Average Displaced Emissions Rate (ADER): Approach and Methodology

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Recognizing the analytical limitations of existing methodologies in estimating displaced emission from energy efficiency measures and clean energy technologies, US EPA and ICF Consulting have developed a new approach to estimating the potential for displaced emission — the "Average Displaced Emissions Rate" (ADER) methodology. ADER is an analytic improvement because it accounts for the integrated response of power markets to changes in electricity demand/supply and the methodology also has broad application potential in that it may be applied to a wide range of energy efficiency measures and clean energy technologies. The methodology consists of two parts: (1) estimation of ADER parameters and (2) application of ADER parameters to energy efficiency or clean energy technology load impact estimates. ADER parameters are estimated for SO_2, NO_x, CO_2 and Hg using ICF's Integrated Planning Model (IPM$^®$) and describe the change in emissions for a unit change in electricity demand/supply. The parameters vary by year, region, season, and hour type. To produce estimates of displaced emissions, these ADER parameters can be applied to the total displaced generation from any energy efficiency measure or clean energy technology taking into account the region of penetration and the hourly load shape that describes the impact of the measure or technology. This paper provides background on emissions estimation issues, explains the ADER approach, and discusses the possible uses and limitations.

I.   INTRODUCTION

In the United States, the development of environmentally benign sources of energy and efficiency in energy use has become key goals for both government and industry. Recent efforts to displace (or save) emissions from electric generation through use of clean energy and efficiency have focused around two initiatives: promotion of end-use energy efficiency, which includes conservation; and increased generation from clean energy sources. While it is recognized that energy efficiency and clean energy technologies have the potential for significant emission reductions through displaced generation[1], there is a need for a robust and analytically sound method to quantify the potential for displaced emissions[ii].

This paper presents a new approach to estimating displaced emissions in electric generation resulting from implementation of energy efficiency and/or clean energy technologies. The approach utilizes estimated parameters for average displaced emission rate (ADER) to derive displaced emissions. The new ADER methodology overcomes the analytical limitations of existing approaches in two ways. First, ADER explicitly accounts for the complexities of electricity markets in assessing how displaced emissions result from changes in electric demand or supply. Second, the methodology can be used to estimate the emissions benefits of many different types of end-use energy efficiency measures and clean energy technologies.   In particular, the methodology allows variation in the performance, operation and penetration characteristics of different energy efficiency measures and clean energy technologies to be captured in the estimates of displaced emissions. ADER produces regional, national, short-term and long-term estimates of displaced emission of carbon dioxide, nitrogen oxide, sulfur dioxide, and mercury (CO_2, NO_x, SO_2 and Hg) from electric generation.

EPA plans to incorporate the results of the ADER analysis into its forthcoming on-line "Emissions Profile Tool," which will enable individuals and businesses to compute the environmental impacts of their electricity consumption systems. Results of ADER analysis are not currently available, but modeling is underway. EPA expects to make the results of this ADER analysis available in the latter part of 2002.

This paper describes methodologies currently under consideration by EPA and does not necessarily reflect policy decisions by the Agency.

A.   Background

The US Environmental Protection Agency (EPA) has developed ENERGY STAR® and other voluntary partnerships with industry to encourage the use of energy efficiency and Clean Energy Technology (CET). These programs form a key component of EPA's overall strategy for mitigating the risk of global climate change. While end-use energy efficiency reduces the demand for electricity, CET provides cleaner alternatives to conventional supply. Both approaches have tremendous potential for reducing emissions from electricity generation.

Energy efficiency, which includes conservation measures, reduces electricity demand through efficiency improvements in end-use technologies in the residential, commercial, industrial and manufacturing sector. Such improvements may include enhancement to industrial processes, the insulation of commercial buildings or private homes, or the use of high-efficiency appliances.

EPA's ENERGY STAR[iii] program, for example, seeks to promote energy efficiency by offering technical assistance, tools and advice to participants wishing to upgrade their buildings, processes, equipment or appliances to improve energy performance. In most cases, energy savings are achieved primarily by reducing electricity consumption through improved construction, insulation, or retrofitting existing equipment with higher-efficiency equipment. Similarly, EPA's ENERGY STAR Homes program

offers homeowners and homebuyers energy-efficient solutions through labeled homes and consumer products. Much of the emission reductions of such programs are likely to be achieved through reductions in electricity use.

Unlike energy efficiency programs, CET programs are supply-side options that seek to displace conventional electricity generation with newer, more advanced units that have low emission rates, higher efficiencies, cleaner fuels, or a combination of these factors. These clean energy technologies often include combined heat and power (CHP) units, natural gas-fired distributed generation systems, and renewable sources such as wind, solar, geothermal, biomass or small hydro units. CET's potential for emissions savings comes from the emissions displaced by reduced generation from conventional electricity generation units.[iv]

EPA is involved in various initiatives to encourage the use of CET for electricity generation. Most notable among these efforts includes the Combined Heat and Power (CHP) Partnership program[v], the Green Power Partnership program[vi] and the Landfill Methane Outreach Program (LMOP)[vii]. The CHP program seeks to promote the development of cogeneration units, which are more efficient because they produce both usable steam and electricity from a single combustion source. Similarly, programs targeting green power seek to promote the awareness and development of generation from renewable energy sources, while LMOP encourages development of small-scale power generation using methane from landfills.

While energy efficiency and CET programs appear to have significant potential for displaced emissions, there is a need for a robust and manageable methodology to estimate these emission benefits across the entire range of programs and technologies. Such a methodology has benefits beyond the programmatic support for EPA in that it can support a wide array of industry and government initiatives that need quantifiable estimates of displaced emission.

The difficulty in estimating displaced emissions from energy efficiency and CET stems from two issues. First, energy efficiency and CET encompass a wide range of measures, technologies, and operation patterns. The performance of these technologies is often dependent on weather, time and geography. To estimate the impacts from the full range of energy efficiency and CET measures therefore requires a methodology that is flexible enough to handle the variations in the operation, performance and penetration characteristics across the programs and technologies. Existing methodologies, such as the use of the average or marginal emission rate, often fail to adjust for such variations across the programs and technologies.

