Adoption of Energy Efficient Technologies from a Demand Side Management Perspective: Taxonomy of Adoption Drivers, Barriers and Policy Tools

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Abstract Energy efficiency is considered an alternative to building a power plant. However products and services enabling these efficiencies sometimes hit bottlenecks in adoption. This chapter reviews this important issue.

1 Barriers Research Approaches

An extensive research effort has been put towards identifying the barriers and drivers associated with adoption of energy efficient technologies. Studies have been conducted with respect to various different contexts such as; are country, technology, industry, energy intensity and many others. In this study, a special effort is going to be focused on understanding body of barrier studies in these contexts. It has been observed that barrier studies show contextual difference in terms of variables such as; case technology, country, industry and organization related characteristics, methodology employed etc. This section is going to review and analyze energy efficiency barrier literature as well as touch on criticisms attracted by other approaches.

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1.1 Effect of Barriers to and Drivers for Energy Efficiency Investments

One of the most comprehensive and recent barrier models has been developed by Sorrell et al. [62]. Proposed model has been applied in organizations serving under higher education, brewery and mechanical sectors in each of the countries Ireland, Germany and UK. Accordingly, suggestions for improving existing policies have been stated for organizational, sector and national levels. It has been observed that adoption barriers are ranked differently depending on the contexts; country and sector. Thus, it has been stated that one type fits all kind energy efficiency programs are not suitable for large scale energy efficient technology adoption. As a result, requirement for more comprehensive analysis of market segmentation and alignment of related policies have been stated [62]. A recent study has been conducted by Thollander and Ottosson [67] to explore and rank barriers and drivers to implementation of cost effective energy efficiency measures in Swedish pulp industry. Results imply that there is an energy efficiency gap in the Swedish pulp industry and majority of the barriers are related to market related failures whereas some of the most important barriers are related to inexistence of organizational capabilities to absorb energy efficiency technologies within the firms. Thus, market interventions cannot be effective in influencing adoption decisions. Biggest barriers to cost effective energy efficiency investments were found to be risk of production disruptions, cost of production disruption/hassle/inconvenience, inappropriate technology, lack of time and capital, existence of other priorities and slim organizational structure. Surprisingly, the most significant driving forces for energy efficiency investments were found to be efforts put by employees with environmental awareness and existence of long term energy strategies within the firms where as efficiency gains is ranked relatively low. Additionally, potential increases in cost of energy, electricity certification system and long term agreements have been observed to be significant drivers as well. Based on the different regions and industries barriers and drivers to energy efficiency measures are stated to differ. Thus, one size fits all type energy policies have been stated as not being effective and as a result energy policies are suggested being more diversified depending on significant factors [62]. An improvement area derived from this study emerges from the fact that some of the most significant energy efficiency barriers such as; lack of time, existence of more important duties, slim organizations, lack of staff awareness, long decision chains are organization related barriers, but not market failure; thus, traditional market based interventions cannot be helpful. Further studies are advised to look into reducing organizational and behavioral barriers within the firms [67]. Another study conducted by Rohdin and Thollander [52] has focused on non-energy intensive industrial organizations. Accordingly, aim of the study has been stated to investigate barriers to implementation of energy efficiency measures in the Swedish non-energy intensive manufacturing industry. Major barriers are found to be cost/risk of production disruption/hassle/inconvenience, lack of time and sub metering about energy efficiency conservation, existence of other prior tasks or capital investments, cost of gathering information about an energy efficiency measure and split incentives with energy service providers. Also, an example for market imperfection that inhibits energy efficiency adoption has been observed through a market oligopoly forced by a few manufacturers who can dictate the market. Important drivers for energy efficiency measures are found to be long term strategic energy policies, increasing energy prices, people with environmental awareness within the company where as environmental management systems were not found to promote adoption although it has been shown to be a contributor in a prior study [62]. Barriers and drivers to adoption of energy technologies and management practices are advised to be researched for the case of non-energy intensive industries [52]. Differences between energy and non-energy intensive industries in terms of adoption of more efficient technologies have also attracted attention. Accordingly, Hasanbeigi et al. [23] has attempted to explore drivers and barriers associated with energy efficiency investments in textile and cement industries which are representative of non-energy intensive and energy intensive industries. Case study has been conducted among 16 SMEs in Thailand. Based on the results, authors have proposed improvements on existing energy efficiency policy frameworks, which consist of raising awareness and information and support of implementation action steps [48, 54, 78]. Proposed additional step has been stated to be motivation campaigns that promote raised awareness towards actions by use of policies which are setting accurate standards and regulations in place, providing demonstration projects and pursuing voluntary agreement campaigns. In textile industry it has been observed that existence of more important production related priorities, uncertainties about cost and performance about the newer technologies are the biggest barriers where as potential production disruptions caused by new technologies, investment cost and required implementation time are the biggest barriers for cement industry. Lack of internal coordination has been stated to be another barrier by textile industry as cement industry perceives lack of coordination among external entities. It has further been indicated that due to higher priority put over manufacturing, production managers have more power than energy or maintenance managers where energy efficiency related project proposals actually come from. As a result, power differences among organizational units have been stated to be a barrier to energy efficiency investments. Experts' judgments on barriers mainly emphasize lack of knowledge and uncertainties associated with new technologies at both operational and engineering levels. Top drivers for investing energy efficient technologies have been potential improvements on product quality, working conditions and reduction in energy costs. Interestingly, improving reputation and increasing recognition has been important for textile industry where as compliance with regulations has been rated as an important driver by cement industry which is perceived as environmentally harmful industry from public view. Findings also indicate another significant finding that might favor carbon tax debate that proposes incur more costs on carbon dioxide intensive businesses. Both textile and cement industries have ranked introducing more energy efficient solutions as an alternative strategy in case of increased energy prices while increasing prices of final products were ranked lower [23]. A barrier study in a small and medium enterprises context has been conducted by Thollander et al. [68] in Sweden in order to give insights about an energy efficiency program that has been undertaken in a Swedish region for promoting energy efficiency in manufacturing SMEs. Largest barriers identified in this study are related to existence of other prior tasks or investments, lack of access to capital which are non informational barriers although previous studies have shown that informational barriers about existing or upcoming technologies is a big inhibitor for adoption in case of SMEs [59]. This situation has been stated to be an indicator of auditing activities' success for this specific case. Additionally, employees with environmental awareness and existence of long term energy strategy are found to be highly ranked drivers. Although improvements in reducing informational barriers have been observed it has been stated that there are still open spaces for improvements in auditing procedures [68].

Apart from industrial context, adoption behavior of commercial and services sector has also been researched. For instance, Schleich and Gruber [56] have attempted to determine the relationship between a limited sample of energy efficiency barriers identified in the literature and energy efficiency investments in German commercial and services sector. It has been observed that statistical significance of explanatory variables is more heterogeneous in sub-sector level than sector level. This situation has been stated to be an indicator for supporting the inhibiting role of adopter heterogeneity. For instance, split incentives have been identified as an important inhibitor to energy efficiency among commercial and service sub-sectors as it was also proven to be so for private housing sector by a study conducted by Scott [57]. Moreover, lack of information about the energy consumption profiles of individual firms has been found to be playing an inhibitor role. Finally, low prioritization of energy efficiency related projects has been observed as a common behavior in sector level analysis. As a further research initiative, it has been stated that grounded research has been a main focus point in energy efficiency research, however empirical studies in energy efficiency has not been fully explored. Thus, more empirical research studies are required to reveal existence of market barriers and market failures for specific contexts [56].

