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Agricultural demand response for decarbonizing the electricity grid

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Agricultural demand response for decarbonizing the electricity grid

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Abstract[1]

Historically, the focus of the agricultural industry has been increasing profit through maximizing crop yield. Costs for energy and water are small compared to equipment and personnel, and are thus often overlooked. However, energy costs for irrigation are increasing and could be exacerbated with declining water levels in many Western states. This trend has motivated many farmers to explore sustainable irrigation water and energy management practices. Much of this new focus has been directed towards the adoption of new agricultural technologies with a misplaced assumption that technology alone will inherently bring all the benefits. On one hand, farms are going through a paradigm shift, and are turning into net electricity generators, and on the other, higher penetration of intermittent renewable sources into the electricity grid, require dynamic loads to help the grid balance its intra-hour variability and short duration ramps. The agricultural industry could be restructured to utilize larger amounts of renewable energy such as wind and solar and provide a great deal of flexibility to the grid. As emerging producers of clean energy, farmers are required to learn and speak the complex language of the electricity grid in order to monetize their energy generation while making the renewable electricity grid more resilient and reliable. In this paper, we develop a foundational approach for understanding and connecting three important concepts that can help the agricultural industry during this critical transition period. Those three concepts are: (a) current and future needs of the electricity grid, (b) available electricity market mechanisms through which farms can provide services to the grid, and (c) understanding electricity consuming/generating equipment on farms. Defining these concepts and condensing them into a standardized framework, can remove a significant barrier for enabling farms to provide services to the electricity grid while improving their bottom line.

Keywords: Agriculture; Irrigation; Demand Response; Ancillary Services; Electricity; Water

1 *Abbreviations:* AC, Alternating current; ADR, Automated demand response; AF, Acre foot; AgTech, Agricultural technology; AutoDR, Automated demand response; CPP, Critical peal pricing; CPUC, California public utilities commission; DR, Demand response; ET, Evapotranspiration; GHG, Greenhouse gas emissions; GW, Groundwater; ISO, Independent system operator; kWh, Kilo Watt hour; OpenADR, Open automated demand response; RPS, Renewable portfolio standard; SW, Surface water; TOU, Time of use; VFD, Variable frequency drive; VSD, Variable speed drive

1 Introduction

Globally and within the United States, the cost of energy associated with crop irrigation is increasing as growers convert to higher pressure systems and pump more groundwater from greater depths as water tables continue to drop (Ringler et al., 2013; Siebert et al., 2010). Additionally, parts of the electric grid are under a significant or increasing amounts of strain due to elevated demand and ambitious Renewable Portfolio Standard (RPS) targets (Mohd et al., 2008). Consequences of increased reliance on groundwater pumping extends beyond the energy implications and can results in irreparable environmental damages. Those consequences include aquifer contamination by seawater intrusion or depletion beyond the point of recharge, land subsidence, infrastructure damage, and harm to groundwater-dependent ecosystems (Famiglietti, 2014).

Demand management strategies such as Demand Response (DR) can help farmers better manage electricity consumption and unlock new revenue streams while providing benefits to the electricity grid (e.g. reliability, lower rates) and the environment (Aghaei and Alizadeh, 2013). Traditionally DR has been a strategy primarily used to shift and/or lower electrical loads during peak hours (e.g. hot summer days). In recent years, due to evolving grid needs, the value of DR has expanded beyond load shifting (or shedding) to include various services as dictated by the grid needs (CAISO, 2016).

The goal of this paper is to establish a clear understanding of current and future needs of the electricity grid, available electricity market mechanisms, and electricity consuming/generating equipment on farms. This paper aims to achieve that clear understanding by putting forward a standardized framework similar to the illustration shown in Figure 1, which allows farm equipment to be mapped to respective grid needs through available market mechanisms. This mapping will allow for the widespread adoption of DR within the agricultural industry by removing a significant knowledge gap that exists between the farm, utilities, and the grid. Such analysis can also identify market mechanism(s) that are required for addressing current and future grid needs and are not captured through existing ones.

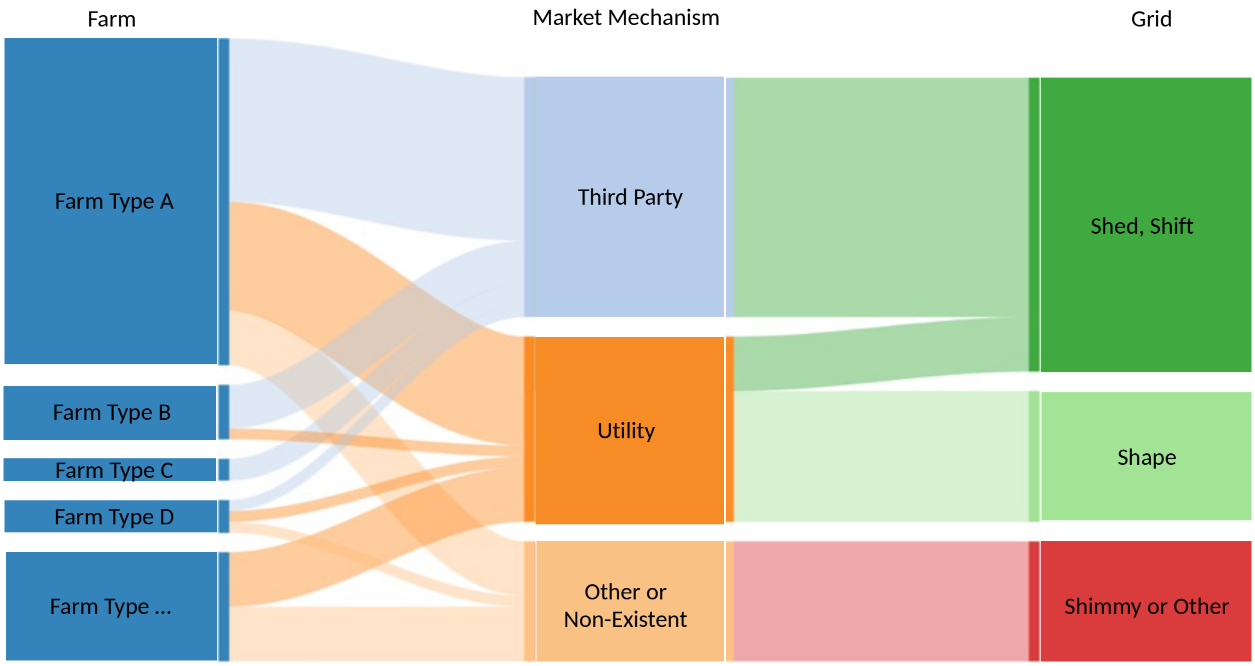

Figure 1: the relationship between farm electricity demand, available market mechanisms, and DR service types[2] as needed by the grid

While there are promising technologies under development aimed at increasing the reliability of agricultural DR participation, little attention has been given to educating the farmer, utility/DR aggregator, and grid operator about the electricity grid, electricity consuming/generating equipment on farms, available electricity market mechanisms, and how all those connect and interact with each other.