Second, despite the performance variation, the common feature is that all displaced emission originates from changes in production at electricity generation facilities triggered by changes in electric demand or supply. A methodology seeking to estimate displaced emissions from energy efficiency and CET must, therefore, be based on the anticipated response of the power market to changes in supply or demand. Part of the complexity in making the methodology applicable across programs and technologies is the fact that the response of power markets is highly dependent on when and where the supply/demand impact occurs. For instance, the power market will respond differently if the change in demand/supply occurs during the peak summer hours than if the demand/supply change happens in the off-peak winter hours or year round. Additionally, the response will also be dependent on where (i.e., geographic location) the change occurs. Existing methodologies, such as the use of average or marginal emission rate, do not account for the underlying power market components of displaced emissions.

B.   Average Displaced Emissions Rate (ADER) Overview

The ADER approach proposed in this paper is designed to overcome the limitations of existing methodologies while also providing robust estimates of displaced emissions. The innovation in this

approach comes primarily from the fact that rather than estimating displaced emissions for specific programs or technologies, the approach seeks to better capture the primary determinants of displaced emissions.

ADER relies on estimated parameters that capture how emissions from electricity generation change when power markets adjust to supply/demand impacts caused by energy efficiency and CET. These parameters, describing displaced emission per unit of electricity saved, are a function of time (i.e., when the impact occurs) and region (i.e., where the impact occurs). The displaced emissions from any energy efficiency or CET can be estimated if the time, region and magnitude of impacts of the program or technology are known. For instance, if an efficient residential air conditioner is installed in the Northeast and saves 200 kWh of electricity in the weekends of June and July, ADER parameters reflecting the displaced emissions rate in the weekend hours of June and July would be applied to total electricity savings to derive total displaced emissions. Since the parameters are a function of both hour and region, ADER approach ensures that the variations across programs and technologies will be adequately captured. Furthermore, the estimated parameters are developed through analyses of power markets grounded in the economic-engineering fundamental, thus explicitly incorporating power market adjustments to impacts from energy efficiency measures or CET operation.

There are two components of the ADER methodology: (1) estimation of ADER parameters; and (2) application of ADER parameters to electricity saved or displaced from energy efficiency programs and CET. In estimating the ADER parameters, the approach relies on ICF's Integrated Planning Model (IPM®), which is a linear programming model that simulates integrated economic activity of fuel, emissions, capacity and generation markets of the electricity sector. IPM is particularly powerful in examining the effects of changes in electricity demand or supply on air emissions from electricity generation. It has been extensively used by the US EPA, industry, other government and non-governmental agencies in analyzing power markets, air emission changes, changes in fuel use and prices, renewable energy system power system changes, and other impacts of various approaches to air pollution control. The model contains a feature designed specifically for DSM analysis, which can analyze power market and air emission impacts of various load management, demand reduction options. Additionally, the model is well-equipped to handle the complexity of electricity production from renewable resources such as wind, solar, geothermal, small hydro, and biomass. Through IPM, estimates of ADER parameters for SO_2, NO_x, CO_2 and Hg are developed for unique combinations of hour type and geographic region.

The application of ADER parameters to electricity demand/supply impacts from energy efficiency and CET combines the hour-specific electricity savings with the associated ADER parameter to generate an estimate of displaced emissions. For instance, if a technology in a specific region provides 2/3 of its electricity savings in the summer weekdays hours and 1/3 of its saving in the summer weekend hours, the summer weekday and summer weekend ADER parameters for that region would be applied to total electricity saved within those hours to estimate the total displaced emissions. Users of this approach must know the total electricity savings from the program or technology along with a load shape that describes how the impact varies by the hour type. Alternatively, users may elect to use a pre-defined load shape profile to distribute the total electricity savings[viii].

The remainder of the paper is organized as follows: Section II contains a discussion of the operation of power markets in the United States and its relationship to displaced emissions, along with a discussion of the factors that determine emission impacts and existing approaches to estimating displaced emissions. Section III describes the ADER methodology in greater detail. The key features of the ADER approach and the procedure used to estimate displaced emission rates is also described in detail. The use of the ADER rates in the calculation of the total emission impacts from energy efficiency or CET is then illustrated through an example. Conclusions are presented in Section IV.

II. THE US POWER MARKET

A. Relationship Between Power Markets and Displaced Emissions

Displaced emissions from energy efficiency and CET are realized through the response of power markets to changes in demand and/or supply caused by penetration of energy efficiency and CET. Energy efficiency reduces the level of electricity demand, while CET provides alternative sources of electricity supply. However, the reduction in demand or the availability of alternative supply sources does not necessarily result in displaced emissions. For energy efficiency measures or CET operation to impact emissions, they must also cause a change in the operation of one or more generating plants in the power market.

While changes in demand or supply fundamentally affect the generation mix in power markets, it would be misleading to estimate displaced emissions only through changes in generation. Rather, an integrated view of how changes in demand and supply affect electric capacity adjustments, fuel and emissions markets is also important to understanding the determinants of displaced emissions. Such an integrated view is a more accurate reflection of the forward-looking tendencies of electricity markets: they adjust to both short-term changes through generation and also respond to anticipated long-term impacts through deeper changes in capacity and fuel. Additionally, an integrated view of power markets is important because examining one or a class of units in isolation cannot fully explain emission changes. A change in the behavior of even a single unit in the market will likely have ripple effects through electric, fuel and emission allowance prices and lead to further adjustments in generation mix, capacity choices and inter-regional power trades. Since a multitude of factors constantly interact to affect the change in emissions from displaced generation, the ADER approach takes an integrated view of power markets in establishing the primary determinants of displaced emissions.

The operation of power markets in the context of the impacts of energy efficiency and CET are discussed in the next section.

B. Power Market Operations

The electric power market in the United States consists of multiple regional power markets. These markets are highly interconnected, with significant power flows across regions and where a change in one region often affects electric markets in surrounding regions. Much of the inter-regional power flow originates from the fact that there are substantial differences across regions in capacity and generation mix, fuel cost, environmental regulations, transmission capabilities and other physical operation limitations. These differences are visibly highlighted by the differences in wholesale electricity prices across the power markets. In addition to electric system differences across power markets, regions also differ significantly in electricity demand patterns and electricity supply options. Some parts of the country, for instance, have significant weather-dependent peaks in electricity demand, while other regions exhibit more stable demand across seasons. Such regional variations are even larger on the supply side. The western US, for instance, has significantly more resource availability for wind capacity than any other region in the country.