1.2 Effects of Organizational Characteristics on Energy Efficiency Investments

As observed from the research studies mentioned above organizational characteristics have been observed to have significant effects on energy efficient technology adoption. For instance, a study conducted by DeCanio [12] has attempted to observe organizational and economical factors on energy efficiency investments' payback periods. In the case study, it has also been observed that economical factors are not the only set of variables that can fully explain variations in energy efficiency investments, but also that organizational factors are significant in explaining firms' investment behaviors and decisions. As a result, it is concluded that even though economical benefits gained from energy efficiency investments might be the same given an action taken, organizations' level of interest differ depending on their characteristics [12]. This aspect has been studied by various researchers in different contexts. For instance, DeCanio [11] combined data acquired by questionnaires and interviews conducted on firms participating in Green Lights Program which was started in 1991 by Environmental Protection Agency. Purpose of the study has been stated to explore barriers to economically profitable energy efficiency investments. Findings show that; long payback periods, hurdle rates, dependence on overall managerial performance, existence of strategic priorities, control and monitoring problems due to decentralization, inappropriate incentives-tenant/owner problem, capital availability and bad experiences in the past can play inhibiting role against energy efficiency investments. Implications for corporate policies have been stated as creation of internal department that is dedicated to energy management for supporting internal incentives, monitoring and analysis of energy use, building awareness around energy conservation and environment [11]. A more recent and comprehensive study has been conducted by De Groot et al. [10] who have aimed to explore effects of market barriers, motives and organizational characteristics on energy efficiency related investment behaviors of various industries in Netherlands. Changes in firms' energy efficiency related investments and strategic decisions have been observed by using cases that incur different energy and environmental policies. It has been observed that potential cost savings is the most important driver for energy efficiency related investments where as existence of prior projects that may provide more return on investment and available lifetime for existing equipment are the most important inhibitors. Provided that profitability and international competitiveness will not be affected, firms are stated to be willing to adopt new environmental policies. Moreover, this attitude has been observed to be driven by firm size, energy intensity of the processes and competitive position of the firms. Future studies are advised to look into developing policies for promoting energy efficient technologies for energy intensive SMEs [10]. Significance of organizational factors have also been observed by Kounetas and Tsekouras [31] Accordingly, corresponding study has attempted to explain energy efficiency paradox by incorporating two different approaches which are profitability and adoption factors. Results indicate that firm specific characteristics have significant effects on decisions towards adoption of energy efficient technologies. It has been confirmed that firms with energy intensive processes, subsidies and regulations towards reducing environmental damage have positive effect on energy efficient technology adoption decisions. Moreover, available age of the existing equipment subject to replacement and uncertainty in the economic environment have been found to be negatively correlated to adoption decisions due to sink costs and organizations' tendency towards reducing input costs in an uncertain environment. On the other hand, barriers associated with energy efficiency technologies have been confirmed to affect adoption decisions negatively. What's more existence of research activities within a firm and profit margin has been found to be affecting adoption decisions negatively. This implies that energy efficiency related investments are perceived to have lower priorities in research intensive firms or firms with more payback expectations [31]. Kounetas and Tsekouras [32] have also analyzed energy efficient technologies' impact on Greek manufacturing firms' productive performance by utilizing trans logarithmic cost functions. Country and time specific variations in mind, it has been observed that adoption of energy efficient technologies have positive impact on technical efficiency where as its impact on productive performance. Moreover, energy efficient technologies have positive effect on the firms characterized as high energy intensive where as the opposite applies to low energy intensive firms [32]. Organizational characteristics have also been analyzed to understand their effects on information absorption [33]. For instance, objective of the study has been stated to determine the factors affecting the degree of energy efficient technology related information absorbed by energy efficient technology adopters. It has been observed that different forms of resource constraints are the major obstacles causing information barriers. For instance larger companies have been found to be reaching epidemic type technology information easier than smaller firms due to their advantages in information gathering and processing. However, the same relationship between amount of R&D activities and information acquisition has not been proven to be positive as innovation efforts, which are perceived as more vital, and energy efficiency related tasks are competing for the same resources. Thus, free technical support regarding technological information is proposed to be an appropriate mediator for information barriers. It has further been emphasized that firms' interest on different technologies is the main cause of heterogeneity in level of information acquisition [33]. Please see Table 1 for list of organizational variables studied in the literature.

1.3 Effects of Information and Decision Making Practices on Energy Efficiency Investments

Use of different decision making practices in the organizations and its implications on adoption of energy efficient technologies has been another area of research. Harris et al. [22] has attempted to analyze the factors affecting firms' decisions on energy efficiency investments. Data has been acquired from an energy audit program called Commonwealth Government's Enterprise Energy Audit Program (EEAP) undertaken in Australia around 6 years until 1997. 100 firms have been surveyed and descriptive statistics have been presented. According to the findings, it has been observed that more than 74 % of the firms have indicated that they pay attention to environmental issues in their investment decisions processes, however methods used for evaluating investment alternatives have been observed to be solely financial methods such as; NPV, ROI, payback period and upper limit on debt/equity ratio. It has also been observed that main reasons for not adopting

Table 1 Organizational variables studied in the energy efficient technology adoption literature

Organizational variables	References
R&D and innovation activities	[31, 33]
Number of R&D employee	[33]
Cooperating with an external energy efficiency expert	[33]
Employing an internal energy efficiency expert	[33]
Information acquisition channels	[33]
Geographical location of the organization	[33]
Decision making practices in the organization	[33]
Firm size	[5, 31, 33]
Market concentration	[31]
Ownership structure	[31]
Financial structure of the firm	[31]
Scarcity of managerial time	[31]
Scarcity of skilled personal	[31]
Firm's age—learning by doing effect	[31]
Firm specific capital vintage	[31]
Decentralization	[5]
Delegation	[5]
Contract maintenance and priority	[5]
Managers' ability to pursue energy efficiency investments	[5]
Managers' ability to process different information types	[5]

energy efficient solutions are stated as risks involved in the projects, belief that audit results are inaccurate, low rate of return, too long payback period, and lack of access to capital. That the most important drivers are economic variables is stated to indicate that firms go after the investments that have the highest benefit/cost ratios. This situation is also stated to be supported by claiming that organizations do not have the techniques that can incorporate other factors related to business practices such as quality, scheduling, cycle times and so on. Another interesting finding is that average of $88000 has been invested by all firms where as average cost of all audit investment recommendations were $121000. This result is stated to support findings of another study conducted by Thollander et al. [69] which states that firms tend to invest more on smaller investments rather than costly ones. Moreover, effects of risk on investment decisions have also been observed to prevent energy efficiency investments and majority of the firms have been stated to agree that constant changes on information, adjustment costs during and after the installations and potential costs associated with breakdown of the new systems are the main risks. Existence of risks is observed to increase expected rate of return from investment projects which is named as "hurdle rate" barrier in the literature [22]. A study conducted by Harris et al. [22] has revealed that 80, 53, 30 % of the companies have been using payback period, IRR and NPV respectively whilst dealing with making investment decisions. Moreover, Pye and McKane [49] and Ramesohl et al. [50] have stated that non financial criteria are also used in assessment models as well where as Harris et al. [22] have claimed the opposite.

