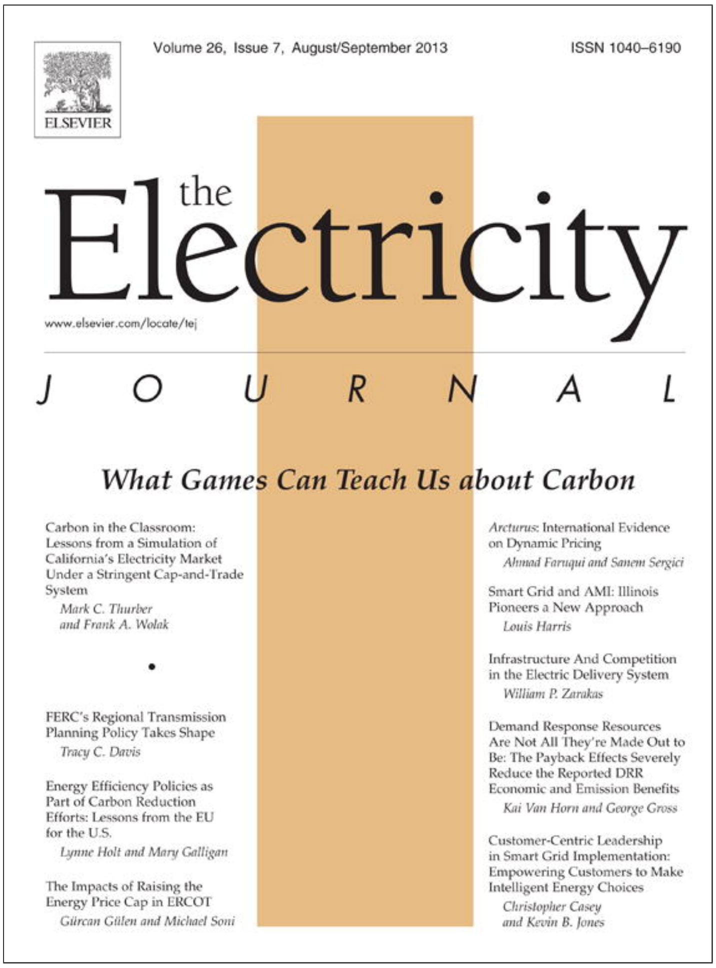
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Demand Response Resources Are Not All They're Made Out to Be: The Payback Effects Severely Reduce the Reported DRR Economic and Emission Benefits

While demand response curtailments result in lower loads, which reduce prices and emissions at specific nodes in the system during the curtailment hours, some portion of the curtailed energy is recovered in future hours, resulting in impacts on prices and emissions in those hours. The economic and emission impacts of energy recovery have important ramifications for DRR policy formulation.

Kai Van Horn and George Gross

I. Introduction

The objective of demand response (DR) is to make the load an active participant in balancing electricity system supply and demand around the clock. Participating consumers provide reductions in their electricity consumption by curtailing portions of their load in response to incentive payments designed to induce lower electricity consumption at specified times.[1] We focus on those loads that compete side by side with supply-side resources in the wholesale market and refer to them from

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here on out as DR resources (DRRs). DRRs evolved out of demand-side management programs initiated by vertically integrated utilities in the 1980s.[2] DRRs offer independent system operators and regional transmission organizations (ISOs and RTOs) an attractive alternative to the use of generation to meet the supply-demand balance without the need to invest in new supply-side resources and without additional pollution. DRRs are distinct from other demand reductions approaches: energy efficiency, energy conservation, and price-responsive load. Energy efficiency and energy conservation measures, such as the replacement of old appliances or the installation of additional building insulation, make a part of the load disappear permanently and so reduce energy consumption. Such measures result in reduced emissions and lower electricity payments. These measures, however, do not offer the system operator additional flexibility to balance supply and demand around the clock. Similarly, price-responsive load programs, such as time-of-use or real-time pricing, are considered as passive measures that use prices to limit consumption in line with the temporal willingness to pay off the loads. While DRRs, energy efficiency, energy conservation, and price-responsive load render various system benefits, only DRRs compete side by side with supply-side resources in the wholesale markets so as to make loads active participants in maintaining the supply-demand balance.

DRRs currently account for the majority of responsive demand capacity operating in wholesale markets.[3] While DRR curtailments result in load reductions in some hours, and the perceived price and emission reduction benefits, these load reductions are not permanent.

The perception of DRR curtailments as being purely beneficial has been the driving force behind the promotion of deeper DRR penetrations.

DRRs provide load modifications which may not reduce overall electricity consumption but rather shift electricity consumption from periods of high demand to those with lower demand — the so-called DRR payback effects.

DRRs have been championed by regulators, DR providers, environmental advocates, and other grid stakeholders for their associated economic and emission benefits. The CEO of Duke Energy, Jim Rogers, famously once asserted that ''the most environmentally responsible plant you build is the one that you don't build.''[4] Indeed, Mr. Rogers' comments equally well apply to electricity consumption and economics: the most environmentally responsible and cheapest MWh consumed is the one that is not consumed. The perception of DRR curtailments as being purely beneficial has been the driving force behind the promotion of deeper DRR penetrations. However, this characterization of DRRs totally ignores the energy recovery impacts. We find that the reported DRR curtailment benefits are not realized when DRR payback effects are taken into account.

