Primer on Energy Efficiency

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If you ever have been to an electricity conference, at some point, someone will utter the following “the cheapest megawatt hour (MWh) of electricity is the one that is not produced” – sometimes this concept is referred to as a negawatt.[1]

Arizona is projected to have a population of over 10 million by 2030 and 12.8 million by 2050.[2] This estimated influx of population will inevitably mean that additional electricity generation resources will be required to match the increase in demand.

When examining how and what generation resources are available to meet the growth in electricity demand typically a gamut of options, including energy efficiency, are typically explored.[3] Also energy efficiency measures are often discussed as a potential (cost-effective) method of reducing carbon emissions within the electricity sector.[4]

In Arizona alone, it has been estimated that, in the energy sector (including electricity, natural gas, petroleum and other fuels) the total *capital* investment in energy infrastructure required to serve Arizona’s growing population to 2032 will be approximately $74 billion - $86.5 billion depending upon the mix of generation technologies employed going forward.[5] [6]

Potentially with all this in mind, the Arizona Corporation Commission (ACC) recently introduced an energy efficiency standard for all regulated electricity providers that requires a cumulative annual electricity savings of at least 22 percent[7] by 2020.

[1] Something similar to this is often mentioned at any infrastructure-based conference.
[2] Arizona Department of Economic Security. These estimates are now a little dated; however the consensus is still that Arizona will grow in population terms.
[3] See Energy Information Administration (EIA) annual energy outlook (AEO) 2010 for an example. For an Arizona-specific example see Arizona Public Service Resource Plans which are filed annually with the Arizona Corporation Commission.
[4] See Electric Power Research Institute (EPRI) (2009)“The Power to Reduce CO_2 Emissions” for an example of how much CO_2 reduction may come from energy efficiencies.
[5] This is only the additional fixed costs and does not include variable costs such as fuel payments.
[6] See Seidman Research Institute. (2008). *“Infrastructure Needs and Funding Alternatives For Arizona: 2008-2032.”* For more details.
[7] of 2019 retail sales.

Given that energy efficiency measures/options are being increasingly discussed by policy-makers, below is a discussion of five key points that all interested individuals need to keep in mind when discussing energy efficiency – with a focus on electricity usage in Arizona.

1) Energy Efficiency versus Energy Conservation

Electricity usage/consumption is known in economics as a derived demand. That is, individuals and businesses do not demand electricity for its own sake but instead we "consume" electricity because the goods and/or services (output) that we ultimately desire requires electricity as an input in its production.

For example, in Arizona individuals may want to use their air-conditioning units to cool their homes (output). It is the desire to cool homes (output) which ultimately determines our demand for electricity (input).

With the link between goods and services (output) and inputs (electricity) in mind the two major ways to reduce electricity usage/consumption occurs via Energy *efficiency* and/or energy *conservation*. Energy efficiency and energy conservation attempt to achieve the same outcome, namely reduced electricity consumption, however each mechanism attempts to achieve this in two separate ways.

In a broad manner energy efficiency focuses on adjusting directly *input* requirements whilst energy conservation focuses on *output* requirements - which indirectly affect the demand for the input component due to energy being a derived demand.

Energy *efficiency* attempts to achieve reduced electricity consumption by *reducing* the amount of electricity required to produce a given amount of a good/service. In effect energy efficiency reduces the electricity-intensive nature of the production process.

Typically, energy efficiency programs in the electricity sector in Arizona attempt to achieve a reduction in the demand for electricity related to the usage of air-conditioning units given that air-conditioning usage drives much of the demand profile seen in Arizona – especially during peak periods.

For instance, ICF international (2007) estimated that for APS's service territory approximately 35.5 percent of all residential energy usage was due to central air conditioning.[8] Central air conditioning usage is nearly triple the next highest single cause of usage which was heating at 10.5 percent.[9] [10] [11] For commercial and industrial consumers, the highest single component of usage was estimated to be interior lighting which accounted for 30 percent of all usage, whilst cooling accounts for 22 percent and ventilation accounts for 12 percent.[12]

To achieve reductions in the electricity used via air-conditioning usage two separate but related mechanisms are generally promoted via energy efficiency programs. First, more efficient air-conditioning (AC) units could be installed, such that it takes less electricity to cool a given floor space to a particular temperature. The efficiency of an air-conditioning unit is described by its Seasonal Energy Efficiency Ratio (SEER) rating.[13] The higher the SEER rating the more efficient the air-conditioning unit and thus less electricity is required to cool a given floor space.