The interconnected nature of power markets along with the regional variations makes geographic location an important dimension for analysis of displaced emissions. In understanding displaced emissions, it is not enough to know that energy efficiency or CET displaces some generation. It is important to understand which power market bears the first order impacts and how the response filters through connected power markets.

Fundamentally, power markets serve to equate electricity demand with the supply of power from operating plants in a least-cost manner. Supply decisions in the market are based on two major

components: generation, or dispatch, and capacity expansion. Dispatch decisions are based on the variable operating cost. The plants with the lowest variable cost will be dispatched before the higher-cost units. Such economic dispatch, however, is subject to the physical, resource and operational constraints on the system. Such constraints may include transmission congestion, ramp-up time and cost, fuel availability and environmental regulations.

While the economics of generation or dispatch are based on variable operating cost, capacity decisions are based on the fixed (capital, operational and maintenance costs) of the plant along with projected future plant utilization. Capacity decisions, which can consist of retrofits to existing units or addition of new plants, often require a longer period to implement. Despite the differences in the nature and economics of capacity and dispatch decisions, power markets involve simultaneous decisions on both issues. Any changes in demand or supply invariably lead to adjustments to both capacity and dispatch, as generation owners seek out the least-cost method to respond to those changes.

Since displaced emissions from energy efficiency and CET arise from changes in market, the ADER methodology relies on the power market based determinants of displaced emissions. The determinants of displaced emissions are discussed more fully in the following section.

C.   Determinants of Displaced Emissions

A large number of diverse measures and technologies currently exist for energy efficiency and the production of clean power. Each measure possesses unique operating characteristics, so estimating displaced emissions by modeling each and every type of energy efficiency measure or CET is not analytically feasible. The ADER methodology presents an alternative approach, one that allows for application across a variety of measures and technologies. The broad applicability of the ADER methodology derives from the fact that the ADER parameters are not estimated based on any specific measure, technology, or program. Rather, the ADER parameters are based on the primary determinants of displaced emissions, which can consequently be applied to the entire range of energy efficiency and CET.

The common elements that influence displaced emissions include the following:
1) Generation and capacity changes in power markets;
2) Location and regional interactions; and
3) Duration, durability and magnitude of impact.

Generation and Capacity Changes in Power Markets

Regional power markets simultaneously adjust generation and capacity in response to changes in demand or supply. While the change in electricity supply may come from the marginal generating unit, it is not always the case. The change in generation may just as easily come from the unit that is not the marginal generation unit because changes in generation are often accompanied by changes in capacity. The change in capacity may take the form of a plant altering its decision to install a particular pollution control or alter a decision on new capacity. Capacity changes are most pronounced in the long term where there is more flexibility in making these types of adjustments. In addition, there are operational and/or physical constraints, such as cycling restrictions that make it too expensive for units to switch on and off, that limit which units may alter their generation patterns. Because of the interdependence of capacity and generation in power markets, it is important that any analysis of displaced emissions examine both simultaneously.

The emission impacts of energy efficiency and CET will be highly dependent on the characteristics of the displaced generation unit(s) or units. More often than not, the displaced generation will typically consist of a set of units rather than one identifiable unit whose characteristics can be easily

identified. Furthermore, the set may consist of units with very different characteristics, such as coal-fired and gas-fired combustion turbine units. Consequently, any method that seeks to examine displaced emissions must examine the entire emission impacts on the electric power system rather than a few units or types of units.

Location and Regional Interactions

As noted earlier, regional electricity markets are highly integrated. Electricity transmission flows therefore become an important consideration when estimating the emission impacts of energy efficiency and CET. In many cases, the emission impacts of CET and energy efficiency will extend beyond the region in which those technologies or programs are implemented. In some cases, the impacts may even occur primarily in other regions. This is because the interconnected nature of power markets will often cause changes in one region to have spillover effects in neighboring or further away regions as the entire power system adjusts to the new levels of demand and supply. Though the inter-regional impacts are largely based on transmission flow changes, they may also be motivated by changes in common factor input price such as such fuel or emission allowances. Consequently, the analysis of displaced emissions must not only examine the region where the energy efficiency program or CET is implemented but also related impacts in all other regions.

Duration (Timing), Durability and Magnitude of Impact

Displaced emissions depend fundamentally on when the impact from efficiency or CET occurs. This is because power markets respond differently at different times of the year and even in different hours of the day. For instance, the response of power markets to changes in demand during peak summer hours will be different from the response during non-peak winter hours. Power markets clear on an hourly basis and the composition of units in service at any one time varies significantly over the year. This is particularly relevant for energy efficiency and clean energy since these programs and technologies do not share the same hours of operation. A single estimate of displaced emissions applied uniformly across all technologies or programs fails to capture the full flavor of the time-sensitive impacts. Efforts to estimate displaced emissions from energy efficiency and clean energy technology, therefore, must account for such time-sensitive variations in power markets.

An issue often overlooked but important to the analysis of displaced emissions concerns the durability of demand/supply changes introduced by energy efficiency and CET. Displaced emissions are affected by whether or not the change is sustained. A temporary reduction in demand will likely invoke short adjustments in generation, while a sustained demand reduction may cause long-term adjustments involving generation and capacity. The degree of foresight may have a similar effect, with significant advanced knowledge of anticipated energy efficiency measures or CET operation often leading to long-term adjustments in capacity and generation.

The magnitude of energy efficiency and CET penetration can have a major effect on total emissions since it significantly affects the mix of units that are displaced by energy efficiency or CET. For example, if the penetration of energy efficiency or CET is high, the displaced units may consist of a broader mix of different types of generating units. Changes of smaller magnitude, however, are likely to affect a smaller range of generating units.

D.   Existing Methodologies

Several different methodologies have been developed and employed in the past to estimate the emissions displaced by energy efficiency measures and CET development. Although there are many variations of such methodologies, all these methods derive from the average emission rate method, the marginal unit method, or historical emissions/generation data.

