Holistic Building Technology Selection for Sustainability: A Market Analysis and Multi-Attribute Decision Making (MADM) Approach for Residential Water Heaters in U.S.

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Abstract

Water heating in the United States has the largest energy consumption of any residential related use. It uses more energy than all other home appliances combined. They have also been implicated as the source of waterborne disease outbreaks. With such high stakes, it is recommended that a Decision Support Tool (DST) be used prior to selection of a water heater for new construction or replacement. Although there are numerous tools available, it is challenging to find a tool that takes into account all factors critical to the selection of water heaters, addresses gaps and barriers, provides adequate information to all stakeholders and finally, assists in rational decision making towards more sustainable choices.

The purpose of this research is threefold: (a) to inventory, organize and characterize web-based existing water heater Decision Support Tools (eDSTs) to highlight gaps and/or shortcomings; (b) to develop a Decision Support Tool Skeleton (DSTS) containing a comprehensive list of sustainability capital, criteria and indicators based on Multi-Attribute Decision Making (MADM) approach; (c) to create a stakeholder map comprising supply chain, stakeholder system, decision making process during water heater selections as well as other market factors, using meta-synthesis of collected documents.

The findings of this research indicate that considerable gaps and shortcomings exist in the current pool of water heater DSTs. To address these barriers, information was captured from various documents in a process of qualitative data analysis called coding. The coding process generated attributes which were used to generate a comprehensive set of capital, criteria, sub-criteria and indicators using MADM approach. This organizing structure developed on lines of sustainability assessment will serve as a starting point towards achieving global sustainability in real life. Importantly, information asymmetry between various stakeholders is evidence of the fact that the existing tools are not addressed in an equitable manner. This study will help determine the stakeholder system and the decision making process for selection of water heaters in the residential sector, so as to effectively implement new tools being created.

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Complementary Works

Doshi, P., Pearce, A. R., Pruden, A. J. and Taylor, J. E. (2015). "Multi-Criteria Decision Support Tool Skeleton (DSTS) for Water Heaters: Facilitating Selection among Residential Sector Stakeholders." Poster Presentation, *Interdisciplinary Research Day*, Blacksburg, VA.

Doshi, P., Pearce, A. R., Pruden, A. J. and Taylor, J. E. (2015). "Multi-Criteria Decision Support Tool Skeleton (DSTS) for Water Heaters: Facilitating Selection among Residential Sector Stakeholders." Poster Presentation, *Graduate Student Assembly (GSA) Research Symposium*, Blacksburg, VA.

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Chapter 1: Introduction

1.1 National Overview

Residential water heating is responsible for a significant portion of energy consumption in the United States. In 2012, the residential sector accounted for 21% of total primary energy consumption and about 20% of carbon dioxide emissions in the United States (EIA 2013a). Over the past decade, between 3.3-5.5% of the total annual U.S. energy demand is used in residential water heating, which slightly exceeds the estimated 3-4% combined energy demand of the water and wastewater utility sectors (EIA 2010; EPA 2009). Water heating is a ubiquitous energy use in the housing sector and has the largest energy consumption of any water related use (ACEEE 2012). Additionally, as of 2009, it is the second largest energy use after space heating and cooling (when lighting is considered separately), and accounts for 18% of total residential energy use as shown in Figure 1.1 below (DOE 2010; EIA 2013b).

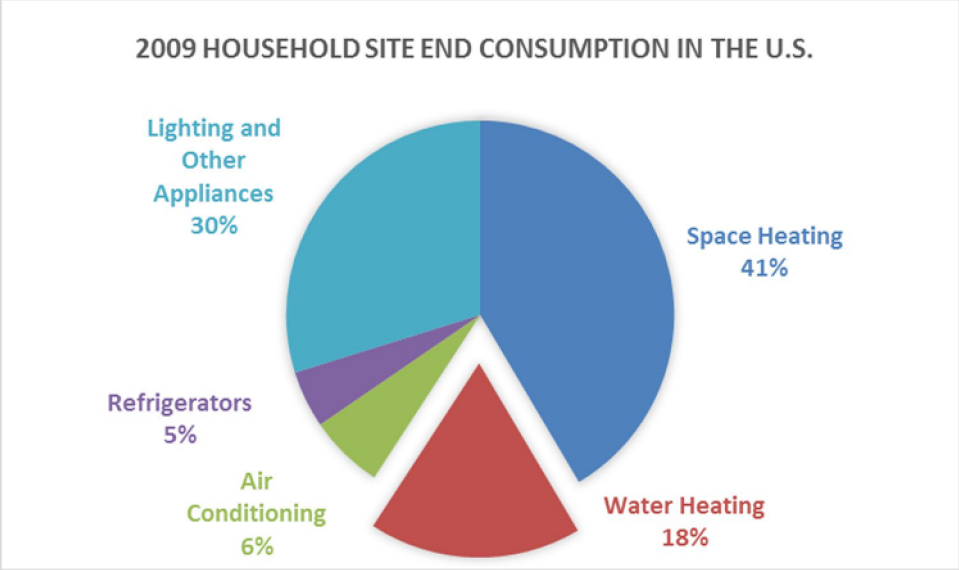

Figure 1.1: The site end consumption of total energy use in homes in U.S. (EIA 2013b)
(Other appliances include cooking appliances, clothes washers, dryers, dishwashers, computers, televisions, small electronic devices, pools, hot tubs)

The costs of residential water heating are high with $31.65 billion in total being spent as household end-use expenditure in 2009 (EIA 2013b). Significantly, an average household spends between $400-600 each year on water heating (DOE 2013a).

It is estimated that for more than 92% of U.S. households, individual water heaters represent the water heating application of choice (DOE 2012a). For the remaining ~8% of households, central water heaters serving multiple households represent the most common system type (DOE 2012b).These households are single-family homes or multifamily buildings with four or fewer units (DOE 2012a). Of the 113.6 million residential water heaters that existed in 2009, 58.3

million are gas, 46.8 million are electric, and the rest comprising of propane and fuel oil among others (EIA 2013b).

Over the past 70 years, storage water heaters have been the predominant water heater type in the United States (DOE 2012b), accounting for 97.3 percent of all existing installations (EIA 2013b). Storage units dominate both the gas-fired and electric water heater markets, with shipments of 8.29 million for gas and electric units combined in the U.S in 2013, up from approximately 7.5 million units in 2009 (AHRI 2014). However, with 5 percent of annual sales (approximately 400,000 units per year), the installation of tankless water heaters is increasing (Parker 2011).

The majority of water heaters in use today are of low-efficiency (DOE 2010), with limited sales and availability of high-efficiency units (AHRI 2010). Currently, the majority of residential gas-fired water heater sales in the U.S. are for minimum-efficiency tank-type models with Energy Factors of 0.58 and 0.59 (ACEEE 2010). Efficiencies of electric tank-type water heaters are generally between 0.90 and 0.95 EF, with slightly higher efficiency for electric tankless water heaters between 0.95 and 0.99 EF (AHRI 2010). However, the market for more energy-efficient water heaters is expanding (DOE 2010). Major manufacturers are slowly beginning to produce these units in larger quantities and retailers and plumbers are offering these units on a more frequent basis (AHRI 2010).

More stringent federal equipment standards for residential water heaters and a surge of innovative technologies are creating more water heating options for builders, contractors and homeowners than ever before (PERC 2011). At present, in both new and existing homes, the five main water heating options include traditional storage, tankless systems, heat pump water heaters, solar hot water systems and indirect tankless & coil water heaters (DOE 2013a; PERC 2011). Other systems include condensing storage tank systems, tankless systems (condensing and non-condensing), and even systems that combine space heating with water heating (PERC 2011).

Market data and initial program experience suggest that the key influences during decision-making for water heater selection are consumer needs, expert advice, information at point of purchase, and price (DOE 2010). The largest market barrier for energy-efficient water heaters for residential applications is the high first cost (Maguire 2009; ORNL 2011). Energy savings from a more efficient water heater can offset the higher first cost over its lifetime, but it does not typically provide a strong enough incentive for consumers (NREL 2013). This is particularly true if the water heater is installed for someone other than the occupant or user (NREL 2013).

In order to fully understand how decisions on water heater purchases are being made in the marketplace, it is essential to highlight some background information on the current residential water heater selections as well as decision support tools that aid in these selections. They have been explained in the section below.

1.2 Background

This section discusses knowledge of existing residential water heater types as well as the definitions, functions and barriers of using decision support tools that aid in water heater selections. Both these topics are essential to the research study undertaken and are important to know beforehand, as explained in the subsections.

1.2.1 Types of Residential Water Heaters

The table below classifies the main types of residential water heaters on several parameters such as cost, life expectancy, pros., cons., and performance improving tips. Other water heater systems such as condensing, non-condensing, etc. have not been included as they are relatively new to the market and are outside the scope of this study. It is important to note that the comparison is relative and may not have a baseline from which it is measured on.

Table 1.1: The 'main' types of residential water heaters (DOE 2013a)

	Storage	**Tankless**	**Heat Pump**	**Solar**	**Tankless Coil & Indirect**
Cost	$	$$	$$	$$$	$$
Life Expectancy	10-15 years	20+ years	10-15 years	About 20 years	10-11 years
Pros.	Lower purchase cost	Provides a constant supply of hot water and is 8-34% more efficient than a storage water heater	2-3 times more energy efficient than a storage water heater and lower operating costs	50% more efficient than gas or electric water heaters, depending on system design	Low installation and maintenance costs
Cons.	Standby heat loss – energy can be wasted to keep the water in the tank heated to the set temperature during periods when hot water is not required	Limited flow rate of hot water means simultaneous, multiple uses of hot water can stretch a tankless hot water to its limit	Performance is dependent on the installation location, and heat pump water heaters exhaust cold air – increasing the load on space conditioning appliances during heating months	May require a backup system for cloudy days and times of high demand	Inefficient choice for many homes, especially in warmer climates
Performance Improving Tips	Look for an insulated tank to reduce heat losses and lower operating costs	Install 2 or more water heaters connected in parallel or separate ones for appliances that use a lot of hot water	Switching the heat pump water heater to regular resistance mode will stop cold air exhaust but also reduce the appliance's efficiency	Make sure you buy a solar water heating system that includes a storage water heater as a part of the system package	

Importantly, electric water heaters typically suffer from cost-to-operate concerns because of fuel price differences in many regions, despite the appearance of higher Energy Factor ratings (ACEEE 2010). In addition, overall efficiency of electric units is not fully represented by efficiency ratings, as the source energy needed to generate electricity is not taken into account and has the potential to increase overall energy consumption (DOE 2008).