Advanced Energy (2005) examined the energy characteristics for 7,141 homes built between 1995 and 2004 in the Phoenix metropolitan area. They found that the average SEER rating for these homes was between 11.6-11.9.

Recently there was a change in the minimum SEER rating allowed for new residential AC units. Air conditioners manufactured after January 26, 2006 now must achieve a SEER of 13 or higher.[14] Thus, through time, due to new residential construction (driven by population

[8] ICF International (2007) Table 5-3.
[9] We say single cause because "other" which accounts for 14.3 percent includes *"all "not elsewhere classified" consumption, including items such as plug load and computer equipment, etc"*.
[10] Heating is relatively high because APS service territory includes some "high country" which is areas of the state that is not desert climate.
[11] Informal discussions with representatives with other utility companies in Arizona also suggest that usage is tied to air-conditioning.
[12] ICF International (2007) Figure 5-5
[13] See the Department of Energy (DOE), Energy Efficiency & Renewable Energy for more details on for a technical explanation of how SEER is calculated.
[14] Source: DOE.

growth) and replacement of older less efficient AC units, the average SEER rating in Arizona will increase.[15]

Secondly, rather than focusing on improving the efficiency of AC units, instead, improving the efficiency of homes/business through altering their physical characteristics via "weatherization" program can be implemented. Weatherization may include, improved roof and wall insulation, repairing of any leaking air-ducts, sealing of doors and window frames and screens on windows.

Overall, weatherization assists with ensuring that it takes less air-conditioning to cool a given space to a particular temperature due to a reduction in "cool-air" leakages as well as a reduction in "hot-air injections" into a particular home or business.

Simply put, weatherization assists with reducing (increasing) how hot (cold) a home or place of work would get for a *given amount* of air-conditioning output – and thus less AC output is needed to *maintain* a given temperature.[16] Overall, weatherization assists with reducing the total amount of time that a given SEER rating AC unit will be running during a given year – which ultimately leads to less electricity being consumed within a given home/business.

However, caution has to be taken when translating efficiency improvements in AC units and/or improved weatherization characteristics into overall *reductions* in electricity consumption *per home or business* – especially when looking at newly constructed homes.

For instance, Advanced Energy (2005) found that homes constructed between 1995 and 2004 that were more energy efficient, due to higher rating SEER AC units being installed and/or more energy efficiency characteristics of the home, consumed 8.22 kilowatt hours per square

[15] Note it will increase at a relatively slow pace given that AC units are durable goods and thus last for many years.

[16] For instance it is expected that if the air-conditioner was switched off (or the thermostat is increased significantly) it would take a lot longer for a "weatherized" home to achieve a particular increase in ambient temperature than a non-weatherized home. In some cases the weatherized home may never reach certain ambient temperatures. All of which would assist with reducing the amount of air-condition, and as a result electricity usage, needed within a home/business.

foot whilst comparable baseline homes consumed 8.36 kilowatt hours per square foot.[17] However, due to energy efficient homes (1,967 square foot) being larger than baseline homes (1,735 square foot) the overall electricity consumption for an energy efficient home (15,831 kWh annually) was *larger* than a baseline home (14,107 kWh annually).[18]

Thus, it appears that to reduce total electricity consumption via energy efficiency improvements Arizona needs to first begin reversing a trend of building larger homes. ICF International (2007) reports that the average home size in APS's territory has increased such that for home built pre-1980 the average single story home was 1,884 square feet whilst homes built after 2000 the average single story home was 2,125 square feet.[19]

Even if the increasing house-size trend is not reversed another way to potentially lower electricity consumption per home is to retro fit (weatherize) and installing new AC units within the *current* housing stock as these homes are already built and thus there is a relatively low probability that they will ever increase in size.[20]

Energy *conservation* on the other hand attempts to reduce electricity consumption by reducing the total amount of goods and services purchased/consumed that require electricity as an input. Examples of electricity conservation include, turning off lights/television when not in a room, unplugging all devices when not in use rather than leaving them on "stand-by" (including devices used to charge mobile electrical devices),[21] only having one fridge[22] and setting the AC thermostat to a hotter (cooler) setting during the summer (winter) months.

[17] Their most preferred comparison case is to compare energy efficiency homes versus baseline homes that do not have a swimming pool and use gas as the major source of heating. Advanced Energy, (2005) Table 11.