2 Literature Review

As discussed by Aghajanzadeh, et. al. (2018), agricultural loads, with their potential flexibility, can help reduce their energy cost, and improve grid stability as energy markets move into a future of increasingly distributed and renewable electricity generation. However, agriculture's operational constraints, conventional irrigation system design and management standards, and low penetration of in-field automation limit farms from taking advantage of more flexible energy and water use strategies that could benefit the grower, utility, and the grid.

Several studies have highlighted the technological and operational hurdles for widespread adoption of DR in the agricultural sector. Olsen, et. al. (2015) provide foundational information on the status of agricultural DR in California (Olsen et al., 2015). In this work Olsen et. al. identified several factors as barriers for farmers to participate in existing DR programs. Those

2 Shape, Shift, Shed, and Shimmy are the four categories of DR service types as defined by Alstone et al., (2016) and are discussed in more detail in section 3.1 of this paper.

barriers include insufficient irrigation capacity, lack of communications, controls, and financial incentives. Other factors hindering DR adoption include inflexibility of water delivery, application methods, and labor.

According to Pacific Institute and Ringler et. al., the agricultural industry has the opportunity to improve its bottom line by tapping into new revenue streams such as DR incentives or implementing energy and water efficiency practices that reduce farm operation costs (Pacific Institute, 2014; Ringler et al., 2013). However, agricultural demand management programs have proven to be unsuccessful in facilitating the needs of the farm and helping the utilities manage their demand and reduce cost (Aghajanzadeh et al., 2018). Many DR programs offered by electric utilities are developed with no regard to on-farm operational constraints. Many customers may not even be aware of available DR enabling technologies or operational measures (Jang et al., 2015). Marks et al., also point out that the complex process of DR program enrollment, enablement, and participation has led to unsuccessful adoption of existing demand management programs within the agricultural industry (Marks et al., 2013).

Literature review regarding the uptake of DR in the agricultural sector identified three key topics that need to be well studied and understood. The goal of widespread agricultural DR will remain elusive unless a clear understanding of the following topics is established:

(a) Current and future needs of the electricity grid,
(b) Available DR market mechanisms on both supply and demand sides, and
(c) Farm loads including on-site electricity generation and storage.

The next section of this paper will provide more information about each of the identified key topics. Using that information, a framework can be created for satisfying the needs of the grid through available market mechanisms by the electricity consuming/generating equipment on farms.

3 Methodology

3.1 Grid Needs and DR Service Types

The electricity grid has evolved and integration of intermittent renewable sources such as wind and solar has made balancing the grid more complex. Figure 2 shows the generation mix of California's grid under a 50% RPS scenario which is expected to be achieved by the year 2030 (Alstone et al., 2016; CEC, 2018). Intra-hour variability and short-duration ramps are one of the immediate challenges faced by a 50% renewable California grid. In a 50% RPS scenario, thermal power plants need to ramp down as solar resources come online in the early hours of the day (1). However, they cannot drop to zero since a minimum capacity need to remain spinning for contingency as well as the evening ramp up, and in the absence of cheap energy storage, excess solar generation needs to be curtailed in order to maintain grid stability (2). As the solar resources stop generating electricity in the evening hours (3), thermal power plants (mostly natural gas) need to ramp up to make up for the lost solar generation. The ramp up to meet the evening peak will be more pronounced due to lower than usual net demand due to high solar penetration (4).

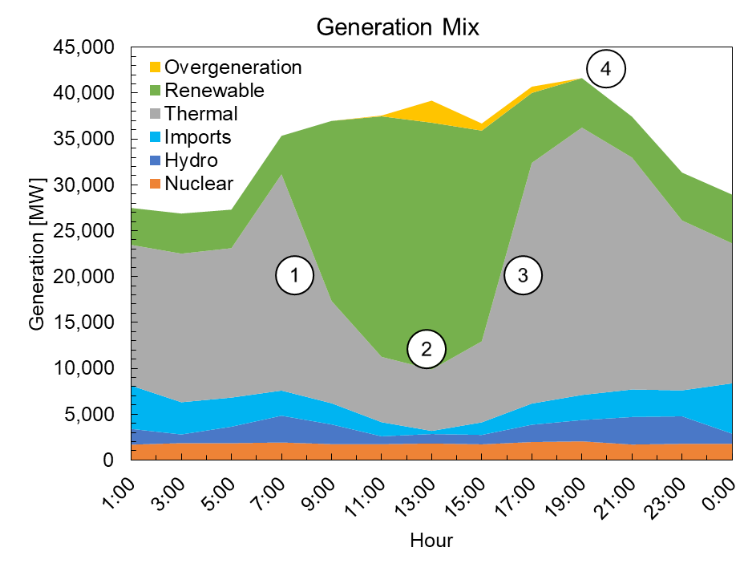

Figure 2: California grid under a 50% RPS (E3, 2014)

In the recent California Public Utility Commission's (CPUC) DR potential study, DR service types based on future grid needs were identified as: Shape, Shed, Shift and Shimmy (Alstone et al., 2016; CAISO, 2016). These needs were identified to address the challenges 1 through 4 outlined above. Figure 3, provides a visual representation of timescales and needs that each of the four DR service types address.