1.2.2 Public Health Considerations

It is also important that water quality and long-term performance impacts are also considered in cost-effectiveness and life-cycle cost analyses to make sure homeowners, utilities, and other stakeholders achieve the desired energy savings expected over the lifetime of the water heater (PNNL 2013). There are confirmed instances of health hazards when storing domestic hot water for human use and/or contact at temperatures known to sustain growth of harmful bacteria (ASSE 2012). Additionally, the local water quality is one of the factors that contributes most significantly to the long-term performance and longevity of water heating equipment (PNNL 2013).

Preliminary investigation has revealed that independent of energy or heat source, water heater design and operation are major determinants of public health risk and energy consumption in water heaters (Brazeau and Edwards 2011). In terms of public health, growth of opportunistic pathogens such as Legionella, etc. in building plumbing systems (i.e., premise plumbing) is now the primary source of waterborne disease outbreaks in the U.S. and other developed countries (CDC 2008; EPA 2009). Notably, they affect a significant portion of the U.S. population and have important health and economic implications (Pruden et al. 2013). It is essential that the public be made aware of the potential repercussions of water heater usage and its impact on the surroundings.

1.2.3 Decision Support Tool (DST)

This division talks about the fundamentals of decision support tools (DSTs) such as its definition, characteristics or functions, formats, and barriers to effective adoption by tool users. This information is highly essential to this study, as the ultimate aim is to develop a decision support tool skeleton for residential water heaters selections, from which several effective DSTs can be created for educational, awareness or selection purposes.

1.2.3.1 Definition

Selection is one of the most important tasks faced by decision makers in any setting. Balancing multiple, often conflicting objectives, criteria or attributes are the reasons why selection problems are challenging (Georgilakis 2005). Hence, “a Decision Support Tool (DST) allows stakeholders to compare multiple alternatives across multiple criteria, making selections easier” (Ewing and Baker 2009).

DST can be defined very broadly as “any tool that informs the decision making process by helping actors understand the consequences of different choices” (CMHC 2004); “any tool used as part of formal or informal decision process” (Kapelan et al. 2005). The California Healthcare

Foundation in its report on 'Consumers in Healthcare: Creating Decision Support Tools That Work' in 2006, states that "DSTs help the decision maker winnow a large set of options and thereby reduce the number of different information inputs to be factored into a decision" (CHCF 2006).

1.2.3.2 Characteristics of DSTs

Every DST may have been customized to cater the specific objective of its creation. The particular functions and characteristics of a tool depend on its purpose and the type of decision being supported (CHCF 2004).

Primarily, the characteristics of DSTs (Georgilakis 2005) are:

- To support the decision making process in complex problems
- To focus on user-friendliness through design and development so that decision makers that are not familiar with computer technology can take full advantage of the capabilities that the tool provides

The California Healthcare Foundation in its 2006 report provides several functions served by a DST such as (Adapted from CHCF 2006):

- Framing the decision context for the consumer
- Providing essential data and background information in an unbiased way
- Storing, sorting and processing complex information
- Clarifying user's values and preferences and guiding choices
- Providing structured guidance through the process of decision making

1.2.3.3 DST Formats

The format of Decision Support Tools (DSTs) exist in various forms as shown in Table 1.2 (CHCF 2006; CMHC 2004):

Table 1.2: DST formats (CHCF 2006; CMHC 2004)

Print Publications:	Booklets, Worksheets, Reports, Product Specifications, etc.
Computer Applications:	CD-ROMs, Websites, Software, Interactive Webpages, and Other Online Web Tools (which may constitute a small majority of the total tools available on the Internet)
Personal Counseling	Coaching or Counseling from a Trained Advisor
Other	Audio Guided Workbooks, Videotapes, etc.

1.2.3.4 Barriers to Effective Use of DSTs

Although the availability of decision support tools is increasing, a number of barriers impede their widespread and effective use (CHCF 2006). Many of the barriers arise from the design, content, format, and dissemination of the tools themselves, including (ibid):

- Lack of relevant content
- Limited consumer awareness of information on residential water heaters and on water heater decision support tools
- Poor tool design and confusing presentation of information

Other barriers to effective use are related to the characteristics of the intended audience such as (ibid):

- Lack of trust in the source of decision support tool
- Low levels of literacy and lack of online access to web-based tools especially among the elderly and the poor

In all, it is clear that residential water heating has enormous economic, social and technical implications, which can be addressed through the development of a decision support tool to aid in selection problems. The next section provides insight to specific problems in the decision making process on the selection of residential water heaters in the U.S. market.

1.3 Problem Statement

Currently, a majority of water heater sales are commercialized technologies with low level of efficiencies (DOE 2012a). They may not be entirely sufficient to enable true market transformation to higher and more energy-efficient equipment (ORNL 2011). Most U.S. homes use either natural gas or electric storage water heaters (EPA 2012). However, many higher efficiency water heating options are available including tankless water heaters, condensing storage water heaters, heat pump water heaters (HPWHs), and solar water heaters. All these technologies could provide energy savings to consumers (NREL 2013).

Also, there is knowledge deficit regarding what DSTs are available and the potential benefits associated with their use (Mackley et al. 2000). Specifically, these tools are designed at assisting users in selection of optimum water heaters. Yet, these tools are directed to one or more key players and do not encompass all stakeholders of the water heating arena such as homeowners, plumbers, utilities (offering efficiency programs to the marketplace), trade groups, builders, building occupants, etc. among several others (DOE 2012a).

Correspondingly, there are various complexities associated with existing DSTs for selection of water heaters. There is a need for ready access to available tools (Mackley et al. 2000). Moreover, the assortment of tools is continually expanding, making reviews and evaluations out-of-date. This complexity is also what challenges the potential user in finding and using tools (Keysar and Pearce 2007). Lastly, these tools may not address equally well, the concerns of, and the opportunities available to all stakeholders.

The involvement of experts in the decision-making process complicates the standard analysis of consumer choice due to information asymmetry (Bartels et al. 2001). Consumers may not be well placed to immediately judge product attributes, a situation which leads to a derived demand for information through consumer search, product advertising and/or from experts who provide

advice (ibid). This continued involvement of experts in the market means that their skills enable them to detect a product's quality, on which the consumers may rely (ibid).

Because of information asymmetry, there is typically a strategic element in the transmission of information between various stakeholders, which could complicate the decision making process of purchase of water heaters (Bartels et al. 2001). For example, a plumber advising a consumer on their choice of water heater, will most likely also install the appliance (ibid). Statistically, plumbers directly or indirectly influence about 60% of water heater purchases (DOE 2010). Hence, there is a strategic interaction between the plumber and the consumer because of asymmetric information and potential differences in preferences (Bartels et al. 2001).

Additionally, phone and online surveys, coupled with evidence from in-depth interviews, strongly suggest that homeowners rarely think about their water heaters (NEEA 2012). Benchmark water heater programs emphasize that residential customers need price discounts and adequate information in order to make the right decision to purchase a high efficiency water heater (PG&E 2012).

Eventually, the behavior of a building's occupants has significant impact on the total hot water use and overall hot water demand (ORNL 2011). For example, an experiment involving 4700 occupants in Virginia Tech., VA showed that there was significant reduction in water consumption, when participants were provided with feedback on their water consumption as well as the associated embodied energy in the water consumed (Jeong et al. 2014).

Typically, the speed of the water heater purchase decision depends on whether the decision is an emergency or planned (DOE 2010). Although nationally 23 percent of water heater purchases are planned, this number is down from the peak of 40 percent of planned water heater purchases (NEEA 2012). The decline in planned water heater purchases nationally, gives a relative market share advantage to plumbers, contractors and retailers who cater to emergency water heater replacement (ibid). In many cases, these installers make recommendations based on their own interests, in terms of profit revenues, the chances of getting the job, a lasting relationship with the client, and their reputation in general (ibid).

In conclusion, there is an urgent need for a DST for residential water heater selection in the market that is user-friendly, sufficient with comprehensive information and that can enable informed and rational decision making. Making informed choices also offers a tremendous opportunity to positively impact energy use and carbon emissions on a wide scale, because the replacement cycle of water heaters is roughly 12-15 years. With this replacement frequency, every year there is a window of opportunity in millions of U.S. homes to impact the energy and carbon performance of one of the largest energy consumers in the home (PERC 2011).

Furthermore, the tools must be accessible by all stakeholders involved. Selection decisions are quite often significantly influenced by other stakeholders besides the homeowner, and therefore there may be a mismatch between the tools that exist and the way the decision is actually made. Ultimately, the question arises as to who are the major decision makers for water heater selection in the residential construction sector? At the same time, what are the major factors that influence the decision-making process and what information would help users tackle the above stated

problems? This study focuses on development of a decision support tool skeleton (DSTS), comprising a comprehensive list of selection factors to aid in the decision making process, in addition to an analysis of existing DSTs as well as insights into the U.S. residential water heater market.

References

Air-Conditioning, Heating and Refrigeration Institute (AHRI). (2010). "Directory of Certified Product Performance." *AHRI Directory*, <http://www.ahridirectory.org/ahridirectory/pages/home.aspx> (Dec 23, 2013).

Air-Conditioning, Heating and Refrigeration Institute (AHRI). (2014). "Residential Automatic Storage Water Heaters Historical Data." *AHRI Historical Data*, <http://www.ahrinet.org/site/495/Resources/Statistics/Historical-Data/Residential-Storage-Water-Heaters-Historical-Data> (Mar. 5, 2014).

American Council for an Energy Efficient Economy (ACEEE). (2010). "Working Together to Transform the Market for Water Heaters." *ACEEE Summer Study on Energy Efficiency in Buildings*, 9: 321-330, Washington, D.C.

American Council for an Energy Efficient Economy (ACEEE). (2012). *Emerging Hot Water Technologies and Practices for Energy-Efficiency as of 2011*, No. A112, Washington, D.C.

American Society of Sanitary Engineering (ASSE). (2012). *Understanding Potential Water Heater Scalds,* Westlake, OH.

Bartels, R., Fiebig, D. G. and Soest, A. V. (2001). "Consumer and Experts: An Econometric Analysis of the Demand for Water Heaters." No. 2003-26, Center for Economic Research, University of Tilburg, Netherlands.

Brazeau, R. H. and Edwards, M. A. (2011). "A Review of the Sustainability of Residential Hot Water Infrastructure: Public Health, Environmental Impacts, and Consumer Drivers." *Journal of Green Building*, 6(4), 77-95.

California HealthCare Foundation (CHCF). (2006). *Consumers in Health Care: Creating Decision Support Tools That Work,* Oakland, CA.

Canada Mortgage and Housing Corporation (CMHC). (2004). "Types of Tools." Annex 31 - Energy-Related Environmental Impact of Building, *Energy Conservation in Buildings and Community Systems,* Ontario, Canada.

Centers for Disease Control and Prevention (CDC). (2008). "Possible Link of Poor POU Devices, Plumbing to Disease." *AWWA Annual Conference and Exposition,* Atlanta, GA.