[18] The authors note that many of the baseline homes may actually have an energy efficiency level that is comparable with the energy star homes but were not certified. Thus, the very presence of energy efficiency building standards may increase the energy efficiency of new homes that are built but not targeting/receiving certification. This raises another question which is, "should credit under the energy efficiency standard be received for this "spillover" effect?"

[19] A similar story is true for multi-story homes.

[20] To maximize the savings would require no change in behavior. This is discussed in more detail in Point 4.

[21] The electricity consumed by these devices – even when they not being used to charge the device in question - is sometimes called vampire losses.

[22] Rather than say a second refrigerator in the garage or outside on the patio.

The 2005 Residential Energy Consumption Survey[23] reports that 22 percent of all households in the US have a second refrigerator with the mode being it is 10-19 years old. Whereas the mode for the primary refrigerator is only 5-9 years old.[24]

Looking at personal computers, 68 percent of households use a personal computer (PC). Of those people who use a personal computer 17 percent leave their computer on when not in use, and 26 percent place their computer in sleep mode when not in use.

23 percent of households have at least a secondary personal computer that is used. Of those households who use a secondary personal computer 13 percent leave the computer on when not in use, and 17 percent place the secondary computer in sleep mode when not in use.

Just from some of these observations there appears to be some areas where households *could* engage in energy conservation – switching off completely PC's when not in use and getting rid of the second (older refrigerator). However, whilst households *could* reduce our energy usage the question that remains is *why* relatively large percentages of the population in fact do not.

Economics is fundamentally based upon the notion that people attempt to maximize their satisfaction with all given knowledge. Thus if households have two refrigerators and/or do not switch off appliances when not in use then have a valid and rational (maximizing satisfaction) reason for doing so.

Now, one counter-argument is that households do not necessarily know fully the cost of each consumption decision they make in real-time within their home – in economics that is known as imperfect information.

That is, households generally receive a total electricity bill each month and do not necessarily know how that is broken down by usage.[25] This lack of information may be causing households

[23] Most recent available.
[24] This provides some evidence that people –if they have a second refrigerator tend to keep their original refrigerator as their second refrigerator when they purchase a new primary refrigerator.
[25] Although many utilities do provide some "guide" on what households are using electricity for.

to be making "incorrect" consumption decisions. Thus, overall welfare *may*[26] be improved by improving the information relating to electricity usage for household – improving consumers' knowledge about the costs of their consumption decisions is generally one common theme found within many energy efficiency/conservation programs.[27]

However, the largest potential barrier to substantial energy conservation within a particular household is due to consumer surplus. Consumer surplus is the satisfaction from a consumption decision that households receive but did not have to pay for.

For instance, at the margin, for the last good or service consumed the marginal benefits obtained from the consumption decision (additional satisfaction received) is equal to its cost (the electricity consumed to enjoy the product). Therefore, the consumer surplus is approximately zero on the *final* unit consumed – on all *previous* units consumed the consumer surplus would be positive. Simply put, households feel like they got a "bargain" on those units or the majority of units consumed reflected "good value for money".

However, suppose a household begins to adopt energy conservation measures, potentially because they become fully-informed of their consumption decisions, such that they find that at their initial position their marginal cost was greater than their marginal benefit. Thus, the household would in fact realize they were not getting good value for money on the final units consumed.

As they reduced their electricity consumption a significant divergence may be created between the marginal cost of a consumption decision (price of electricity) and its marginal benefit (the satisfaction received from that consumption decision) and thus the individual stops engaging in energy conservation activities.[28]

[26] Concepts like this are known as "market failures" and will be discussed more in Point 2.
[27] Ehrhardt-Martinez et al. (2010) provide some evidence that improved information flows through smart meters and other devices may tend to encourage reductions in energy consumption.
[28] This assumes that the individual was only just consuming more than their optimal amount of electricity due to lack of information on marginal costs.

A simple example can be offered to illustrate this point. How much would you accept in monetary compensation as an individual to set your AC thermostat 1 degree higher – say from 77 to 78 degrees Fahrenheit during the summer? First off, would you need more than the simple reduction in electricity bill? If so, then you (rationally) are not going to conserve electricity by turning your thermostat up without market intervention that offers additional financial incentives (or the price of electricity would need to increase).

What about setting your thermostat 5 degrees higher? Or ten? Would you be willing to take five or ten times as much financial compensation as what you wanted to go from 77-78? Or would you need greater than that amount? What about to turn off your AC completely? Is the total reduction in your electricity bill enough?

