Technology Assessment for Energy Efficiency Programs in Pacific Northwest

Ibrahim Iskin, Tugrul U. Daim
Dept. Engineering and Technology Management, Portland State University, OR - USA

Abstract--**This paper introduces a hierarchical decision modeling framework for energy efficiency program planning in electric utilities. The proposed approach focuses on assessment of emerging energy efficiency technologies and is proposed to bridge the gap between technology screening and cost/benefit evaluation practices. The proposed approach is expected to identify emerging technology alternatives, which have the highest potential to pass cost/benefit ratio testing procedures, and contribute to effectiveness of decision practices in energy efficiency program planning. Proposed framework also incorporates a rank order analysis for testing the robustness of results from different stakeholder perspectives in an attempt to enable more informed decision making practices. Proposed framework was applied for the case of Northwest U.S., results of the case application and future research initiatives are presented.**

I. INTRODUCTION

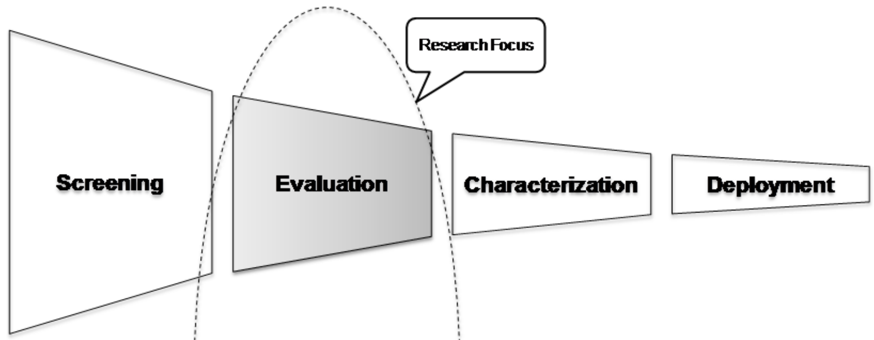
Nature of resource planning has changed dramatically since 1970s due to increased diversity in resource options such as renewable alternatives, demand side management (DSM), cogeneration of heat and power (CHP) in industrial applications, and deregulation of the energy market. New objectives have been added to the utilities' decision making processes beyond cost minimization, requiring utilities to address environmental and social issues that may emerge as a result of their operations [1]. Moreover; rapidly changing business conditions caused by technological development, instability in fuel markets, and government regulations have significantly increased complexity of and uncertainty involved in utility decision-making practices.

Prior to 1970s, utilities' main strategy in meeting increasing demand mostly consisted of capacity extensions, however due to increasing marginal cost of generation this approach was abandoned and replaced with more efficient use of existing resources. As a result, DSM initiatives were considered as a resource and a part of integrated resource plans. DSM programs have been widely utilized to meet increasing demand until the mid-1990s when the oil prices were again at a relatively lower level. Until this point, electric utilities were required to prove cost effectiveness of DSM programs within certain definitions imposed by the Public Utilities Commission. These definitions were primarily set in order to ensure proposed programs would recover cost of investments from a number of stakeholder perspectives. After reduction of oil prices and restructuring of electricity markets in 90s; new approaches for justifying cost effectiveness of DSM programs emerged. For instance, feasibility of DSM programs was evaluated by accounting for market externalities that had not been taken into consideration by the preceding assessment approaches. Inclusion of social and environmental externalities led recognition of societal and environmental perspectives which eventually enabled a large number of energy efficiency programs, which were previously infeasible, to be feasible [2]. Although DSM programs have often been characterized as being part of integrated resource planning, their value as a resource has not reached to its full potential due to a number of reasons discussed in the barriers literature.