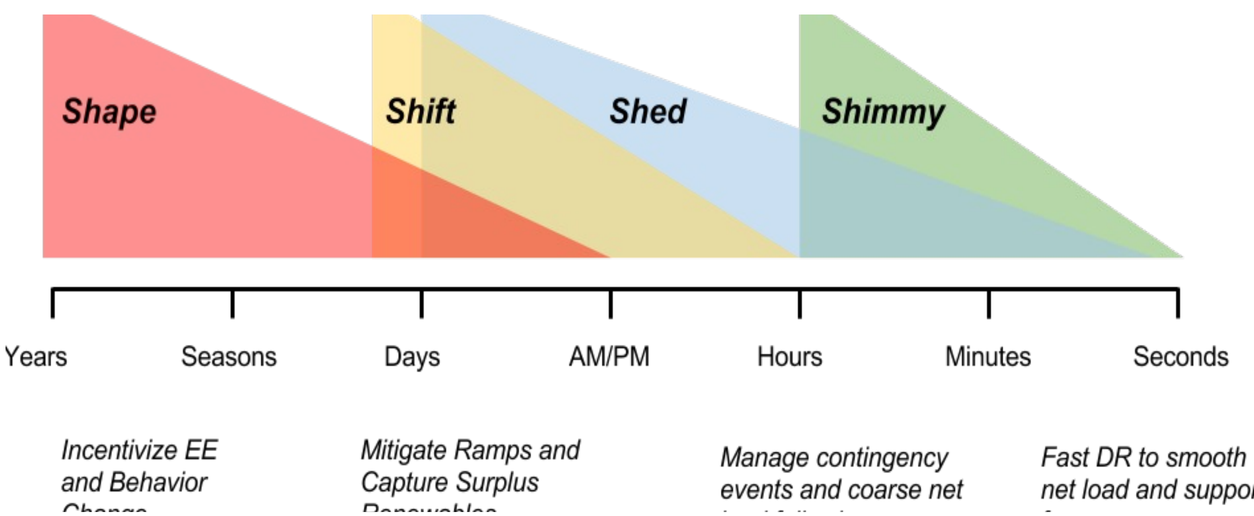

Figure 3: DR service types presented over timescale for grid dispatch frequency and/or response (Alstone et al., 2016)

The following definitions of DR service types are extracted from the CPUC DR potential study and Figures 4-7 provide visual illustrations for each type of DR service type (Alstone et al., 2016):

Shape captures DR that reshapes the underlying load profile through relatively long-run price response or on behavioral campaigns—"load-modifying DR"—with advance notice of months to days. Examples of shift DR includes time-of-use (TOU) and critical peak pricing (CPP) rates.

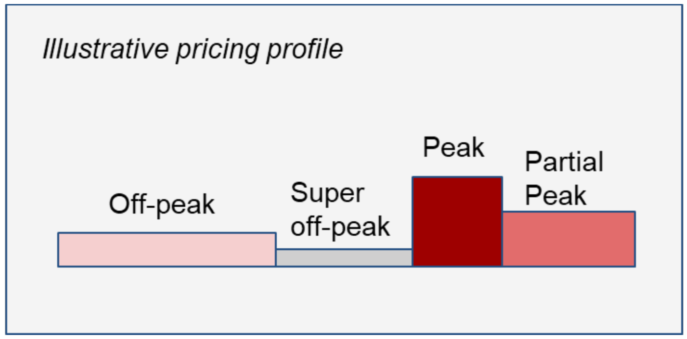

Figure 4: Re-shaping load profiles through prices and behavioral DR (Alstone et al., 2016)

Shift represents DR that encourages the movement of energy consumption from times of high demand to times of day when there is surplus of energy, typically from renewable generation. Shift can smooth net load ramps associated with daily patterns of solar energy generation. Examples of Shift technology pathways are behind-the-meter storage, rescheduling flexible batch processes such as electric vehicle charging fleets or pre-cooling with air conditioning units.

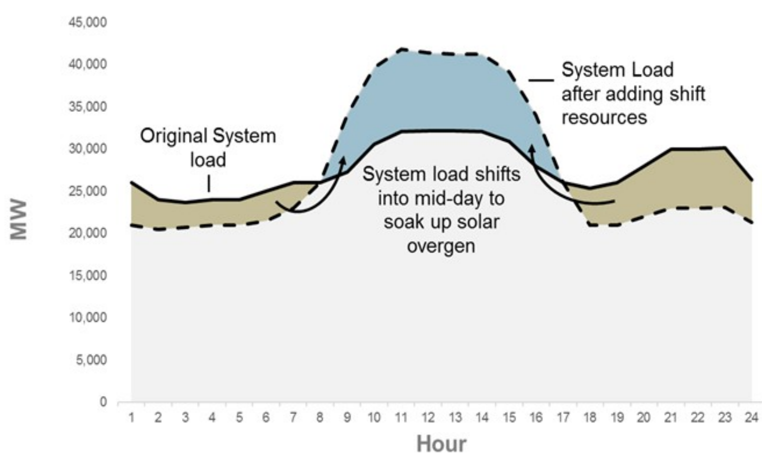

Figure 5: Shifting load from hour to hour to alleviate curtailment/overgeneration (Alstone et al., 2016)

Shed describes loads that can occasionally be curtailed to provide peak capacity and support the system in emergency or contingency events—at the statewide level, in local areas of high load, and on the distribution system, with a range in dispatch advance notice times. Examples of Shed DR are interruptible processes, advanced lighting controls, air-conditioner cycling, and behind-the-meter storage.

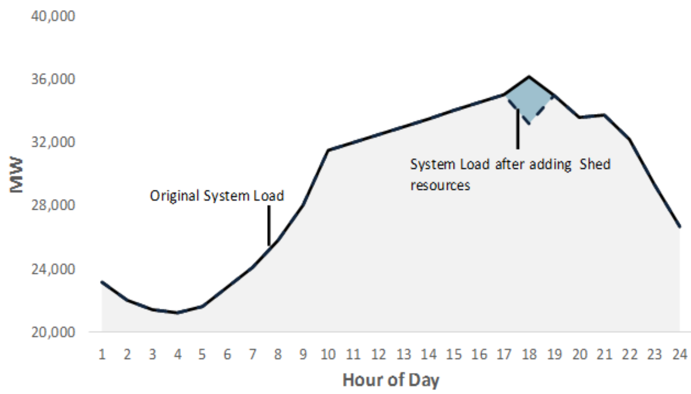

Figure 6: Shedding load during peak hours through DR (Alstone et al., 2016)

Shimmy involves using loads to dynamically adjust demand on the system to alleviate short-run ramps and disturbances at timescales ranging from seconds up to an hour. Shimmy has high value for managing short-term fluctuations in the net load. An example would be freeing up battery storage to prioritize soaking up cheap renewable power instead of managing short-run variability - essentially freeing the batteries to provide additional Shift resources.

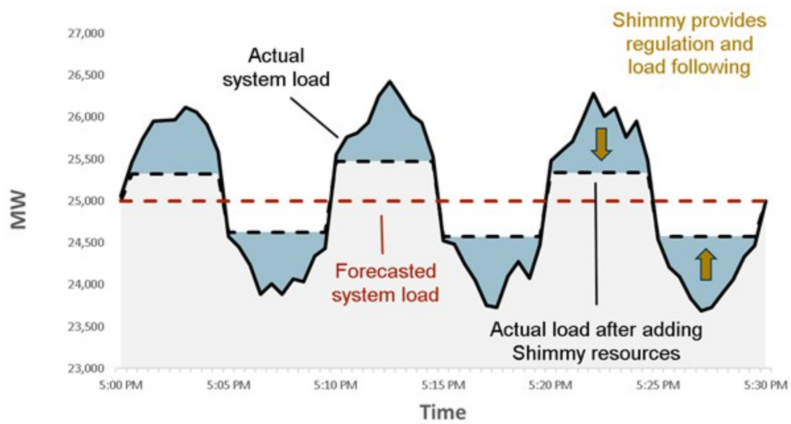

Figure 7: Load following and regulation DR (Alstone et al., 2016)

The terms Shape, Shift, Shed, and Shimmy introduced above are only simplifications of existing nomenclature. Table 1 summarizes different terms that are traditionally used for each of the four DR service types introduced in this section.