If you needed more than just the financial savings associated with turning your thermostat setting to a hotter temperature or the financial savings associated with switching off you AC unit would not be enough to compensate you for the enjoyment/satisfaction you receive from running your AC unit then you are receiving consumer surplus from your current consumption decisions. You are receiving satisfaction that, if required, you would pay for but you don't have too.

Of course here we are focusing on just the financial incentives. It is entirely possible that households engage in energy conservation, not because of just the pure financial savings, but because they receive satisfaction knowing they are "doing their part for the environment".

The satisfaction gained from being environmentally friendly (along with the financial savings) would have to be more than the lost satisfaction caused by the reduction in the consumption of goods and services to induce individuals to adopt energy conservation measures.

Attitudes to the environment can potentially explain why some households engage in more energy conservation measures than other households even if we keep certain general characteristics (income etc) constant.

However, energy conservation measures ultimately tend to fall foul to consumer surplus. That is, even if we begin conserving electricity, the consumer surplus associated with the next consumption decision that we are thinking of foregoing becomes increasingly large. Thus the "penalty/cost" associated with energy conservation increases as we engage in more and more energy conservation measures. This increasing penalty may therefore place limits on the effectiveness of programs that attempt to encourage reductions in electricity via energy conservation alone.

2) Energy Efficiency Gap: Explaining why People are leaving "Money on the Table"

One notion within the energy efficiency arena is the idea of an energy efficiency gap. Simply put, the energy efficiency gap focuses on trying to explain reasons why there is only a relatively low penetration rate for apparently cost effective energy-efficiency technologies.

For instance, when looking at energy efficiency measures, often each measures' net present value (NPV) is estimated (and is positive) and/or the cost per kilowatt "saved" is calculated (and it is less than the price of electricity).[29]

At first glance it appears, due to the lack of wide adoption, that households and businesses are effectively not engaging in profitable opportunities by *not* adopting energy efficient measures. Thus households and businesses are effectively "leaving money on the table' by their apparent hesitancy to fully engage in adopting energy efficient measures. Thus, the next task is attempting to explain this type of behavior – in economics this is known as identifying the reasons for the apparent market failure.

The core approach to examining energy efficiency options is generally an investment-based one. With the investment strategy examining the trade-off between, accepting higher initial capital/installation costs (adoption of the energy efficiency measure instead of a "standard measure") for "riskier" lower future energy operating costs – forecast lower electricity bills during the lifetime of the energy efficiency measure.

[29] Or from the utility's perspective it is less than the fuel component.

Within much of the energy efficiency literature the implicit assumption is that the household/business examining the financial viability of energy efficiency options is at the *replacement* stage with respect to their current measure installed. For example the household's current AC unit is broken and they are evaluating either the adoption another standard AC unit against a more energy efficient unit.[30]

This implicit assumption is made because typically only the incremental costs (the difference in the price between the energy efficient AC unit and the standard/baseline unit) associated with the adoption of the energy efficiency unit is included in the "initial up-front cost" calculation. This type of analysis is only correct if the current standard measure is non-existent, either because it is not functioning or was not installed in the first place.

Thus, individuals who are *not* at the replacement stage implicitly have to bear an additional cost (fore-going some years of useful life from their current AC unit) if they adopt the energy efficient measure before current measures are in need of replacement.

Within a framework where the household is attempting to minimize overall *lifetime* electricity costs, and including this additional cost of adopting "early", could explain the hesitancy to replace standard devices with more energy efficient ones. This could potentially explain the relatively low penetration rates of energy efficient options.

Another potential reason for the energy efficiency gap is the idea that households apply higher discount rates (interest rates) than what is assumed when calculating the net present value of a given option. This is sometimes known as a *behavioral* market failure. That is, why are households applying a larger discount rate to energy efficiency investment decisions than what they may use when evaluating other investment decisions?

Hausman (1979) was one of the first to document the idea that households may apply relatively high discount rates when evaluating appliances that have different costs and energy savings

[30] Or the household does not even have a "standard measure" installed in the first place.

associated with them. Overall, Hausman estimated the aggregate discount rate was between 15-25 percent. He also found that the discount rate applied varied *inversely* with income.[31] Other studies have found similar, and sometimes even larger implicit discount rates, ranging from 25 percent to over 100 percent.[32]

There have been numerous reasons put forward to explain these high implicit discount rates. A reduction in product attributes,[33] uncertainty surrounding actual future energy savings,[34] [35] the irreversibility/sunk cost nature of many large energy efficiency investments, and the indecision about when to invest,[36] have all been highlighted as potential explanations.[37]

Of course, one way to improve the rate of return (discount rate) on energy efficiency options is to intervene in the market and offer improved financial incentives. For instance as part of many energy efficiency programs utilities offer rebates on many energy efficiency options which attempt to reduce the out-of-pocket expenses for customers and further improve the financial incentive to adopt.