Combined with uncertainties and risks associated with future, decision-making becomes a very complex system. Simon [60] claimed that maximizing multiple objectives is impossible due to complexity of decision-making, so purpose of companies is stated to reach satisfying results rather than optimized solutions. This phenomenon is called bounded rationality and has been widely studied in barriers to energy efficiency literature.

Sandberg and Soderstrom [54] have attempted to understand decision-making processes and variables used in large organizations from a managerial perspective with an emphasis on energy efficiency technologies. Decision processes have been analyzed with respect to four interrelated subjects which are energy auditing, monitoring and benchmarking practices, investment routines of the organizations, follow up and knowledge transfer, and risk management and uncertainty. Responses from the interviews have been observed to often emphasize the necessity of having a wide spectrum of assessment criteria that deal with potential consequences of energy efficiency investments on non-financial parameters such as; environmental improvements, increased production efficiency etc. Another study conducted by Thollander et al. [69] have addressed some of this issue and proved that information regarding manufacturing related consequences of an energy efficiency investment may help adoption decisions positively. Sandberg and Soderstrom [54] have stated the necessity of accessing clear and accurate information by giving a practical example, which refers to difficulty of obtaining energy consumption data due to high temperatures or type of energy used in the process. This situation is stated to limit the ability to realize potential savings that can be derived from energy efficiency investments. It has also been realized that firms often tend to delay their replacement investments as long as possible as it is perceived as the cheapest alternative of all and this situation is stated to emerge as a barrier to energy efficiency investments. Risk management practices have been observed to be widely used by both of the industries and it has also been observed that their investment decisions are highly risk averse.

Decentralized organizational structures have also been observed to be having difficulties in following consequences of investment decisions due to difficulties in knowledge transfer from one facility to another. One significant finding is stated to refer to the fact that large organizations tend to outsource energy efficiency related projects, as they are perceived as non-core business activities. Future research initiatives have been suggested looking into potential effects of outsourcing energy efficiency related projects on diffusion of energy efficiency technologies. Dynamics between internal and external actors is stated to bring up new problems as well as opportunities [54]. An interesting study has been conducted by de Almeida [9] in order to explain the relationship between energy efficiency gap and market forces. Study has analyzed limitation of market forces with respect to variables such as; market agents' characteristics and their decision-making processes and transaction types. It has been observed that split incentives is an inhibiting factor for diffusion of high efficiency motors (HEMs) in French motor industry. Motor manufacturers in France are stated to align their manufacturing and marketing practices based on the market, which is stated to be not aware of the opportunities of high efficiency motors over existing models. Due to existence of a market associated with information asymmetry manufacturers are stated not to intend to promote HEMs claiming that there is no interest in the market. Furthermore, market agents' decision practices have also been found significant on market forces. Based on the agent characteristics, agents' perceived value from energy efficiency feature has been found to be relatively low compared to set of other product features that are taken into consideration in decision making process. Due to constraints involved in agents' decision making processes adoption of HEMs has been found to be low. Suggestions for removing imperfect information in the market have been stated to be establishing standards and labeling programs along with a more comprehensive DSM programs [9].

Dieperink et al. [15] has attempted to combine different perspectives employed in Dutch diffusion literature in one framework in order to provide a more holistic approach for policy makers and diffusion scholars. Diffusion literature explaining the slow diffusion rate of energy efficiency technologies has been stated to focus on different pieces of a sophisticated problem. Both economical and behavioral models individually have been claimed to be lacking explaining the energy efficiency gap. Difference between widely accepted studies conducted by Rogers [51], Kemp et al. [26] and Daft [7] have been stated to be that corresponding framework is centered on decision making process and assessment rather than considering it as a small part of a bigger adoption process. As stated, focus point of the proposed framework is decision making process and assessment combined with company characteristics. This built is stated to enable understand the mechanism of other influences which are economic and technical aspects of the technology, macro developments in the business environments and company context which refers to government, market and societal variables. Based on the framework, given more complex and detailed decision models can be drawn and validity of them can be tested by employing questionnaires asking different actors' judgments about relative importance of explanatory decision variables. Results can provide valuable information regarding the direct and indirect effects of decision variables on potential adopters' priorities. Implications from the results are stated to be a strategic tool to develop more accurate policy tools [15]. Along with Dieperink et al.'s [15] work, Vermeulen and Hovens [72] have applied integrative framework [15] for explaining diffusion of energy innovations adoption for the case of new office buildings. Two levels of analysis have been employed to determine relative representativeness of variables which are nature of decision making, economic, technology and company characteristics, government policy and influences from market and society. First level analysis attempts to find out relative importance of assessment variables and nature of decision making process over energy innovation adoption decisions. Second level attempts to further explain the effects of variables over assessment and process variables. Findings are stated to show that for the case of newly diffusing technologies economic assessment criterion along with non-financial criteria and process aspects have been significant in explaining adoption decisions where as mature technologies' adoption is explained by routine applications given that the innovation is favorably rated with certain assessment variables which are economic performance, functionality and technical fit. Moreover no statistical significance has been found for supporting government supported information campaigns' on promoting adoption decisions where as suppliers' promotions have been proven to be effective. Lastly, energy performance standards and subsidies have been found to be effective for promoting adoption of both diffused and newly diffusing technologies with a slightly more effect on newly diffusing technologies [72].

1.4 Criticisms on Barriers Research Approaches

Koomey [29] has identified four causes that might result in low adoption of energy efficient technologies. These causes are stated as hidden costs, wrong parameter specifications, marketing acceptance time lag and market failures. Koomey's [29] research methodology has employed two measures one of which is more energy efficient and compared them against each other. Results of the study has shown that although there was no significant difference between the energy efficient technology and the baseline technology in terms of hidden costs, parameter specifications, marketing acceptance time lag and market failures, adoption of energy efficient alternative was still slow. Based on this, it has been claimed that economic models are not fully capable of explaining energy efficiency gap. Accordingly, it has been suggested that more emphasis on behavioral research should be put in order to address economic models' weaknesses. Particularly, it has also been suggested that further studies should be specifically focused on very small niches by defining market segments, end use, technology and type of operation [29]. The claim that adoption decisions may not always be explained by economic principles has also been supported by Weber [74] who has suggested combining behavioral approaches with traditional barrier studies by reviewing barrier models and give insights about their weaknesses. One of these weaknesses is stated to be barrier models' energy efficiency potential which is achieved by favoring only technical solutions and positive actions. Barrier models are stated to make wrong assumptions by defining improved energy efficiency as a result of positive actions, which may refer to purchase of more energy efficient products, but omission of actions that inhibit excess energy use is not considered so. This assumption is claimed to block all potential energy conserving options that is based on negative actions. Barrier models are also stated to focus on minimizing energy consumption without justifying the potential implications of the action taken. This situation is stated to prevent barriers from going further than technical solutions by neglecting social aspect of the issue. Another assumption associated with barrier models is stated that potential energy efficiency is the energy consumption derivation between existing and state of the art technologies without considering behavioral methods that can help utilize energy use and increase energy efficiency through changing users' energy behavior. However, regarding definition of energy efficiency a previous study, which is a widely cited by many energy researchers, conducted by Jaffe and Stavins [25] seems to have been neglected.

