Demand Response Advanced Controls

Database User Manual v.1

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Glossary of Terms

Automated Demand Response (ADR): Demand response programs where a third party (e.g. utility or aggregator) is able to control customer's load for DR purposes. ADR involves installation of advanced control and communication programs where an automated signal from the dispatcher (e.g. utility) triggers a pre-defined response from the customer's end-use.

Behind-the-Meter (BTM) Storage: Energy storage devices such as batteries that are on the customer's premise and metered electrical system. These devices are owned and operated by the customer or a third party that has been contracted by the customer. This is in contrast to utility- or grid-scale storage that is owned and operated by a utility provider.

Capacity: A power rating for generation or DR. Often the maximum amount of power able to be supplied by the electric grid at any time. Other usages include: to describe peak net load, i.e. the maximum need for generation from dispatchable energy resources; to describe a service that reduces the maximum generation ability needed (e.g. "DR has the potential to provide capacity").

Configurable DR opportunities: Programs that provide a utility or ARC with the ability to control the electricity consumption of one or more customer devices for a specified period of time but the customer can configure the control technology to override the DR signals that are received under certain conditions.

Controllable DR Opportunities: Programs that provide a utility or ARC with the opportunity to directly control (via radio, internet, telemetry or other remote means) various customers' electricity consuming end-uses (e.g., electric water heaters, pool pumps) or some portions of their load which could be increased, decreased or even physically disconnected from the grid with little to no notice.

Critical Peak Pricing (CPP): Rates that institute a single or variable predetermined price for electricity during a narrowly defined period (e.g., summer weekday between 4 PM and 7 PM) that is only applied during specific system operating or market conditions and generally limited in the number of times it can be dispatched (e.g. twelve times per year).

Demand Response: A mechanism through which an end-use's load profile is changed (by the user, a third party, or a utility) in response to system needs, often in return for economic compensation (e.g., payments or a different rate structure).

Enabling Technology: A set of on-site hardware and software that enables a particular end-use or set of end-uses to provide DR service across one or more products.

End-Use: A service performed using energy (e.g. lighting, refrigeration) or a type of energy-using devices (e.g. refrigerators, pool pumps). These end-uses and their demand for electricity make up customer load.

Flexible Loads: End-use load that is able to change its demand profile for DR purposes. This may refer to the total load of the given end-use or some fraction of the total load that is able to be modified. For example, only half of a customer's HVAC load may be "flexible", as the portion providing the ventilation services may be required to stay on at all times.

Investor-Owned Utility (IOU): A business organization providing utility service(s) that is managed as a private enterprise rather than a function of government or a utility cooperative.

Internet of Things (IoT): The inter-networking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data over a network without requiring human-to-human or human-to-computer interaction .

Open Automated Demand Response (OpenADR): An open and interoperable information exchange model and communication standard. OpenADR standardizes the message format used for ADR controls, gateways, and energy management systems to enable standardized communication of price and DR signals between customer facilities and utilities, Independent System Operators (ISOs), or Energy Service Providers.

Regulating Reserves: An amount of reserve responsive to Automatic Generation Control, which is sufficient to provide normal regulating margin.

Sector: A market or population segment sharing common characteristics. For the purposes of this study, the relevant sectors are: residential, commercial, and industrial (which includes agriculture).

Shed DR Service: A reduction in load that provides relief to the grid during times of peak demand or contingency reliability constraints or emergency events. This service includes conventional DR products as well as the peak load reduction that is realized through various forms of time-based pricing.

Shift DR Service: An energy-neutral movement of load from times of peak demand (typically afternoons or evenings) to times of very low net load (typically middle of the day or overnight hours). This service benefits the grid by reducing peak load, reducing curtailment of renewables, and reducing system ramping requirements (e.g., evening, morning).

Shimmy DR Service: Load that is able to follow a fast dispatch signal in order to either increase or decrease load in order to make real-time generation match demand. This service supports frequency and voltage management on the grid and reduces the need for conventional generation to provide these services. This service can be provided by DR Resources on either a 5-minute or 4-second dispatch signal,

Telemetry: An automated communications process by which measurements are made and other data collected at remote or inaccessible points and transmitted to receiving equipment for monitoring.

1 Overview

Over the last several years, Berkeley Lab has collected national data on the costs of demand response enabling technologies that can provide various grid services to the bulk power system.[1] We have organized this information in a Demand Response Advanced Controls (DRAC) database of costs, categorized by customer sector, bulk power system service, end-use and DR enabling technology. This User's Manual is intended to provide an overview on the structure of the data within the DRAC database and how to interpret the cost categories. The end-use and DR enabling technologies for each sector included in the database are described below in Table 1.