Ewing, B. and Baker, E. (2009). "Development of a Green Building Decision Support Tool: A Collaborative Process." *Decision Analysis*, 6(3), 172-185.

Georgilakis, P. S. (2005). "State of the Art of Decision Support Systems for the Choice of Renewable Energy Sources for Energy Supply in Isolated Regions." *International Journal of Distributed Energy Resources*, 2(2), 129-150.

Jeong, S., Gulbinas, R., Jain, R. and Taylor, J. (2014). "The Impact of Combined Water and Energy Consumption Eco-Feedback on Conservation," *Energy and Buildings*, 80: 114-119.

Kapelan, Z., Savic, D. A., and Walters, G. A. (2005). "Decision Support Tools for Sustainable Urban Development." *Proceedings of the Institution of Civil Engineers*, *Engineering Sustainability*, 158(3), 135-142.

Keysar, E. and Pearce, A. R. (2007). "Decision Support Tools for Green Building: Facilitating Selection Among New Adopters on Public Sector Projects." *Journal of Green Building*, 2(3), 153-171.

Mackley, S., Odell, W. and Lazarus, M. A. (2000). "Environmental Education for the Building Industry: An Internet Resource." *Proceedings of the International Conference on Sustainable Building*, 174-176.

Maguire, J. B. (2009). "A Parametric Analysis of Residential Water Heaters." M.S. Thesis, Department of Mechanical Engineering, University of Colorado, CO.

Northwest Energy Efficiency Alliance (NEEA). (2012). *2011 Water Heater Market Update*, No. 12-234, Portland, OR.

National Renewable Energy Laboratory (NREL). (2013). *Comparison of Advanced Residential Water Heating Technologies in the United States*, No. TP-5500-55475, Denver, CO.

Oak Ridge National Laboratory (ORNL). (2011). *Research and Development Roadmap for Water Heating Technologies*, Oak Ridge, TN.

Parker, M. (2011). "Water Heating, Distribution and Use Efficiency." *ACEEE Hot Water Forum*, Berkeley, CA.

Pacific Gas and Electric Company (PG&E). (2012). "Market Focused Program Design to Accelerate Penetration of ENERGY STAR Water Heaters." *PG&E's Emerging Technologies Program*, No. ET12PGE3191, San Francisco, CA.

Pacific Northwest National Laboratory (PNNL). (2013). *Impacts of Water Quality on Residential Water Heating Equipment*, No. 22921, Richland, WA.

Propane Education and Research Council (PERC). (2011). *Comparing Residential Water Heaters for Energy Use, Economics, and Emissions*, Washington, D.C.

Pruden, A., Edwards, M. A. and Falkinham J. O. (2013). "Research Needs for Opportunistic Pathogens in Premise Plumbing: Methodology, Microbial Ecology and Epidemiology." *Water Research Foundation,* Denver, CO.

U.S. Department of Energy (DOE). (2008). *Energy Star Residential Water Heaters: Final Criteria Analysis and Proposal,* Washington, D.C.

U.S. Department of Energy (DOE). (2009). *Energy Star Qualified Water Heaters - Partner Resource Guide*, Washington, D.C.

U.S. Department of Energy (DOE). (2010). *Energy Star Water Heater Market Profile - Efficiency Sells,* Washington, D.C.

U.S. Department of Energy (DOE). (2012). "Building America Program - Water Heating Standing Technical Committee." *Residential Energy Efficiency Stakeholder's Meeting*, Austin, TX.

U.S. Department of Energy (DOE). (2012). *Strategy Guideline: Proper Water Heater Selection*, Washington, D.C.

U.S. Department of Energy (DOE). (2013). "Energy Saver 101." *Water Heating Infographic,* <http://energy.gov/sites/prod/files/2013/04/f0/waterHeaters101-final.png> (Dec. 27, 2013).

U.S. Energy Information Administration (EIA). (2010). "Annual Energy Review." *Independent Statistics and Analysis,* <http://www.eia.doe.gov/emeu/aer/consump.html> (Aug. 6, 2014).

U.S. Energy Information Administration (EIA). (2013). *Monthly Energy Review,* No. 0384, Washington, D.C.

U.S. Energy Information Administration (EIA). (2013). "2009 Residential Energy Consumption Survey." *Independent Statistics and Analysis,* <http://www.eia.gov/consumption/residential/> (Dec. 27, 2013).

U.S. Environmental Protection Agency (EPA). (2009). "United States Energy and Water/Wastewater Infrastructure." <http://www.epa.gov/region1/eco/energy/ew-infrastructure.html> (May 6, 2013).

U.S. Environmental Protection Agency (EPA). (2012). *Water Sense New Home Specification*, Version 1.1, Washington, D.C.

Chapter 2: Literature Review - Analysis of Existing Web-based Decision Support Tools (eDSTs) on Selection of Residential Water Heaters

2.1 Gap Analysis of Existing Literature

Existing DSTs are diverse, which makes their evaluation extremely challenging and helps explain why little evaluation literature is available (Keysar and Pearce 2007). In this section, the population of literature on U.S. water heater market and water heater selection strategies has been investigated for shortcomings and/or gaps. Primarily, focus has been given to the overall decision making process for water heater selections, consideration of critical factors, barriers encountered, market penetration factors and parameters that have not been recognized. Furthermore, they have been analyzed to identify areas of further research.

2.1.1 Gap Analysis of Literature Reviewed

Table 2.1 shows the gap analysis of the literature collected for preliminary analysis in this study. These documents are comprehensive market reports on residential water heaters in the U.S. and are assumed to contain detailed information on which preliminary analysis could be performed. They have been mapped against a set of collective components that were gathered from speed reading of the documents themselves, and which are believed to be critical factors in the selection of residential water heaters. The components gathered were: social factors, technology description, economics, market profile, environment considerations, decision making, and maintenance/retrofit options.

Table 2.1: Gap analysis of literature reviewed

S. No	Author/ Publisher	Social Factors	Tech. Desc.	Economics	Market Profile	Environmental Considerations	Decision Making	Maint./ Retrofit
1	EPA (2012)	x	x			x		
2	DOE (2010)		x	x	x	x	x	
3	PG&E (2012)		x	x	x	x	x	
4	DOE (2012)	x	x		x			x
5	NEEA (2012)	x		x	x	x	x	
6	NREL (2013)		x	x	x	x		
7	ACEEE (2012)		x	x		x		
8	ASPE (2010)	x	x	x		x		

From the analysis it is clear that all the documents do not encompass either one or more components. While most of them include the description of one or more water heater technologies, only one document talks about maintenance and/or retrofitting of existing water heaters. In conclusion, it is evident that gaps such as lack of information on water heater maintenance & decision making aspects, public health & safety hazards, role of major stakeholders during selection in new construction and replacement, among others, need to be addressed. The specific problems in the above documents have been explained in detail below.

2.1.2 Detailed Analysis of Literature Reviewed

Existing DSTs may be continuously evolving which makes their evaluation further demanding. This is because decision support tools are available in many forms such as recommendations, reports, interactive websites, guidelines, manuals, databases, directories, standards, consumer forums, blogs, software and simulation tools, and other relevant sources.

DSTs may be inconsistent in providing comprehensive information on water heaters. For example, the Environmental Protection Agency's 'WaterSense New Home Specification Version 1.1' was developed to "help consumers identify water efficient products and programs" (EPA 2012). However, it does not provide any advice for decisions related to water heaters.

DSTs may not take into account all categories and/or technologies of water heaters. For reference, the 'Energy Star Market Profile' document was developed by the United States Department of Energy in 2010 and launched with the aim "help businesses and individuals save money and protect the climate through superior energy efficiency" (DOE 2010). It mentions that Energy Star qualified units must meet certain energy-efficiency requirements to be eligible for branding (ibid). However, there are currently Energy Star standards for all water heater technologies except electric storage and tankless units (ibid). Moreover, condensing storage water heaters have not yet been Energy Star certified, even though there has been a standard for them for over a year (Maguire 2009). Similarly, PG&E's Emerging Technologies Program issued a report which does not include solar and gas condensing water heaters which have been included in the Energy Star program (PG&E 2012).

Also, several DSTs may possess shortcomings in their evaluation of water heater technologies. For reference, Northwest Energy Efficiency Alliance's '2011 Water Heater Market Update' report was aimed at understanding the factors driving the water heater sales in today's economy, with a special focus on high efficiency heaters (NEEA 2012). However, their survey recognized only tankless and heat pump water heaters as high efficiency water heating options whereas many more are available such as indirect water heaters, solar water heating systems, and others.

Existing DSTs do not encompass all principal stakeholders in the fray. For instance, the U.S. Department of Energy's Building America Program, in its presentation by the Standing Technical Committee on Water Heating at Austin, Texas in February, 2012 mentioned improved health, safety and comfort as one of its strategic goals (DOE 2012). However their target population were homeowners, builders and contractors and did not include other critical stakeholders such as retailers, plumbers or immunocompromised people who may be susceptible to public health and safety issues.

Additionally, DSTs may not explicitly mention the decision making process or its importance to the users. The National Renewable Energy Laboratory published a technical report on 'Comparison of Advanced Residential Water Heating Technologies in the United States' in May, 2013 (NREL 2013). The report published strengths, weaknesses, model descriptions, energy, and economic analysis of several water heaters (ibid). However, no aspect of decision making or leverage points for intervention in the stakeholder system is explicitly mentioned in the document.

Of the DSTs that do acknowledge the decision making process of selection of water heaters, not all details or aspects are taken into consideration. Northwest Energy Efficiency Alliance's '2011 Water Heater Market Update' report mentions significant 'touch points' in the supply and purchase process, but it fails to state other external factors or stakeholders that could influence the consumer before or during selection (NEEA 2012).

Moreover, social factors that can contribute to users' insight of water heaters may be ignored by DSTs. For example, the American Council for an Energy Efficient Economy's report on 'Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011' describes several environmental and economic factors that could influence the selection process (ACEEE 2012). But, it fails to mention social factors such as user acceptance, awareness, control strategies, tips for maintenance, etc. which can be paramount for market penetration of water heaters. Unlike Energy Star, this guide does not recommend specific manufacturers or trade names.

Details within the residential sector such as location or type of household setting may not have been taken into account by all DSTs. For instance, the American Society of Plumbing Engineers through its '2010 Domestic Water Heating Design Manual' provides comprehensive information and up-to-date knowledge to consulting engineers, designers and contractors on rational methodologies in the field of plumbing engineering (ASPE 2010). However, in the residential sector it addresses only multi-family buildings.

DSTs may not be transparent in their assumptions, and especially in regards to the weighting given to different issues like human health (CMHC 2004). Microbial organisms can establish and grow within the hot water distribution system itself (Pruden et al. 2013). In April 2010, The U.S. Department of Energy announced new, more stringent, federal standards to take effect in 2015 (DOE 2010). This new standard could be a significant driver for change, leading to a wide adoption of more energy efficient water heaters in the coming years (Maguire 2009). Yet, it does not incorporate any health or safety factors.