Economic analysis methods have been used exhaustively to justify economic feasibility of energy efficiency programs. Along with economic analysis methods; decision analysis, decision support systems, and systems analysis methods have been extensively studied as well. Particularly, multiple criteria decision making methods; analytic hierarchy process (AHP), multi-attribute utility theory (MAUT), PROMETHEE, ELECTRE; have been heavily utilized in technology screening problems. Multi criteria decision-making methods have been favored for their ability to account for multiple decision criteria and stakeholders by providing clear and easily interpretable results. Due to multi criteria decision making methods' ability to address increasing complexity and uncertainties associated with energy planning decisions; they have become widely accepted and gained ground against conventional assessment methods.

II. ENERGY EFFICIENCY PROGRAM EVALUATION AND DEPLOYMENT PROCESS

A review of existing energy efficiency program management practices reveals that there are four major components associated with energy efficiency program evaluation and deployment. These are program screening, evaluation, characterization, and deployment. Aforementioned process starts with screening of energy efficiency technologies, which have savings potential for a given case. Criteria for screening practices are mostly technical considerations. Following the screening phase, candidate technology applications are defined and evaluated based on their potential benefits. Evaluation phase mostly employs multiple perspectives considering technical, economical, and environmental impacts. Those technology applications, which pass evaluation phase, are moved to characterization phase where field tests are conducted for quantification of costs and benefits associated with them. Based on the quantified data cost benefit ratio tests are conducted, reimbursement levels are determined for specified cases. Lessons learned are documented and used as input for creating measure implementation procedures for ensuring reliable energy savings. Those measures, which pass cost benefit ratio tests, are moved to deployment phase where energy efficiency measures are officially released and marketed through various channels. See Figure 1 below for a simple review of existing energy efficiency program evaluation and deployment practices.



What	Identify energy efficiency technologies that have savings potential	Evaluation of potential benefits to identify candidate technology applications to create programs	Field tests to characterize technology applications accurately through programs	Release of official measures and program implementation
How	Technical considerations	Multiple Perspectives	Economic methods	Commercialization
Case Study	Pacific Northwest, U.S. E3T Database 371 program alternatives identified	13 high priority energy efficiency program alternatives	Measures are developed and tested	Developed measures are deployed

Figure 1: Energy efficiency program evaluation and deployment framework

At this point it is worth mentioning that this research is not intended to replace conventional economic analysis methods, which are very strong in cases where there is sufficient quantitative data. Parallel to that, in the context of energy efficiency these methods are heavily used in decisions dealing with program feasibility and determination of reimbursement levels. However, in today's fast changing world it should be taken into consideration that the number of potential energy efficiency programs is very large due to the existence of numerous energy efficiency technologies and end use types. Most of the time energy savings data for the emerging energy efficiency technologies are not in place, and data collection becomes a serious issue, especially in cases where the number of savings variables is significantly large. Accordingly, it has been observed that there is a need for a systematic evaluation that can bridge program screening and characterization phases. Proposed research approach is intended to utilize expert judgment and provide a comprehensive way of evaluating energy efficiency program alternatives. This approach is expected to save resources by filtering those alternatives, which have the highest potential to pass cost benefit ratio test, and contribute to decision practices of energy efficiency program planning.

The objective of this research is to develop a holistic assessment framework for emerging energy efficiency programs. The proposed approach is to expand the existing assessment models by incorporating energy efficiency program management considerations rather than only the quantifiable variables that are largely employed by economic decision analysis methods. Incorporation of program management considerations is expected to enable a strategic perspective on technology planning practices in electric utilities and lead to more comprehensive decision making practices.

III. CASE BACKGROUND

Energy efficiency has been traditionally a significant part of Pacific Northwest's energy portfolio and its increasing contribution is expected to continue in the future. In the last 30 years, energy conservation programs in the Pacific Northwest have achieved 4000 average megawatts of electricity savings, meeting the half of the region's demand growth between 1980 and 2008. Conserved amount of electricity is expressed as being enough to power the states of Idaho, Western Montana and city of Eugene for 1 year; avoiding 8 to 10 new coal or gas fired power plants and saving ratepayers $1.8 billion. Energy efficiency savings have been contributing to the region's power system in a number of ways by keeping electricity rates low, avoiding new construction projects, reducing environmental footprint, and contributing to regional economic growth. Recent increases in cost of energy resources, increasing electricity demand and straining the limits of the existing power system, potential carbon policies have increased the importance of energy conservation more than ever before. Accordingly, region's resource plan demands 80% of the load growth in the next 20 years to be met by energy efficiency efforts.