Over the past decade, there has been a concerted effort to deepen the DRR penetration with federal policy initiatives such as the Energy Policy Act of 2005, the FERC Order Nos. 719 and 745 along with various state-level policy initiatives.[5] These policies require the consideration of DRRs as a competitive alternative to supply-side options for meeting the supply-demand balance and provide incentives for DRR participation. Indeed, the policies are effective in encouraging new DRRs to enter the electricity markets to compete side by side with supply-side resources. The 2011 FERC Order No. 745 requires that, whenever the threshold price criterion is met, DRRs which operate in ISO/RTO-run markets receive payment at the locational marginal price (LMP) for the *energy* avoided to be generated by the load curtailments. These incentives are in addition to the savings from the energy *DRRs* no longer purchased. In the months of 2012 after Order No. 745 was implemented, electric load reductions from DRR curtailments in PJM grew by nearly an order of magnitude over the same months in the previous year.[6] FERC estimates the achievable 2019 DRR capacity to be 4 to 14 percent, and the maximum technical potential to be 20 percent, of an ISO's annual peak load.[7] As of 2010, the capacity of DRRs as a percentage of peak load in ISO-run markets ranged from a low of 2 percent of the peak load in ERCOT and a high of 10 percent of the peak load in PJM.[8]

Studies have been conducted to both qualitatively outline and quantify the economic and emission impacts of DRR curtailments. Early studies qualitatively assessed the benefits of DRRs and recommend greater participation from DRRs.[9] Later studies quantified the DRR benefits.[10] DRR curtailments for 1 percent DRR capacity as a percentage of PJM peak load in the five-hour block of each of the 25 days with the highest prices in the PJM for 2005 reduced average prices by 5 to 8 percent in those peak hours.[11] The extrapolated results of this PJM study estimate the national-level annual increase in social welfare for 5 percent DRR penetration to be $5–10 billion.[12] While the impacts of DRR payback on the DRR curtailment benefits have been recognized[13], the studies discussed above do not consider the impacts of DRR payback effects in the assessment of the overall impacts of DRR curtailments. The use of DRRs is not without controversy. While DRRs are a means by which to correct the inefficiency which results from the lack of demand-side participation in wholesale electricity markets, the mandatory provision of incentives required by FERC Order No. 745 is often viewed as an unnecessary double payment, which creates new market inefficiencies.[14]

It is highly questionable whether all the reported economic and emission benefits of DRRs can actually be realized when DRR payback effects are taken into account.

In this work, we offer a quantitative assessment of DRR economic and emission impacts with energy recovery explicitly considered. We detail the diminishing returns of the DRR benefits and uneconomic outcomes which occur with deepening DRR penetrations when energy recovery is explicitly considered. Our assessment is based on representative cases from sensitivity studies carried out on two test systems using scaled 2010 load and offer data from the Midwest ISO (MISO) and the ISO-New England (ISO-NE) networks. This work makes highly questionable whether all the reported economic and emission benefits of DRRs can actually be realized when DRR payback effects are taken into account.

This article consists of three additional sections. In Section II we describe the nature of our sensitivity studies and our findings on the economic and emission impacts of deepening DRR penetration explicitly considering energy recovery. In Section III we interpret the findings from our sensitivity studies and discuss their impacts on policy initiatives. In Section IV we summarize our key findings and conclusions.

II. *DRR* Sensitivity Studies

We performed a wide range of studies under different scenarios and assumptions to assess the economic and emission impacts of DRR curtailments on different test systems. For the purposes of discussion here, we present representative results carried out on two test systems: a modified IEEE 57-bus test system with scaled 2010 load and offer data from MISO — the S_{57} system — and a modified IEEE 118-bus test system with scaled 2010 load and offer data from ISO-NE — the S_{118} system.[15] The offer and load profiles and the generation mix of each system is representative of the ISO from which the respective data are drawn. For this

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Table 1: The Generation Mix for Each Test System

Test System	Generation Capacity Percentage by Fuel Source				
	Nuclear	Hydro	Coal	Natural Gas	Oil
S_{57}	6	9	52	26	7
S_{118}	15	12	8	43	22

discussion, we limit our focus to a single year's duration in the various sensitivity studies that we examine.

In our studies, we investigate the impacts of DRR capacity in the range of 1 to 20 percent of the peak load, the range of DRR potential developed in the FERC DRR potential study.[16] For each penetration case, we consider DRR energy recovery in the range of 0 to 120 percent of curtailed energy. Since off-peak DRR curtailments are rare, we assume DRR curtailments only occur between the hours of 1:00 p.m. and 9:00 p.m. and only if the threshold price is met.[17] Furthermore, we assume energy recovery takes place between the hours of 12:00 a.m. and 1:00 p.m. and 9:00 p.m. and 12:00 a.m. on the same day the electricity is curtailed. To account for the fact that individual DRRs may not be available for curtailment in all the hours in which DRR curtailments are permitted, we consider three DRR utilization intensity scenarios. In these scenarios, individual DRRs provide two, four, or six hours of curtailment per day out of the eight possible hours, which we term low, medium, and high intensity utilization, respectively.

To facilitate the calculation of the CO_2 emissions in each case, we assume a price-based loading order. We assume nuclear units are the first to be loaded, since the operators of these units typically run them at full load unless they are offline for maintenance or a forced outage, followed by hydro units. Coal-fired units are assumed to be loaded third followed by natural-gas-fired units and oil-fired units based on the relative costs of their fuel sources. The ISO-representative generation mix used in each test system is shown in Table 1. We use CO_2 emission rates of 1.02, 0.51 and 0.76 tonness/MWh for coal, natural gas, and oil, respectively, to calculate the overall CO_2 emissions in each case.[18]

Our reference case for comparison is the system under consideration without DRRs. The average LMP (ALMP) and the average per MWh DRR profits are our basic metrics to assess the economic impacts of DRRs. The ALMP is defined as the total payments for purchased energy in the study period divided by the study period total purchased energy. The average per MWh DRR profits are defined as the total DRR profits minus the total value of energy not consumed plus the total DRR curtailment incentive payments minus the total payments for recovered energy, divided by the total purchased energy. Similarly, in the discussion of emissions, the average per MWh CO_2 emissions, defined to be the total CO_2 emissions divided by the total purchased energy, is our basic metric of comparison. The ALMP, average per MWh DRR profits and average per MWh CO_2 emissions, computed by dividing the average results by the total purchased energy, facilitates the comparison of the DRR economic and emission impacts in the various recovery cases despite changes in the total electricity consumption.