	DR Service Product	California Market
Shed	Peak Capacity	System and Local Resource Adequacy Credit
	Economic DR	Economic DR / Proxy Demand Resource
	Contingency Reserve Capacity	Ancillary Services- spinning
	Contingency Reserve Capacity	Ancillary Services- non-spin reserves
	Emergency DR	Emergency DR / Reliability DR Resource
	DR for Distribution System	Distribution
Shift	Economic DR	Combination of Energy Market Participation
	Flexible Ramping Capacity	Flexible Resource Adequacy -- energy market participation w/ ramping response availability
Shimmy	Load Following	Flexible Ramping Product (similar)
	Regulating Reserve Capacity	Resource Adequacy - Regulation
Shape	Load modifying DR - Event-based	Capacity Peak Pricing
	Load Modifying DR - Load shaping	Time of Use

Table 1: Explaining the simplified nomenclature for DR service types (Alstone et al., 2016)

3.2 Market Mechanisms for Demand Response Services

Market mechanisms are platforms that connect electricity end users, generators, and grid operators. These mechanisms are needed to ensure that the needs of the electric grid are satisfied while entities providing services to the grid are fairly compensated. While more intermittent renewable sources are integrated into the grid as dictated by the RPS targets, grid operation becomes more complex thus giving rise to more complicated and nascent market mechanisms. While new systems such as Automated Demand Response (AutoDR or ADR)[3] are seen crucial in addressing the challenges faced by the future grid, today's wholesale DR systems seem experimental, and retail DR systems typically work on slow time scales as open-loop systems to address peak load reduction (Kiliccote et al., 2010).

In order to address the variable generation mix and the dynamic demand of electricity, new market mechanisms are introduced and existing mechanism are constantly modified. The constant evolution of market mechanisms has led to a lack of understanding and a knowledge gap in how the electricity markets operate and the ways through which end users can participate in them. Moreover, the DR needs and availabilities of different actors may evolve over time needing constant modification of existing market mechanism (Annala et al., 2018) which can further widen this knowledge gap.

Another layer of complexity is the hardware requirements (e.g. OpenADR certified modem, settlement meters) and communication protocols used for each market mechanism and by various service providers (i.e. aggregators, utilities, etc.). This will leave many end-users unaware of technological or operational measures available to them (Jang et al., 2015). Although this paper does not discuss communication protocols, telemetry, and settlement metering requirements, it lays the groundwork for further exploring those requirements by providing

3 AutoDR is a machine-to-machine enablement of DR in response to grid signals without a human in the loop (Lanzisera et al., 2015).

conceptual DR participation pathways.

All DR service types fall into two main categories. Demand Side or load modifying resources, which reshape or reduce the net load curve; and Supply Side or supply resources, which are integrated into the Independent System Operator (ISO) energy markets. Figure 8 summarizes these two categories and requirements for participating in each category.

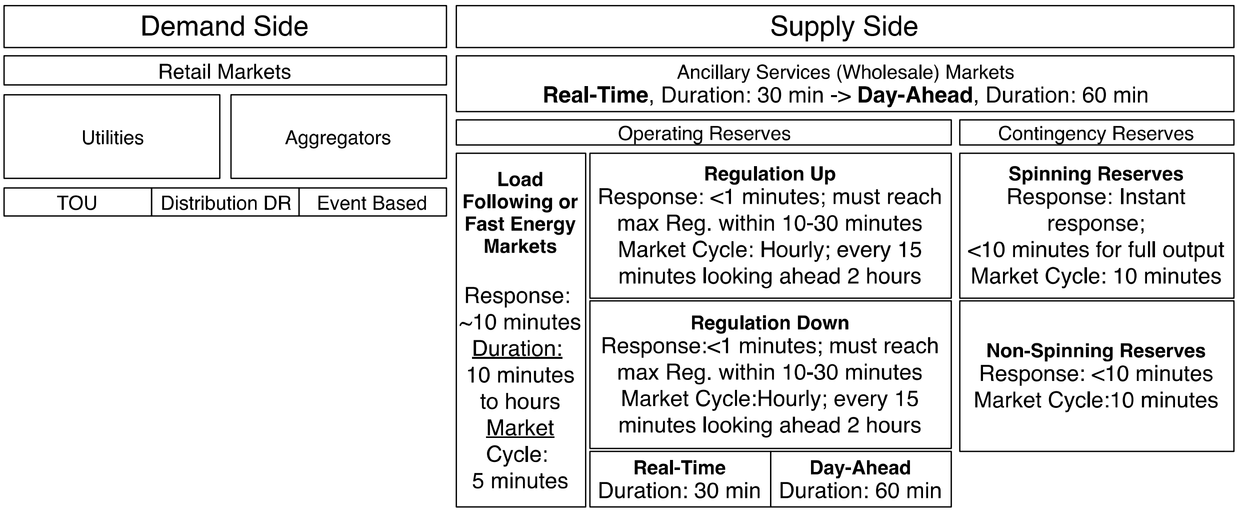

Figure 8: Summary of demand and supply side resources characteristics

3.2.1 Demand Side Resources

Energy efficiency and load management programs offered through the utilities in many US states are collectively called demand side resources. Such retail DR systems typically work on slow time scales as open-loop systems to address peak load reduction (Lanzisera et al., 2015). Currently agricultural loads (e.g. irrigation pumping) can only participate in demand side DR by enrolling in a TOU, DR, or ADR program offered by their local utility.

3.2.2 Supply Side Resources

Any resource that transacts with the electricity grid by providing a bid, price, and duration with short (minutes) or no notification is treated as a generator and required to adhere to the same requirements (Lanzisera et al., 2015). Transaction for such resources happen in wholesale ancillary services markets, operated by the ISO. This type of advanced DR will become more valuable over time, as the ISOs across the US integrate additional renewable energy sources and curtailment becomes more significant during the midday hours (Alstone et al., 2016). There are currently no mechanisms in place that allows agricultural loads to directly provide supply side DR.

