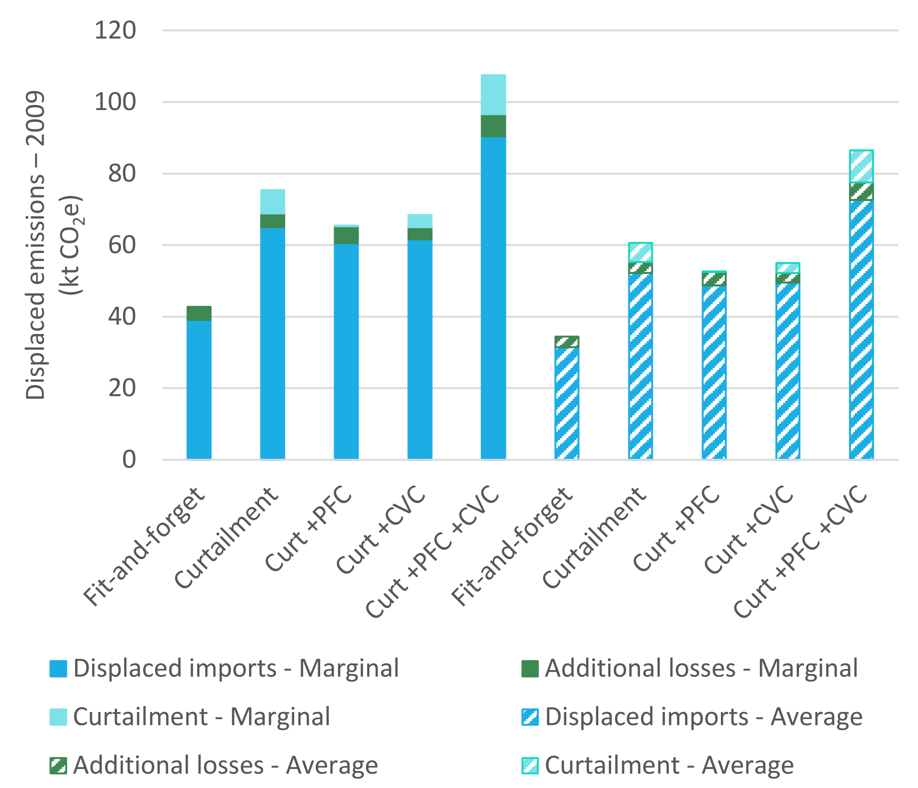

Figure 3 – Potential displaced emissions across ANM scenarios based on 2009 emissions intensities

Figure 4 – Emissions displacement and revenue for different ANM scenarios

Impact of carbon emissions factors

- Marginal emissions displacements of DG are generally higher than estimated using annual average data (Figures 3 & 5 and Table 1)
  - The emissions reduction return on investment is greater
  - The carbon payback time is shorter
- There are significant inter-annual emissions fluctuations. Decisions should not be based on factors from only one given year (Figure 6).

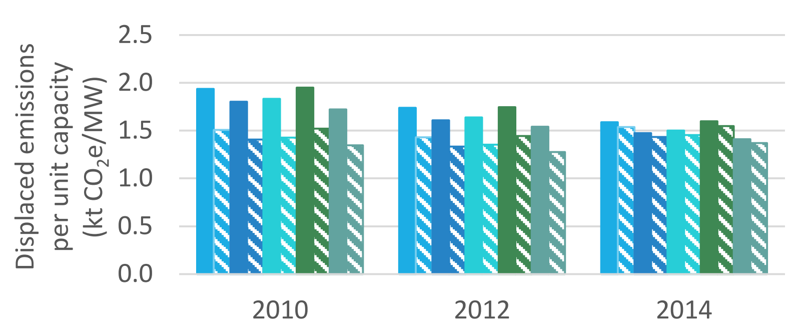

Figure 5 – Displaced emissions per unit capacity for selected years, based on marginal and average emissions factors.

Figure 6 – Fluctuations in one decision metric with marginal and average emissions factors across all years

Legend for Figures 4, 5 and 6

Fit-and-forget - Marginal; Fit-and-forget - Average; Curtailment - Marginal; Curtailment - Average; Curt+PFC - Marginal; Curt+PFC - Average; Curt+CVC - Marginal; Curt+CVC - Average; Curt+PFC+CVC - Marginal; Curt+PFC+CVC - Average

Effects of carbon taxes

- Annual fluctuations in carbon emissions factors are linked to relative price of coal and gas-fired generation, including carbon taxes [3,4].
- Total emissions displacement of DG are found to increase with slight increases in carbon price, and then fall as carbon price increases further (Figure 7).
- This is a function of the overall reduction in average emissions factors (Figure 7).

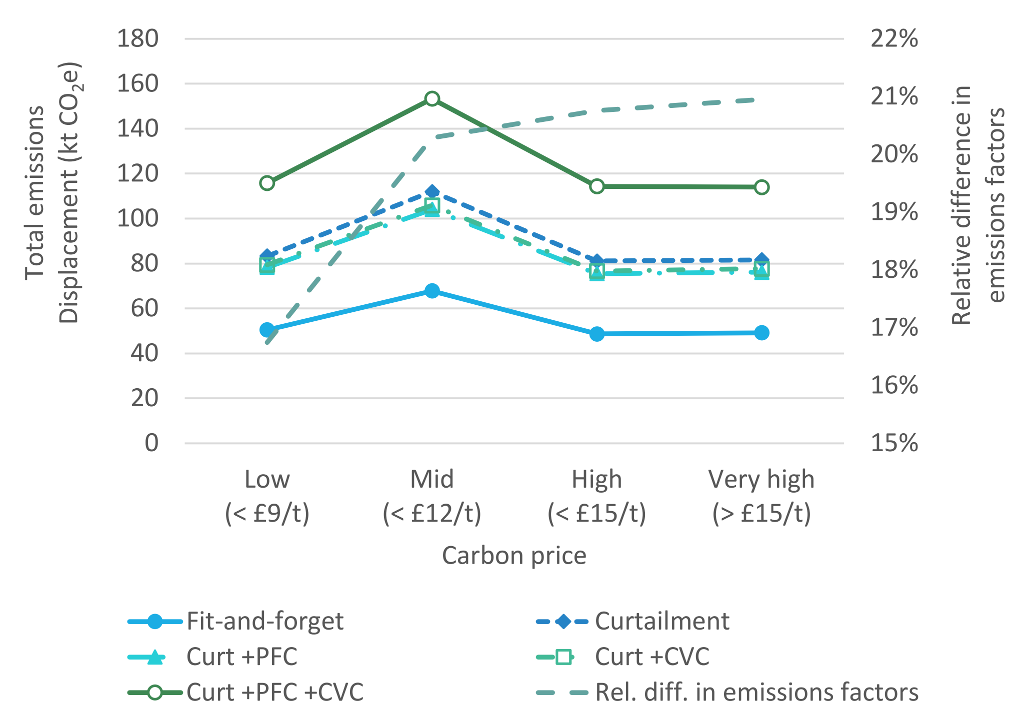

Figure 7 – Impact of carbon taxes (including EU Emissions Trading Scheme and Carbon Price Support)

Conclusions

- The use of average data to estimate carbon emissions displacement disguises the impacts of temporal variation.
- Carbon emissions displacement cannot be assumed to remain constant over the project life. Ideally the emissions intensities should be forecast over the whole project life.
- No significant difference was seen in the temporal effects of curtailment across the strategies considered.
- Further work should investigate distributed generation with more significant diurnal effects, such as solar power.

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CESI National Centre for Energy Systems Integration

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