The DRR economic and emission impacts are system dependent and so we have selected two distinct systems which differ in the generation mix and consequently in the reference case price profile. The overall DRR economic impacts depend on the relationship between the electricity supply and associated economics in the curtailment and the recovery hours, the impacts of deepening DRR penetration level and the energy recovery percentage. We summarize the reference case curtailment- and recovery-hour ALMP for each of the test systems in Table 2.

The S_{57} and the S_{118} system curtailment- and recovery-hour ALMP differences indicate the extent of the arbitrage opportunity bandwidth in the system. This bandwidth impacts

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Table 2: Reference Case Annual Curtailment- and Recovery-Hour ALMP for the S_{57} and S_{118} System

Test System	ALMP (\$/MWh)		
	Curtailment-Hours	Recovery-Hours	Difference
S_{57}	62.23	54.56	7.67
S_{118}	78.14	55.38	22.77

the penetration at which buyer benefits are maximized — the level above which additional DRR capacity ceases to reduce the ALMP — and the penetration at which DRRs become uneconomic — the penetration above which additional DRR capacity raises the ALMP compared to the reference case ALMP. Our results on each test system demonstrate a range of arbitrage opportunities and generation mixes and are therefore representative of a broad array of systems. The S_{57} reference case ALMP is \$57.34/MWh and the S_{118} reference case ALMP is \$63.94/MWh. All reported DRR percent penetrations in our analysis are a percentage of the reference case peak load.

As a first step, we examine the case studies of economic impacts as the penetration level varies from 0 to 20 percent under different recovery energy percentages and DRR utilization intensities. **Figure 1** shows the reductions in the S_{57} system ALMP for a selection of DRR penetration levels and with different recovery percentage cases under low intensity utilization.

We note the reduction in the ALMP is less than 2 percent at most even in the cases with 0 percent energy recovery, which shows the limited impact of DRRs even absent the DRR payback effects for the S_{57} system. In the 0 percent recovery and 50 percent recovery cases the ALMP decreases as the DRR penetration deepens. However, when recovery of 80 percent or greater is taken into account, the ALMP decreases for penetration from 2 to 12 percent and for deeper levels the reductions are lessened. While, in the low utilization intensity scenario depicted in Figure 1, DRR curtailments are economic, the ALMP reductions are severely diminished by energy recovery. At 10 percent penetration, well within the FERC's achievable participation range, the ALMP reductions with 80–120 percent of the curtailed energy recovered are 40–70

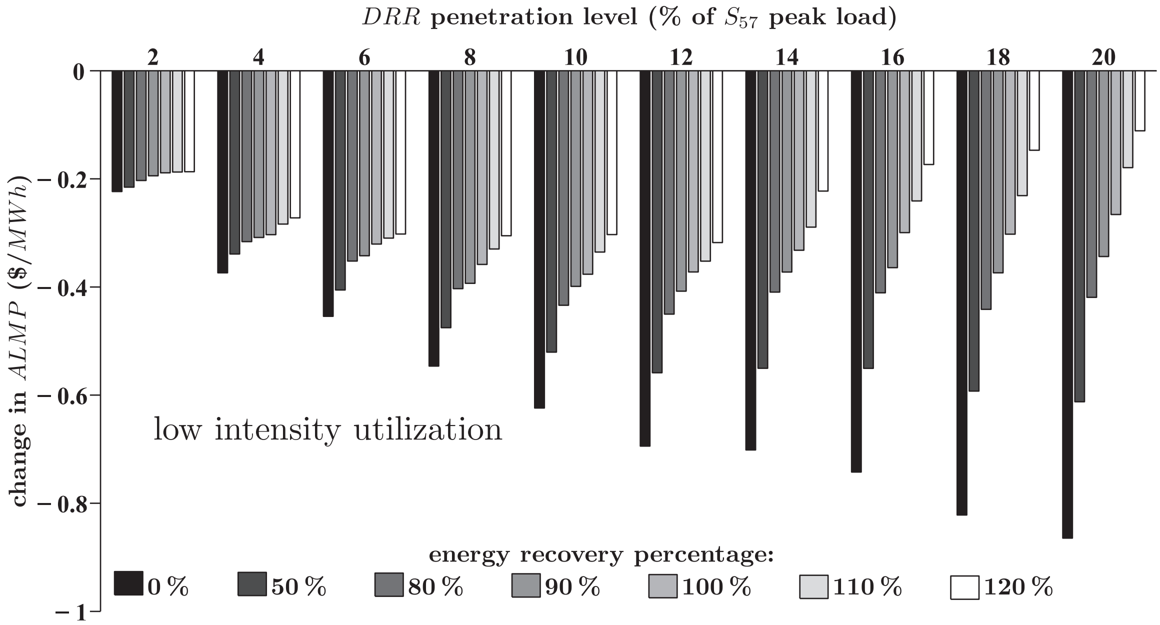

Figure 1: Changes in the S_{57} System ALMP under Deepening DRR Penetration Levels and with Different Energy Recovery Percentages under Low Intensity Utilization