3.3 Electricity Consumption, Generation, And Storage on Farms

Agricultural operations consume a variety of energy types for different purposes: directly as gasoline, diesel, natural gas, propane, or electricity (breakdown provided in Figure 9), and indirectly as fertilizer or pesticide (Hitaj and Suttles, 2016). Given that the focus of this paper is providing DR services to the grid, only direct electricity consumption is discussed. The number of farms producing electricity on-site through renewable sources doubled between 2007 and 2012 (Hitaj and Suttles, 2016). Farms that produce their own electricity are linked to energy markets on both the supply side and the demand side. This exposes farms to volatility in energy prices as energy consumers and uncertainty of revenue from the production of electricity generated on-site and sold back to the grid (Xydis, 2015). For example, electricity prices affect the costs of crop irrigation due to water pumping but also affect the value of renewable power generated on-farm (Hitaj and Suttles, 2016). While similar analysis can be carried out for other energy types (e.g. oil, natural gas, biomass, etc.) consumed or generated on a farm, the focus of this paper is only on direct electricity consumption or generation on a farm specifically for the purposes of crop irrigation.

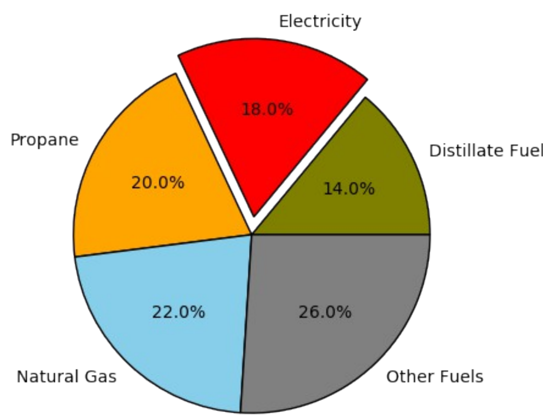

Figure 9: US direct energy consumption for crops

Agriculture is a major user of ground and surface water in the US, accounting for approximately 80% of the nation's consumptive water use. In many Western drought-prone states that number increases to 90% (Schaible and Aillery, 2012). In Western states, irrigation provides most of the crop water requirements, while in eastern areas irrigation is largely supplemental (Wichelns, 2010). Unlike turf irrigation, which is mostly done at night, irrigating farms require a constant supply of water to meet crop requirements (David Zoldoske, 2015). Therefore, a large amount of agricultural pumping occurs during period of high evapotranspiration[4] (ET) including summer afternoons which are prone to having the highest levels of ET.

Irrigation pumps are primarily powered by electricity. According to 2013 Farm and Ranch Irrigation Survey, 85% of irrigation pumps are electric and only 13% of pumps are powered by diesel (UC Davis, 2016). Since most pumps on farms use electricity to convey water, the large water pumping demand for agriculture can be translated to large electricity consumption. About 70% of the electricity consumed on a farm is due to water pumping (UC

4 Evapotranspiration or ET for short is defined as the water lost to the atmosphere due to evaporation from the soil surface and the transpiration by plants. ET is the main driver behind crop irrigation.

Davis, 2016). Electricity is consumed on a farm to either pump water out of the ground, divert surface water, or pressurize water for irrigation applications.

While pumps use the majority of the electricity on the farm, there are other equipment and generation sources that complicate the analysis of energy consumption on a farm. Those equipment include solar panels, variable frequency drives (VFD) on pumps, and water storage. Presence of those components can affect the timing and manner of electricity consumption and its controllability on a farm.

To take full advantage of available loads on farms, their DR potential, level of automation, response time (in seconds, minutes, or hours), and required notification time should be characterized. Figure 10 illustrates a generic representation of available assets on a farm as well as the electricity and water flows. Figure 10 is representative of a generic farm and does not include all possible equipment found a farm (e.g. cold storage and electric vehicle chargers such as lift trucks).

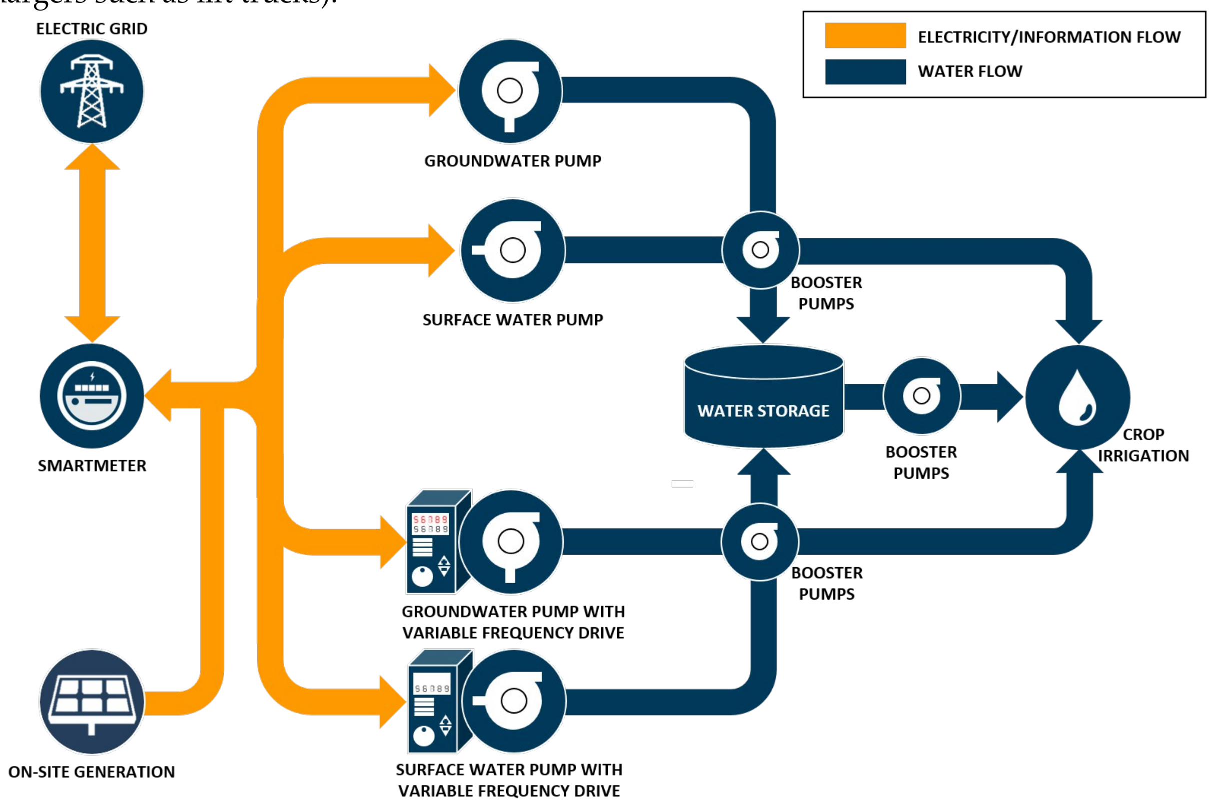

Figure 10: Generic irrigation system schematics on a typical farm

This paper focuses on water related energy consumers on a farm; therefore, all the equipment listed in Figure 10 and the rest of this analysis include equipment that are involved in water conveyance, pressurization, and storage. In the following sub-sections, each relevant piece of farm equipment will be analyzed in detail, including its manner and timing of energy use, level of automation, and ways through which they can impact electricity consumption on a farm. A summary of farm equipment characteristics discussed in this section is presented in Table 2. In order to integrate agricultural loads into the grid their level of automation, response time, and demand flexibility need to be characterized. Three levels of automation is assigned to each farm end-use (automated, manual, semi-automated).