Management of technology has been critical to Northwest's historical success in utilizing energy efficiency as a resource. It has been asserted that many of today's successfully diffused energy efficiency technologies; compact fluorescent lamps (CFLs), resource efficient clothes washers, super-efficient windows and premium efficiency motors; were results of research projects initiated in the 1980s and 1990s. Due to deregulations taken place in mid 1990s, utility driven technology development efforts have halted significantly and its impacts are felt today in a way that there is no portfolio of technologies that can enable significant savings potential for the future. In order to meet the aggressive energy efficiency goals Pacific Northwest's public power, investor-owned utilities and other energy efficiency organizations have restarted technology management initiatives in 2008. Collaborating with universities, national labs, and utility experts a task force named "E3T emerging technologies" was formed within Bonneville Power Administration's (BPA) energy efficiency group. The goal of the effort was defined to contribute to the Pacific Northwest's medium and long term energy savings targets by providing a robust pipeline of energy efficiency technologies. E3T program has been identifying emerging energy efficiency technologies through a number of channels. The group has currently identified 371 program alternatives, some of which are at different stages along the program management life cycle. In order to successfully manage its technology portfolio, the group has been developing a management framework that can identify high priority technologies from a large number of alternatives with limited quantitative information. Currently, 13 high priority program alternatives have been identified as having the most program actualization potential for Pacific Northwest. These program alternatives were moved to next stage of evaluation phase which is the focus of this research. See Table 1 below for list of high priority emerging energy efficiency program alternatives in the Pacific Northwest.

Considering its background in energy efficiency investments and future plans, Pacific Northwest U.S. has been identified as a potential case application for this paper. This research focuses on aforementioned 13 emerging energy efficiency program alternatives that were previously identified as high priority by the region. Results of this study will help identify the highest priority program alternative and provide insights to each program alternative's weak and strong points with respect to assessment considerations employed. Successful demonstration of the case application will justify the usefulness of the assessment model and provide a generalized assessment framework for similar efforts elsewhere.

IV. RESEARCH METHODOLOGY

Methodology employed in this research is hierarchical decision modeling (HDM), which is one of the widely used multi variable decision making methodologies. HDM breaks down complex decision problems into smaller sub-problems and provide decision makers a systematic way to evaluate multiple decision alternatives. HDM can be used for decision analysis problems with multiple stake holders and provide basis for group decision making. Its ability to make use of qualitative and quantitative decision variables makes it very flexible and applicable to wide range of application areas. For instance, HDM has been applied in a number of energy related applications such as; policy development and analysis [3], [4], electricity generation planning [5], [6], technology evaluation [7]–[11], R&D portfolio management [12], site selection [13], [14], integrated resource planning [15]–[18], evaluation of DSM implementation strategies [19], [20], evaluation of lighting efficiency measures [21], and prioritization of energy efficiency barriers in SMEs [22]. Further information about the mechanics of the methodology can be obtained from studies published by Dundar F. Kocaoglu and Thomas L. Saaty, who are the leading contributors to development of this methodology.

Case application of this research consisted of multiple phases, which include model development, model validation, and data collection. In the following sections you will be provided with further detail on aforementioned phases.