2 Psychological Research Approaches

There is a considerable amount of behavioral research studies attempting to explain energy conserving behavior as well as acceptance of energy efficient, in some cases referred as clear production, technologies in the psychology literature. Psychological research studies contributing to energy efficiency studies have been gathered together by Stern [64]. For instance, particular study has been covering the years from 1970s to 1980s. Accordingly, traditional policy analysis approaches have been stated to focus on two aspects of diffusion which are namely finance and information. What psychology based research studies have criticized most about traditional approaches is that policy analysis underestimates significance of different levels of money or information wise interventions by mostly focusing on amount of resource invested rather than their implications on user decisions. Information programs have been stated to fail due to less attention given to importance of information delivery [13, 17]. This is also supported by several researchers acclaiming that information is more effective when it is specific, vivid and personalized [4, 65, 66]. For instance, case studies have been mentioned to support different aspects of information delivery such as observation that closed-circuit video programs change user behaviors and provide more energy savings than paper based energy consumption reports [76] and constant reporting of the energy consumption support energy saving behavior [58]. Morgenstern and Al-Jurf [39] have analyzed effect of free information on commercial buildings' energy efficient technology adoption decisions. Case study has focused on lighting technologies, which are namely compact fluorescent, occupancy censors, and specular reflectors. A dataset acquired through a survey conducted by United States Department of Energy on commercial buildings energy consumption and expenditures has been analyzed. It has been concluded that free information has positive effect on commercial buildings' adoption decisions on energy efficient lighting technologies. For instance, it has further been realized that free information has more positive impact on adoption decision of those organizations that have already invested in advanced lighting systems than first time investors. This situation is stated to imply that user heterogeneity affects impact of free information [39].

2.1 Effects of Peer Evaluation on Technology Adoption

In the literature it has also been observed that some non-expert suggestions have had significant influence on consumer decisions [8, 35]. Existence of this situation is stated to support importance of information source on energy saving behavior. Moreover, credibility has been determined as one of the significant variables associated with information source as it has been observed by local energy programs' efficiency and success due to existence of established trust in local environment [19, 45]. Another branch of research studies have been focusing on consumers' perception about the costs associated or incentives provided [63]. Existence of householders that value dollar savings more than electricity savings is an example that has been provided to justify the point [27]. Future energy research studies such as; forecasting, evaluation, implementation techniques for energy efficiency programs are suggested being enriched with psychological variables rather than just technical and economical [64].

2.2 Effects of Technological Characteristics on Information Processing and Decision Making

Evaluation of energy audits conducted in Swedish industry implies that firms focus investing in low-cost measures such as; ventilation, lighting and compressors rather than more strategic measures such as manufacturing systems [68]. Reasons for such investment behavior has been found out to be risks involved in manufacturing disturbances, lack of access to capital and budget funding [52]. Depending on the project size, existence of different organizational behaviors towards investments has also been supported by Björkegren [3]. Basically, corresponding study states that organizations tend to approach big projects as an organizational learning process rather than a traditional project management approach [3]. Based on this, Thollander et al. [69] has attempted to explore use of optimization tools in order to provide additional information about potential implications of strategic energy efficiency investments on manufacturing related variables. Potential energy savings information provided by traditional auditing systems has been observed to be lagging in promoting costly investments. Findings suggest that in order to promote adoption of high cost energy efficiency investments it is important to inform decision makers about investments' potential effects on core business. Thus, energy audits may need to provide firms' with strategic information such as potential competitive advantages and higher productivity that can be gained aside from reduced energy costs only. Further studies can incorporate results of this study into manufacturing simulation models to observe the potential strategic energy efficiency investments' effects on production related variables such as scheduling, bottlenecks, quality and so on [69].

2.3 Effects of Organizational Human Factors on Energy Efficient Technology Adoption

Sola and Xavier attempted to find out the relationship between organizational human factors and levels of energy loss by surveying 40 Brazilian firms, which consist of pulp and paper, food, wood, and chemical industries. Research framework for determining factors affecting energy efficiency has been based on a study conducted by Meier et al. [38]. Framework approaches evaluation of energy efficiency from three factors; which are construction factor, which refers to level of technology embedded in a product or a service; operational factor, which refers to optimum operation level of a product or a service with respect to energy consumption; and maintenance factor, which refers to lost energy due to equipment wearing out. One of the most interesting findings of this study is that the majority of energy loss occurs because of operation and maintenance related issues rather than construction. This indicates the importance of energy consumption related behavioral issues in the organizations. Regression between organizational human factors and energy loss data obtained from sample electrical motors has revealed that level of cooperation between employees, incentives for collaboration between companies and universities, employee education, existence of future vision on energy technologies and policy for long term energy efficient technologies, firm receptivity of new ideas, use of energy consumption data in production management, and monitoring energy quality have been found to have negative correlation with energy loss. This is stated to indicate that firms with characteristics mentioned above are more likely to conserve energy. Based on the findings authors suggest policies on promoting use of energy management procedures, establishing collaborations between universities and organizations as well as long term energy efficiency policies, incentives for employee education, and more receptive culture towards energy related ideas. Further research initiatives have been suggested to focus on developing mechanisms to promote collaborations between universities and companies as well as studying more comprehensive set of factors that impact conservation behaviors in organizations [61]. Please see Table 2 for list of human factors studied by Sola and Xavier [61].

Due to difficulties in explaining energy efficiency gap with engineering and economics based barrier models Cebon [5] has analyzed energy efficiency gap with organizational theory perspective by observing the interaction between technology and organization specific variables. Study has found out that energy efficient technology adoption decisions can be explained by two different levels. First level explains adoption decisions by analyzing managers' ability to process different information types, which are named as technical, contextual and connected information as well as decision makers' influence to drive the actors towards a defined goal. Second level refers to adoption decisions by analyzing effects of organizational structures, whose explanatory variables are named as decentralization, size, delegation, contract maintenance and priority, on managers' ability to pursue energy efficiency investments. Findings suggest four strategies

Table 2 Human factors related to energy efficient technology adoption [61]