Equipment	Automatio n	Response Time	Demand Flexibility [%]	Operational Limits
Groundwater Pump (GW)	Manual	Minutes-Hours	± 100%	Requires advance notice, planning, and reallocation of labor
Surface Water Pump (SW)	Semi-Automated	Seconds-Minutes	± 100%	Limited by water allocations and surface water deliveries
Booster Pump	Semi-Automated	Seconds	± 100%	Limited by irrigation schedules and irrigation system type
Groundwater Pump + VFD	Automated	Minutes	Variable	VFDs are not suited for high static head systems (e.g. GW pumping)
Surface Water Pump + VFD	Automated	Seconds	Variable	Limited by water allocations and surface water deliveries
Booster Pump + VFD	Automated	Seconds	Variable	Limited by irrigation schedules and irrigation system type
Water Storage	Semi-Automated	Hours-Day	Variable	Building surface storage reservoirs are costly and currently not common on farms without pressurized irrigation
On-Site Generation	Automated	Seconds	Variable	Limits imposed by the local utility (e.g. Net metering)

Table 2: Summary of available equipment on an agricultural farm. ±100% indicates that systems can only operate in a binary mode, meaning they can either shutoff (shed) or ramp up to full capacity (take)

3.3.1 Groundwater Pumps

The largest energy consumers for irrigated agriculture, especially in water scarce regions are groundwater pumps. Irrigated agriculture in the US uses 74 million Acre-Feet (AF) of water annually for crop production, with 52% originating from surface water sources and 48% percent pumped from wells that draw from local and regional aquifers (Schaible and Aillery, 2012).

With more extreme weather conditions, uncertainty of surface water availability and a switch to pressurized irrigation, the share of groundwater pumping is expected to increase. During California's recent drought the share of groundwater used for irrigation increased from 31% in an average year to 53% in the year 2015 (a 71% increase) (Howitt et al., 2014). Energy intensity for groundwater pumping in California is approximately 500 kWh/AF and can range from 250 kWh/AF to 1,000 kWh/AF (Cooley et al., 2006). The average energy intensity for surface water pumping is estimated to be 300 kWh/AF (Cooley et al., 2006). Therefore, a 71% increase in groundwater pumping translates to a 47%[5] increase in cost of electricity for pumping which will increase a farm's operation cost significantly while putting a significant amount of stress on the electricity grid. Around one-third of water pumping for irrigation on farms happens during expensive peak hours. However, groundwater can be pumped during off-peak hours and stored until needed (UC Davis, 2016). This provides a great deal of flexibility to the

5 Energy intensity of groundwater pumping is on average 66% higher than surface water pumping. Therefore, 71% increase in share of groundwater pumping will translate to 47% raise in electricity demand (66% x 71% = 47%)

farmers assuming that the infrastructure (storage capacity, automation, centralized controls, etc.) are in place to enable such operation. The term water storage is used generically throughout this paper to represent various methods (e.g. ponds, reservoirs, tanks) through which a farm can store water.

Given the large magnitude of electricity demand for groundwater pumping, most groundwater pumps are operated manually with long notification periods required. Once a groundwater pump is turned off, it cannot be immediately turned back on and usually require a time period of several minutes before it can be started up again. These limitations hinder groundwater pumps to provide any fast DR services such as ancillary services to the grid and can only provide longer timescale DR services.

3.3.2 Surface Water Pumps

Surface water pumps divert water from surface water sources and distribute the water throughout the farm for irrigation purposes. Surface water originates from both on-farm and off-farm sources. On-farm surface water comes from ponds, lakes, or streams and rivers, while off-farm water sources are generally supplied to the farm through local irrigation districts; mutual, private, cooperative, or neighborhood water-delivery companies; or from local or municipal water systems (Schaible and Aillery, 2012). Surface pumps are low static head systems with most of the energy expended to overcome the dynamic head. As of 2008, 52% of irrigation water needs were satisfied through surface water sources, but that number has been decreasing in recent years with groundwater withdrawals increasing to make up for the surface water shortage. Operation of surface water pumps are limited by surface water availability and delivery schedules with little inherent flexibility. Dwindling surface water sources has made operation of surface water pumps even less flexible as they are dictated by water availability and not the irrigation schedule, energy cost, and/or the grid needs.

3.3.3 Booster Pumps

Booster pumps are used to pressurize water for irrigation applications. Booster pumps in California use nearly two-thirds the same amount of energy that is expended by well pumps. But unlike groundwater pumps, booster pumps need to keep the water in the irrigation system pressurized which makes them less flexible and thus cannot only run during off-peak hours (UC Davis, 2016).

3.3.4 Water Storage (Energy Storage)

The most convenient form of energy storage on a farm is not a battery or similar technology but is in the form of water storage. Water can be pumped during off-peak hours and stored on a farm in many different ways. Soil moisture is the most common form of water storage on a farm. Adjusting the soil properties (i.e. increasing the biochar content of the soil) can significantly increase soil's moisture uptake capacity. More recently, farmers in California have started a new form of water storage by flooding their fields even outside of the irrigation season. This will recharge the groundwater aquifers during times of year when excess surface water is available (Charles, 2014). Another form of water storage that can be beneficial for DR participation is above groundwater storage (either in a pond or a tank). On-farm water storage can act equivalently as a battery, smoothing the electricity demand for irrigation. Availability of water storage allows irrigation when needed, or when it makes the most economical sense (in terms of water availability, energy cost, and crop yield) and not when water is available.

3.3.5 Variable Frequency Drive

The speed of an alternating current (AC) electric motor in a pump system is directly proportional to the frequency of the power supply. A Variable Frequency Drive[6] (VFD) takes the electrical supply from the utility and changes the frequency of the electric current, which results in a change of motor speed (U.S. Department of Agriculture, 2014). VFDs are most commonly installed for energy saving purposes; however, improved process control is another reason for installing VFDs.