Putting the issue/debate of higher implicit discount rates aside there are other explanations put forward to further explain the "energy efficiency gap". The energy efficiency gap concept represents a potential market failure in that, the market is failing to allocate resource to their optimal use by *not* adopting energy efficiency options and thus requires further explanation.

[31] Hausman estimated that households with a mean income of $10,000 (1979$) have a discount rate of 39 percent whilst the households with a mean income of $50,000 (1979$) have a discount rate of 5.1 percent.
[32] See Sanstad et al. (2010) and Durbin (1992) for a good review of the literature.
[33] for instance a common criticism of CFL lighting is its relatively "poor brightness quality" (ICF International (2007))
[34] And this savings may be lower if the rebound effect is present (see Point 4 for more details).
[35] Metcalf (1994) shows that if there is uncertainty in energy prices, households and businesses should investment in energy efficiency options (and therefore accept a *lower* rate of return on these options) as energy efficiency options represent a hedge against risks in other areas of the economy.
[36] Should you invest in the current energy efficient product or wait for the next generation.
[37] See Gillingham et al. (2009) for a good overview of these issues.

Generally there are four main types of market failure or "barriers" put forward to explain the energy efficiency gap. These are:

- Imperfect Information;
- Behavioral;
- Liquidity constraints, and
- Principal/Agent problems.

Imperfect or lack of information is a common argument often highlighted to explain why customers seemly under-invest in cost-effective energy efficiency options. Simply put, customers lack sufficient information about types of energy efficiency options exist, the difference in characteristics associated with the products and the differences in future operating costs between more-efficient and less-efficient goods necessary to make proper investment decisions. Also, the cost of acquiring this knowledge (search costs) may be sufficiently large to offset any benefit from adoption. Thus the customer remains rationally ignorant with regards to energy efficiency options.

The classic behavioral issue that may affect the adoption of energy efficiency measures is loss aversion. Kahneman & Tversky (1979) famously showed that satisfaction/utility changes tend to be much *greater* from a loss (initial extra up-front capital costs) than from an expected gain of the same magnitude (future electricity savings). Thus customers place a greater emphasis on what is fore-gone during the adoption phase of the energy efficiency measure than on the savings that will be received in the future[38] Thus the end result is that even if an energy efficiency measure has a positive net present value customers will still not adopt.

Another barrier that may prevent a high penetration of energy efficiency measures that are relatively expensive (AC units for example) is liquidity constraints (credit-worthiness). A lack of access to credit markets may prevent a significant percentage of potential customers being able to afford the (profitable) energy efficiency measure. Therefore, some potential energy efficiency customers have to purchase the less energy-efficient (lower up-front cost) product instead.

[38] Even after the standard discounting of future savings has been taken into consideration.

The principal–agent problem occurs when one group makes the investment decision but another group receives the benefits of the investment decision. For instance one party (the agent), such as a landlord, decides to invest in energy efficiency measures, whilst a second party (the principal), such as the tenant, is generally responsible for paying the energy bills. If the agent cannot recoup, via say charging higher rent, at least the costs of the energy efficiency investment then they would not install the measure.

Overall, there are numerous potential reasons that explain the "energy efficiency gap". Some of these reasons may be/are surmountable via interventions in the market place by public-policy makers and utilities. However, some barriers may remain in place for the foreseeable future, which will continue to hinder the overall deployment of energy efficiency measures throughout the economy.

3) The Time Distribution of the Negawatt Generated Matters

Within a given day the demand for electricity is not constant. For instance, in Arizona, demand for electricity generally increases initially when everyone wakes up for work or school (AC units, TVs, lighting etc are on), then during the day electricity demand tends to be relatively stable whilst everyone is at their place of work or school – this is generally known as baseload demand.

As evening approaches and people filter back home the demand for electricity begins to increases relatively dramatically. AC units are working hard to cool homes (most thermostats are turned up when people are not at home),[39] interior and exterior lights come on (as it is now dark outside), people begin cooking, favorite TV shows are being watched, people are surfing the internet, mobile devices are being charged – this time period is known as peak demand.