The usage of DSTs will lead to results that may vary and may often not be directly comparable (CMHC 2004). These differences mainly occur because of the established system boundaries, i.e. what is included and what is excluded from analysis (ibid). This variation of results could have the potential to create confusion among some users.

The above examples highlight some of the major problems that existing DSTs possess. In order to fully establish the current state of residential water heater DSTs, this research will attempt to collect and analyze web-based existing decision support tools (eDSTs) to highlight these shortcomings, as explained in the subsequent sections.

2.2 Analysis of Web Based Existing Decision Support Tools (eDSTs)

This chapter examines the range of web-based existing Decision Support Tools (eDSTs) available to make selection (of water heater) decisions, summarizes evidence regarding their effectiveness, and offers possible strategies for overcoming some of the barriers to their more widespread and effective use (CHF 2006). The specific objectives include:

- To collect web-based eDSTs
- To store the tools as inventory in a hybrid organizing framework
- To characterize the tools by performing parametric analysis
- To identify and analyze gaps, deficiencies, inconsistencies, and opportunities in eDSTs
- To extract useful and relevant information for the DST skeleton, explained in Chapter 3

2.2.1 Introduction

The residential water heater market is growing with more advanced technologies being introduced and more stakeholders being increasingly involved. This may lead to the proliferation of decision support tools available on the Internet, to ultimately help users make informed choices after careful considerations. Currently, eDSTs can offer the following functions: selection, sizing, and software modelling among others. They can occur in several formats such as product guides, technical reports, white papers, expert blogs, consumer forum webpages, catalogues, brochures, charts, we-based directories, online tools, and software.

The application of DSTs for the selection or assessment of water heaters may lead to results that are not directly comparable (CMHC 2004). The differences in the results are a direct result of system boundaries – what is included and what is excluded in the analysis (ibid). Other common reasons for the variations in results include (ibid):

- Target audience/ Intended tool user and their role in the decision making process
- Data sources
- Quality of information
- Tool format and Data presentation

Additionally, many web based tools lack the functionality consumers have come to expect from the Internet (CHCF 2006). Key complaints may include inadequate content, poor navigation structures, and missing transactional capabilities (ibid). Contributing to the lack of good design and functionality in DSTs is the very limited use of formative testing that has been done with consumers to evaluate what features work and what elements are absent or confusing (ibid). Moreover, many consumers particularly the elderly and the poor remain on the other side of the 'digital divide,' without access to computers, connections, and skills to use online or web-based eDSTs (ibid).

2.2.2 Methodology

A primary driver of this research is to create an inventory of web-based eDSTs. This goal will be accomplished by identifying tools through an extensive Internet based search and then investigating approaches to inventorying, characterizing, and mapping the tools that will be accumulated (Keysar and Pearce 2007).

The collection of eDSTs was conducted using the Internet. The Internet has become an important means of communicating information and its ease of use ensures continued prominence (Mackley at al. 2000). The search portion was based on the assumption that stakeholders of the residential water heater market have access to the Internet and may turn to this resource of information. The following subsections present the detailed methodology for collection and analysis of web-based eDSTs in this part of the study.

2.2.2.1 Formulation of an Internet Search Strategy

The search for web based eDSTs began by formulating an Internet search strategy. By adopting a search strategy, factors that affect the outcomes will be concentrated in the direction of the research objectives. The strategy mainly consisted of (Adapted from CMHC 2004):

- Setting a Goal and Scope for the Task
- Creating Task Boundaries

Setting Goal and Scope for the Task

Establishing a goal, task, and scope is pertinent to the Internet search for eDSTs on residential water heaters because of the range, diversity, and intricacy of tools available online. It addresses the purpose of research in terms of what type of problem is addressed, why is it being undertaken and its field of application (CMHC 2004). In this study, the following goal, task, and scope were used:

- ***Goal:*** 'To create a database of web based Existing Decision Support Tools (eDSTs) on selection of residential water heaters which can be subjected to qualitative or/and quantitative evaluation techniques'
- ***Task:*** 'To search, screen and store relevant eDSTs that assist in the selection of residential water heaters, using the Internet'
- ***Scope:*** 'The scope of the Internet search is the collection of eDSTs that are directly or indirectly accessible as an outcome of the search results through a popular search engine'

Creating Task Boundaries

Boundaries define the scale at which the task is performed or analyzed (CMHC 2004). In general terms, it refers to what data can be included or excluded while performing the task. The system boundaries that were considered for this task are:

- ***Type of Search Engine***: Usage of different search engine yields different results. For this task, 'Google web Search', commonly referred to as 'Google Search' was used as it is the most-used search engine on the World Wide Web.
- ***Geographic Scale of Tools***: Only the eDSTs within the U.S. were considered for this task. This included tools that were national, regional, and local.
- ***Search Location:*** The search results may differ due to the location of the searcher. In this case, the search was performed from Blacksburg, VA.

- ***Date (Month) of Search:*** The Internet is continuously evolving. The search results on a given day and time may yield a different outcome than that performed a couple of months earlier. The search for eDSTs began in June, 2014 with an estimated duration of 2 or more months to complete the task.
- ***Type of Water Heating Technologies:*** While the task boundary may include tools for all water heating technologies available in the residential sector, the outcome was limited to what was obtained in the search results.
- ***Type of Construction Sector:*** The search was directed towards tools that addressed the residential construction sector (also referred to as 'residential sector'). However, tools that were not solely directed at the residential sector and appeared in documents that contained/combined other sectors as well, were also included within the boundaries of this task.

2.2.2.2 Internet Search of Web-based eDSTs

The search for web-based eDSTs started primarily with an Internet search on the popular search engine 'Google' using the strategy described earlier. The search was however limited to what was readily accessible via the Internet. It was fulfilled by establishing keywords that would yield direct results. However, to attain a more comprehensive view of the tools, these keywords were organized in categories and were used in the order in which they appear below:

- ***Category 1:*** Search by Topic – Search in this category will be based on the topic of research. ***Keywords:*** 'Decision support tool for residential water heaters', 'Water heater decision support tool', 'Selecting a residential water heater', 'how to choose a residential water heater', etc.

- ***Category 2:*** Search by Format – Search in this category will be based on the format of EDSTs. ***Keywords:*** 'Water heater selection guide', 'Technical reports on residential water heaters', etc.

- ***Category 3:*** Search by Stakeholder – Search in this category will be targeted towards some, if not all stakeholders that have been known to purchase water heaters. ***Keywords:*** 'Decision support tool for homeowners on selection of water heaters', 'Designer tool for selection of residential water heaters', 'Water heater selection tool for plumbers', etc.

- ***Category 4:*** Search by Fuel type – Search in this category will be based on the fuel used by residential water heaters namely natural gas, electricity, propane/LPG, fuel oil, and others (EIA 2013a). ***Keywords:*** 'Decision support tool for electric water heaters', etc.

- ***Category 5:*** Search by Prior Knowledge – Search in this category will be based on the researcher's knowledge and discretion of existence of tools. For example, it may include searching websites of government and trade groups, search for tools by leading retailers, etc. ***Keywords:*** 'Water heater decision support tool by Ferguson', etc.

- ***Category Z:*** Search by References – This search will not occur in order and will be performed simultaneously with the above listed categories, while coming across references or links.

The pursuit for tools was concluded when tools already identified were found to be repeatedly appearing in new searches and the number of new websites appearing with subsequent searches was decreasing.

2.2.2.3 Preliminary Assessment/Screening of eDSTs

The differences in the tools available on the Internet can be easily tackled by establishing a 'Cut-off Criteria' to enable assessment. This method of preliminary assessment is called as 'Screening'. After the search results for eDSTs were generated, each result was individually screened and collected simultaneously (explained in the next step). This helped make the process simpler and reduced the occurrence of human errors.

Establishing Cut-off Criteria for Preliminary Assessment

As mentioned earlier, the internet search revealed variations in the results because of corresponding system boundaries. The logic behind this task was to differentiate the relevant tools from those that were outside the scope of this task, using the cut-off criteria.

The following cut-off criteria were used to segregate eDSTs:

- ***Tool Source:*** Tools that are undocumented or have been developed from unrecognized sources were not included. Credibility of eDSTs is essential to extract desired information.
- ***Access to Tool Information:*** Tools available online that have restricted access or need to be purchased were excluded from the preliminary assessment. However tools that were partially accessible (such as visibility of table of contents page, and others.) were included.
- ***Tool Context/Relevance:*** The Internet search showed tools that were irrelevant to the topic at hand and hence, were not included in subsequent research tasks.
- ***Tool Format:*** eDSTs in the form of web based literary documents such as reports, papers, brochures, guides, online web tools, checklists, etc. were the main focus of the search. Audio and video DSTs were discarded.
- ***Tool Presentation:*** There may be a possibility of arriving at tools which present the requisite information in continuous text without any provision of title, headings, sub-headings, or any other form of highlights within the text (For example, consumer opinions, etc.). These were beyond the scope of the current research study and as a result, were excluded from analysis.

2.2.2.4 Typology of EDSTs and Data Storage as Existing Tool Inventory (ETI)

Before adding the eDSTs (obtained after the preliminary screening) into a database, it was necessary to classify the data, to give it recognition, and to make subsequent analysis easier. Therefore, the eDSTs were captured into an organizing framework in a non-hierarchical manner based on certain criteria (shown in Table 2.2) to create a database in the form of an excel spreadsheet. This classification is termed as 'Typology of eDSTs' and the resultant database of web based eDSTs is known as Existing Tool Inventory (ETI).

Criteria used for Typology of eDSTs:

Table: 2.2: Typology criteria for eDSTs

Tool Category	Selection, Sizing, Educational, Selection & Sizing, Other, or Cannot be Ascertained
Tool Type	Website, Publication, Software, Database, Checklist/Matrix, or Other (Keysar & Pearce 2007)
Source	(Source of the tool) (Keysar & Pearce 2007)
Cost	(Cost of the tool) (Keysar & Pearce 2007)
Web Link	Web Link to Tool
Web Linked Changed?	Yes, No, or Cannot be Ascertained
Additional Description	Taglines, etc.

Tool Category: The 'Tool Category' criterion was used to primarily distinguish eDSTs as selection, sizing, or educational in nature as shown through an algorithm shown in Figure 2.1.