TABLE 1: HIGH PRIORITY EMERGING ENERGY EFFICIENCY PROGRAM ALTERNATIVES UNDER RESPECTIVE FOCUS AREAS

Area	Technology	End Use
Lighting	Bi-Level Lighting Controls	Commercial Offices
Lighting	Bi-Level Lighting Controls	Parking Lots and Garages
Lighting	Bi-Level Lighting Controls	Stairwells
Lighting	LED Lighting	Area and Parking Lot Lighting
Lighting	LED Lighting	Street Lighting
Lighting	LED Lighting	Outdoor Wall-Mounted Area Luminaries
Lighting	LED Lighting	Commercial Offices
HVAC	Demand-Controlled Ventilation	Commercial Kitchens
HVAC	Variable Capacity Compressor	Packaged Rooftop Units
HVAC	Advanced Controls with Remote Access and Energy Monitoring	Packaged Rooftop Units
HVAC	Air-Side Economizers	Data Centers
Energy Management	Low-Cost Energy Management and Control System	Small to Medium Commercial Buildings
Energy Management	Web-Enabled Thermostats	Small to Medium Commercial Buildings

TABLE 2: TAXONOMY OF ENERGY EFFICIENCY PROGRAM ASSESSMENT LITERATURE

Perspectives	Objectives	Goals	References
Social	Promoting regional development	Creating or retaining job opportunities	[15], [17], [21], [23], [24]
		Keeping local industry competitive	[17], [21], [23], [24]
		Improving life standards (non-energy benefits)	[17], [21], [24]–[26]
Environmental	Reducing environment-al impacts	Reducing GHG emissions	[15], [17], [21], [24]–[32]
		Reducing emission of soil, air and water contaminants	[15], [17], [21], [23]–[28], [30]
		Avoiding flora and fauna habitat loss	[15], [17], [24], [30]
Technical	Increasing operating flexibility and reliability	Reducing need for critical resources	[15], [21], [23], [24], [26]–[30], [32]–[39]
		Increasing power system reliability	[15], [21], [24], [27], [29], [30], [32], [33], [36], [37], [39], [40]
		Increasing transmission and distribution system reliability	[15], [21], [24], [27], [29], [30], [32], [33], [36]–[42]
Economic	Reducing system cost	Reducing/postponing capital investments	[15], [17], [21], [23]–[31], [34], [35], [37], [38], [42]–[45]
		Reducing operating costs	[15], [17], [21], [23], [24], [26], [28]–[32], [34], [35], [37], [42], [45]
Political	Reducing adverse effects on public	Avoiding noise and odor	[17], [24]
		Avoiding visual impacts	[17], [24]
		Avoiding property damage and impact on lifestyles	[17], [21], [24], [25]

A. Model Development

Model development process was initiated by constructing a preliminary assessment model based on findings from a comprehensive literature review on energy efficiency program assessment. It was observed that energy efficiency programs are utilized to accomplish a number of power system objectives and goals. Parallel to that a large body of assessment literature was observed to utilize utility objectives and goals as a measure for evaluation purposes. See Table 2 below for breakdown of the current literature with respect to assessment perspectives, utility objectives and goals.

Preliminary assessment model was presented to a group of five experts, whose participants had 15+ year experience in the area of emerging energy efficiency technologies. Based on the focus group feedback it was observed that the preliminary model would be suitable for post-evaluation of energy efficiency programs at government level. However, for the case of emerging energy efficiency programs it was emphasized that it would be difficult for experts to provide judgment for each utility value stream due to lack of data and complexity of the system. It was further noted that value of programs vary depending on different parts of the system, thus it would be difficult for experts to account for all sub-systems and come up with a value for the whole system. Accordingly, use of variables that could combine all value streams was suggested being more practical and accurate. Another important suggestion referred to the notion that program selection should not be limited to value potential only, but also address program development and market diffusion considerations. Within the evaluation of value streams, it was communicated that non-energy savings are important, however should be separated from energy savings. Based on the focus group feedback preliminary model was revised.