[39] See ICF International (2007) for more details.

As a result of these (regular) fluctuations in overall electricity demand, electricity utilities have a portfolio of different generation technologies –all of which have various characteristics - which they utilize to ensure that demand (baseload and peak) is met in a cost-effective manner.

Due to the variation in generation resources utilized within the electricity sector not all megawatt hours generated are equal. That is, each megawatt, on average, may potentially have different characteristics in terms of being a "baseload"/peak MWh, average cost of production, capital/fuel intensive, renewable/non-renewable, CO_2 content, water usage etc.[40]

Therefore, when energy efficiency options are adopted, in order to measure the impact of the negawatts "generated" it is important to know *when* the negawatts will occur. Thus the overall *time distribution* of the negawatts is potentially more important (in terms of measuring the "performance" of energy efficiency options/standards) than even the total amount of reductions required/obtained.

For instance, along with many other factors, resource planners at the major electricity utilities have to "plan for the peak". That is, they must ensure that enough generation resources are in place to ensure that they meet the *highest* demand forecast at any point in time.[41] Thus, if adopted energy efficiency measures do not reduce the peak forecast – energy efficiency options do not "shave off the peak" - then resource planners still have to make sure that enough total generation capacity is available for that time-frame when it is required.[42]

Thus, it is conceivable that the energy efficiency measures adopted may cause the price of electricity to increase (not simply because the total amount of electricity sold has fallen)[43] because the measures cause the peak forecast to be an even *greater percentage* relative to baseload estimates which may mean that a greater percentage of the overall total generation capacity installed/available is used *less often* throughout the year.[44] That is, the total amount of

[40] Of course there may be some correlations between these characteristics.
[41] There are also reserve margins (buffers) that must be maintained.
[42] Either through generation it owns itself or the ability to purchase any additional generation if/when required.
[43] See Point 5 for more details on this discussion.
[44] The average capacity factor of total generation resources will fall.

generation *capacity* is not reduced - because it has to available/in place for those times (potentially even one hour) when it is required – but it still has to be paid for, even if it's just the capital cost components.[45]

Thus it is a fallacy to assume that a reduction of say "x percent" of total MWh consumed equates into exactly "y reductions" in total generation capacity required. The time distribution of the negawatts will ultimately determine how large the reductions[46] in total generation capacity will be.

The time distribution of the negawatts (and thus the MWhs generated it displaces) will also determine for instance the total CO_2 emissions and fuel costs avoided. Given that various technologies are utilized at different times of the day and/or technologies that are used throughout the day increase/decrease in terms of their percentage of overall generation this implies that the average CO_2 content and/or average fuel cost per MWh avoided may fluctuate throughout a given day.

Thus the energy efficiency options which are most cost-effective to implement (and their given time distribution of negawatts) may not necessarily coincide with the MWhs which tend to have, on average, higher fuel costs components and/or CO_2 emissions. Thus, there may well be a trade-off between the cost-effectiveness of reducing total MWh generated and reducing, for instance, total CO_2 emissions in the most cost effective manner.

That is to say, that an option that reduces MWhs at a time where CO_2 emissions per MWh on average is relatively high may be relatively more expensive to implement than an option that reduces MWhs at a time where CO_2 emissions are relatively low. At the moment the energy efficiency standard in place in Arizona primarily focuses on the cost-effectiveness of reducing

[45] Note, there is already some potential concerns that the total nameplate generation capacity installed within Arizona will increase due to more (intermittent) renewable resources being required (due to the renewable energy standard in place in Arizona).
[46] Or the smaller the additional generation requirements necessary (as Arizona is forecast to be a growing state in terms of population).

total MWhs in Arizona and not necessarily which options reduce CO_2 emissions in the most cost effective manner.[47]

Finally, as the regulated utilities also introduce more renewable generation resources into their portfolio mixes to comply with the renewable energy standard that is in place in Arizona,[48] the environmental benefits and fuel costs avoided- due to adoption of energy efficiency options - may potentially fall.

This is because the addition of renewable generation resources into the overall generation portfolio mix will potentially reduce the average CO_2 content of MWhs generated whilst the renewable resources are being utilized.[49] Also renewable generation resources are relatively capital intensive, and if we focus on solar and wind, the "fuel is free".

In the worst case scenario if the time distribution of the negawatts created due to the adoption of energy efficiency measures coincides with when the output from solar and wind generation resources would have taken place then the fuel payments avoided and the CO_2 emissions offset by the adoption of the energy efficiency measure would be zero.