The algorithm follows a level of priority given by:
i. Sizing
ii. Selection
iii. Educational

Any eDST that provided details on 'sizing' of water heaters were deemed 'Sizing Documents'. Those eDSTs that compared two or more residential water heaters, represented as headings, subheadings, or any form of text highlights (bolded, underlined, italicized, or other unique representations) and provided any additional information such as other critical factors in consideration, advantages/disadvantages, etc. were considered 'Selection Documents'. The eDSTs that did not meet any of the criteria mentioned above were categorized as 'Educational Documents' that provide useful information. Additionally, those eDSTs that satisfied both sizing and selection criteria were termed as 'Selection & Sizing Documents'. Some tools were not accessible, and therefore could not be ascertained as selection, sizing, both, or educational in nature.

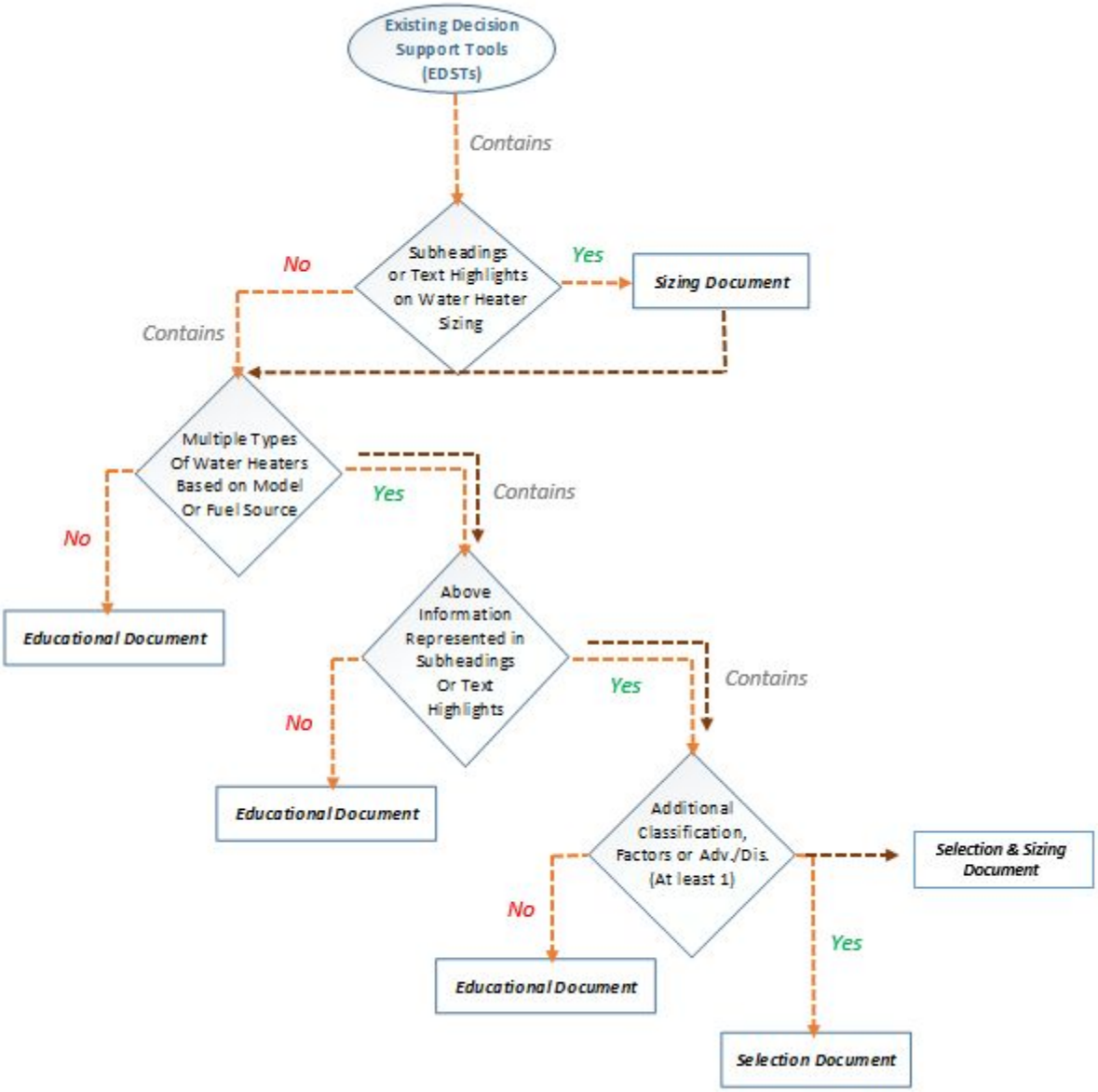

Figure: 2.1: Algorithm representing 'Tool Category' criterion

'Tool Type' criterion was used to distinguish eDSTs based on their format as a Website, Publication, Software, Database, Checklist/Matrix, or other formats. The ***'Cost'*** and ***'Source'*** of the tool were also recorded. Interestingly, a few months had passed between the tim e the eDSTs were collected to the time they were analyzed. As a result, there were some tools whose web links had changed or could not be accessed. This led to the addition of ***'Web Linked Changed'*** criterion to the typology of eDSTs. Other supplementary information such as taglines, etc. that could be used to easily collect the tools was added via the ***'Additional Description'*** criterion.

The hybrid organizing framework (shown in Appendix A) was used to capture the eDSTs based on tool category, tool type, source, cost, and change of web link resulted in the creation of a database that was used to enhance user ability to find relevant tools, similar to the approach used by Keysar and Pearce (2007). After the typology of eDSTs, the resultant database was known as

Existing Tool Inventory (ETI) to avoid confusion and to give identity. It should be noted that the resultant ETI was a potential research outcome in itself and could facilitate selection of effective eDSTs by potential users of the database (as in Keysar and Pearce 2007). Further research techniques were then adopted to evaluate ETI to obtain results that meet the research objectives.

2.2.2.5 Characterization of Existing Tool Inventory (ETI)

The last step in the methodology involved the Characterization of ETI. Parameters were adopted to characterize or classify the data (in a process called parametric analysis), ensuring refinement of choices that potential database users could make. Table 2.3 below gives a brief description of the various parameters used.

Parameters used for Characterization of ETI:

Table 2.3: Characterization parameters for ETI

Goals	Any Explicitly Mentioned Goals in the Tool (Bosch and Pearce 2003)
Water Heater Type Based on Model	Storage/Tank, Tankless/On-Demand, Solar, Heat Pump, Tankless Coil & Indirect, or Others (DOE 2013)
Water Heater Type Based on Fuel	Electric, Gas, Other, Electric & Gas, Electric & Other, Gas & Other, or None (EIA 2013a)
Installation & Post-Installation Considerations	Installation/Replacement, Repair/Retrofit, or Operation/Maintenance
Health/ Safety Factors	Any Explicitly Mentioned Health or Safety Factors

Common Assumptions during Characterization of ETI:

- The parameters had to be explicitly mentioned in the content of the DST.
- Similar to the methodology used in section 2.2.2.4, the parameters should be displayed as titles, headings, sub-headings, or text highlights that would enable the researcher to identify relevant information during speed reading of the tools in ETI.
- For those tools that were inaccessible, a ‘D’ would be marked for the corresponding parameter meaning it ‘Cannot be Ascertained’.
- Some parameters were called by synonyms. For example, a DST in the ETI mentioned ‘Smart-Use’ as sub-headings or text highlights, inferring operation or maintenance of residential water heaters. The acceptability of these synonyms in this analysis was at the behest of the researcher.

Each tool in the Existing Tool Inventory (ETI) was reviewed to assess its content in terms of explicitly stated goals, the types of water heaters they addressed based on model and fuel, installation and post-installation considerations, and their mention of health or safety factors. The following subsections explore each of these parameters in detail and describe the mappings of the tools across each parameter (as shown in Appendix B).

Goals: The first step in the characterization of ETI was to identify any explicitly mentioned goals for the use of the document (Bosch and Pearce 2003). Their search was however, limited to those appearing at beginning of the document, for they could help a potential user decide if they should pursue the DST or not. Most importantly, note that the emphasis here was on the mention of the goal and not in the content of the goal. For example, one selection document was mentioned as 'Congratulations on your decision to buy an Electric Water Heater!'. Those tools that did mention 'Goals' were marked with a 'Yes' and 'No' otherwise.

Water Heater Type Based on Model: Next, the ETI was characterized by the mention of the type of water heater based on the 'model' parameter. The various models of residential water heaters were obtained from an infographic webpage on the United States Department of Energy website (DOE 2013). They were classified as 'Storage/Tank, Tankless/On-Demand, Solar, Heat Pump, Tankless Coil & Indirect, and others'. The 'others' category comprised of a conglomeration of other water heater types such as condensing, non-condensing, steam water heaters, wood-fired water heaters, hydro-power gas tankless, desuperheaters, combined water heaters, etc., whose individual classification was beyond the scope of this study. All parameters that occurred within the document and satisfied the assumptions given at the beginning of this section, were marked with a 'X'.

Water Heater Type Based on Fuel: Results from the 2009 Residential Energy Consumption Survey conducted by United States Energy Information Administration showed that of a total of 113.6 million housing units in the U.S., 51.3% used gas water heaters and 41.2% used electric water heaters (EIA 2013a). The remainder consisted of other fuel types such as propane/LPG, fuel oil, solar energy, geothermal energy, etc. in addition to some housing units that did not use hot water (ibid). Since electricity and natural gas represented a vast majority of existing residential installations, they were used as the main classification parameters for the ETI, with the provision of an 'Others' parameter.

Installation & Post-Installation Considerations: The penultimate step in the characterization of ETI involved classification of tools based on the life cycle phase they were intended to address, namely Installation/Replacement, Repair/Retrofit, and Operation/Maintenance. Essentially, 'Installation Considerations' could be used as a separate parameter for characterization of ETI. However, during the preliminary assessment of eDSTs, it was observed that it appeared in conjugation with the other post-installation considerations. Hence, for simplicity and ease of tool classification they were grouped together in one parameter. All parameters that occurred within the document and satisfied the assumptions given at the beginning of this section, were marked with a 'X'

Health/ Safety Factors: Ultimately, each ETI was analyzed to see if it explicitly mentioned any health and/or safety factors as titles, headings, sub-headings, or text highlights within the DST. DSTs that provided information on health and/or safety factors were marked with 'Yes' in the category 'Health/Safety Factor' and 'No' otherwise.

2.3 Evaluation of Research Findings

The last task in this methodology dealt with the analysis and evaluation of findings, obtained as a result of typology of eDSTs and characterization of ETI. The findings were mapped in graphical forms such as bar charts, pie charts, and other forms of representation as shown in separate sections 2.3.1 and 2.3.2. Inferences were made from them, which would then be used to complement as well as develop other phases of research.

2.3.1 Typology of EDSTs

The typology of the eDSTs resulted in the collection of a total of 203 unique web-based DSTs. They were collected in a hybrid organizing framework (shown in Appendix A) and identified through the title of the DST, source of the tool, its web link, and any additional description. While at first, they were recorded in the order in which they appeared in the search results, they were later arranged in an alphabetical order by the DST title. This was done to identify any potential duplicates, which were deleted from the database.