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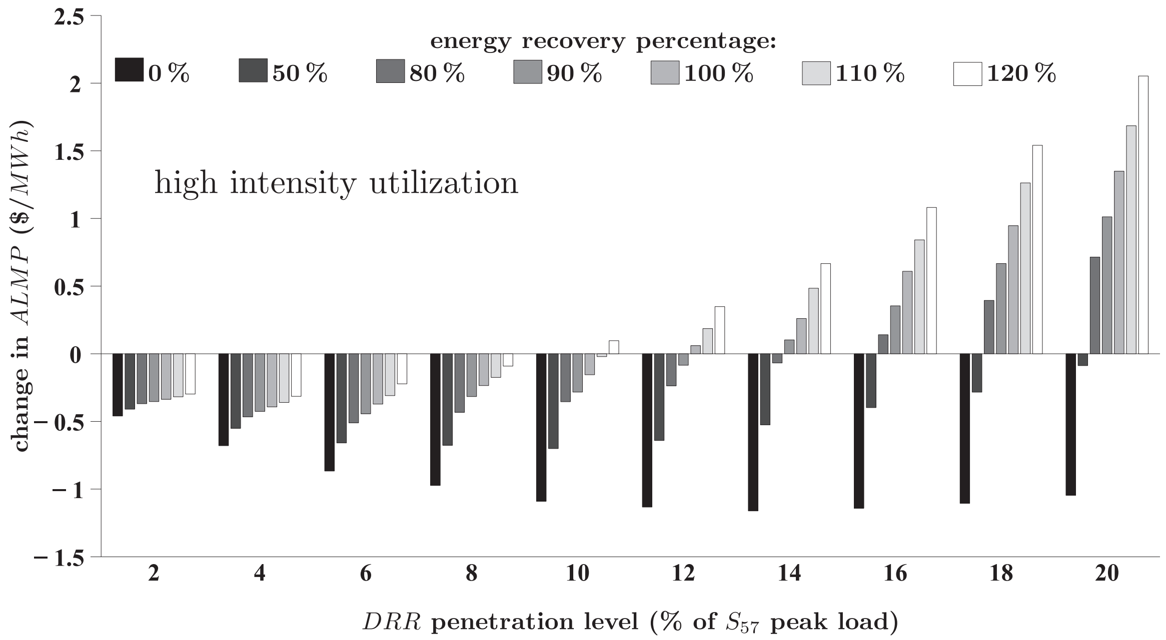

Figure 2: Changes in the S_{57} System ALMP under Deepening *DRR* Penetration Levels and with Different Energy Recovery Percentages under High-Intensity Utilization

percent of those for the respective 0 percent recovery cases. At the 20 percent penetration level, the ALMP reductions with 80–120 percent of the curtailed energy recovered are only 15–50 percent of those for the 0 percent energy recovery case.

The impacts of DRR energy recovery are even more pronounced under high-intensity utilization. Figure 2 shows the reductions in the S_{57} system ALMP for a selection of DRR penetration levels and with different recovery percentage cases under high-intensity utilization.

Under high-intensity utilization, the maximum ALMP reduction is attained at 14 percent penetration in the 0 percent energy recovery cases and no further reduction are realized above that level indicating there are no further benefits to the system at DRR penetrations deeper than 14 percent. Even at 50 percent energy recovery, the ALMP reductions are highest at 10 percent penetration. With energy recovery of 80–120 percent the ALMP reductions are maximized at penetrations as low as 4 percent and DRR curtailments become uneconomic for penetrations as low as 10 percent. At 10 percent penetration, the ALMP reductions with 80–120 percent of the curtailed energy recovered are 9–65 percent of those for the 0 percent energy recovery case. At 20 percent penetration, DRRs become uneconomic with 80–120 percent of the curtailed energy recovered and the ALMP increases by 1.2–3.5 percent above the reference case. In fact, at the 20 percent penetration level, the ALMP increase with 100 percent energy recovery is greater than the ALMP reduction with 0 percent energy recovery. Such an outcome underlines the important role of the energy recovery impacts in the assessment of the overall DRR economic impacts.

Figure 3 shows the reductions in the S_{118} system ALMP for a selection of DRR penetration levels and with different recovery percentage cases under high-intensity utilization.

As in the penetration cases for the S_{57} system low-intensity utilization scenario shown in Figure 1, the S_{118} system ALMP decreases with deepening DRR penetration with 0 or 50 percent energy recovery. However, the highest S_{118} system ALMP reduction with 0 percent energy recovery is close to 10 percent compared to less than 2 percent on the S_{57} system with 0 percent energy recovery. In the cases with 80 percent or greater energy recovery, the ALMP decreases for penetrations from