Therefore, it may become increasingly difficult to encourage the adoption of energy efficiency measures such that the time distribution of the negawatts generated coincides with when (mainly) fossil fuel generation would take place[50].

4) Change in Behavior Altering the Energy Efficiency Outcome

An improvement in energy efficiency, via technological advancement, for a particular device (AC units) that requires electricity as an input will generally decrease the *marginal* price[51] [52] of

[47] As part of the energy efficiency standard the regulated utilities are asked to calculate CO_2 emissions avoided due to reductions in total MWhs sold but they do not have to target reducing CO_2 emissions in the most cost-effective way.
[48] Regulated utilities in Arizona are required to meet 15 percent of their electricity sales in 2025 using renewable generation methods
[49] Assuming they offset coal and natural gas resources and not nuclear generation resources.
[50] When CO_2 emissions and fuel payments are relatively high.

using the device and therefore reduce the cost of achieving a given outcome – for instance cooling a home to a particular temperature.[53]

Thus, due to the law of demand, this reduction in marginal price could potentially lead to an *increase* in consumption/usage of that device. This effect is known as the direct rebound effect.[54]

If we focus on Arizona, and higher-rated energy efficient AC units for the moment, it is clear that an energy efficiency program that attempts to incentivize building owners (residential as well as commercial and industrial) to adopt more efficient AC units are going to potentially face the problem of the rebound effect.

The largest potential concern is that after the installation of more efficient AC units and/or weatherization the building owners alter their behavior from before the new unit was installed and instead decide (due to the marginal price being lower) to simply have a thermostat setting *below* what it was set before the energy-efficiency intervention – therefore consuming more AC services than before and thus reducing the potential electricity savings.

The size of the total rebound effect relating to instances of space cooling is an empirical question. Review of the empirical literature suggests that the largest determinants of the rebound effect tend to be, how close the household/business is to their AC satiation point,[55] the initial capacity utilization rate of currently installed AC units, weather conditions throughout the year, and income levels.[56] Overall the hotter the conditions, the lower the income of the

[51] We are using marginal price rather than marginal cost to distinguish that the impact measured is at the consumer level rather than the producer level.
[52] The technological advancement may cause the up-front (fixed) costs to increase or decrease.
[53] Note, weatherization would cause the same effect by lowering the amount of time an AC unit would have to be working to lower the temperature to the desired level.
[54] See Croucher, M. (2010a) *"Potential Problem to Maximizing Energy Efficiency Savings in Arizona"* for more details on the definition of the rebound effect.
[55] Are households setting their thermostat to the lowest optimal setting or are they trading off between lower home temperatures and the consumption of other goods and services.
[56] Of course there may be some correlation between determinants.

household and the lower the current AC capacity utilization rate the larger the potential rebound effect.[57]

This result is generally driven by the observation that low-income households may be further away from their satiation point for cooling – especially during the summer months.[58] Also, low-income households may have a lower capacity utilization rate for their AC unit than high-income households. That is to say, that because the electricity bill of low-income households will represent a greater proportion of their overall income they may tend to not use their AC unit as much, time wise, as high-income households do.[59] [60]

Thus the changing of behavior, as measured by the rebound effect, will potentially mean that forecast electricity savings may differ from actual savings realized. The larger the rebound effect the greater the amount of energy efficient measures that will have to implemented to achieve a given reduction in actual sales.

Overall then, the rebound effect may reduce the cost-effectiveness of energy efficiency programs as typically the cost per kWh saved reported is calculated using technical specifications and estimates of the saving – which will be over-stating the actual savings if the rebound effect is present.

[57] See Durbin et al. (1983) Greening et al. (2000), Sorrell et. al (2009) and Costa & Kahn (2010) for more details.

[58] Although due to the high temperatures in the summer months in most of Arizona this may well be true across all income groups. Especially if we factor in that higher income households tend to live in bigger homes which potentially take more AC output to cool to a given temperature.

[59] This in turn may re-enforce the concept that lower income households will be further away from their satiation point at a given point in time.

[60] However, high-income households tend to live in larger homes and thus even though they may use their AC unit more often than low-income households they may well still be not at their lowest optimal thermostat setting.

5) Large (successful) Energy Efficiency Measures Deployed May Cause Electricity Prices to Increase

At first glance at this point an obvious question generally follows which is "if customers purchase less electricity and therefore the utility is selling less electricity shouldn't the utility's costs fall and thus offset any resulting reduction in revenue?" However, that is not the case.