Average Emission Rate Method

One of the most common approaches to estimating displaced emissions is to use the average emission rate of electricity generating units in a particular region or nationally. In this approach, the average emission rate is applied to the total displaced generation (energy saved) to obtain the emissions impact. The average emission rate may be based on the average emission characteristics of all electricity generating units or fossil-fired units (coal, oil, and natural gas) only. Average emission rates are often obtained from historic generation and emissions data, or are based on projections of future generation and fuel use patterns.

Simplicity is the most alluring quality of the average emission rate method since it provides a simple, straightforward way to estimate emissions impacts. Average emission rates are readily available, so complex computations are not required. Despite the simplicity, the approach suffers from a major drawback since it ignores the notion of displaced units entirely. There is little or no correlation between the average emission rate and the emission rate at which the emissions are displaced by energy efficiency measures or CET development. As a result, estimates of the emission impacts are likely to be inaccurate and do not adequately reflect the realities of power markets.

Marginal Unit Method

The marginal unit method attempts to improve on the average emission rate approach by identifying a particular unit or type of unit that may be displaced by energy efficiency measures or CET development. Similar to the average emission rate method, the average emission characteristics of the displaced units or type of units are applied to total electricity saved to estimate displaced emissions. This approach includes the assumption that at any point in time, the marginal unit, by virtue of being the most expensive generating unit to operate, will be the unit that is displaced.

While this approach may conceptually appear to be more reasonable than simply using an average emission rate, it also has several disadvantages. Identifying the marginal unit is a difficult task, particularly in regions with large or frequent variations in hourly electricity demand. Even when the high cost unit can be identified with reasonable certainty, that unit may not always be the unit displaced, or it may be only one of several units that are displaced. Further, it is difficult to derive the hourly marginal unit for all the different regions in the country. In addition, like the average emission rate approach, marginal unit rates are generally not forward-looking and therefore do not provide the best index for forecasting future emission impacts.

Approaches Based on Historic Emissions/Generation Data

Displaced emissions can also be estimated using statistical techniques based on historical data. Rather than identifying the average or marginal emission rate of particular units, this approach seeks to forecast how displaced emissions arise from observed changes in electricity demand/supply. Data most relied upon for such estimation often includes regional generation, emissions, and electricity demand.

In addition to the computational difficulty and data availability problems, there are broader limitations related to the use of historic data. Not only is historic data unlikely to provide accurate estimates for future displaced emissions, the approach fails to explicitly account for the links between displaced emissions and future changes in power markets.

III.   THE AVERAGE DISPLACED EMISSION RATE (ADER) APPROACH

A.   Definition

The *average displaced emission rate* (ADER) method proposed in this paper provides a more flexible and robust methodology for estimating displaced emissions from energy efficiency and clean energy technology. The *average displaced emission rate*, or ADER, is a parameter that measures the total change in emissions (displaced emissions) for each (kWh) change in electric demand/supply. ADER parameters are expressed in units of pounds of emissions displaced per kilowatt-hour (kWh) of electricity saved and are developed for emissions of CO_2, NO_x, SO_2, and Hg.

The ADER approach does *not* calculate displaced emissions directly. Instead, ADER is a set of parameterized emission rates that describe the relationship between generation saved (or displaced) and emissions displaced. These displaced emission rates (or ADER parameters) are defined by year, US geographic region, emission type (i.e., SO_2, NO_x, CO_2 and Hg) and impact duration (i.e., season, day and hour type). While the parameters can be updated regularly as more/new data become available or if more specificity is required in the estimates, new parameters are not required each time emission benefits of a different energy efficiency or CET measure needs to be estimated. Since the ADER parameters take into account the primary variations in the performance, operation and penetration characteristics of different energy efficiency and CET, the parameters can be applied to the total electricity saved or generated (measured in kWh) of *any* energy efficiency or CET to estimate displaced emissions.

B.   ADER Methodology: Key Features

The ADER approach for estimating displaced emissions addresses many of the potential shortcomings inherent in other methodologies. In particular, ADER is a detailed and robust approach that takes into the account the complex interactions of US power markets. Since estimates of ADER parameters are derived from simulations of energy efficiency and/or CET using an integrated model of electric power markets, the approach captures the full complexity of power markets. Use of an Integrated Power Market (IPM) model ensures that the estimated parameters reflect the simultaneous changes in electric capacity and generation along with the related impacts from fuel and emission markets. The model is also dynamic and the ADER parameters capture the inter-temporal interactions in power markets. Furthermore, since a national model is used, the estimated parameters reflect the impacts arising from adjustments in inter-regional power flows. In fact, the best analytical feature of the ADER approach derives from its grounding in the integrated analysis of power markets.

The ADER approach is not estimated with any specific energy efficiency or CET in mind but is designed to be applicable across all programs and technologies. The flexibility in this approach is based on the fact that ADER parameters are dependent on the factors important to displaced emissions. For instance, different energy efficiency and CET programs are unique in the hours during which they operate. Some efficiency measures, such as air conditioners, run only during the summer months, while others, such as exit sign lighting, operate year round. The air-conditioner and exit sign lighting program will lead to different amounts of displaced emissions since power markets will adjust different to those two changes in demand. To account for this variation across programs and technologies, ADER parameters depend on a number of factors important to displaced emissions.

The ADER parameters proposed in this paper are a function of hour types (season, day and hour) and region and are developed for unique combinations of hour types and region. Once the pattern of operation and region of penetration of the energy efficiency measure or CET is identified, the associated ADER parameters can be readily applied to electricity displaced by the program or technology to derive an estimate of displaced emissions. The ADER approach has two components: (1) Estimation of ADER

parameters, and (2) procedure for application of ADER parameter. The estimation and procedure for application of ADER are discussed below.

C.   Estimating ADER Parameters

ADER parameters are estimated using ICF's Integrated Planning Model (IPM), a linear programming model that simulates economic activity in electricity, fuel and emissions markets. It has been extensively used by the US EPA, industry, other governmental and non-governmental agencies in analyzing power markets, air emission changes, incremental electric power system changes, changes in fuel use and price and other impacts of various approaches to air pollution control. The model relies on an extensive set of user input data and assumptions characterizing the power system, fuel prices, environmental regulations and economic parameters.