B. Model Validation

After the revised preliminary model was obtained, web-based content validity instruments were developed. All instruments were tested by a group of ETM PhD students. Any design and communication related problems were identified and corrected. Appropriate links were provided to the experts via an e-mail. Brief information about the objective of the study, purpose of the data instrument, definitions of the model hierarchy and decision variables were provided to the experts. Experts were asked to provide their judgment whether proposed variables were appropriate within the scope of the assessment study by rating each variable either “0” (not appropriate) or “1” (suitable).

Model validation was conducted through 6 content validity instruments, which were focused on different parts of the assessment model. Total of 44 experts; 8 from worldwide identified through social network analysis, 36 from Pacific Northwest; were distributed over 6 content validity instruments based on their expertise. In order for a variable to be included in the assessment model, at least two thirds of the experts in a panel had to agree on its suitability. Accordingly, large majority of the respondents agreed that the proposed variables were suitable for this research. Based on content validity results revised research model was modified and final research model was obtained.

C. Data Collection

Data collection phase focused on quantifying relative importance of model variables and decision alternatives. Judgment quantification instruments were developed by using an electronic spreadsheet software package. All instruments were tested by a group of PhD students. Any design and communication related problems were identified and corrected. Appropriate instruments were provided to the experts via an e-mail. Objective of the study, purpose of the data instrument, instructions were provided to the experts. Definitions of the decision variables were also provided in each question for further clarification.

Total of 26 subject matter experts with various backgrounds; 15 utility, 7 non-profit organization, 2 research lab, 1 university, and 1 consulting; participated in judgment

TABLE 3: FOCUS AND REQUIRED EXPERTISE PER EXPERT PANEL

Panels	Focus	Required expertise
Panel 1	Energy efficiency program management considerations	Executive management
Panel 2	Variables under energy savings potential	Program planning and evaluation
Panel 3	Variables under ancillary benefits potential	Program planning and evaluation, market transformation
Panel 4	Variables under program development & implementation potential	Project and program management, Measurement and verification
Panel 5	Variables under market dissemination potential	Market research and market transformation
Panel 6	Program alternatives level	Engineering, Academics

quantification process. Experts had experience in the areas of management, planning, engineering, and economics. A large number of energy efficiency organizations; 5 utilities, 4 non-profit organizations, 2 research labs, 1 university, and 1 consulting company; from the Pacific Northwest region were represented.

Judgment quantification was conducted through 6 expert panels, which were focused on quantifying different parts of the assessment model. Each panel required different types of expertise and experts were assigned to panels accordingly. See Table 3 below for focus of each expert panel and required expertise.

Judgment quantifications for panels 1 through 5 were performed by using pairwise comparison method. Unlike panels 1 through 5, panel 6 dealt with 13 decision alternatives, which is significantly a larger number for paired comparison method. In order to reduce excess workload on the experts judgment quantification for panel 6 was performed by using chainwise paired comparison method. Ratio scale used in all panels was constant-sum method, which required experts to allocate 100 points between two decision variables at a time with respect to their relative importance to a higher level decision variable that they were associated with. Experts' internal consistency and disagreements among the experts were measured by using indices developed by Ra (1988). Responses with inconsistencies greater than a predetermined threshold value of 0.10 was communicated back to its owner for further treatment. Expert panels with disagreements greater than a predetermined threshold value of 0.10 was further analyzed. Sub-groups with similar opinions were identified by using hierarchical clustering method. Rank order analysis was conducted for identified sub-groups in order to determine whether differences in opinions would have significant impact on end results. All experts demonstrated acceptable degree of consistency in their judgments; however there were significant group disagreements in panels 2 and 3.

V. RESULTS AND DATA ANALYSIS

Results and data analysis section is divided into two major threads. Synthesis of priorities section provides relative importance of model variables and decision alternatives derived from aggregation of expert judgments. The following section provides results of rank order analysis based on expert disagreements that were identified.

A. *Synthesis of Priorities*

Based on panel results, synthesis of priorities is calculated for different levels of the decision hierarchy. For instance, relative importance of sub-factors with respect to mission, relative importance of program alternatives with respect to program management considerations, and overall importance of decision alternatives with respect to mission are presented in this section. See Figure 2 below for overall importance of model variables with respect to mission.