Areas	Human factors
Management system	Adequacy of work place
	Adequacy of work-load to the people
	Adequacy of tasks complexity to the individual potential
	Internal cooperation between managers of departments
	Action of the company to motivate the staff to the work
	Integrated management: energy, environment and technology
	Quality management procedures
	Energy management procedures
Employees	People motivation to work
	Initiative to learn and to present projects in the company
	Level of professional cooperation between employees
	Level of personal cooperation between employees
Education	Incentive and support of the company for employee's education
	Initiative of the company to search partnership with university
	Initiative of the universities to search partnerships with the companies
	Initiative of the company for qualification in training institutions
Strategic vision	Future vision on energy and technology
	Policy of long-term for energy-efficient technologies
	Policy for energy and energy efficiency in the company
	Receptivity on the part of company for ideas and projects of employees
Energy management	Use of energy indicators in the production
	Reduction of electricity energy cost for adequacy of the tariff system
	Initiative of the company to efficiency projects with energy concessionaire
	Using of software for diagnostics and projects on energy efficiency
	Study and monitoring of electric energy quality
	Use of industrial nets by company for monitoring of energy losses
	Implemented procedure of periodic energy auditor ship in the company

that can be utilized for improving energy efficiency policies. First strategy (select technologies which fit existing organizations) suggests that energy efficiency policies should promote those technologies which are likely to be adopted by existing organizations due to compatible characteristics. Second strategy (reconfigure technologies to fit existing organizations) suggests utilizing information campaigns that can help organizations understand the technology better. Depending on the feedback coming from the adopters technologies can be modified in the long term. Third strategy (select organizations likely to be receptive to target technologies) suggests analyzing absorption capacity of the organizations with respect to different technologies and providing incentives to those which are more likely to be adopted easier. Last strategy (modify organizations so they can select the technology) suggests providing interventions that can eliminate power problems within the organizations such as providing credits, funds for energy efficiency specific projects in organizations [5].

2.4 Relationship Between Economics and Energy Use Behavior

Nassen et al. [43] has analyzed short and long term price elasticity of Swedish residential buildings' space and heating energy consumption by using the data gathered for the years between 1970 and 2002. Analysis employs income levels, time and energy prices as independent and energy consumption as dependent variables and attempts to determine the consumers' reactions towards energy price changes. Price elasticity have been divided as short and long term in order to observe effects of price fluctuations on direct impacts and large energy efficiency investments respectively. Findings claim that there is significant but a very low correlation between energy consumption and energy prices in the case of existing buildings however the same relation does not exist for the new buildings. Payoff between comfort and energy savings has been shown as one of the reasons behind low price elasticity since energy consumption is just 3–4 % of the total expenditures in Swedish residential buildings. This point has also been stated to be studied by a prior behavioral study [16]. In order to get insight to what other factors might have been influential, authors have interviewed with experts working in government and commercial organizations. Accordingly, it has been acclaimed that split incentives and transaction costs associated with information gathering on energy efficient technologies have been a major barrier. Interestingly, for the case of new buildings existing; national building energy standards have been stated to be a significant barrier due to its norm based nature rather than providing a minimum standard for energy efficiency [43].

2.5 Educational Programs as Policy Tools

As mentioned by Weber [74] technical or engineering based energy model approaches promote replacement of existing technologies with more efficient alternatives and lack focusing on changing human behavior and promote conserving energy. As also can be realized from the sample of studies mentioned above behavioral research approaches promote educational policy tools as a solution. For instance, it would be beneficial to focus on a study conducted by Dias et al. [14] who has attempted to address energy efficiency barriers from a pure behavioral perspective. Study has aimed to resolve short and medium term energy efficiency barriers by adding an educational system perspective on Haas' [21] basic schema of interactions between individual behavior and external factors in energy context. Proposed framework is anticipated to address energy efficiency related barriers associated with lack of awareness and human behavior. Case study has shown that typical Brazilian consumer is not aware of rational use of energy due to the fact that awareness programs are already in position. Inclusion of energy related education in schools is proposed to play an important role in utilizing students as educational agents in their families and in the medium run steer society towards being more responsible in smart use of energy [14].

3 Socio-Technical Research Approaches

In his article, Lutzenhiser [36] has discussed some of the weaknesses of energy efficiency research studies that are associated with economical, engineering and psychological research perspectives; and proposed an approach aiming to address social context of the energy efficient technology adoption. For instance, these weaknesses are stated as; engineering based systems approach energy consumption by focusing on the technological aspects and underestimate human factors that cause different energy use profiles. This point has been supported by the example of users' tendency to change factory settings or even use things different than they were actually intended in case of air conditioning or heating systems. Reason for this situation is stated to be the fact that products or systems are designed for average customer needs rather than whole range of customers with different requirements. Thus, consumers whose needs are outside the level of what product can offer are not satisfied by the average conditioning levels. On the other hand, economical energy use models have been stated to have two weaknesses one of which refers to existence of two conflicting forces, which are various decision variables and users' bounded rationality; and lack of ability to explain the dynamics behind the causal relationship between price and demand changes, staying at a level that helps experts verify whether the relationship exist or not. Achieving level of detail that can give insights to the dynamics behind the causal relationships has been stated to be a key for designing better energy policies. Apart from technical and economical energy use models, psychological attitude models used in energy use models have also been stated to fail due to misconception. Accordingly in order to address some of the gaps existing in traditional energy use research approaches, Lutzenhiser [36] proposes a social energy use model that attempts to address impacts of social norms, culture, social network on energy use based on previous studies stating that energy is a center piece of socio-cultural change as also emphasized by many other researchers [1, 6, 53, 75]. Cultural model is proposed to have three levels of applications which are descriptive, explanatory and predictive analysis of energy consumption. Descriptive level involves explanatory research that maps existing cultures and lifestyles in a given area where as explanatory level deals with rationalization of the reasons why different life styles have different energy use behavior. This level is stated to help identification of the relationships between variables and provide a basis for smarter policy intervention. Third level which is predictive stage is stated to use the data provided by empirical research studies that have been conducted in the first two stages and help design better forecast models for future energy consumption as well as provide data for adoption decision models with respect to different consumer groups [36]. Parallel to afore mentioned study Lutzenhiser [37] has looked into understanding barriers to energy efficiency technologies by observing organizational networks' effects on technology diffusion. Results of the study provide wide range of barriers to energy efficiency investments. For instance, it has been stated that small changes in interest rates are rapidly impacting construction companies as well as the whole supply chain including material suppliers, land and labor market. Resulting from a highly uncertain market structure, actors are stated to have tendency to be risk averse. Moreover, existing business practices driven by consumer desires and demands in the construction industry have also been found to create barriers to diffusion of more energy efficient technologies. One of business practices have been acclaimed to be standardized building designs which are more energy efficient but less consumer-favored, and customized building designs which are more consumer-favored but less energy efficient. As also supported by de Almeida [9] organizations react to market needs and as a result market is not aware of new energy efficient technologies, on the other hand as market is not aware of energy efficient technologies there is no demand for new technologies and as a result organizations do not tend to make use of new technologies. As a result, diffusion of energy technologies tends to be slow due to negative feedback loops between market actors' actions. Existence of such contradictive forces with organizations' main objective has been found to be inhibiting positive actions towards energy efficiency investments. Another important business practice causing construction organizations to disfavor adoption of more energy efficient technologies is firm size. Due to operating in different regions or countries, construction companies tend to promote standard designs that enable mass production which decrease costs and increase quality. As a result, standard designs in climate zones, where standard designs are not intended to be built for, consume more energy than region-customized alternatives. Competition and its implications on energy efficiency investment decisions have also been analyzed. Interestingly, existence of either too strong or weak competition among construction companies has been found to cause barriers which are namely risk aversion and complacency consecutively. Moreover, long term stability requirement let by large scale manufacturing and distribution systems as well as hidden costs associated with construction industry, industrial and organizational level inertia have also been identified as barriers to energy efficient investments. Significance of information related factors over energy efficiency investments has also been mentioned in the study. With respect to information channels, receivers and environment other external variables; perceived trust and validity of the information have been found to may or may not inhibit actions towards energy efficiency investments. Additionally, different user cultures, organizational power conflicts, adopters' difficulty in accessing capital, codes, standards, utility practices and counter acting trends have been found to be important factors in energy efficiency adoption decisions. Further research initiatives have been suggested to focus on exploring the effect of design on users' decisions on energy efficient investments. Role of decision makers along the supply chain is advised to be analyzed with respect to socio technical approaches [37].