Table 1: The End-Uses and DR Enabling Technologies Included in the DRAC Database

Sector	End-Use	Enabling Technology Summary
Commercial and Residential	Battery-electric & plug-in hybrid vehicles	Automated Demand Response (ADR)
All	Behind-the-meter batteries	ADR
Residential	Air conditioning	Direct load control (DLC), programmable communicating thermostats (PCT).
	Electric hot water heaters	DLC or ADR
	Pool pumps	DLC
Commercial	HVAC	Depending on site size, energy management system ADR, DLC, and/or PCT.
	Lighting	A range of luminaire, zonal & standard control options.
	Electric hot water heaters	ADR
	Refrigerated warehouses	ADR
Industrial	Processes & Large facilities	Automated load Shedding & process interruption.
	Agricultural pumping	Base Switch & ADR
	Wastewater treatment	ADR

1.1 Definition of Service Types

To facilitate the assessment of DR enabling technologies and the services that they can provide to the bulk power system, we borrow the DR service type taxonomy from the 2025 CA DR Potential Study

[1] Berkeley Lab conducted the 2025 California Demand Response Potential Study on behalf of the California Public Utilities Commission, completing Phase 1 and Phase 2 of the research in 2016 and 2017, respectively. The DRAC database includes cost data that was collected during that research project and we have subsequently expanded upon those data to include additional end-uses and national costs estimates, which are presented in this study. For more information on the CA DR Potential Study, see: http://www.cpuc.ca.gov/General.aspx?id=10622

(Alstone et al., 2017), which provides a simplified nomenclature for discussing DR resource services. In the following sections, we present three key service types: Shed, Shift, and Shimmy. The service type taxonomy established a generalized nomenclature to enable clear conversations about DR capabilities beyond the provision of traditional peak capacity service, with less jargon. The service type taxonomy also permitted the development of generalized system modeling frameworks, where the various bulk power system services and retail DR products are matched to the service types.

End-use loads, batteries and the technologies which enable them as DR resources in the residential, commercial, and industrial sectors are able to provide a number of different bulk power system services by modifying demand. In Table 2, we identify different service types that each represent a number of bulk power system services which a DR resource could provide.

Table 2: Service Types in Relation to Key Bulk Power System Needs

Service Type	Description	Bulk Power System Grid Service Provided
Shed	Reduction of demand	Annual capacity, operating and contingency reserves
Shift	Energy-neutral shift in load within a 24-hour period, at intervals greater than 1 hour[2]	Flexibility: Alleviate ramps and curtailment, encourage load building energy consumption during periods of excess supply
Shimmy	Fast-responding load that can increase or decrease with system need	Short-run load-following, voltage support, ancillary services and regulating reserve capacity

In order to determine which DR enabling technologies can provide each service type, we match the response and telemetry capabilities of specific enabling technologies and end uses with the response characteristics required to provide various grid services which fit underneath this service type. We then classify end-uses based on their eligibility to provide specific grid services, such as flexibility or ramping[3], again underneath a broad service type. Each service type has temporal attributes that characterize the dispatch and response times that the corresponding DR resource must meet. Figure 1 below provides a mapping of the service types to a timescale of response.

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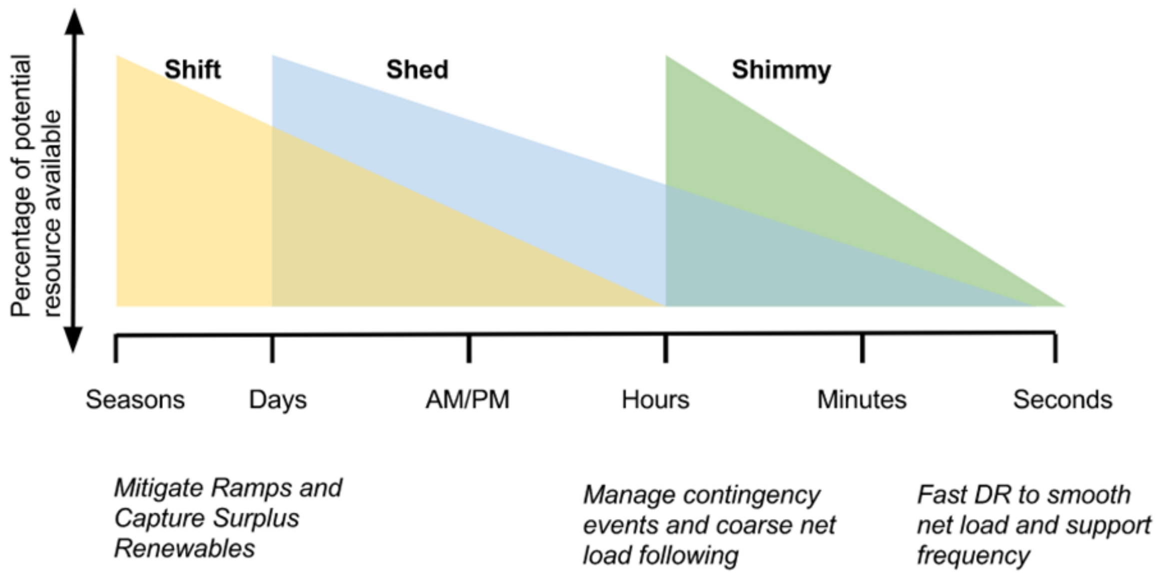
[2] For the purpose of our study, Shift service type resources are utilized for a minimum of 2 hours, one hour to "take" load, and one hour to "shed" load. Based on the needs of the bulk power system, Shift service type resources could typically be dispatched for approximately 2 to 12 hour windows, but could potentially be used to move load over a full 24 hour window, if needed. Shift isn't a capacity resource, so it isn't conducive to discussing it in capacity (kW) terms. Shift service type is measured energy over a temporal window. A kW of "take" for an hour is a kWh, for 2 hours, it is 2 kWh. A few hours after that, we reduce 1 kW for 2 hours--- for a total shift of 4 kWh. It is still 1 kW, but what we are using that resource as an energy source, not a capacity resource, to provide 4 kWh of load rearrangement in the day.