This estimation of ADER parameters are developed using IPM and the assumptions developed by the Clean Air Markets Division (CAMD) of the US EPA for their EPA Base Case 2000. The EPA Base Case 2000 includes detailed data and assumptions on electric system operation, electric supply options, environmental regulations and economic (including financial) parameters and is used for analysis of air regulations, regulatory support and power market analysis through IPM. Detailed documentation of the EPA Base Case 2000 can be found at http://www.epa.gov/airmarkets/epa-ipm/. However, since the EPA Base Case 2000 includes assumptions on projected electricity demand savings of the U.S. Climate Change Action Plan (CCAP) and one of the objectives of the analysis is to estimate displaced emissions of programs under CCAP, ADER parameters will use assumptions developed for the EPA Base Case 2000 but will include pre-CCAP electricity demand assumptions. As described later in this section, the change to EPA Base Case 2000 demand assumptions represents an effort to select the best reference point for estimating ADER parameters. Estimating ADER parameters with CCAP demand reductions already in place may not provide the best reference point estimation of ADER parameters that could be used to project displaced emissions from energy efficiency and CET that might be part of the CCAP effort.

ADER parameters estimated using IPM by examining how the electric sector emissions change when electricity demand is reduced or clean energy is introduced. The parameters are calculated as the ratio of displaced emission projected from IPM and displaced generation input into the model. Each region is analyzed separately, in that the displaced generation input into the model is specific to a region and captures a unique combination of season and hour type. Though the inputs apply only to one geographic region at a time, the parameter captures the impact for all regions. ADER parameters will be estimated for SO_2, NO_x, CO_2 and Hg emissions. Details of geographic regions, seasons, hour types and levels of displaced generation used for the estimation of ADER parameters through IPM are discussed further in the sections below.

Geographic Region

The data and assumptions that are contained in the EPA Base Case 2000 and are used in estimating ADER parameters in this analysis model the contiguous US as 26 separate power market regions. Though the IPM simulations will use all 26 model power market regions, ADER parameters will be reported for five geographic regions. Although each of the power market regions could be reported separately, five US geographic regions are used to minimize the number of simulations required.

As shown in Figure 1, five geographic regions in the continental United States will be used: Northeast, Southeast, Midwest, Texas, and West. The geographic regions are based on broader power market regions.

Figure 1. Geographic Regions for ADER Methodology.
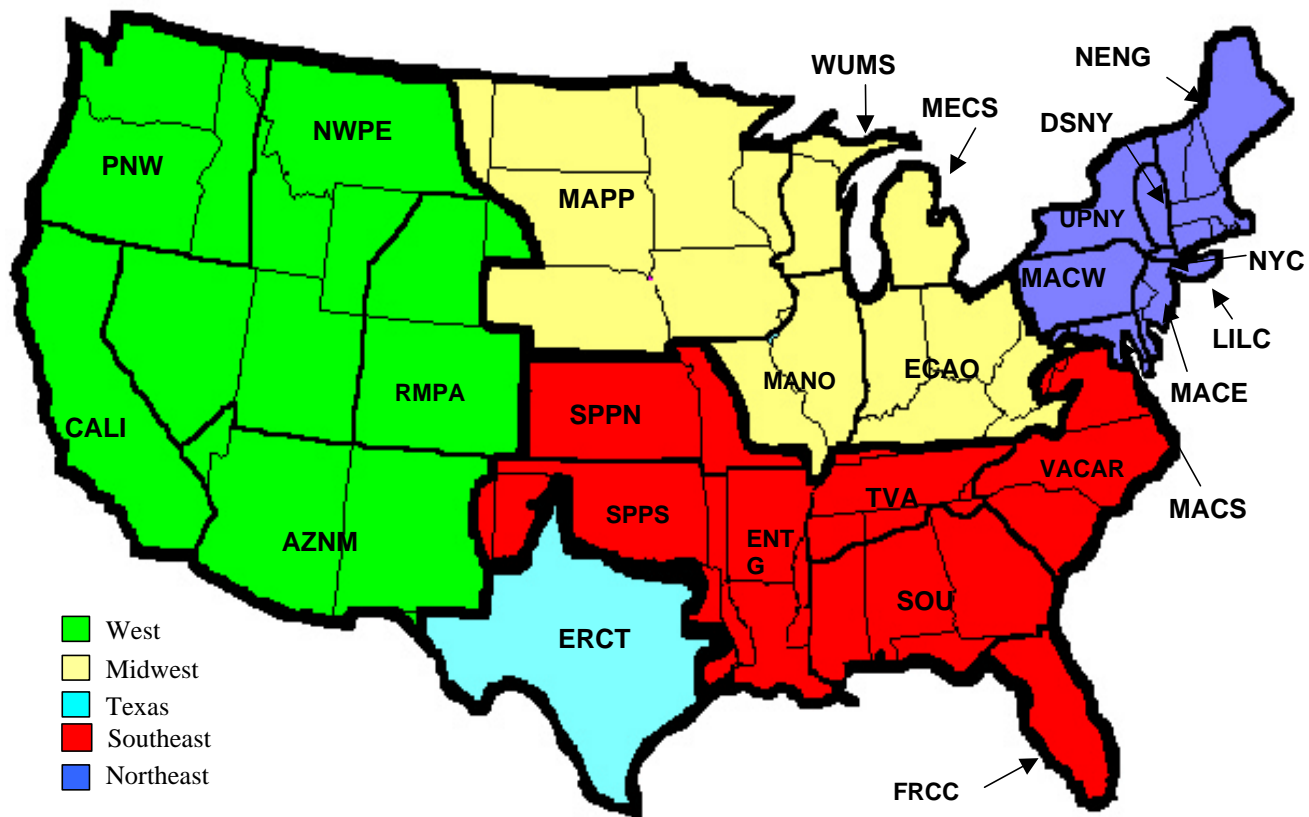
Seasons

The data and assumptions in EPA Base Case 2000 divides each year into two seasons, the ozone (summer) and the winter season. The ozone season is defined as the months May through September and winter includes the remaining seven months.

Hour Types

Ideally, for any year, the IPM approach would contain 8760 single hour type and over 3 million unique combination hour types. However, all the unique single and combination hour types cannot be used since it would require an unworkable number of simulations. To minimize the number of simulations, the entire set of unique hour types are grouped into 11 different hour types. These hour type separations are based on the following:
1) Two seasons, and

2) Three typical 24-hour days for each season representing weekday, weekend, and peak day.