4 Life Style Analysis Research Approaches

It has been observed that residential energy efficiency studies are making use of life style analysis approaches more than industrial and commercial studies in attempting to explain adoption of energy efficient technologies. Although there is considerable amount of life style analysis regarding the residential energy efficiency context we will present some of the recent works as a representative sample. Andrews and Kroggman [2] have focused on explaining the relationship between US commercial buildings' adoption of energy efficient heating, cooling, windows and lighting technologies and explanatory variables that are specific to building characteristics, occupant activities and region. It has been observed that energy efficient technologies are mostly being adopted by new buildings due to feasibility of initial costs and design efforts. For instance, split incentive barrier has been proven to be significant in adoption decisions. Owner occupied buildings have been found to be adapting energy efficient technologies more than rental buildings. Implications from the study suggest that existing buildings offer a huge energy efficiency potential, but adoption rates in these buildings are slow. Thus, market barriers associated with existing buildings can be addressed with new policies. Relationship between adoption of individual innovative technologies and new high performance buildings should be explored. How energy intensity and efficiency relates to each other has been stated to be another area of research [2]. A similar study has been conducted by Nair et al. [41] has surveyed the factors that are proposed to affect Swedish residential house owners' energy efficiency investments. Factors are divided into two clusters which are namely personal and contextual factors. Descriptive statistics show that perceived annual energy cost has a positive correlation with energy efficiency investments where as annual income does not have the same pattern. In particular, middle income groups show higher investment initiatives than high income groups. Younger population groups have been identified as having tendency to invest in energy efficiency more than older age groups. It has also been found out that higher education levels lead more energy efficiency investments than lower levels. Furthermore, it has been observed that some geographic locations show tendency to invest in energy efficiency measures more than others. In some cases, depending on the predictive factors some locations are supposed to invest in energy efficiency measures more than other locations, whereas in reality they are lagging. Other set of factors specific to these locations might be causing this situation. Thus, further studies are suggested looking into exploring these unexplored factors [41].

4.1 Life Style Analysis Approach in Industrial and Commercial Energy Efficiency Context

As stated by Palm [46] social energy modeling approaches have been largely used in residential energy efficiency literature however there is no similar approach conducted for the industrial purposes. Accordingly, Palm [46] has attempted to find out how lifestyle categories used in residential energy efficiency literature can be adapted to industrial energy efficiency literature. Life style categories approach is stated to help understand energy culture of companies by observing perceptions, habits, and routines and in turn provide information for more accurate policies. Although sample of the study is not sufficient enough proposed categorizations regarding firms' attitudes towards energy efficiency technologies are ignorant companies, implementer of easy measures, economically interested companies and innovative environmentalists. As stated traditional market barrier researches have focused on identifying technological and economical context of the energy efficiency gap issue however, social barriers within the firms might be as important. In particular, existence of a myth like energy efficient technologies will not pay off, might be an important inhibitor however observing its existence is not possible with economical and technological approaches. Thus, studies concerning myths, established norms, values and attitudes are stated to create a different set of tools that can be utilized in categorizing SMEs. As a result, more comprehensive lifestyle analysis is suggested being conducted for industrial energy efficiency context by addressing situated knowledge, routines and behavior, how employees act in practical situations and what attitudes, norms and routines determine their actions [46]. Similar to Palm [46] a follow up research initiative has been carried out by Palm and Thollander [47] aiming to combine traditional energy efficiency diffusion approaches with social science approaches since different elements in different levels such as company, industry and policy decision maker levels that operate in different social contexts that have their own tacit knowledge, perceived truths and routines. Existence of social diversity is stated to affect companies' perception of energy efficiency measures and in turn be one of the reasons why energy efficiency gap still exists. Innovative ideas are more likely to be introduced from outside the dominant regime since traditional context prevents outside the box thinking. Thus, increasing synergy among different social networks is claimed to promote diffusion of information and energy efficient practices. Moreover, quality of information is also acclaimed to be a very important factor in adoption decisions and it is further emphasized that similar feedbacks from two different information sources can have different effects on adoption decisions and this situation can be better explained by social network context. Further research studies are suggested exploring effects of organizational perceptions on energy efficiency investments. Exploring perceptions on sustainability, costs, comfort, norms, attitudes, and routines is advised to be beneficial initially. Another worth exploring matter is stated to be mapping industrial energy regimes and exploring different existing perceptions given an energy efficiency barrier or driver with respect to different control variables [47].

5 Adoption Process Approach

Nair et al. [42] has attempted to survey Swedish home owners' perception on adopting building envelope energy efficiency measures. Study has been based on different phases that potential adopters may go through in adoption process. Basically, these phases have been stated as occurrence of a need for adoption, information collection and selection. In this study, each stage has been defined by related variables and influencers accordingly end users' adoption tendencies have been observed. It has been observed that although many home owners did not know about their building envelope components they were satisfied with the thermal performance, aesthetics and physical conditions. It has been stated that this situation might lead homeowners' make biased adoption decisions. Interpersonal sources and energy related service organizations have been found to be important in gathering information where as home delivered leaflets are perceived as less important. Cost items such as annual energy savings, initial costs, maintenance and functional reliability have been observed as important adoption decision variables [42].

6 Diffusion Models Approach

Persson et al. [48] have analyzed convergence patterns of carbon dioxide efficient technologies in iron and steel, paper, board and pulp, coal and natural gas fuelled power plants by analyzing CO_2 emission per output in purchasing power parity terms for 12 countries. Data has been gathered between 1980 and 1998. Energy consumption and carbon dioxide emission related indices such as SEC: Specific energy consumption [18, 77], PPI: Physical energy indicator, SE: Structural energy efficiency, TOT: Actual notational energy use in sector, SE: Sector wise carbon dioxide emission efficiency [28] have been employed in order to eliminate variances associated with country specific variables. Accordingly, diffusion of technologies have been stated to be observed better since non-technical matter variables are filtered by making use of the aforesaid indices. Accordingly, indicators have been observed to converge in each sector across the countries especially for the case of carbon dioxide efficient technologies. This is stated to imply that countries have been using similar performance level technologies more and more. It has been further stated that developing countries tend to adopt efficient technologies more than developed ones due to high energy prices [48].