[3] For more information, please see the corresponding LBNL report "Demand response advanced controls framework and assessment of enabling technology costs"



Adapted from Alstone, et.al, (2017)

Figure 1: Service Type Temporal Attributes for Dispatch and Response of DR Resources

1.1.1 Shed Demand Response Resources

The Shed service type can be provided by DR resources that are dispatched to reduce customer load. Shed resources include and go beyond conventional DR, which is often dispatched many hours or a day ahead to manage forecasted peaks at the system level. It also includes fast-shedding resources that can respond in the event of contingency and emergency conditions. DR resources that provide Shed support the grid by reducing the peak capacity required to maintain service levels, which reduces the need to dispatch peaking generation units, and therefore improves reliability. Voluntary load curtailment is the most common type of DR resource that provides Shed.

1.1.2 Shift Demand Response Resources

The Shift service type[4], which can be provided by DR resources dispatched to increase hourly energy consumption at certain points in the day and decrease consumption during alternative hours of the same day - effectively rearranging the load. System operators can use Shift DR resources to smooth net load ramps associated with variable generation resources or market conditions that warrant load shifting, including daily solar energy generation patterns. The Shift service type involves one or more periods of

[4] To the best of our knowledge, there is currently no Shift bulk power system market product. However, for our study, we have defined the characteristics of the Shift service to be an energy (kWh) neutral resource that an ISO/RTO could procure and dispatch. As previously discussed, there is a growing need for flexible resources that can provide load building and peak shedding service at different points in the day in response to high penetrations of variable generation resources. Therefore our study includes DR resources that can provide this Shift service, assuming at some point soon this service will become available to meet the clear market need.

Shed (load reduction) paired with one or more periods of “take” (increasing load) during a single calendar day. It is a relatively small daily change in load, which should create a minimal impact on the customer. DR resources providing Shift services can be dispatched daily.

1.1.3 Shimmy Demand Response Resources

Certain types of advanced DR resources are capable of providing fast and continuous response services to the bulk power system. Customers that can follow sub-hourly to seconds-level control signals are characterized as Shimmy DR resources. These DR resources modify end-use loads to attenuate ramps and disturbances at timescales at the sub-hourly level and reduce the need for generation units to provide these services. Because of the need for fast response with very minimal, if any, advanced notice of dispatch, DR resources providing Shimmy services must be highly dependable. Thus, participants must have dispatchable control technology without the opportunity for customer override, thereby limiting Shimmy to only be provided via Controllable incentive-based programs.

2 DRAC Application

As mentioned in Footnote 1, most of the data that is presented in this database was collected by Berkeley Lab for the California Demand Response Potential Study project (Alstone et al., 2017). Our research utilized Lab reports focused on DR technologies in specific sectors (industrial, commercial, agricultural) for data on the cost of DR enablement. For DR technologies with limited publicly available cost data, we consulted industry experts, including DR providers, to obtain estimates of DR technology cost. For the residential sector, we also referenced prices for DR technologies that are currently on the retail market.

For the CA Demand Response Potential Study and subsequently in this study, we derived a portion of the cost data from Navigant Consulting (2014). The study provides cost estimates for a limited number of automated DR enabling devices for residential, commercial, agricultural and industrial sectors. The study also estimated overall "Enablement Costs" that included technology costs and installation costs.

Based on our research, the data presented in the DRAC database is representative of costs for enabling technologies across the United States. The costs estimates represent average data points for the enabling technologies from the various sources discussed above. However, costs for the various technologies may differ depending on vendors, geographic location, customer sector, and technology application. These data should be considered as estimates rather than actual quotes for procuring the enabling technologies that one might receive through a competitive bid process.

2.1 Definition of Enablement Costs

As noted in Alstone et.al (2017), DR enabling technology can be defined as the mix of load control and communications hardware and software that make it possible to change the energy consumption patterns of end-uses. The enabling technologies examined in the current study are defined in terms conducive to estimating the expected costs and performance.