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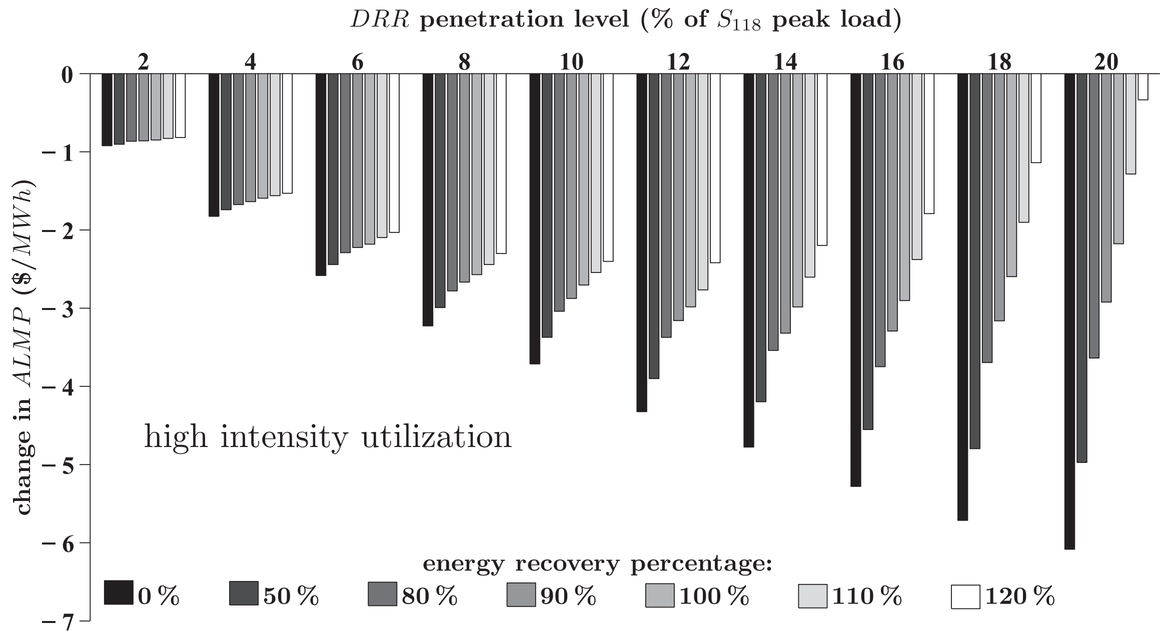

Figure 3: Changes in the S_{118} System ALMP under Deepening DRR Penetration Levels and with Different Energy Recovery Percentages under High-Intensity Utilization

2 to 10 percent for 120 percent recovery and 2–16 percent for 80 percent recovery above which the magnitude of the reductions declines. At 10 percent penetration the ALMP reductions with 80 percent or more of the curtailed energy recovered are 65–82 percent of those for the respective 0 percent recovery cases. At 20 percent penetration, the ALMP reductions with 80–120 percent of the curtailed energy recovered are only 6–60 percent of those for the respective no-recovery cases. Indeed, the ALMP reductions are nearly eliminated with above 100 percent of the curtailed energy recovery at the 20 percent penetration level and severely

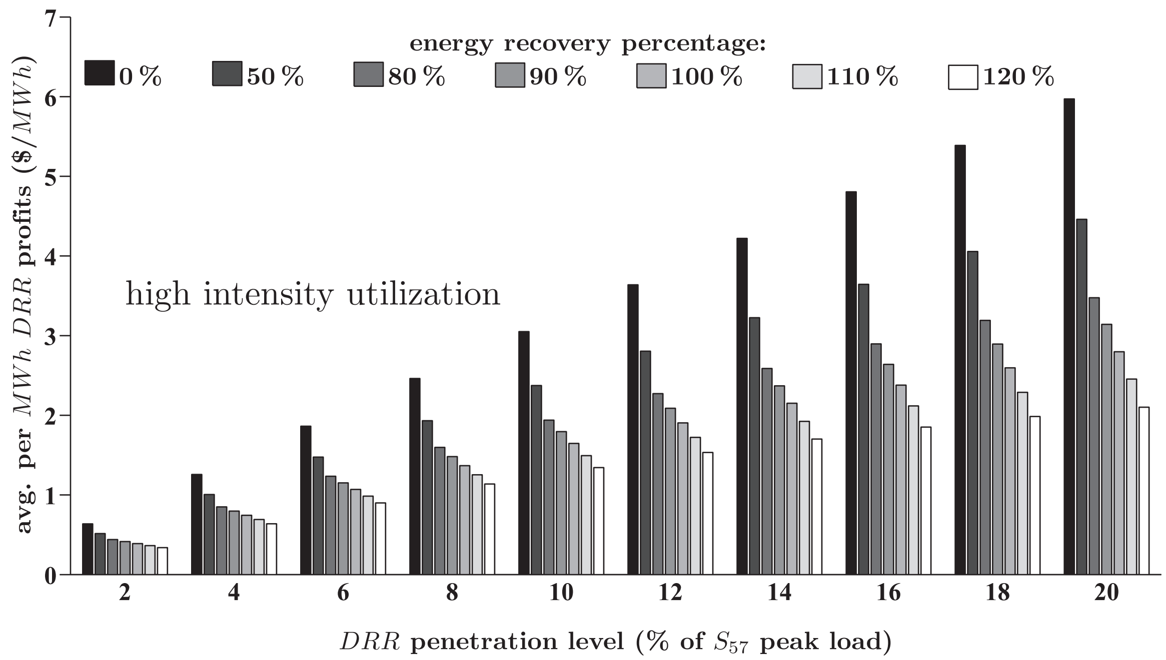

Figure 4: Changes in the S_{57} Average per MWh DRR Profits under Deepening DRR Penetration Levels and with Different Energy Recovery Percentages under High-Intensity Utilization