Count of Tool Category: The count of tool category, as shown in Figure 2.2 below, revealed that 42% of the 203 tools had an element of 'selection' in them, with 28% of the tools being 'selection' only. Of similar importance is the fact that 41% of the tools were 'educational' in nature. 'Sizing only' tools comprised only 13% of total collected tool population. Interestingly, there were 7 eDSTs that could not be assessed since they could not be found at their original URL after the time they were stored in the ETI database, and were hence deemed 'Cannot be Ascertained'. The following results had appeared on the computer screen when in pursuit of tools that were inaccessible:

- Error dialogue box appears on screen saying the tool could not be opened
- Error page appears on the web link
- Blank page appears on the web link
- Web link did not direct to the original web page

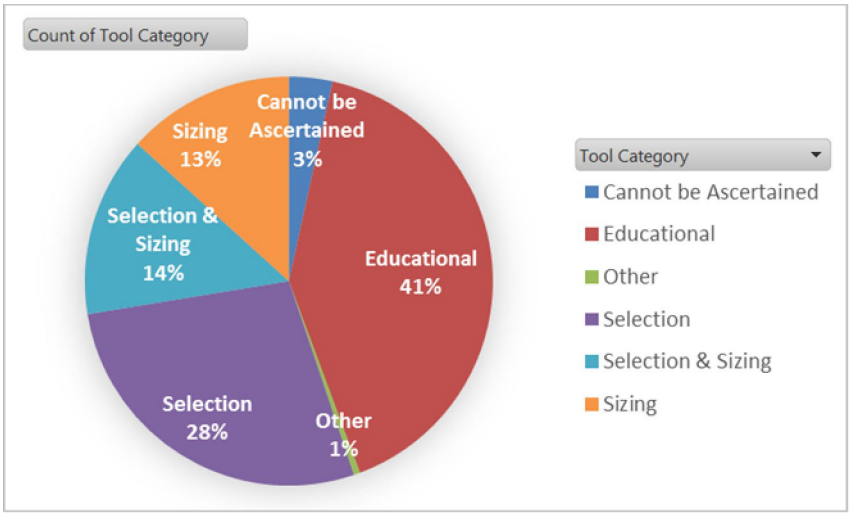

Figure 2.2: Results showing count of 'Tool Category'

Count of Tool Type: The count of search results during typology of eDSTs for tool type, as shown in Figure 2.3, revealed that the majority of tools were websites. They constituted 138 of the total 203 tools collected. Publications, which may have mainly consisted of market and technical reports, constituted roughly 20% of all tools collected. Also, there were seven software and 12 checklist/matrix tools collected, the majority of which may have been for water heater sizing. However, only one database was recorded in the search for eDSTs.

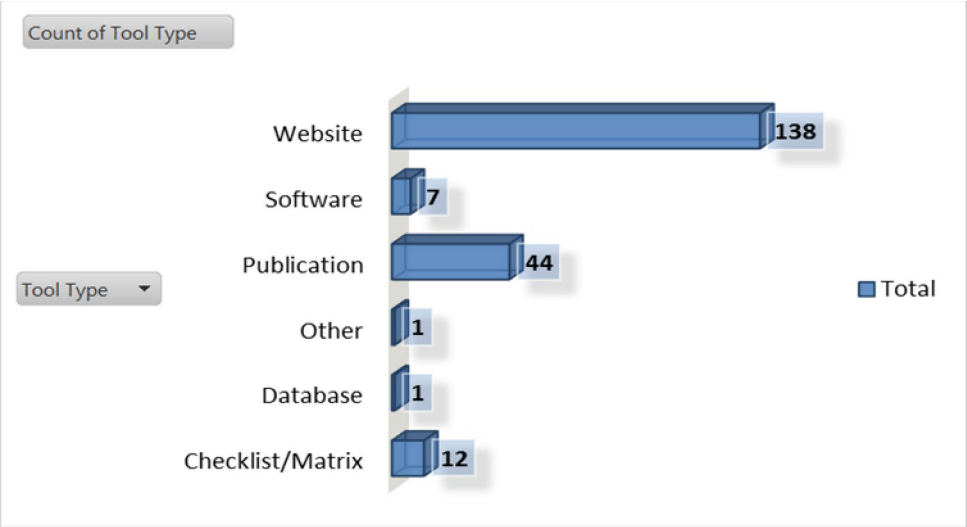

Figure 2.3: Results showing count of 'Tool Type'

Count of Tool Cost: An overwhelming majority of the tools collected, 200 of the 203, were accessible for free, as shown in Table 2.4. However, there were three tools (books or publications) that cost money to access them, with the costliest one valued at $209.95. However, kindly note that for subsequent parametric analysis of these three tools, their respective 'table of contents' were analyzed to determine if a parameter was mentioned or otherwise.

Table 2.4: Results showing count of 'Tool Cost'

Row Labels	Count of Tool Cost
Free	200
$0.99	1
$35	1
$209.95	1
Grand Total	**203**

Change of Web Link: Surprisingly, the analysis of eDSTs showed that 12 tools (6%) of total tools collected, had their URLs changed and displayed different results. This prompted the use of the criterion 'Change of Web Link' to check whether the web links of the tools collected had changed over a period of time, as shown in Figure 2.4 below. Earlier, the 'Count of Tool Category' showed that seven DSTs were marked 'Cannot be Ascertained' simply because they could not be accessed through their URL. An attempt was then made to relocate them after the

original search (through a new search of the DST's title). However, five tools still remained inaccessible and were again branded as 'Cannot be Ascertained'.

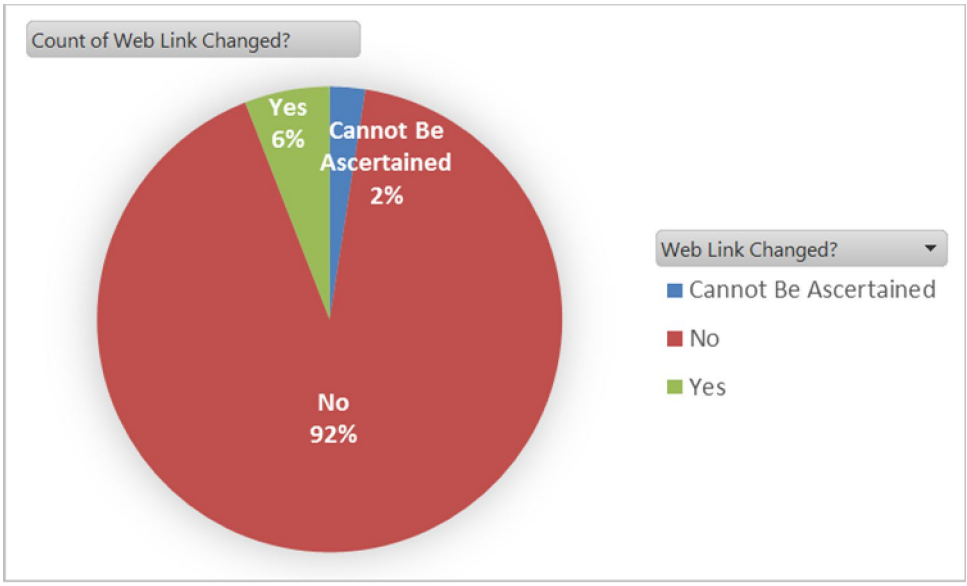

Figure 2.4: Results showing count of 'Change of Web Link'

While it is now clear that the DSTs on the Internet may be continuously changing (as from the analysis above) it should be noted that an effort was made to retrace and recover the original web links of those tools in the ETI that were marked 'Yes' in Count of Change of Web Link, for subsequent parametric analysis. In a way, this would also show validity of the research findings from the characterization of ETI at the time they were being recorded and not when they were being subsequently analyzed after seven months.

2.3.2 Parametric Analysis of ETI

The parametric analysis of ETI (shown in Appendix B) was the last step in the process and involved the use of parameters such as count of goals, water heater types, installation and post installation considerations, and health/safety factors. A detailed evaluation of the research findings in given in subsequent subsections below:

Goals: The parametric analysis of ETI on mention of explicitly stated goals revealed that more than half of the total 203 tools collected, displayed clear goals as showed in Figure 2.5. In contrast, 87 of the 203 tools had no mention of any goal in the tool whatsoever, based on the assumptions explained in section 2.2.2.5. It must be remembered that the usage of goal(s) in the DST could help identify it easily and enable faster adoption by potential users. Also, seven tools were inaccessible and hence were marked 'Cannot be Ascertained'. Do note that the emphasis here was on the mention of goals, and not on the content.

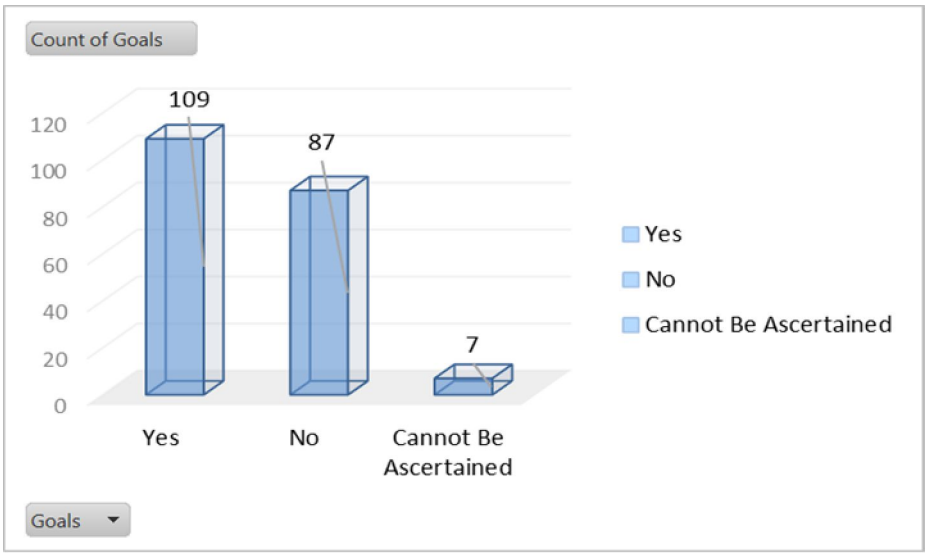

Figure 2.5: Results showing count of 'Goals'

Count of Water Heater Type Based on Model: The next step in the parametric analysis of ETI was that of the tools containing residential water heater type based on model such as storage, tankless, solar, heat pump, indirect, etc. as shown in Figure 2.6. The analysis showed different patterns for the various water heater models. More than half of the tools mentioned tankless water heater whereas fewer than half mentioned storage/tank heater. Among the newer or advanced technologies, solar water heaters were mentioned most frequently in 52 of 203 tools, followed by heat pump with 46 of 203, and finally tankless coil & indirect water heaters with 29 of 203.