Our cost assessment provides estimates of initial costs for the installation, communication resource interface, telemetry, and control hardware for DR enabling technology.[5] This assessment is organized to provide the costs by each customer sector (i.e., residential, commercial, and industrial), by electricity consuming end-use, and enabling technology for our three types of bulk power system services: Shed, Shift, and Shimmy service types. Our approach uses an independent perspective of estimating the total costs to enable a site. That is, our estimates cover all the costs to enable the site or end-use, irrespective of the entity responsible for commissioning (e.g., aggregators, retail service providers, or business owners).

The majority of the cost data that is presented in this study was collected by Lawrence Berkeley National Laboratory (LBNL) for the California Demand Response Potential Study project (Alstone, et.al. 2017). That research utilized prior LBNL reports focused on DR technologies in specific sectors (industrial,

[5] It is important to note that non-dispatchable/non-controllable demand response is not included in this assessment because it is not a DR enabling technology, but rather a manual or behavior based response to a DR signal. Our research focuses solely on technology based control DR solutions.

commercial, agricultural) for data on the cost of DR enablement (e.g., Lekov et al., 2009; Olsen et al., 2012; Piette et al., 2015). For DR technologies with limited publicly available cost data, the research team consulted industry experts, including DR providers, to obtain estimates of DR technology cost. For the residential sector, the research team also referenced prices for DR technologies that were currently on the retail market. Costs estimates use 2017 prices for the technologies.[6]

For each of the end-uses, we estimate the initial up front enablement costs for a customer site and end-use, based on customer sector and size. These include technology and installation costs, and are either provided as an aggregate cost for enabling an entire site (in $/customer site), or calculated by enablement costs per unit of load enabled to provide DR (in $/kW), or the costs to enable an end-use ($/end-use).

In the commercial and industrial sectors, enablement costs are estimated for each unit, in kW, of load that is enabled. For example, a commercial customer could have multiple package HVAC units that would be controlled by an Energy Management System (EMS) enabled with ADR. The HVAC load for the commercial customer site could total 100 kW, of which 70 kW could be controlled with DR enabling technologies. In this example, the cost estimate for each unit (kW) is assessed in $ per kW enabled. If we assume that the cost is $280/kW, then we would multiply $280/kW by 70 kW for a total of $19,600 for the ADR controls technology at the customer site. The unit costs in $/kW are intended to provide a scalable cost estimate for commercial and industrial sites, and are representative of how enablement costs are reported in the industry (Piette et al., 2015).

A description of each category is as follows:

- The fixed initial **communication and hardware costs** for achieving controllability "per site" for the given end-use (e.g., paying for communication and control gateways). These are reported in $ per site.
- The variable initial **costs for the control technology** for achieving controllability "per kW" (e.g., office vs. retail lighting controls). These are reported as $ per kW enabled for DR services.
- The fixed initial **end-use control technology and communication costs** for achieving controllability "per end-use". These costs are specific to Electric Vehicles and the Residential sector end uses and are reported as $ per end-use enabled for DR services.

For DR resources with control technology that provides Shimmy services, we assume the same control technology may also be used to provide Shed as well as Shift (e.g. Auto DR, energy management systems, and end-use local controls). For example, a Variable Frequency Drive (VFD) pump that can be ramped up or down for frequency regulation can also provide a Shift service resource that increases load by ramping up the pumping speed during several hours of the day to build load and slowing pumping speed in the evening hours to curtail energy consumption. As such, for the same customer sector, size and end-use, the hardware and installation costs for the control technology to provide Shimmy services is the same as it is to provide both Shed and Shift services. However, telemetry and communication system

[6] Cost data we utilized was collected by researchers between 2007 and 2017. Data that was collected prior to 2015 were first converted to 2015 CPI in Alstone et. al. (2017) and then further adjusted to CPI 2017 in this study. For the 2016 and 2017 data, we used the most recent published value at the time the data was collected and adjusted for inflation to 2017 CPI.

upgrades are incurred to enable a site to provide Shimmy services, which could include metering, a resource interface, a gateway or similar components.
For the commercial and industrial customer sectors within the database, Shimmy DR technology costs are captured in the Communication and Hardware Cost field, are considered applicable to the entire customer site, and are incremental to the control technology costs ($/kW). For the residential customer sector and electric vehicle technologies, the control technologies, communication, and hardware costs for each end-use are organized by the applicable bulk power system service type. [7]

For those technologies that are listed as providing Shift and Shed service, they are limited to providing those two services. Technologies that are listed as only providing Shed service can only provide peak capacity shedding.

Table 3 provides a summary of the metadata options for the database, including the description of each field. Behind the meter lithium-ion battery technology costs have been organized in the database differently from the other technologies because of their unique characteristics for installation and variable costs; therefore they are not included in Table 3. Please see Section 2.4.6 for a detailed description of the organization of enabling costs for battery technologies.