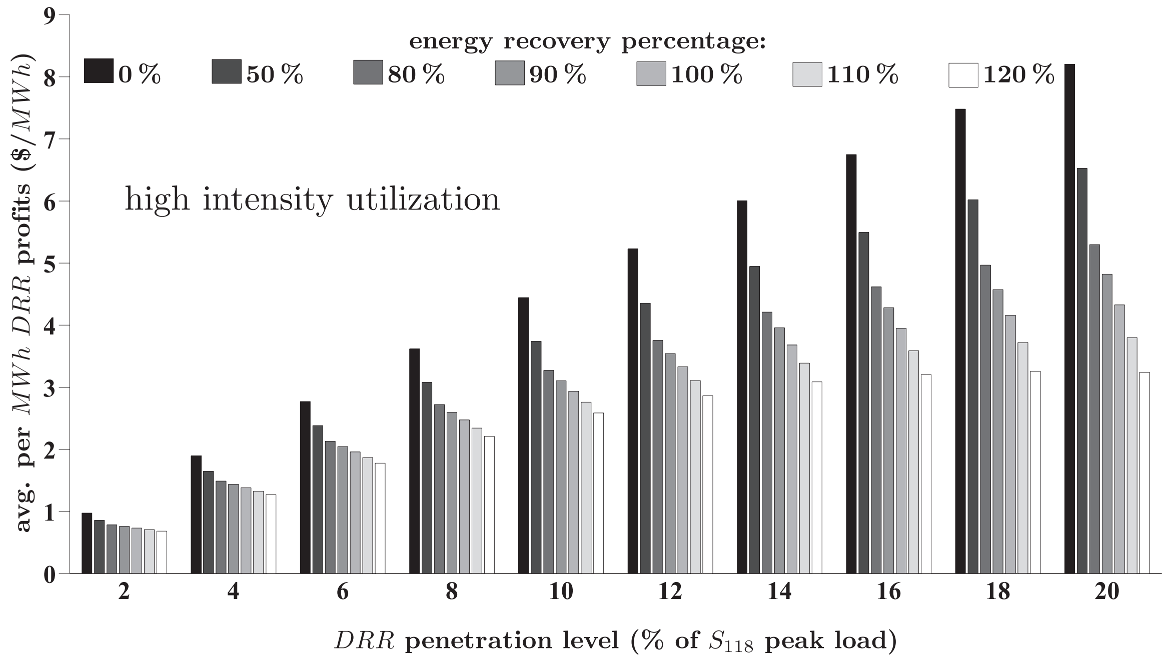

Figure 5: Changes in the S_{118} Average per MWh DRR Profits under Deepening DRR Penetration Levels and with Different Energy Recovery Percentages under High-Intensity Utilization

diminished at levels below 20 percent.

We next consider the energy recovery percentage, penetration level, and utilization intensity impacts on average per MWh DRR profits. Figure 4 shows the S_{57} system average per MWh DRR profits for a selection of DRR penetration levels and with different recovery percentage cases under high-intensity utilization.

Recall that under high-intensity utilization for the S_{57} system, the greatest ALMP reduction is attained at 14 percent penetration in the 0 percent energy recovery case and at penetrations as low as 4 percent with energy recovery in the range of 80–120 percent. However, we see in Figure 4 that the S_{57} average per MWh DRR profits increase under each deeper DRR penetration, albeit at a lower rate, with energy recovery taken into account. In such a case, DRR self-interest drives DRR participation even at penetrations which result in ALMP increases. We observe similar results for the S_{118} system.

Figure 5 shows the S_{118} system average per *MWh DRR* profits for a selection of *DRR* penetration levels and with different recovery percentage cases under high intensity utilization.

Under high-intensity utilization for the S_{118} system with 120 percent energy recovery, the average per MWh DRR profits are maximized at 18 percent penetration. With all other energy recovery percentages, the average per MWh DRR profits increase with deepening DRR penetration. However, recall the ALMP reductions are highest with energy recovery of 80–120 percent under penetrations of 12–16 percent. Consequently, as is also true under the high-utilization intensity for the S_{57} system, the persistent average per MWh DRR profit increases as the DRR penetration level deepens drives DRR participation at penetration levels deeper than those which result in the lowest ALMPs.

We next examine the DRR impacts on system-wide per MWh CO_2 emissions. Figure 6 shows the percent change in the S_{57} system average per MWh CO_2 emissions for a selection of DRR penetration levels and with different recovery percentage cases under high-intensity utilization.

The generation mix of the S_{57} system is dominated by coal-fired generation, which represents more than half of the capacity in the system. However, in the curtailment hours, the marginal

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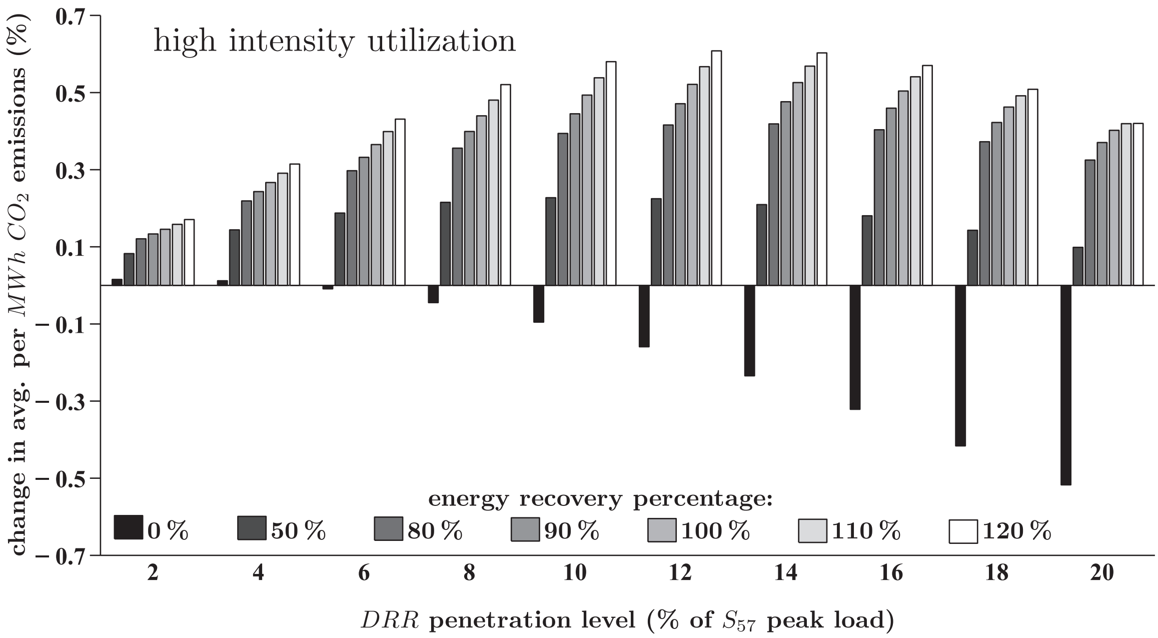