The electricity sector is characterized as having a cost structure where a significant amount of their overall costs are *fixed* costs.[61] Fixed costs include such things as transmission and distribution costs. Transmission and distribution costs are the costs associated with the delivery network which is needed to move electricity from its generation location to consumer's location – homes and businesses.

Also, most technologies utilized to generate electricity are relatively capital intensive. Thus, there are also significant fixed costs associated with the generation component of electricity provision. The largest *variable* cost is typically the cost of fuel used at the generation facility or purchased power from the wholesale market.[62]

The result of these significant fixed costs coupled with most rate designs currently in place is that when electricity sales fall the reduction in revenue is a *greater* percentage than the overall reduction in the costs of provision – thus a reduction in rate of return occurs.[63]

This occurs because most regulated (and non-regulated) electricity providers current rate design include some amount of fixed customer charges per month – which is often less than the actual fixed cost per month of provision - and a variable component which is based upon actual electricity consumption. The variable component, the per unit price's level, is a function of

[61] These substantial fixed costs are the very reason why it is preferable to only have one "transmission and distribution network" provider – in economics these entities are called "natural" monopolies. That is, it makes no sense to have more than one "wire" from a home/business to the electricity generation source. As a result we generally have regulated monopolies in the electricity sector.
[62] Some purchased power are part of purchasing power agreements which can be for a significant long time period and thus represent fixed costs/obligations. The power may have to be paid for regardless.
[63] Note, as the required amount of renewable generation increases in Arizona (which are mainly capital intensive with no fuel payments) this effect will become amplified.

variable costs (fuel) and the remaining fixed costs that are not recouped in the upfront fixed cost charge.

Therefore, under most current rate designs the price of electricity (the variable charge) is a *mixture* of fixed and variable cost elements. Thus, reductions in overall sales will inevitably push a utility towards a rate case (generally requesting an increase in price) with the relevant corporation committee. Rate cases can be expensive and time consuming. Thus, it is generally preferable if mechanisms are in place that will automatically adjust to assist with ensuring the utilities receive an acceptable rate of return.[64] [65]

One increasingly popular mechanism that assists with ensuring utilities receive their acceptable rate of return in an environment that promotes energy efficiency without the need for increasingly regular rate cases is decoupling.[66]

Decoupling is typically defined as *"a regulatory mechanism/tool that is designed to separate a utility's revenue (and thus rate of return) from changes in the utilities overall energy sales"*. Thus, utilities revenue becomes "decoupled" from their sales. If this link is broken then reductions in sales do not adversely affect the utilities revenue.

In its simplest form decoupling is a mechanism that *adjusts* rates/electricity prices periodically - monthly, semi annually, annually - to ensure that a utility receives the amount of revenue authorized independent of its volume of sales.[67]

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[64] For instance most regulated utilities have a fuel adjustment escalator which allows them to charge customers extra if the price of a particular fuel used in generation changes significantly.

[65] One obvious solution is to eliminate the component of electricity prices that reflects partially some fixed cost of provision. So instead electricity prices only reflect any variable costs such as the fuel costs incurred to generate the electricity consumed. To achieve this, alterations to the fixed charge per month would be required such that the monthly fixed charge reflects *all* of the fixed costs associated with provision rather than it only reflecting a reduced percentage. This approach is often not adopted for numerous reasons. For one, this method may adversely affect low-income households such that their electricity bill would increase. There may be difficulties – from an "fairness" position - in determining which fixed costs should be paid by which consumers. Also from an energy efficiency point of view it would lower the financial incentive to reduce electricity consumption at the margin.

[66] As of 2009 a total of 28 natural gas local distribution utilities and 12 electric utilities, across 17 states, have operative decoupling mechanisms (Lesh, 2009).

Simply speaking, if sale volumes fall – potentially due to successful energy efficiency programs - then prices automatically adjust on some regular basis in an upwards manner. Importantly, the financial incentive to adopt energy efficiency measures remains and in fact may increase (as the price of electricity increases).

[67] See Lesh, P. G. (2009). "*Rate Impacts and Key Design Elements of Gas and Electric Utility Decoupling: A Comprehensive Review*" and ICF International. (2007). "*Aligning Utility Incentives with Investment in Energy Efficiency.*" for a more detailed discussion of potential variations in decoupling mechanisms.

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