[7] Residential sector and electric vehicle charging unit enabling DR technologies are applied to each end-use under control typically at a fixed price (e.g. the cost for a Smart Thermostat is $160 and enables the entire central HVAC unit in a single family home), and thus are not estimated in variable $/kW. Therefore, for this study, we report all end-use control technology and communication costs for the residential sector and electric vehicles into a single field of initial costs titled.

Table 3: DRAC Database Metadata Summary

Field Name	Description	Field Options for Residential Technologies	Field Options for Electric Vehicles	Field Options for Commercial	Field Options for Commercial Lighting	Field Options for Industrial
DR Technology	The technology that controls the customer end-use	DLC, Smart Thermostat, ADR Control, Manual	ADR Control	DLC, Smart Thermostat, ADR Control	ADR Control	ADR Control, Base Switch, Variable Frequency Drive w/ADR
End-use	An electricity consuming device or appliance (e.g. HVAC, pool pumps).	HVAC, Pool Pump, Electric Water Heater	PHEV, EV	HVAC, Refrigerated Warehouses, Electric Water Heaters	Luminaire, Standard, Zonal	Processes & Large Facilities, Agricultural Pumping, Wastewater Treatment
Service Type	The bulk power system service that demand response resources provide to the grid (e.g. shed, load shift)	There are three DR service type options used in the database: Shed, Shift, and Shimmy.				
Communication & Hardware Costs ($/Site)	The initial cost for DR technology hardware & site level communication required to enable a premise to provide DR services (e.g. Smart Thermostat (Residential), Energy Management System (Commercial), or Remote Intelligent Gateway (Commercial & Industrial)	*Not Applicable: Enablement Costs for Residential and Electric Vehicles are reported under End-Use Control Tech & Communication Costs*		One time, upfront costs to install and enable a communication platform, such as an Energy Management System, or DR technology hardware that can receive dispatch signals, such as a Smart Thermostat. The hardware and communication costs are presented as $/site.		
Control Tech Costs ($/kW)	The costs for DR enabling technology controls that enable an end-use to provide DR services. These costs are variable and reported in $/kW.	*Not Applicable: Enablement Costs for Residential and EVs are reported under End-Use Control Tech & Communication Costs*		Costs for technologies such as ADR which control larger end-uses, or more than one end-use component in a commercial or industrial building. For example, ADR that controls multiple HVAC package units on a Retail building are based on the kW under control by an Energy Management System.		
End-use Control Tech & Communication Costs ($/End-use)	The costs for DR enabling technology controls that enable an end-use to provide DR services. These costs are fixed and reported in $/End-use.	One time, upfront costs to install and enable end-use technology controls and communication.		*Not Applicable: Costs are reported under the control tech and communication & hardware costs fields, (see above).*		

2.2 Non-DR Economic Benefits

For certain end uses, some technologies or device upgrades that enable DR (e.g., smart thermostats, building EMS, or lighting controls) to provide one of the service types also produce other cost benefits (e.g., by allowing a building to operate more efficiently (Goldman et al., 2010)). In practice, non-DR economic benefits could be realized through customer bill savings that come from DR-device-induced efficiency or energy efficiency (EE) incentives paid by a retail energy service provider or other third party entity that helps buy down the upfront cost of the DR. The non-DR benefits were not included in our study and cost assessment of the DR enabling technologies, but should be considered as potential revenues that support DR investments.

2.3 Overview Dashboard

An Overview worksheet provides a summary of the metadata options, the end-uses and enabling technologies selected in each of the sector specific worksheets included in the workbook (see Table 2 and Table 3). In addition, the Overview worksheet includes a brief description of the cost categories presented in the tables and graphs.

2.4 Sector-Specific Enabling Cost Dashboards

The DRAC database includes a summary worksheet for each of the following customer sectors:

- Residential;
- Electric Vehicles;
- Commercial;
- Commercial lighting;
- Industrial; and
- Battery.

The data slicers in the sector-specific worksheets organize the data in each pivot graph and pivot table. Each of the field buttons within the slicers can be toggled on and off, and more than one field button can be selected by holding the shift button while clicking the mouse. The field buttons are dynamic, and when a selection is made that limits the available data points, the field buttons in the other slicers become grayed out. Additionally, pivot graphs and pivot tables dynamically update when the slicer field buttons are toggled.

Figure 2 below provides an example of the service type slicer found in the DRAC database. For the Battery Dashboard and Commercial Lighting Dashboard, all enabling technologies provide either "Shed & Shift" or "Shimmy" service types, thus, there is no field button for Shed service.

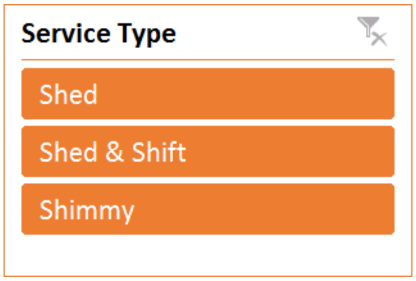


Figure 2: Service Type Slicer for Residential, Commercial and Industrial Dashboards

In the following sections, we provide a description of each of the customer sector end-use worksheets within the database and describe the specific data options available for selection when querying the data.