Although 144 (2 seasons * 3 days per season * 24 hours per day) different hour types are still possible with the two seasons and three different 24 hour day types per season, they are further reduced to 11 different hour types for analytical ease. These 11 different hour types are implemented in the estimation of ADER parameters. Figure 2 below represents the hour types used.

Figure 2. Hour Types Used For ADER.

	Winter			Summer		
	Weekday	Peakday	Weekend	Weekday	Peakday	Weekend
12 AM - 1 AM	1	1	1	6	6	6
1 AM - 2 AM	1	1	1	6	6	6
2 AM - 3 AM	1	1	1	6	6	6
3 AM - 4 AM	1	1	1	6	6	6
4 AM - 5 AM	1	1	1	6	6	6
5 AM - 6 AM	4	4	1	9	9	6
6 AM - 7 AM	4	4	1	9	9	6
7 AM - 8 AM	2	2	5	7	7	10
8 AM - 9 AM	2	2	5	7	7	10
9 AM - 10 AM	2	2	5	7	7	10
10 AM - 11 AM	2	2	5	7	7	10
11 AM - 12 PM	2	2	5	7	7	10
12 PM - 1 PM	3	3	5	8	8	10
1 PM - 2 PM	3	3	5	8	8	10
2 PM - 3 PM	3	3	5	8	8	10
3 PM - 4 PM	3	3	5	8	8	10
4 PM - 5 PM	3	3	5	8	8	10
5 PM - 6 PM	3	3	5	8	8	10
6 PM - 7 PM	3	3	5	8	8	10
7 PM - 8 PM	4	4	5	9	9	10
8 PM - 9 PM	4	4	5	9	9	10
9 PM - 10 PM	4	4	5	9	9	10
10 PM - 11 PM	1	1	1	6	6	6
11 PM - 12 AM	1	1	1	6	6	6

Hour Block 11

The 11 different hour types provide a reasonable representation of the unique time periods within which all energy efficiency and CET installations might be expected to operate. For instance, an efficient residential appliance, such as a television, might be expected to operate in blocks 4,5, 9 and 10 and, therefore provide electricity savings only during those times. So long as the impacts of an energy efficiency program or technology can be distributed to the 11 different hour blocks presented in Figure 2 above, the ADER parameters can be used to estimate displaced emissions from that program or technology.

Magnitude of Electricity Savings Used to Estimate ADER

The estimated ADER parameters may depend on the magnitude of electricity savings since average displaced emission rates are a function of the composition of the types of units displaced. Furthermore, the composition of units displaced will likely change with the level of generation displaced. For instance, a 10% decline in electricity demand may displace only gas-fired units while a higher decline in electricity demand may lead to a mix of coal and gas-fired units being displaced. Both cases would lead to a different displaced emission rates. Ideally, ADER parameters should be a function

of the magnitude of generation displaced. However, to keep the analysis manageable and recognizing that further improvements in ADER estimation are likely, the ADER parameters for this analysis are estimated for only one level of displaced generation. It is worth noting that the approach described in this paper is flexible and could allow for ADER that are a function of the magnitude of displaced generation.

For this analysis, ADER parameters are estimated for demand reductions that are projected to result from programs under the CCAP. Projected CCAP demand savings were selected for ADER estimation since most users of this approach are likely to be interested in analyzing displaced emissions from electricity savings that are in the bandwidth of savings around CCAP levels.

Selected Illustrative ADER Parameters

Two illustrative sets of selected parameters are presented in Table 2 below. As noted in the discussion above, the matrix of ADER parameters will be defined for:
- Five Geographic Regions – Northeast, Midwest, Southeast, Texas and West,
- 11 Hour Blocks,
- Four pollutants – SO_2, NO_x, CO_2 and Hg, and
- Three years - 2005, 2010, 2015.

Table 1 presents illustrative ADER parameters for a subset of the entire matrix, i.e. for penetration in the Northeastern region, hour blocks 4 and 9, CO_2 and 2005.

Table 1. Illustrative CO_2 ADER Parameters for Hours Block 4 and 9 for Penetration in the Northeast 2005.

Geographic Region	ADER Parameters for CO_2 in lbs/kWh	
	Hour Block 4	Hour Block 9
Northeast	-0.78	-0.85
Midwest	0.11	0.21
Southeast	-0.03	-
Texas	-0.007	0.01
West	-	-

Once the entire matrix of ADER parameters has been estimated, they can be applied to the full range of energy efficiency or CET to estimate the resulting displaced emissions. The total emission impacts are estimated based on the penetration level and operational characteristics of the energy efficiency measures or CET in a given region. This calculation procedure for application of ADER parameters is detailed in the next section.

D.   Estimating Displaced Emissions Using ADER Parameters

The second component of this methodology involves the application of the ADER parameters described above to the electricity saved or displaced by energy efficiency or CET. The application of ADER parameters requires that the energy efficiency measure or CET be defined using the following characteristics:

- Performance: Total electricity generation (in kWh) avoided or displaced by energy efficiency or CET. It is worth noting that what is required here is not total electricity consumed by the measure, but rather the electricity savings realized relative to a baseline measure (i.e., one that is

less energy efficient). For example, an energy efficient residential air-conditioner may use 1,000 kWh of energy, but may save only 100 kWh relative to a less efficient one.

- Operation: Distribution of the total displaced or avoided electricity to applicable hour blocks. For example, the 100 kWh of avoided electricity generation from an air conditioner might be apportioned to hour blocks 9 and 10 in the following ways: Hour block 9: 30 kWh and Hour block 10: 70 kWh.

- Penetration: The geographic region in which the energy efficiency or CET is implemented. For example, the energy air-conditioner might be used in Northeast.

The performance, operation and penetration characteristics (based on items 1-3 above) are used to identify the associated ADER parameters. In the case of the stylized air-conditioner, for example, the associated ADER parameters would be for hour blocks 9 and 10, for the Northeast. The associated ADER parameters are then applied to electricity displaced or saved in each of the hour blocks to derive total displaced emissions. For example, in the case of the air conditioner, the ADER parameters for hour block 9 would be applied on 30 kWh and ADER parameters for hour block 10 would be applied on 70 kWh to derive total displaced emissions as the sum of displaced emission from the two different hour blocks.