Peak savings potential (0.166), base load (off-peak) savings potential (0.146), end-use adoption potential (0.115) are the highest; whereas equity considerations (0.021), promotion of regional development (0.026), ease of compliance with codes and standards (0.039), and reduction of environmental footprint (0.039) are the lowest weighted sub-factors. The rest of the sub-factors; direct impact on power system operations (0.075), intensity of market barriers and availability of leverage points (0.074), ease of savings measurement and verification (0.070), supply chain acceptance potential (0.068), ease of measure deployment (0.061), ease of maintaining measure persistence (0.055), degree of rebound effects (0.044); have relatively closer weights.

According to overall results, LED lighting for commercial offices (0.101) ranks the highest weighted program alternative. It is followed by LED lighting for outdoor wall-mounted area luminaries (0.091) and LED lighting for area and parking lot lighting (0.091) program alternatives, which share the second rank. LED lighting for street lighting (0.089) ranks third. See Table 4 below for overall importance of all program alternatives with respect to the mission.

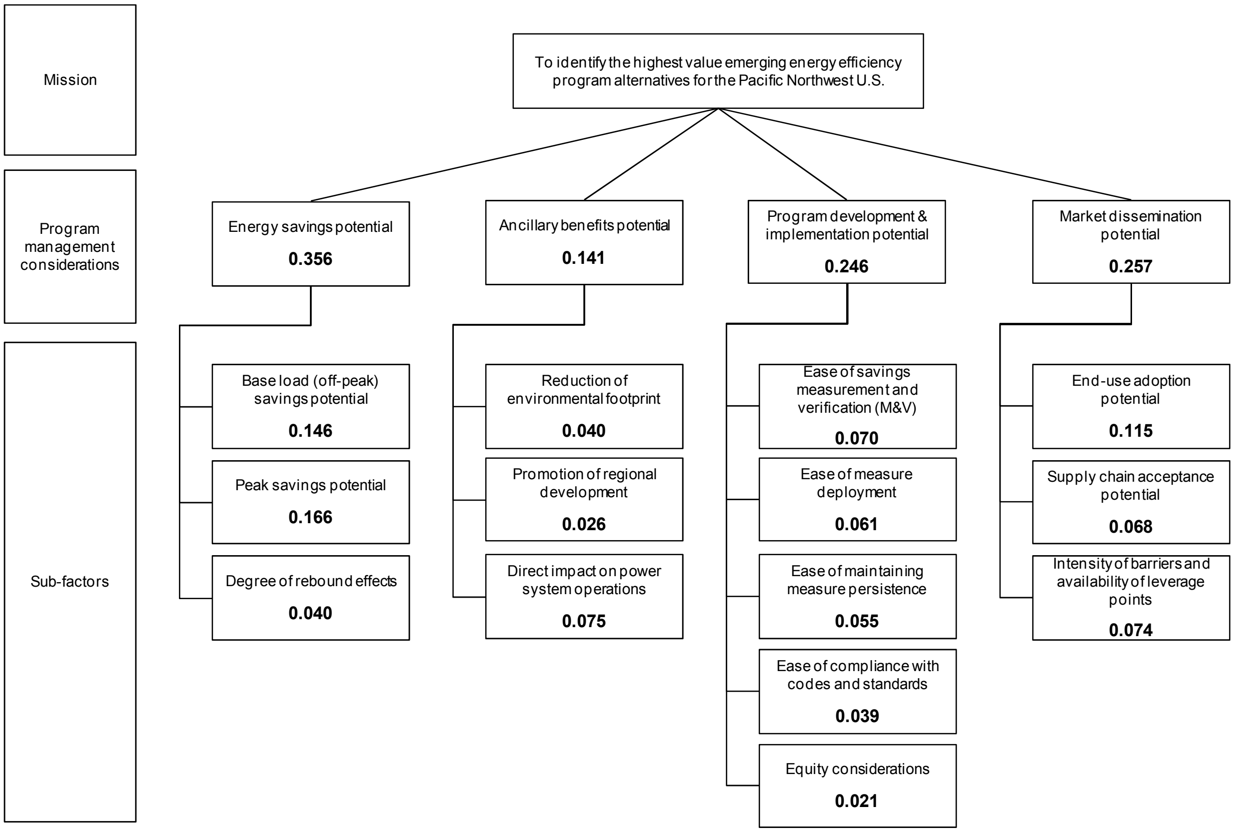


Figure 2: Overall importance of model variables with respect to mission

TABLE 4: OVERALL IMPORTANCE OF PROGRAM ALTERNATIVES WITH RESPECT TO THE MISSION

Program alternatives	Overall weights	Rankings
LED lighting for commercial offices	0.1010	1
LED lighting for outdoor wall-mounted area luminaries	0.0915	2
LED lighting for area and parking lot lighting	0.0912	3
LED lighting for street lighting	0.0891	4
Advanced controls with remote access and energy monitoring for packaged rooftop units	0.0826	5
Bi-level lighting controls for parking lots and garages	0.0774	6
Bi-level lighting controls for stairwells	0.0745	7
Variable capacity compressors for packaged rooftop units	0.0722	8
Low-cost energy management and control systems for small to medium size commercial buildings	0.0694	9
Air side economizers for data centers	0.0673	10
Web-enabled thermostats for small to medium size commercial buildings	0.0653	11
Bi-level lighting controls for commercial offices	0.0613	12
Demand-controlled ventilation for commercial kitchens	0.0572	13