2.4.1 Residential End-Use Dashboard

The Residential End-Use Dashboard provides enablement cost estimates for the residential sector end-uses and DR technologies. For residential space cooling and heating, we focused on technologies that target central HVAC or room AC units. We did not examine technologies that could automate evaporative cooling units within this study. With regards to Water Heater end-uses, we focused on Automated Demand Response technology that controls Electric Water Heaters. While there are technologies that control Heat Pump Water Heaters, those cost estimates are not included.

The enable technology costs estimates for the residential sector are specific to a single end-use and include the costs for the control technology, installation, and any communication platform.
The technologies and end-uses included in the slicer fields of the database are described below in Figure 3.

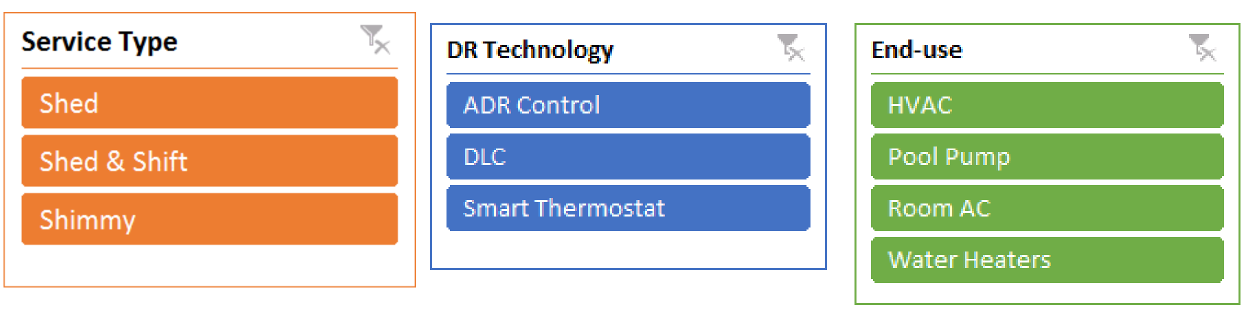


Figure 3: Residential Slicer Options Included in the DRAC Residential End-Use Dashboard

2.4.2 Electric Vehicles Dashboard

Commercial and residential electric vehicle charging units equipped with demand response technologies can enable electric vehicles serve as flexible DR resources that can include both shedding and taking load from the grid. We derive the residential cost estimates from several recent pilots, including SDG&E's Plug-in EV Time-of-Use Pricing and Technology Study (Cook et al., 2014) and the U.S. Department of Energy's Smart Grid Investment Grant EV Charging Pilots (DOE, 2014). The costs included dedicated circuit and meter socket box, a smart charging station with Level 2 power at 240 Volts, and a DC charge port on the vehicle. Costs for Commercial EV chargers are estimated to be higher than for residential applications. Cost estimates for the Commercial EV applications were gathered from EV vendors and California utilities during the California DR Potential Study project(Alstone et al., 2017).[8]

Costs for electric vehicle level 2 charging units are estimated for a end-use charging unit with installation and captured within the "Average of End-use Control Tech & Communication Costs ($/End-use)" in the DRAC database. Figure 4 below provides a preview of the slicer options available in the Electric Vehicle Dashboard.

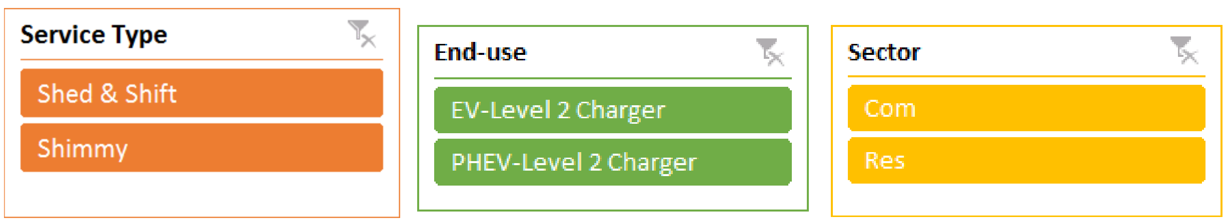


Figure 4: Electric Vehicle Slicer Options Included in the DRAC Electric Vehicle Dashboard

2.4.3 Commercial End-Use Dashboard

The Commercial End-Use Dashboard provides cost estimates for the commercial sector end-uses and DR technologies. Commercial customers are categorized as small, medium or large customers if their peak demand is less than 50 kW, between 50 and 200 kW, or greater than 200 kW, respectively. For small commercial customers, cost estimates are made for enablement at the site (Lanzisera et al., 2015), whereas for medium and large commercial customers, costs are estimated as $/kW enabled. Technology vendors, aggregators, and utilities provided cost estimates for the DR enabling technologies, which were then averaged across data sources for reporting purposes. Cost estimates for ADR technologies in refrigerated warehouses were developed from research previously conducted by Berkeley Lab (Lekov et al., 2009).