VFDs, although promising for AutoDR can pose potential disadvantages such as damage to the motor bearing and other components if operated improperly. Considerations must also be given to VFD reliability, maintenance costs, and skills of available personnel [CITATION USD141 \l 1033]. VFDs are not recommended for pumps with high static head or pumps that operate for extended periods under low-flow conditions [CITATION NSW171 \l 1033]. Therefore, VFDs are not suited for pumps that pull water from deep groundwater wells, and are best fitted for smaller surface/booster and fertilizer pumps. Figure 11 summarizes the operational characteristics of a pump with a VFD under different speeds. Note that there is no static head present in Figure 4, only dynamic head (frictional losses).

6 VFDs are a subset of Variable Speed Drives (VSD) since changing the frequency of power supply is one way of controlling the pump speed. However, the term VFD is used in this report by default as they are most commonly used by the industry.

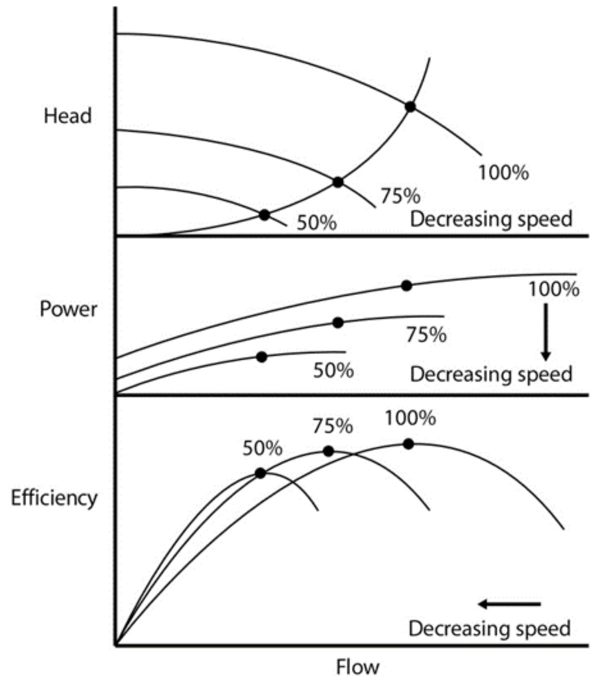

Figure 11: The effect of reduced drive speed on head, power, and efficiency (NSW Farmers, 2013)

As discussed earlier, groundwater pumps can be easily coupled with water storage and be able to shift their operations to off-peak hours. Therefore, VFDs with their drawbacks for high static head systems are not the best fit for groundwater pumps. However, VFDs would be ideal for tapping into the DR potential that booster and surface pumps can provide. Given that booster pumps need to maintain a minimum pressure on the irrigation system, VFDs can allow modulation of their power and allow such systems to provide DR services to the electric grid while meeting the operational requirements of a farm's irrigation system. According to Figure 4, a low static head pump (i.e. booster pump) can reduce its power demand by a third without significant efficiency losses if operated correctly.

3.3.6 On-site Electricity Generation

Over 57,000 farm businesses and other farms (2.7% of US farms) were engaged in producing renewable energy such as solar, wind, and geothermal in 2012, more than twice as many as in 2007 (Hitaj and Suttles, 2016). Solar energy production is the most prevalent from on-farm renewable energy, with an estimated 82% of farms with renewable energy generation reporting solar electricity generation capacity (Schaible and Aillery, 2012). With dropping prices of solar energy, agricultural industry can benefit from dual land use for energy production. Solar panels installed on an irrigation ponds can reduce evaporative losses, and solar arrays installed elsewhere on a farm can provide shading for the livestock or the farming equipment (e.g. tractors). On-farm renewable energy production can also protect farms from volatile energy prices. This trend provides an added incentive for farmers to get a better handle on the timing of their energy use, and restructure their operations to utilize larger amounts of renewable energy such as wind and solar (Bardi et al., 2013). Much of the infrastructure and technology that can be used for AutoDR enablement, can be used for helping farms in maximizing the use of the onsite generated renewable energy. The framework put forward in this paper also helps pave the path for policy development as farms transition from being net energy consumers to net energy generators.

4 Discussion

A high renewable penetration grid requires flexible loads in order to maintain its stability. Agricultural loads, with their large magnitude can provide that flexibility as energy markets move into a future of increasingly distributed and intermittent renewable generation. However, several on-farm constraints, as well as lack of appropriate market mechanisms limit farms from taking advantage of more flexible energy and water use strategies that could benefit the grower, utility, and the grid. Agricultural demand management programs have proven to be unsuccessful in facilitating the needs of the farm and helping the utilities manage their demand and reduce cost. This indicates that current programs and tariffs do not adequately account for the needs of the grid and constraints that exist on farms. New technologies and market-based approaches are needed to give utilities greater flexibility and their agricultural customers greater incentives to balance the grid and meet the high penetration of renewable sources in the coming decades.

To address these barriers for DR adoption, researchers and Agricultural Technology (AgTech) companies have focused on topics such as scientific irrigation scheduling, real-time irrigation prediction using sensor data, and remote scheduling of operations. In the meantime, utilities have done very little to tailor their DR programs to the needs of agricultural operations. A common misconception within the AgTech industry is that technology alone will inherently bring all the benefits. However, technology can lead to more complications if it is not coupled with improved management and training. In recent years, an abundance of AgTech companies (AgTech Insight, 2016), has led to a surge of promising technologies but most lack scalability and impact on the field. For example, various models of water efficiency and environmental benefits have been developed, yet they are under-utilized in irrigation scheduling; at most, they help retrospectively to evaluate seasonal approaches (Steduto et al., 2012). Another example is of soil moisture sensors being ubiquitous on the market but are not easy to handle, lack reliability, and fail to provide adequate spatial data. The same situation applies to technologies geared toward managing energy and electricity demand on farms.

Several years of agricultural DR research has identified that the DR and pathways through which a farm can be approved and enabled for DR, participate in DR events, and receive compensation are complex. Most farms lack the in-house expertise for going through the entire process without the help of external consultants. Without an energy or sustainability manager, it is very challenging and intimidating for farms to even begin to approach DR enablement – unless they put all their faith in a utility or aggregator in spite of their own lack of understanding. The research for facilitating higher uptake of agricultural DR has been segmented by keeping farmers, grid operators, and utilities (or DR aggregators) in silos with little thought to having them talk and understand each other's needs. Moreover, much of

AgTech sector's focus has been on yield increase and crop quality improvement (Pacific Institute, 2014) and little attention has gone towards other operational aspects of the farm including irrigation energy and water management. Ultimately, irrigated agriculture will need to adopt a new management paradigm based on an economic objective which not only includes yield but also takes into account water and energy (English et al., 2002).