Figure 6: Percent Changes in the S_{57} Average per MWh CO_2 Emissions under Deepening DRR Penetration Levels and with Different Energy Recovery Percentages under High-Intensity Utilization

generators are often natural-gas-fired units, which, according to the price-based loading order, are loaded once the coal-fired units are loaded. Consequently, much of the generation offset by DRR curtailments is from natural-gas-fired units, while, in cases with the energy recovery, the additional load is served by coal-fired units, which have roughly twice the CO_2 emission rate of natural-gas-fired units per MWh of generation. The results of shifting energy from low emission rate generators to those with higher emission rates are the S_{57} system average per MWh CO_2 emission increases shown in Figure 6. With energy recovery taken into account, the S_{57} system average per MWh CO_2 emissions increase compared to the reference case at all DRR penetration levels and energy recovery percentages above 0 percent.[19] We note the reductions in system-wide emissions are less than 1 percent in all cases, demonstrating the minor impact of DRRs on emissions even when the DRR payback effects are ignored.

Alternatively, the generation mix of the S_{118} system is dominated by natural-gas-fired generation and the peak load is met by oil-fired generation. Figure 7 shows the percent change in the S_{118} system average per MWh CO_2 emissions for a selection of DRR penetration levels and with different recovery percentage cases under high-intensity utilization.

On the S_{118} system we observe CO_2 emission decreases as low as 1.5 percent at 20 percent penetration with 0 percent energy recovery. However, with energy recovery, the CO_2 emission reductions with 80 percent energy recovery are 30 percent of the 0 percent energy recovery CO_2 emissions reductions and the emissions increase above the reference case emissions with 120 percent energy recovery.

The S_{57} and the S_{118} DRR economic and emission benefits are severely reduced or even eliminated when energy recovery is taken into account. On the S_{57} system, the explicit representation of energy recovery results in uneconomic outcomes in many of the cases with ALMP increases as high as 3.5 percent and CO_2 emission increases in nearly all of the cases. On the S_{118} system, DRRs are economic in all of the cases and the price reductions are as high as 10 percent in the 0 percent energy recovery case. However, the DRR payback effects considerably reduce the S_{118} DRR economic and emission benefits and the highest ALMP reductions are between 4 and 6 percent in the cases with energy recovery. On

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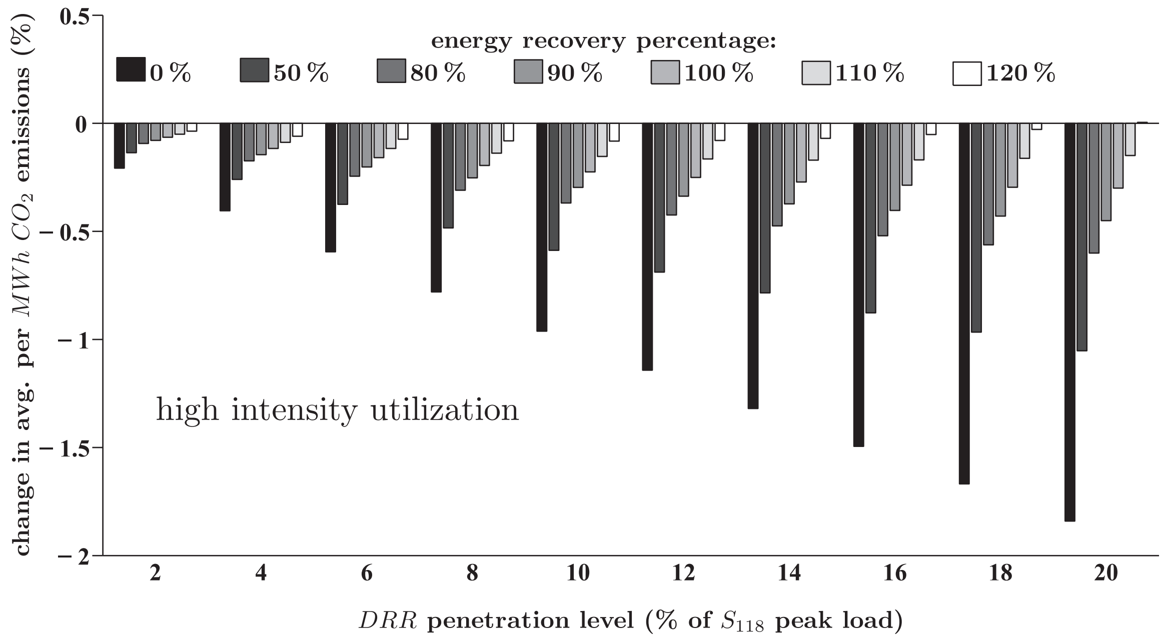

Figure 7: Percent Changes in the S_{118} Average per MWh CO_2 Emissions under Deepening DRR Penetration Levels and with Different Energy Recovery Percentages under High-Intensity Utilization

both systems, the average per MWh DRR profits increase with deepening DRR penetration even as the ALMP reductions decline or DRRs become uneconomic.

III. The Policy Implications

There are three key policy impacts for this work: (1) the critical importance of the DRR payback effects in the assessment of DRR economic and emission impacts; (2) the formulation of DRR incentives; and (3) the design of CO_2 emission reduction policies.