Figure 5 provides details on the end-uses, DR technologies, and commercial size categories included in the Commercial End-Use Dashboard.

[8] In commercial applications, it is not uncommon to have charging units that enable charging for more than one vehicle, however, we did not capture those costs within this database.

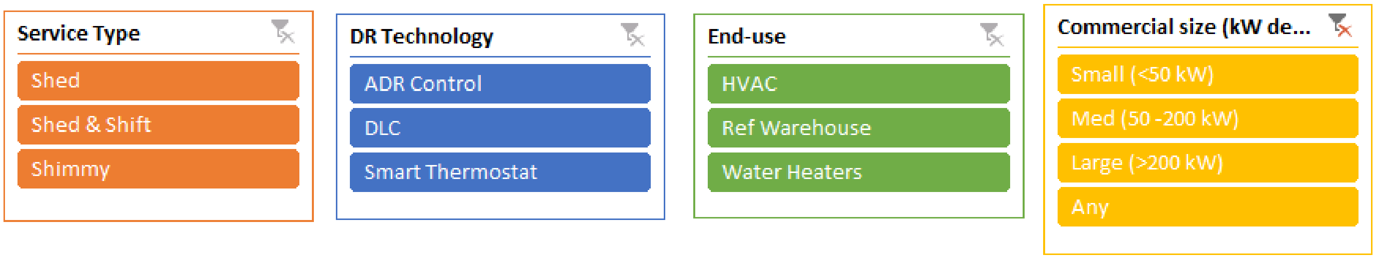


Figure 5: Commercial Slicer Options Included in the DRAC Commercial End-Use Dashboard

2.4.4 Commercial Lighting Dashboard

The Commercial Lighting Dashboard includes the cost estimates for small, medium and large commercial office and retail buildings. A key challenge with estimating the costs to enable advanced lighting control systems for DR is that they are typically installed for purposes other than DR. Rather, these systems are typically installed either for non-energy benefits, such as occupant comfort or for their energy-efficiency benefits. As such, neither the enabling costs nor the associated benefits can be attributed exclusively to DR. However, for this database, we do not attempt to quantify or attribute the enablement costs to demand response, energy efficiency or customer comfort, but rather, we look at the total costs to install a D 5rxR enabled lighting system.

To better capture the costs of lighting controls for DR, we consider three end-use cases with ADR enabled technologies:

- **Luminaire:** highly granular control including digitally addressable, individual luminaires fixtures
- **Zonal**: zonally controlled luminaires
- **Standard**: existing standard practice lighting system consistent with meeting CA Title 24 Energy Code baseline.

All Commercial lighting technologies can provide Shed and Shimmy services. Costs for lighting technologies is estimated for each kW enabled at the customer site.

Figure 6 provides details on the end-uses, DR technologies, and commercial size categories included in the Commercial Lighting Dashboard.

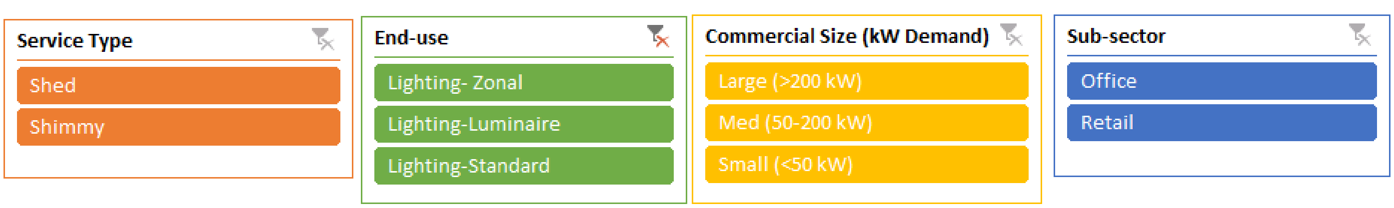


Figure 6: Commercial Slicer Options Included in the DRAC Commercial Lighting Dashboard

2.4.5 Industrial End-Use Dashboard

Within the industrial sector, we focused on DR enabling technologies at three types of customer sites: large production facilities, wastewater treatment facilities, and agricultural water pumping facilities.

For large production facilities such as factories, food processing plants or metal product manufacturing sites, we examined the costs for ADR enabled process load interruption using previous Berkeley Lab research that examines such ADR installations at over 50 sites (Piette et al., 2015). It is important to note that many industrial customers participate in interruptible DR programs by manually shutting down their facility processes. The focus of this research was to examine advanced technologies, so manual interruption was not included in the DRAC database. We used data collected by Berkeley Lab from a variety of pilot efforts that implemented ADR in commercial and industrial facilities to develop the costs estimates for the industrial sector enabling technologies.