An insight from the results is that all of the lighting technologies except for bi-level lighting controls for commercial offices have higher overall importance than HVAC and energy management technologies. Within lighting technologies, it is worth noting that LED lighting technologies have the highest overall importance and constitute the top four ranks.

B. Expert Disagreements and Rank Order Analysis

The results reveal that ranking of the current best program alternative; LED lighting for commercial offices; would remain unchanged for the case of majority of hypothetical decision makers. For instance, expert disagreements on relative importance of sub-factors under ancillary benefits potential constitute no impact on the current best program alternative (Panel 3). However, there is one instance which would change the current best program alternative. The disagreement involves in relative importance of sub-factors under energy savings potential (Panel 2). See Table 5 below for summary of rank analysis for the current best program alternative.

TABLE 5: SUMMARY OF RANK ANALYSIS FOR CURRENT BEST PROGRAM ALTERNATIVE

Panels	Hypothetical decision-makers	Best alternative's ranking status
Panel 2	Subgroup A	Changed
	Subgroup B	Unchanged
	Subgroup C	Unchanged
	Subgroup D	Unchanged
	Subgroup E	Unchanged
Panel 3	Subgroup A	Unchanged
	Subgroup B	Unchanged
	Subgroup C	Unchanged

Expert panel 2 consisted of 5 subgroups whose perceptions on relative importance of sub-factors under energy savings potential significantly differ. Out of all subgroups, subgroup A is found to have potential impact on ranking order of the current best program alternative. Subgroup A is significantly different than the group combined with its high emphasis on peak savings potential (0.704 vs. 0.410) and relatively lower emphasis on base load (off-peak) energy savings potential (0.216 vs. 0.466) and degree of rebound effects (0.083 vs. 0.125). Accordingly, if subgroup A in expert panel 2 was to influence the decision making process current best program alternative; LED lighting for commercial offices; would no longer be the optimum solution and rank 2nd. The new best program alternative would be advanced controls with remote access and energy monitoring for packaged rooftop units. This results is expected since LED lighting for commercial offices is affiliated more with base load (off-peak) savings potential than peak savings potential, whereas this is opposite for advanced controls with remote access and energy monitoring for packaged rooftop units.