The framework put forward in this paper is unique as no similar farm to grid analysis framework has been identified in the extensive literature search in the field of agricultural water and energy. The discussion put forward in this paper can be summarized in a diagram similar to what is presented in Figure 13. With the information provided in previous sections, one should be able to connect various on-farm electricity consuming equipment to the appropriate grid need(s) using available market mechanisms. This framework will allow identification of missing market mechanisms for tapping into agricultural DR potential or can shed light on technology gaps that can facilities higher DR participation of agricultural farms.

Figure 13 is intended to serve as a starting point for addressing the knowledge gap that hinders farms to provide valuable DR services to the grid and benefit from untapped revenue streams. The future work should be focused on data collection that will allow better mapping of farm equipment to various grid needs through existing mechanism or developing new ones. Even though this paper will not provide an end-to-end solution for DR enablement at farms, but it paves the way for widespread DR participation for all significant electricity users on farms.

Figure 12 illustrates a hypothetical application of the proposed framework. In the example below, actual farm load profiles are disaggregated into various end-uses (e.g. groundwater pumps, surface water pumps, and other). Based on the information collected regarding each end-use (e.g. Table 2), the relevant component of the load profile can then be mapped to the appropriate grid need based on its characteristics (e.g. magnitude, response time, automation, etc.).

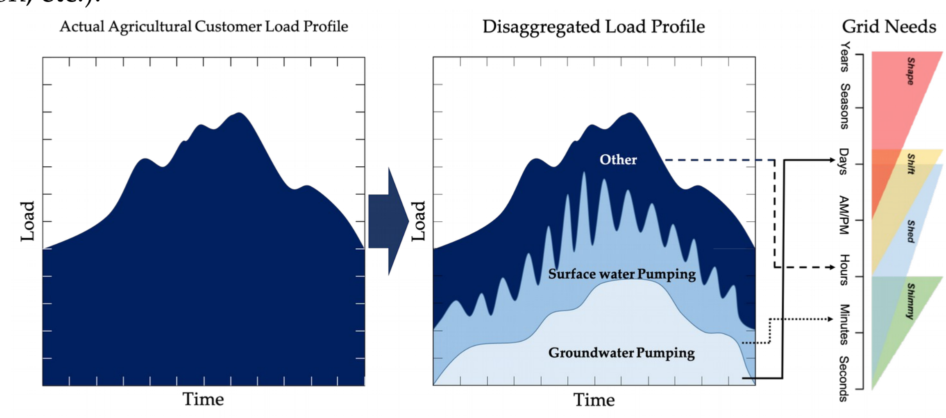

Figure 12: Hypothetical example for the application of the proposed framework

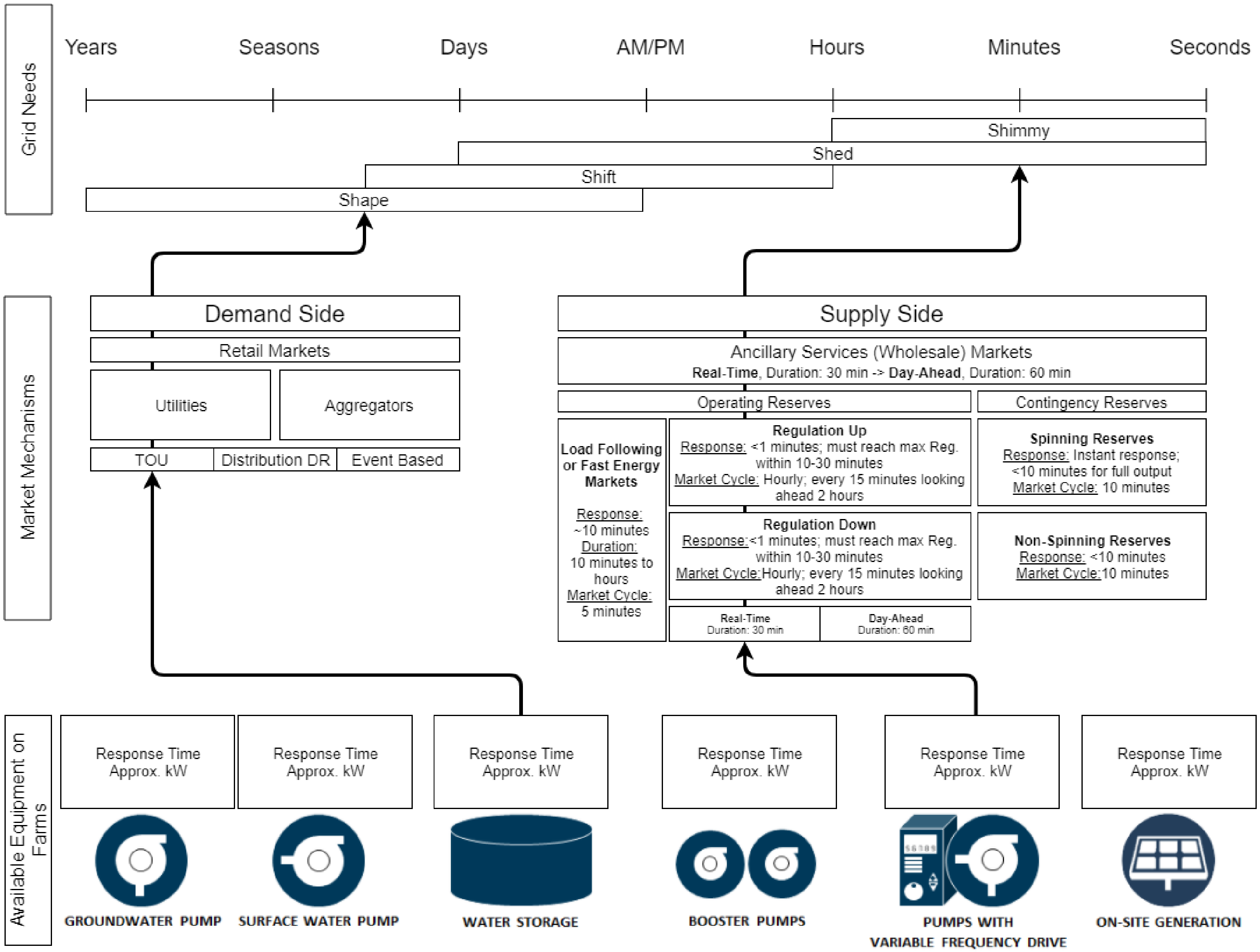

Figure 13: Generic diagram representing some example pathways through which various assets on the farm can provide services to the grid. Pathways shown on the above example are examples and do not represent a complete picture of all possible DR pathways.

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