DR can be enabled for agricultural loads by either a basic DLC switch or with an ADR system on the water pumps and other irrigation devices (Olsen et al., 2015).

Enablement costs for ADR installations in wastewater treatment and pumping facilities are based on previous research conducted by Berkeley Lab(Thompson et al., 2009; Olsen et al., 2012).

Figure 7 provides details on the end-uses, DR technologies, and commercial size categories included in the Industrial End-Use Dashboard.

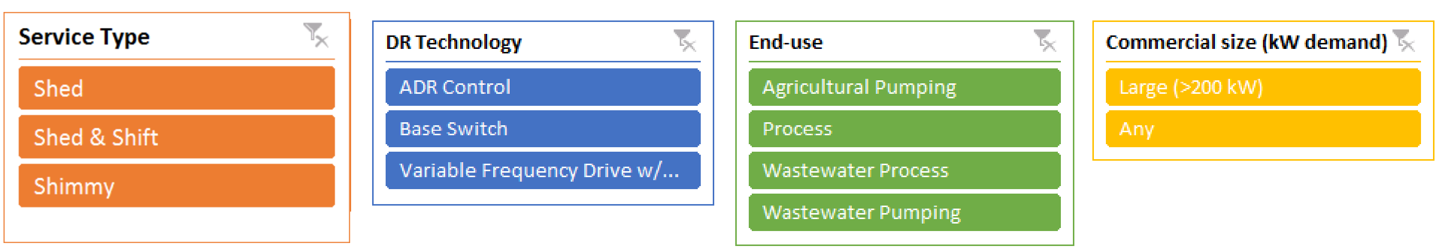


Figure 7: Industrial Slicer Field Options Included in the DRAC Industrial End-Use Dashboard

2.4.6 Battery Storage Dashboard

Storage systems present a unique challenge when categorizing costs, because unlike power plants which are valued at their max capacity value, battery storage has both a maximum power output and a maximum energy output. These are respectively characterized as the capacity (kW) and the energy (kWh). The energy output from a battery can vary considerably because of the duration of discharge and round trip efficiency, even for units with similar capacity. Energy storage systems require equipment such as inverters/converters and specific power electronics to manage the duration and conversion of AC/DC. This equipment, as well as the permitting and interconnection, is commonly called the 'balance of system' (BOS). BOS costs are often not reported by manufacturers; rather, costs are reported only for the energy output ($/kWh) of the battery systems. However, Zakeri and Syri (2015) conducted field research that examined the total installed costs of battery storage systems, which included the cost estimates for BOS ($/kW) in a separate category from the energy output ($/kWh). This study includes the BOS cost estimates from that research.

For this database, we break down the costs as follows: storage costs in $/kWh (the actual battery stacks in case of a battery system), and BOS costs in $/kW (inverter, utility interconnection, BMS, and installation). Therefore, the estimated costs for the Battery Technology Dashboard differ from the other dashboards because costs are reported in three fields: Costs for Communication and Hardware, Costs for kWh installed ($/kWh), and Costs for kW installed ($/kW). An example of the slicer field options are included in Figure 6 below. Costs are independent of the storage capacity of the system, allowing us to examine several scenarios regarding storage capacity.

The behind-the-meter battery storage cost data in the DRAC database is taken from Alstone et al. (2017) which relied heavily on Zakeri and Syri (2015), along with Akhil et al. (2013) and Fitzgerald et al. (2015).

Figure 8 provides details on the end-uses, DR technologies, and commercial size categories included in the Battery Storage Technology Dashboard.

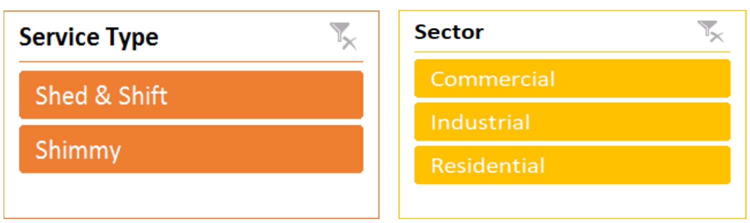


Figure 8: Battery Storage Technology Slicer Field Options in the DRAC Battery Storage Technology Dashboard

2.5 Summary Dashboard

The worksheet labeled Summary Dashboard provides the user with an overview of all the sector-specific pivot graphs in one worksheet. The graphs in the Summary Dashboard worksheet are linked to the pivot tables, slicers, and pivot graphs from each of the sector specific worksheets. Each of the graphs are dynamic and change when the slicer fields on each worksheet are selected or changed.

2.6 Technology Master List Worksheet

The underlying data table for the DRAC Database can be accessed in the worksheet titled “Master Tech List” within the Excel workbook. The Master Tech List is not connected to the sector specific pivot tables but is instead a copy of the data used by those pivot tables. As such, users can access the underlying DRAC data without adversely affecting the sector-specific data summaries.

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