Overall, ranking order of current best program alternative; LED lighting for commercial offices; remains unchanged in all of the cases except for one despite there are a number of sub-groups with different opinions.

VI. CONCLUSIONS

First contribution of the proposed research effort is to enable comprehensive assessment of energy efficiency program alternatives. It was observed that there was no holistic assessment framework although quite a few research studies have identified these points as potential improvement areas.

Second significant contribution of this paper is providing a systematic way to analyze impacts of expert disagreements on rank order of program alternatives. This approach accounts for different opinions within an expert panel and provides a common ground for further discussions. Considering the fact that energy planning decisions involve multiple stakeholders with different interests this contribution constitutes great importance.

Overall, proposed improvements contributed to existing level of knowledge by enabling a more accurate energy efficiency program evaluation and planning approach that can provide better understanding of the potential implications of the strategic decisions.

VII. RESEARCH ASSUMPTIONS AND LIMITATIONS

This research is mainly based on expert panels, which might bring in subjectivity of the experts. It is important to acknowledge that due to the nature of the methodology it is impossible to eliminate expert subjectivity; however a number of measures were taken to improve the reliability of this research. For instance, a number of factors were taken into consideration during panel designs. A special attention was given to make sure expert panels consisted of experts with relevant expertise. It was also made sure that panels included experts from different perspectives, backgrounds and organizations. All experts participated in the study willingly. They were informed that their identity would be kept anonymous and they could withdraw from the study at any time without affecting their relationship with the researcher or any institute. Although these considerations are important to improve rigor of the panels, they are not enough by themselves without proper measurement methods. In order to address this issue, a number of data related validity measures, which are explained in detail in the earlier sections, were employed. These measures were used to detect both experts' individual inconsistencies and group disagreements. Using proper treatment techniques, necessary feedbacks were provided to the experts and data related validity issues were fixed.

Generalizability of the results derived from the research is context and time dependent. Any time in the future; technical, economic, social, political, and environmental drivers may not be in the same state as the time of this study. Changes in any of these drivers may have impact on perception about the use of energy conservation as a resource, which would directly impact role of energy efficiency programs in energy planning. Furthermore, these changes could impact relative importance of program management considerations and sub-factors, causing current best decision alternatives to be no longer optimum.

Value derived from a given energy efficiency programs depend on market, technology and utility specific variables. For instance; potential market size for diffusion, match between program alternative and utility load characteristics are some of the key variables. Since these variables are subject to change for different regions and utilities, values of energy efficiency program alternatives would differ significantly. Thus, it is important to consider that results deriving from this research are only applicable to Pacific Northwest region. Although the results are only applicable to the aforementioned case, assessment model is generalizable and can be replicated in various contexts such as; different countries, regions, utilities, and technologies.

Lastly, this assessment model was developed for assessing technology based energy efficiency program solutions only. Behavioral energy efficiency programs were excluded from the scope of this research. Moreover, assessment model used in this study is only applicable to electric power utilities and does not address those cases, where energy efficiency can also be accomplished through energy resource substitution.

VIII. FUTURE RESEARCH

Results derived from this study is time dependent, thus validity of the results may change overtime. Although it is impossible to foresee potential future changes, it is possible to observe how changes in relative importance of assessment variables can impact the optimality of decisions. For instance, a sensitivity analysis can be incorporated to determine those instances and provide insight to how current best decision alternative would be impacted.

Due to large number of program alternatives chainwise paired comparison method was utilized at the program alternative level in order to reduce number of required comparisons. However, considering existence of hundreds of emerging technologies chainwise comparison method also constitutes limitations. Accordingly, another significant improvement upon the existing framework could be achieved by integrating desirability curve concept. Desirability curve concept could be used to further articulate each sub-factor by defining performance metrics. Evaluation of program alternatives would be performed with respect to developed metrics, eliminate the need to pairwise compare program alternatives among each other. This approach would enable assessment of large number of program alternatives by reducing data collection requirements significantly.

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