7 Analysis of the Findings

7.1 Drivers Studied in Energy Efficient Technology Adoption Literature

It is worth mentioning that there is no adoption driver specific taxonomy study in energy efficiency literature, however there is considerable amount of research efforts put towards identifying and categorizing adoption barriers. In Table 3 below you can see consolidated list of drivers for adoption of energy efficient technologies studied in the literature. Although no taxonomy study has been conducted in this study it should be noted that adoption drivers tend to vary with respect to the entity that receives the benefits resulting from positive adoption actions. First group of drivers can be explained as drivers that derive purely from personal motivations and social responsibility. For instance, Thollander et al. [68] and DeCanio [11] have shown that environmental concerns have been significant drivers for some adopters to invest in more efficient technologies even though benefits of their action do not directly return to them, but to the society in general. Drivers that have similar characteristics to aforementioned situation regarding the receiver of the benefits of positive adoption action cannot be explained by economical methods, but with behavioral models. Second group of drivers refers to the benefits such as; improved quality, reduced energy costs etc. that directly return back to the adopter as a result of their positive adoption decision. This group of drivers can be explained with economical models since adopters' actions are motivated by expectation of a benefit in return. Third group of drivers which is the

Table 3 List of drivers for adoption of energy efficient technologies

Drivers	References
Environmental values	[11]
People with ambition	[68]
Increasing energy price	[43]
Reducing energy costs	[10, 23]
Improving working conditions	[23]
Improving product quality	[23]
Improving company image	[10, 23, 44, 68]
Long term energy efficiency strategy	[23]
Improving compliance with regulations	[23]
Improving corporate environmental goals	[23]
Management commitment and vision	[23]
International and local competition	[23, 68]
Strategic energy efficiency plan	[23, 68]
Installation by public utilities	[10]
Fiscal arrangements	[10]
Subsidies	[10]
Niche finance opportunities	[10]

most interesting one refers to those drivers that derive as a result of some entities' interest in capitalizing secondary entities' interests and motivations. This group of drivers seems to be between the first two groups of drivers and help internalize preuninternalized costs in the free market without requiring government intervention. For instance, improving company image by adopting more environmentally favorable technologies in order to attract more customers with environmental consciousness provides direct benefits to adopter as well as secondary entities, which are customers.

Apart from taxonomy based on the flow of benefits, a secondary taxonomy can be based on the capabilities of potential adopters, which have been studied by the researchers approaching the adoption decisions from organizational perspective. It should be noted that existence of a specific capability such as; strategic energy efficiency plan may or may not be a driver for an organization to adopt a more efficient technology, but its inexistence may be a barrier for adoption. A similar approach has also been stated by Zilahy [78] by dividing adoption motivations in two, which are namely restrictive motivation factors whose existence inhibits adoption decisions and incentive motivation factors whose existence may or may not promote adoption. From the definition given it can be implied that restrictive motivation factors derive from the interactions between organizational capability building and existing adoption barriers associated with a given energy efficient technology. As Cebon [5] also stated policy tools can be aligned either to create new capabilities for organizations to make adoption process easier or possible, or modify technologies, by addressing barriers, in order to make it possible for organizations to adopt without building new capabilities.

7.2 Barriers Studied in Energy Efficient Technology Adoption Literature

There is a considerable amount of research put towards taxonomy of energy efficiency adoption barriers. Due to generalizations by assigning adoption barriers under fewer categories it becomes hard to observe variety of adoption barriers as they appear. In Table 4 below lists of adoption barriers as they appear in the refereed papers can be found. Please note that some of barriers appear to have similar meanings, however it is beneficial to keep diversity since grouping might cause data loss. Importance of creating a list of barriers has been supported by Schleich and Gruber [56] who has suggested there is a need for more empirical research efforts in order to verify existence of the barriers found out by grounded research efforts in a given case. Thus, future empirical research papers can base their questionnaires by making use of the list as a database. By making use of the list proposed here, questionnaires can be constructed more efficiently given a region, energy efficiency technology and user type. With the help of statistical tools significance of the barriers can be identified with respect to context of the

Table 4 List of barriers to adoption of energy efficient technologies

Barriers	References
Access to capital	[22, 37]
Adjustment costs after installation	[22]
Adjustment costs during installation	[22]
Adopter firm size	[37]
Adopter heterogeneity	[31, 37]
Asymmetric information	[43, 55]
Auditors assessment inaccurate	[22]
Bad experiences in the past	[11]
Belief that current equipment is efficient enough	[23]
Belief that current installations are efficient enough	[10]
Belief that technology will become cheaper	[23]
Bounded rationality	[31, 54, 55, 56]
Capital subsidies	[31]
Community environmental impact	[31]
Concerns about energy efficiency investment costs and time required	[23]
Conflicts of interest within organization	[67, 68]
Contradicting codes and standards	[31, 37, 43]
Control and monitoring problems due to decentralization	[11]
Cost of identifying opportunities, analyzing cost effectiveness and tendering	[31, 67, 68]
Cost of staff replacement, retirement, retraining	[67]
Counteracting forces, trends	[37]
Credibility and trust	[37]
Demand uncertainty	[31]
Dependence on overall managerial performance	[11]
Dependency of information validity	[37]
Difficulties in obtaining information about the energy use of purchased equipment	[67, 68]
Discount/Hurdle rates	[11, 31, 54]
Energy costs are perceived as unimportant	[10]
Energy efficiency often overlooked	[22]
Energy objectives not integrated into operating, maintenance or purchasing procedures	[67, 68]
Environmental regulations	[31]
Existence of other prior projects	[10, 11, 67, 68, 76]
Geographically dispersed organization type	[54]
Imperfect information	[30, 31, 55, 56]
Imperfections in finance markets	[55]
Inability to measure energy consumption due to technical difficulties	[54]
Inadequate data and information	[73]
Inappropriate industrial framework	[73]
Inertia	[37]
Informal regulation	[31]

(continued)

Table 4 (continued)

Barriers	References
Insufficient internal budget	[10]
Investments irreversible	[22]
Lack of access to information and knowledge	[10, 23]
Lack of appropriate technologies	[67, 68, 73]
Lack of awareness in energy saving opportunities	[73, 78]
Lack of coordination between government entities	[23]
Lack of educated manpower	[22, 67, 68, 73]
Lack of experience in technology and management	[73]
Lack of financial resources	[10, 11, 23, 67, 68, 73, 78]
Lack of governmental enforcement	[23]
Lack of incentive support	[73]
Lack of information about how to implement	[22]
Lack of internal coordination	[23]
Lack of management commitment	[23]
Lack of managerial influence	[67]
Lack of participation	[73]
Lack of staff awareness	[67, 68]
Lack of strategic planning	[73]
Lack of sub-metering	[67, 68]
Lack of trust in new technologies compliance with standards	[23]
Limited policy framework	[73]
Long decision chains	[67, 68]
Long payback periods	[11, 22]
Low priority given to energy management	[23, 67, 68]
Market structure and conditions	[31, 78]
Objections from different interest groups/power	[37, 73]
Organizational acceptance	[10]
Organizational culture	[37]
Outsourcing energy related projects due to tendency to save resources for core competencies is a new trend	[54]
Payoff between comfort and energy savings	[43]
Peer review on the technology	[10]
Poor information quality regarding energy efficiency opportunities	[67, 68]
Pricing distortions	[55]
Problems related to human factors	[78]
Quality related uncertainty	[10]
Rate of return too low	[22, 78]
Risks associated with the investments	[30, 22, 31, 37, 54, 56, 73]
Slim organization	[68, 67]
Split Incentives	[11, 22, 31, 43, 55, 56, 67]