In essence, the application of ADER parameters to any energy efficiency and CET involves three steps:
  Step 1: Specify performance, operation and penetration characteristics;
  Step 2: Select ADER parameters; and
  Step 3: Apply ADER parameters to estimate displaced emissions.

The remainder of this section details the procedure for applying ADER parameters using an example of an energy efficient television. The example is purely illustrative and is not based on modeling or analysis. In addition, the illustration is limited to estimates of displaced CO_2 for 2005, though estimates from this analysis would also be generated for SO_2, NO_x and Hg and also for years 2010 and 2015.

Step 1: Specify Performance, Operation and Penetration Characteristics

The first step in applying the ADER parameters in order to estimate displaced emissions is to determine the performance, operation and penetration characteristics for the program or technology in question. For this example, we assume an energy-efficient household television in the Northeast that is set to begin operation in 2005. The performance, operation and penetration characteristics assumed for this example are described below.

Technology: energy-efficient household appliance (Television)
Region: Northeast
Year Introduced: 2005
Total Energy Saved: 1,000 kWh
Hours of Operation: Year Round -
            Winter Weekdays 5AM – 7AM, 7 PM – 10 PM: Hour Block 4
            Winter Weekends 7AM – 10 PM: Hour Block 5
            Summer Weekday 5AM – 7AM, 7 PM – 10 PM: Hour Block 9
            Summer Weekend 7AM – 10 PM: Hour Block 10

In this step, the total energy saved by the television needs to be apportioned to the four different hour block in which it operates. In this example, the energy saved is apportioned uniformly to

the hour blocks based on the number of hours in each block. Figure 3 highlights the assumed energy saving by hour blocks.

Figure 3. Electricity Savings by Hour Blocks.

**Electricity Savings per Hour Block**
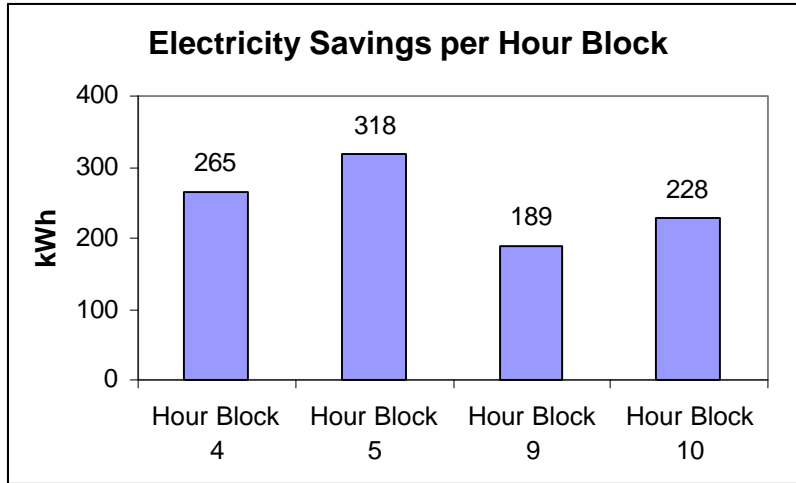
Step 2: Select ADER Parameters

The next step involves selecting the relevant regional ADER for the technology. Since the television is being used in the Northeast and affects hour blocks 4, 5, 9 and 10, the related ADER parameters are selected. The relevant ADER parameters for each of the hour blocks are described in Figure 4 below.

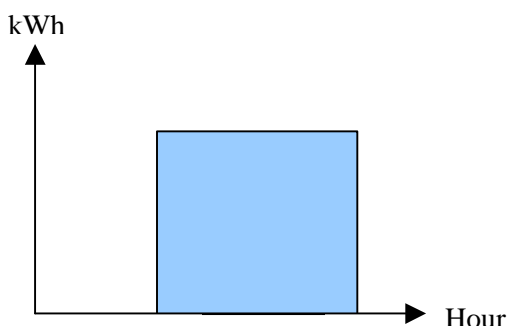**Figure 4.** Selection of ADER Parameters by Hour Block.

Hour Block 4, Winter Weekday, Peak Day
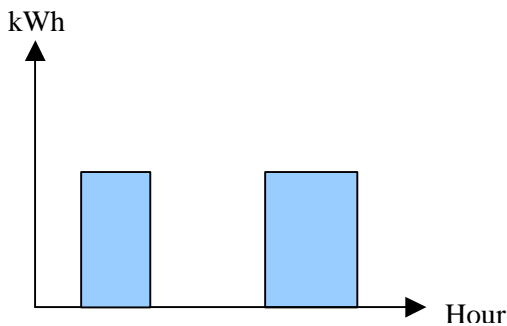
CO_2 ADER Parameters

Geographical Region	lbs/kWh
Northeast	-0.75
Midwest	0.21
Southeast	-0.02
Texas	0
West	0

Hour Block 5, Winter Weekend

CO_2 ADER Parameters

Geographical Region	lbs/kWh
Northeast	-0.82
Midwest	0.18
Southeast	-0.03
Texas	0
West	0

Hour Block 9, Summer Weekday, Peak Day

kWh
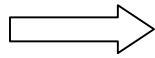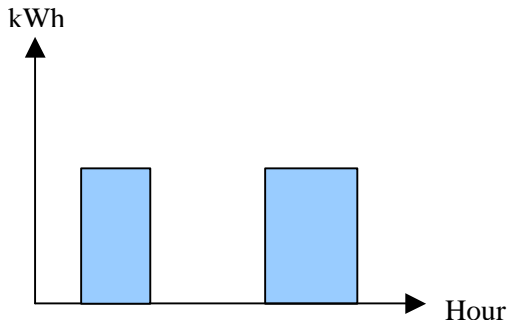
CO$_2$ ADER Parameters

Geographical Region	lbs/kWh
Northeast	-0.71
Midwest	0.25
Southeast	-0.01
Texas	0
West	0

Hour Block 10, Summer Weekend

kWh
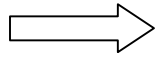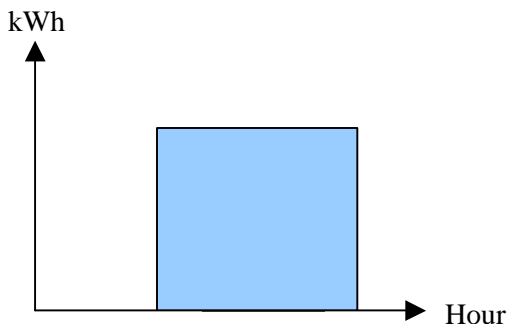
CO$_2$ ADER Parameters

Geographical Region	lbs/kWh
Northeast	-0.87
Midwest	0.15
Southeast	-0.03
Texas	0
West	0

As illustrated in Figure 4, each hour block is associated with a set of ADER parameters, which describe the change in emissions (in lbs/kWh) for all regions. In hour block 5, for instance, a unit of displaced generation in the Northeast will lead CO_2 to be displaced at the rate of –0.75 lbs/kWh in the Northeast. The displaced generation in the Northeast might also affect other regions and, as illustrated in Figure 4 and each set of ADER parameters describes the displaced emission rate for all regions.