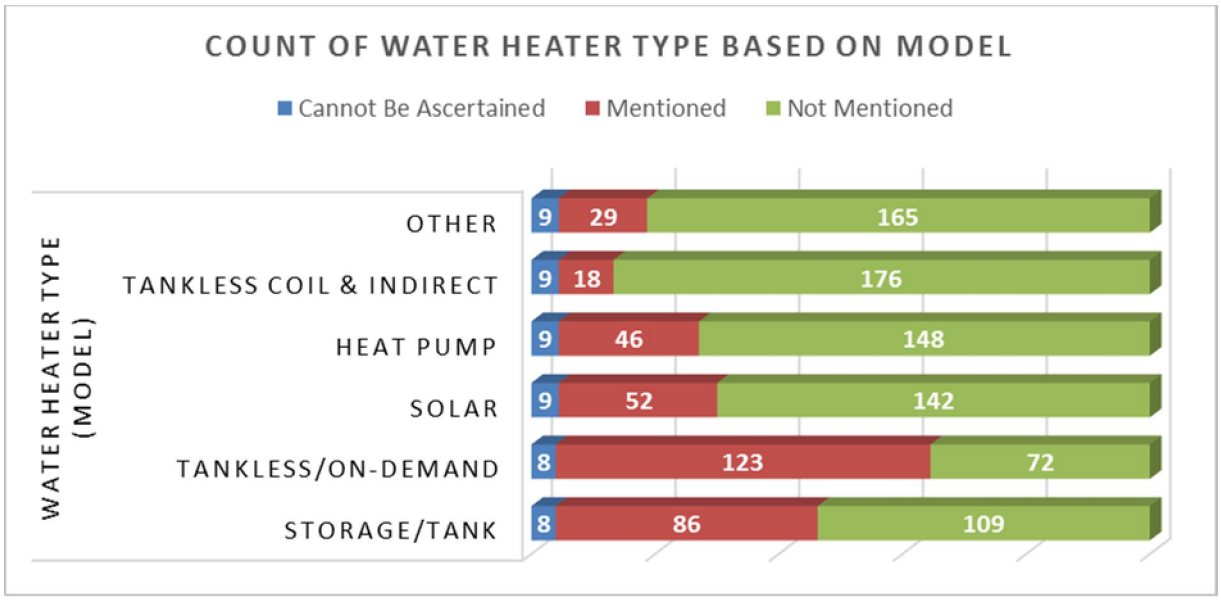

Figure 2.6: Results showing count of 'Water Heater Type Based on Model'

Count of Water Heater Type Based on Fuel Used: The third step in the parametric analysis of ETI involved the tools containing residential water heater type based on fuel used such as electricity, natural gas, etc. A Venn diagram was created to display the results effectively, as shown in Figure 2.7. A compelling observation from the analysis was that 91 of the total 203 tools did not highlight any specific fuel used by the water heater, based on the assumptions in section 2.2.2.5., even though all water heaters require fuel of some type to heat water, and some heater types (e.g,. storage and tankless) are available in different models that utilize different fuel sources. 78 of the total 203 tools highlighted electric and gas water heaters, with some talking about other fuel sources such as fuel oil, LPG/propane, etc. Interestingly, not one tool mentioned alternate fuel sources without including electric and gas water heaters. In similarity to 'Count of Goals' category, seven DSTs were deemed 'Cannot be Ascertained'.

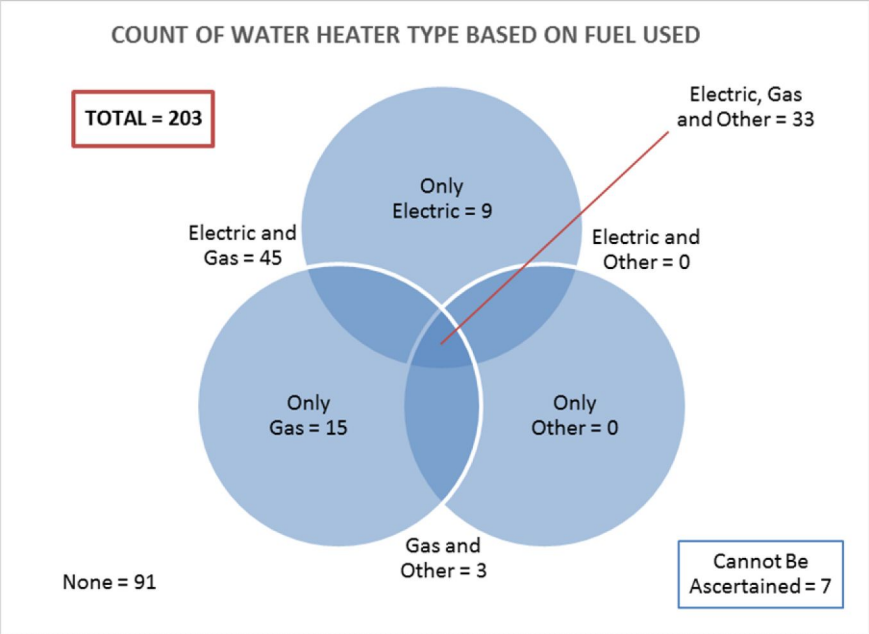

Figure 2.7: Results showing count of 'Water Heater Type Based on Fuel Use'

Count of Installation & Post-Installation Considerations: The count of installation & post-installation considerations during parametric analysis of ETI revealed that fewer than half of these tools mentioned life cycle phases (as shown in Figure 2.8). However installation and/or replacement were mentioned in more tools than operation and/or maintenance and in more than three time the tools mentioning repair and/or retrofit. These results emphasize the need for more provision on water heater lifecycle analysis and assessment, beyond just merely selection.

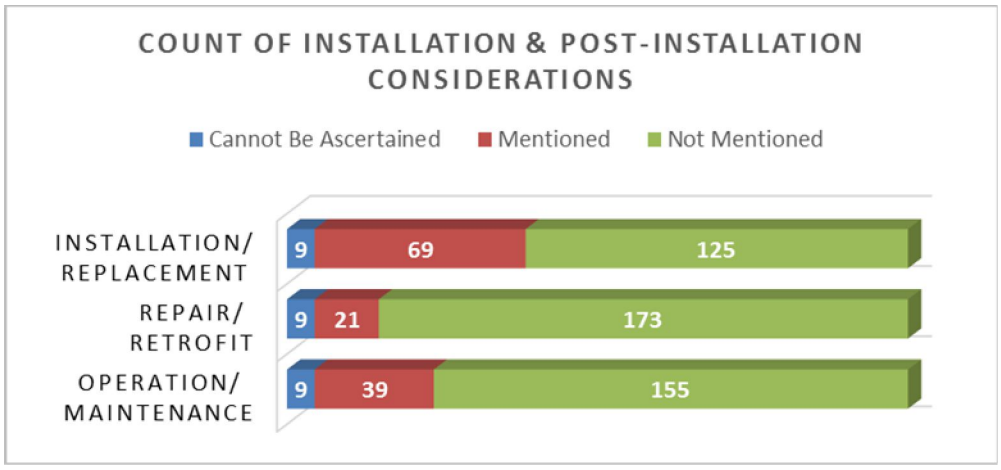

Figure 2.8: Results showing count of 'Installation & Post-Installation Considerations'

Count of Health and/or Safety Factors: The last step in the analysis and evaluation of research findings from parametric analysis of ETI was to check the tools for mention of health and/or safety factors. An overwhelming majority of the tools (87% of total tools) did not mention any health and/or safety factors such as presence of microorganisms (Legionella, etc.), presence of mold and mildew, effects of water heater stratification, CO poisoning due to improper installation or ventilation, etc., as shown in Figure 2.9. These findings show that more research and awareness is needed on potential health implications from hot water usage as well as the importance of safety considerations while using a residential water heater.

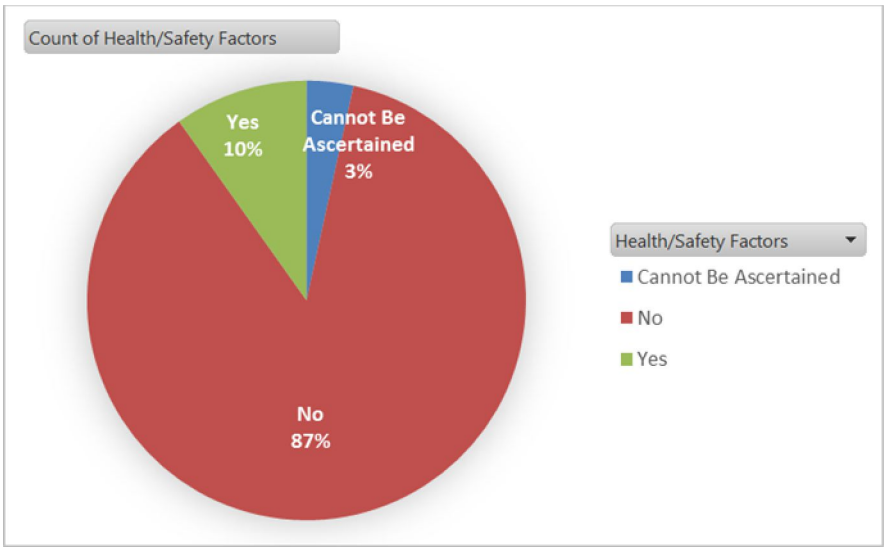

Figure 2.9: Results showing count of 'Health and/or Safety Factors'

2.4 Gap Analysis for Research Needs

From the results on typology of eDSTs and parametric analysis of ETI (Section 2.3.1 and 2.3.2 respectively), it is clear that several factors need to be addressed, such as:

- Health and safety factors
- Types of water heaters (all available)
- Installation considerations
- Repair, retrofit and maintenance strategies
- Sizing criteria

In conclusion, it is clear that there are several gaps in eDSTs which need to filled. While there is a growing body of anecdotal evidence and formal studies on presence of pathogens in water heaters, the current set of tools may not full cover their implications on human health. Currently, more advanced water heating technologies have penetrated the market, but are yet to be incorporated by eDSTs. In addition, water heater life cycle parameters such as installation and post-installation considerations also require attention in eDSTS.

As a result, emphasis has to be given on the design and content of the DST bodywork before it can be applied to create the actual tool. In essence, this DST bodywork should take into account a broad array of all essential factors that can assist in the decision making process for the selection of residential water heaters. Therefore, the next chapter concentrates on the collection and synthesis of all essential factors into a tool bodywork called the Decision Support Tool Skeleton (DSTS), to assist in informed decision making of residential water heater selection(s).

References

American Council for an Energy Efficient Economy (ACEEE). (2012). *Emerging Hot Water Technologies and Practices for Energy-Efficiency as of 2011*, No. A112, Washington, D.C.