(continued)

Table 4 (continued)

Barriers	References
Taxes and permits	[31]
Transaction costs/Hidden costs	[30, 31, 37, 43, 55, 56]
Uncertainties regarding the new technology/Stochastic rate of technological progress	[10, 22, 31]
Uncertainty regarding the cost of production disruption/hassle/inconvenience	[22, 23, 32, 54, 67, 68, 78]
Uncertainty regarding the cost of the technology	[10]
Uncertainty regarding the future	[67, 68]
Uninternalized social costs	[55]
Use of evaluation methods (NPA, hurdle rate, IRR and such) affect the feasibility decisions-non financial investment benefits are hard to obtain	[54]
User culture	[37]

case study. Accordingly, significant adoption barriers can be fed into utility energy efficiency program practices and can be used as a basis for developing new energy efficiency programs as mentioned by Thollander [70]. Having a complete list of adoption barriers associated with a technology given the important limitations, energy efficiency programs can make better determine what the efforts should be focused towards as well as better make use of available resources. Method introduced by Thollander [70] involves in employing a group of experts to identify energy efficiency adoption barriers for specified contexts such as; SMEs in Swedish industry and address identified adoption barriers by using policy tools in latter program design stages. Aforementioned methodology has been favored due to its ability to provide information for ex-ante program evaluation since it makes it possible to link adoption barriers to policy tools. Proposed method could be extended by making use of roadmapping method in order to add a time dimension into the process. Since diffusion of energy efficiency technologies is an ongoing process that happens throughout the time as well as progress of program practices attempting to address adoption barriers, use of roadmapping could provide updated information with regard to certain time points. These time points could be determined by referring to important dates that government agencies set goals for. For instance renewable energy portfolio standards provide valuable information about the goals regarding the percentage of energy generation from each available energy resources given the context and can be very useful for determining aforementioned time points. However, regarding the ex-ante program evaluation, making use of barriers and policy tools alone is important yet not enough. As mentioned by Gellings and Smith [20] demand side management practices need to be integrated into utility planning by considering the fact that depending on the demand curve feasibility of given demand side management technology such as; energy efficiency measures to be pursued may change. A complementary study that contributes to Gellings and Smith's [20] suggestions has been conducted by

Hill et al. [24] who have suggested assessing demand side management technologies by considering their potential implications on the demand curve of a given utility. A model that can incorporate all these concerns have not been studied yet although there is a few research studies available in the literature looking at the issue from different perspectives. For instance Lee et al. [34] has focused more on the project management aspect in assessing candidate technologies where as Nagesha and Balachandra [40] have employed wide range of assessment criteria to explore demand side management implementation strategies.

One of the implications that can be derived from the list is that barriers are multi dimensional. As can be observed, barriers tend to be related to behavioral, organizational, social, economical, political and many other aspects. Existence of such variety of barriers also validates why there are also multiple streams of research working in the area. An interesting observation can be mentioned is that some of the barriers appear to be existing resulting from lack of capabilities within the organizations. For instance implications from the research studies validating this finding are DeCanio's [11] work suggesting creating energy management departments in the existing organizations, Zilahy's [78] taxonomy of motivations as essentials and mediators, Cebon's [5] policy proposal towards either creating capabilities within the organizations or aligning the technologies based on organizations' needs and Kounetas et al.'s [33] work verifying that larger organizations are more successful in finding epidemic kind of information than smaller organizations. From the studies mentioned it can be understood that capability building aspect of the issue has been studied quite a bit in the literature, however authors appear to be interested in small pieces of it and use different terms. Capabilities can appear in many forms such as; existence of internal coordination, educated man power, knowledge to implement and maintain new technologies, ability to obtain information, sub-metering etc. would both help potential adopters to make sure they would succeed as a result of their positive adoption actions. With the help of previously conducted work new research initiatives can focus on explaining adoption behavior of the organizations from a capability approach. Accordingly, inspired by Zilahy [78] significance of capabilities grouped as essentials and mediators can be tested with regard to different control variables, which might either be adoption decisions or other mediators.

7.3 Policy Tools Studied in Energy Efficient Technology Adoption Literature

As mentioned in the earlier section, policy tools are employed by energy efficiency programs in order to address some of the important adoption barriers that prevent energy efficient technologies from diffusing in the market at high rates. Along with that policy tools that have been studied or mentioned in the literature has also been listed as can be seen in Table 5 below. Again as stated before, this list can be used

Table 5 List of policy tools that can be employed for promoting adoption of energy efficient technologies

Policy Tools	References
Internal department that is dedicated to energy management for promoting improvement ideas	[11, 61]
Internal incentives	[11]
Monitor and analysis of energy use	[11]
Building awareness around energy conservation	[11]
Environmental management system	[62]
Electricity certification system	[67, 68]
Cost-based tax incentives	[23]
Performance-based tax incentives	[23, 71]
Machinery import duty exemptions	[23]
Accelerated depreciation	[23]
Energy efficiency investment subsidies	[23, 72]
Project demonstration	[23]
R&D subsidies	[23]
R&D dissemination	[23]
Information campaigns	[23]
Voluntary agreements	[23, 44]
Energy pricing	[23]
Industrial standards/Obligations to perform	[23, 71]
Energy management procedures	[61, 72]
Initiatives for firms to research collaboratively with universities	[61]
Long term energy efficiency technology policies	[61]
Incentives for promoting education of employees	[61]
White Certificates	[44]
Hybrid Policies	[44
Promoting technologies which fit existing organizations	[5]
Modifying technologies to fit existing organizations	[5]
Support organizations which are likely to be receptive to target technologies	[5]
Modify organizations so that they can adapt the technology	[5]
Promotion through industry associations	[71]
Promotion through ESCOs	[71]
Public benefit charges	[71]

as a reference in exploring the strategies available in designing programs as well as good feedback for future research initiatives to develop more comprehensive policy assessment models that have already been pursued to an extent [44]. One of the interesting findings from the list is that there are several policy tools that are based on collaborations between different entities. Along with that a study conducted by Thollander et al. [70] attempting to assess variables impacting energy efficiency collaborations confirms existence of an important area of research. Another interesting implication to note is that although authors such as DeCanio [11], Sola and Xavier [61] and Cebon [5] have proposed developing capabilities for organizations to make adoption processes easier however there is no practical application put forward by utilities towards these suggestions. Applicability of the proposed policy tools may be an area of study for upcoming research initiatives.

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