The realistic assessment of the DRR economic and emission impacts is a critical component of effective DRR policy analysis and formulation. The DRR payback effects have a profound impact on the economic and emission benefits of DRR curtailments. As such, studies that ignore the DRR payback effects cannot provide a realistic assessment of the DRR economic and emission impacts and, consequently, are not likely to translate into effective DRR policy. One aspect of such effective policy is the incentives provided to DRRs and how such incentives impact DRR implementation and the resulting benefits which accrue to the various market participants.

Under the current regulatory environment, the DRR profits are disproportional within the context of the economic benefits they bring to the rest of the market participants. This disproportionality is an unintended consequence of the level of the incentives provided to DRRs to elicit participation. The DRR incentive levels are the policymaker's degree of freedom to encourage appropriate DRR penetrations and thereby affect the balance of the DRR benefits among the market participants. The design of effective policy which sets the level of the incentives provided to DRRs such that, when the DRRs are implemented, the DRR profits are congruent with the level of the economic benefits which accrue to the remaining participants depends upon the realistic assessment of the DRR benefits. The design of effective CO_2 emission reduction policy which includes DRRs is also highly dependent upon the underlying DRR assessment.

The CO_2 emission impacts of DRR curtailments depend on the generation mix of the system in which the DRR operates. In systems with base-loaded units which have high CO_2 emission rates and peak-loaded

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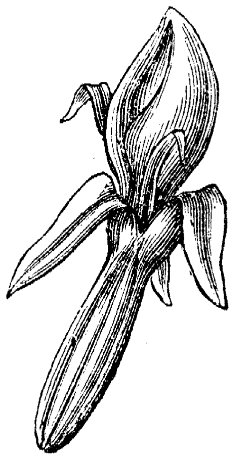
units with lower emission rates, DRR curtailments and the associated payback effects can lead to CO_2 emission increases. Even in systems with base-loaded units with low CO_2 emission rates and peak-loaded units with higher CO_2 emission rates, the explicit representation of energy recovery considerably decreases the CO_2 emission reductions from DRR curtailments. Effective CO_2 emission reduction policy must take into account the CO_2 emission impacts of the DRR payback effects to ensure the emission impacts of DRR curtailments are in line with the overall goals of the emission reduction policy.

IV. Conclusions

To realize the benefits of DRRs to the fullest extent possible, the implementation of DRRs must be based upon realistic assessments of the DRR economic and emission impacts. The explicit consideration of the DRR payback effects reduces drastically the system benefits of DRR curtailments. Our findings that DRR utilization under medium to high intensity utilization, with modest recovery percentages, and under penetration levels within the FERC's achievable participation range result in:

- uneconomic outcomes or severely diminished ALMP reductions, and
- emission increases or severely diminished emission reductions

makes questionable the reported benefits of DRR curtailments. Moreover, with energy recovery, there are significant diminishing returns of the DRR economic and emission benefits. Our insights into the economic and emission impacts of DRRs illustrate the critical importance of the explicit representation of the payback effects in the analysis and formulation of policy which encourages appropriate levels of DRR participation and which balances the DRR benefits between DRRs and the remaining market participants.■



Endnotes:

1. FERC, Final Rule, Order 745, Demand Response Compensation in Organized Wholesale Energy Markets, 18 CFR Part 35, issued Mar. 15, 2011.

2. For an overview of DSM, see, e.g., C. W. Gellings and J. H. Chamberlin, Demand-Side Management Planning (Fairmon Press, 1993) at 2–6.

3. *Assessment of Demand Response and Advanced Metering*, Staff Report, Federal Energy Regulatory Commission, Dec. 2012, at 27, at http://www.ferc.gov/legal/staff-reports/12-20-12-demand-response.pdf.

4. The full text of Jim Rogers' Nov. 29, 2007, Platts Lecture Series speech titled *Building a Bridge to a Low-Carbon World*, can be found at http://www.duke-energy.com/pdfs/platts-lecture.pdf.

5. For DRR policy initiatives stemming from the Energy Policy Act of 2005 and DRR-related FERC Orders, see, e.g., *Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them*, Report to the United States Congress Pursuant to Section 1252 of the Energy Policy Act of 2005, U.S. Dept. of Energy, Feb. 2006; FERC, *Final Rule, Order 719, Wholesale Competition in Regions with Organized Electricity Markets*, 18 CFR Part 35, issued Oct. 17, 2008; FERC, *Final Rule, Order 745*, *supra* note 1. For an overview of recent state-level DRR activities, see, e.g., *Assessment of Demand Response and Advanced Metering*, Federal Energy Regulatory Commission, Dec. 2012, *supra* note 3 at 45–49.

6. The PJM DRR monthly activity reports are available at http://www.pjm.com/markets-and-operations/demand-response/dr-reference-materials.aspx.

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15. The test system data are from the University of Washington Department of Electrical Engineering Power Systems Test Case Archive at http://www.ee.washington.edu/research/pstca/. Offer and load data for the *MISO* are found at https://www.midwestiso.org/Library/MarketReports/Pages/MarketReports.aspx. Offer and load data for the *ISO-NE* are found at http://www.is-one.com/markets/hrlydata/index.html

16. *A National Assessment of Demand Response Potential*, Federal Energy Regulatory Commission, *supra* note 7.

17. We calculate the monthly threshold prices according to the requirements of FERC Order No. 745.

18. Generator average CO_2 emission rates are available from the U.S. EPA at http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html.

19. Due to network congestion effects, small emissions increases are also observed under DRR penetration levels of 2–4 percent with 0 percent energy recovery.

The impacts of DRR energy recovery are even more pronounced under high-intensity utilization.

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