Step 3: Apply ADER parameters to Estimate Displaced Emissions

Once the relevant ADER parameters have been selected for each hour block, the total displaced emissions are estimated from the generation avoided or displaced in each hour block. The procedure is illustrated in Table 2.

Table 2. Illustration of Procedure for Applying ADER Parameters to Displaced Generation.

	Hour Block	Hour Block	Hour Block	Hour Block	Total
Electricity (kWh	265	318	189	228	100
Displaced Emissions (lbs) By Region					
Northeast	-0.75*265 = -199	-0.82*318 = -261	-0.71*189 = -134	-0.87*228 = -198	-792
Midwest	0.21*265 = 56	0.18*318 = 57	0.25*189 = 47	0.15*228 = 34	194
Southeast	-0.02*265 = -5	-0.03*318 = -10	-0.01*189 = -2	-0.03*228 = -7	-24
Texas	-	-	-	-	-
West	-	-	-	-	-
Total	-148	-213	-89	-171	-621

Under this example, with an assumed electricity savings of 1,000 kWh, 621 lbs of CO_2 are displaced nationally. While 792 lbs are displaced in the Northeast and 24 lbs are displaced in the South, the increase of 194 lbs in the Midwest partially offsets the national reductions.

III.   LIMITATIONS AND ISSUES FOR FURTHER CONSIDERATIONS

The ADER methodology provides an analytically sound and flexible method of estimating displaced emissions. However, the methodology needs to be understood and used in the context for which it was developed. The limitations described in this section are not technical limitations of the approach but instead reflect the trade-offs made in restricting the scope of the analytical effort. Many of the limitations could be addressed through additional simulations and/or data analysis.

The primary limitation of the ADER approach concerns the magnitude of penetration upon which ADER parameters are estimated. As noted earlier, the mix of displaced units, and therefore the resulting ADER parameters, varies with the magnitude of energy efficiency or CET penetration modeled. As mentioned earlier in the paper, ADER parameters will be estimated using the projected demand reductions from programs under the Climate Change Action Plan (CCAP). The resulting ADER parameters are, therefore, most applicable to the bandwidth of displaced generation similar to CCAP levels. The CCAP demand reductions were selected for this study because they provide a ready reference point for estimation of ADER parameters. However, alternate levels of demand reductions may yield different ADER parameters and lead to different estimates of displaced emissions. In general, the ADER parameters from this study will be most accurate for demand savings in the bandwidth of CCAP demand savings. This issue is not a technical limitation of the approach but reflects the decision to moderate the analytical requirements of the task. In theory, this limitation could be eliminated by making ADER parameters a function of magnitude. However, this would require additional IPM simulations and data processing; for each new level of magnitude approximately 55 additional simulations would be required.

Another limitation of the ADER approach concerns the use of multiple hour blocks in applying ADER parameters. For example, a technology that achieves electricity savings in hour blocks 1 and 2 uses the ADER parameters for hour blocks 1 and 2. Each hour block, however, is estimated assuming that all else is equal, i.e. in developing ADER parameters for block 1, the modeling does not see the simultaneous impact in hour block 2. The ADER parameters for hour block 1 may have been slightly different if the impacts in hour block 2 were also recognized. Similar to the issues of magnitude, this issue of simultaneity is not a technical limitation but reflects the need to maintain the analytical requirements of the task. This approach has used 11 different hour blocks, 10 of which are unique and hour block 11 is a combination of multiple hour blocks. These 10 unique hour blocks would have translated into 3.62 million unique combinations. Such an analysis is clearly infeasible.

Another possible limitation is that the selection of time blocks for ADER parameters are (of necessity) somewhat arbitrary and might not perfectly match load impacts of certain demand side or supply side measures—a necessary compromise to make computations manageable.

IV.   CONCLUSION

The average displaced emission rate approach provides a sound methodology for estimating displaced emissions. Unlike other approaches, ADER captures the complex operations of the US power market and the parameters are developed using an integrated analysis of power, fuel and emission markets. Parameters vary by geographic region, hour blocks, year and pollutant. ADER parameters can also be used to estimate displaced emissions from energy efficiency and CET that vary significantly in performance, operation and penetration characteristics. The ADER approach should prove helpful to industry, government and public interest in developing robust estimates of displaced emissions from energy efficiency and CET.

KEY WORDS

ADER
Displaced Emissions
Displaced Generation
Average Emissions rate
Emissions Benefits
Energy Efficiency
Clean Energy Technologies
Emissions Estimation
Marginal Emissions

ⁱ <u>Displaced generation</u>: The total electrical energy output, measured in kilowatt-hours (kWh), from conventional electricity sources that is either displaced by CET or avoided altogether through the implementation of energy efficiency measures.

ⁱⁱ <u>Displaced emissions</u>: The change in emissions, measured in pounds (lbs) or tons, that results when conventional electrical generation is displaced by energy efficiency or generation from CET.

ⁱⁱⁱ http://www.energystar.gov

^{iv} Although most CET have little or no emissions, some, such as biomass, have significant emissions of nitrogen oxides.

^v http://www.epa.gov/CHP/

^{vi} http://www.epa.gov/greenpower/

^{vii} http://epa.gov/lmop/

^{viii}Generic load shape impacts for five residential, five commercial, and an industrial technology are being developed along with the ADER parameter. These load shape impacts describe the hourly saving for a representative weekday, weekend, and peak day for each season. The load shape impacts will be developed for each of five EIA climate regions.