American Society of Plumbing Engineers (ASPE). (2010). "Domestic Water Heating Design Manual." 2nd Edition, <https://aspe.org/node/1404> (Dec. 26, 2013).

Bosch, S. J. and Pearce, A. R. (2003). "Sustainability in Public Facilities: Analysis of Guidance Documents." *Journal of Performance of Constructed Facilities*, 17(1), 9-18.

California HealthCare Foundation (CHCF). (2006). *Consumers in Health Care: Creating Decision Support Tools That Work*, Oakland, CA.

Canada Mortgage and Housing Corporation (CMHC). (2004). "Types of Tools." Annex 31 - Energy-Related Environmental Impact of Building, *Energy Conservation in Buildings and Community Systems*, Ontario, Canada.

Keysar, E. and Pearce, A. R. (2007). "Decision Support Tools for Green Building: Facilitating Selection Among New Adopters on Public Sector Projects." *Journal of Green Building*, 2(3), 153-171.

Mackley, S., Odell, W. and Lazarus, M. A. (2000). "Environmental Education for the Building Industry: An Internet Resource." *Proceedings of the International Conference on Sustainable Building*, 174-176.

Maguire, J. B. (2009). "A Parametric Analysis of Residential Water Heaters." M.S. Thesis, Department of Mechanical Engineering, University of Colorado, CO.

Northwest Energy Efficiency Alliance (NEEA). (2012). *2011 Water Heater Market Update,* 12-234, Portland, OR.

National Renewable Energy Laboratory (NREL). (2013). *Comparison of Advanced Residential Water Heating Technologies in the United States*, No. TP-5500-55475, Denver, CO.

Pacific Gas and Electric Company (PG&E). (2012). "Market Focused Program Design to Accelerate Penetration of ENERGY STAR Water Heaters." *PG&E's Emerging Technologies Program*, No. ET12PGE3191, San Francisco, CA.

Pruden, A., Edwards, M. A. and Falkinham J. O. (2013). "Research Needs for Opportunistic Pathogens in Premise Plumbing: Methodology, Microbial Ecology and Epidemiology." *Water Research Foundation,* Denver, CO.

U.S. Department of Energy (DOE). (2010). *Energy Star Water Heater Market Profile - Efficiency Sells,* Washington, D.C.

U.S. Department of Energy (DOE). (2012). "Building America Program - Water Heating Standing Technical Committee." *Residential Energy Efficiency Stakeholder's Meeting*, Austin, TX.

U.S. Department of Energy (DOE). (2013). "Energy Saver 101." *Water Heating Infographic,* <http://energy.gov/sites/prod/files/2013/04/f0/waterHeaters101-final.png> (Dec. 27, 2013).

U.S. Energy Information Administration (EIA). (2013). "2009 Residential Energy Consumption Survey." *Independent Statistics and Analysis,* <http://www.eia.gov/consumption/residential/> (Dec. 27, 2013).

U.S. Energy Information Administration (EIA). (2013). *Monthly Energy Review,* No. 0384, Washington, D.C.

U.S. Environmental Protection Agency (EPA). (2012). *Water Sense New Home Specification*, Version 1.1, Washington, D.C.

Chapter 3: Development of Multi-Attribute Decision Support Tool Skeleton (DSTS) for Selection of Residential Water Heaters

3.1 Abstract

Water heating in the United States is the second largest energy use in residential homes, after combined space heating and cooling. Recently, it has also been implicated as the source of waterborne disease outbreaks such as Legionella. With such high stakes, it is imperative that a Decision Support Tool (DST) be used prior to selection of water heater(s). Many of the existing population of tools have inconsistent level of detail and may not consider critical factors essential for decision making, for example, health and safety factors. The purpose of this study is to develop a Decision Support Tool Skeleton (DSTS) that uses sustainability as the underlying theme, to allow stakeholders to compare multiple alternatives across multiple criteria, thereby making selection easier, through the Multi-Attribute Decision Making (MADM) approach. This skeleton provides a point of departure for development of future DSTs to address a broader set of considerations relevant for water heater selection. To promote the usage of sustainability, it is represented by a quantifiable 'capital-criteria-indicator' approach encompassing five capitals: economic, environmental, technical, social and human. The resultant DSTS will set the stage for developing DSTs to aid better decision making, that could help to improve sustainability of residential hot water infrastructure.

3.2 Introduction

To begin with, this section provides an introduction of the essential characteristics of DSTs to enable appropriate technology selection, followed by the definition of the Decision Support Tool Skeleton (DSTS) and its components, and finally talks about methodology of Multi-Attribute Decision Making (MADM) that was used in developing the DSTS. All these topics are explained in detail in the subsections.

3.2.1 Literature on Essential DST Characteristics for Technology Selection

Several studies have been carried out, that talk about DST characteristics and functionality in assisting decision makers select the most appropriate advanced technology (Kengpol and O'Brien 2001). For example, Riddle and Williams (1987) state that technology selection is the process of determining which (new or old) methods, techniques, and tools satisfy criteria reflecting a specific target community's requirements. According to them, selection requires several capabilities: the ability to identify a set of candidates to be considered, the ability to evaluate (either comparatively or in isolation) the candidates, and the ability to choose from amongst the candidates based upon the evaluations (ibid). Other researchers, such as that by Yurimoto and Masui propose complex decision support tools (Yurimoto and Masui 1995), but Swann and O'Keefe reported that simple decision support tools are more readily trusted and used by firms as sophisticated tools may mislead managers (Swann and O'Keefe 1990).

Decision-making processes are analyzed from different viewpoints and the implementation of models and support tools must take into consideration not only the organizational structure in which the decision occurs, but also the procedures, processes and the dynamics of the decision makers involved (Georgilakis 2005). Each actor involved in the selection process has his or her own scope for decision-making, and may become involved in decisions at a number of stages (CMHC 2004). Decision-support tools must reflect this complex context, which may lead to the creation of specific tools to support good decision-making at the most appropriate stage of the selection process (ibid). As a first approach, the actors may need (ibid):

- Decision aid and assessment tools
- Tools for creating new awareness, tools for educational purposes
- Design aid tools (catalogues of solutions or of products)
- Tools to carefully consider the environment at the local scale
- Tools which speak their language, which are transparent, easy to use and suitable to their operational context

As a result, understanding the importance of the characteristics of DSTs will assist in the development of the DST ontology and help improve its process of development. These considerations could also help positively impact the DSTS structure in ensuring maximum benefits to the tool users.

3.2.2 Decision Support Tool Skeleton (DSTS)

This subsection provides a brief overview of the definition of a DSTS and its components, which form the ultimate research product of this study.

3.2.2.1 Definition

In order to create context-specific DSTs to support good decision making at the appropriate stage of the residential water heater selection process, it is important to gather all relevant information that goes into the tools. In this research, this information is presented in the form of ontology of data having classifications, inter-relationships or hierarchy in a model structure. In this research, this body of data is called a Decision Support Tool Skeleton (DSTS). This DSTS serves a point of departure for developing more holistic decision support tools in future in which model functions or analysis can be applied to the DSTS paradigm to reveal a priority set of data, which could form the fundamental basis of a new DST.

3.2.2.2 Components of DSTS

In this study, the DSTS has been divided into two segments: Exoskeleton and Endoskeleton. The DSTS exoskeleton is the fundamental basis of the tool. It represents the underlying principle, idea or foundation (called as ‘Capital’) on which to create, develop and refine a DST to best suit the goal envisioned. On the other hand, the DSTS endoskeleton is comprised of attributes (comprised of ‘criteria’ and ‘indicators’) that represent the concept. The subsequent sections explain the development of the DSTS in detail.

3.2.2.3 Need for DSTS

Decision making is concerned mainly with the question which alternative or course of action should be undertaken under a specific situation by considering many aspects, including the degree of importance of each criterion (Kalbandi and Thampi 2009). Additionally, in their research paper, Hepting and Maciag (2005) stressed that *"Consumers may not agree on the relative importance of all of the possible attributes that a product may have, yet each distinct attribute contributes to the precision with which any one consumer can make a choice."*

This calls for the need to create a Decision Support Tool Skeleton (DSTS) which will gather all essential criteria or attributes on residential water heaters, enabling selection or assisting in rational decision making. Knowing the basis for these decisions can help to better structure and present information through the DSTS, and also help to target impact information to specific consumer groups (Hepting and Maciag 2005).

3.2.3. Technology Selection using Multi-Attribute Decision Making (MADM) in DSTS

This subsection introduces MADM as a method of technology selection (in this case, residential water heaters) in the DSTS to be developed. The importance of using MADM and its relevance to the decision making process has also been explained. Lastly, the use of sustainability as the main principle for assessment of criteria/attributes within the DSTS has been justified.

3.2.3.1 Definition of MADM

This research requires a decision making method in order to build or create a DSTS for decision-makers that conforms to their objectives and priorities (a constructive or creative approach) (Georgilakis 2005). Thus, multiple attribute/criteria approach is used in this research as it is intended to aid the decision maker in the creation of a set of relations between various alternatives (ibid).

According to Kalbande and Thampi (2009), *"Multi-Attribute Decision Making (MADM) refers to making decisions in the discrete decision spaces and focuses on how to select or to rank different pre-determined alternatives"*. Accordingly, a MADM problem can be regarded as a problem of choice or ranking of the existing alternatives (ibid).

The "ideal" solution, the option that performs best for all the criteria selected, may be difficult to achieve (Georgilakis 2005). Therefore it is necessary instead to find a compromise from among the different possible solutions. It is for this reason that a choice resulting from MADM could be 'justified' and not 'optimum' (ibid).

3.2.3.2 Sustainability Assessment in MADM Approach

The decision making process is multidimensional, made up of a number of aspects at different levels. Therefore, reaching clear and unambiguous solutions may be very difficult. It is from this difficulty that the need arises to develop a DSTS on the basis of sustainability criteria (Georgilakis 2005). *"Sustainability provides a useful concept, forcing people to think about*

where development is taking us" (Hellstrom et al. 2000). Thus, sustainability can be used as an underlying principle to meet the objective of creating a DSTS, which will allow stakeholders to compare multiple alternatives across multiple criteria and/or attributes, making selection easier (Ewing & Baker 2009).

Several authors have in the past used sustainability assessment criteria in MADM approach to solve complex problems, particularly in the field of water and wastewater management or treatment. For example, Balkema and co-authors proposed a general assessment methodology that builds on multi-objective optimization and a complete set of sustainability indicators, yielding insight into the trade-offs made when selecting sustainable wastewater treatment systems (Balkema et al. 2002). Hellstrom and co-authors suggested a framework containing a set of sustainability criteria and suitable indicators for systems analysis of sustainable urban water management in Sweden (Hellstrom et al. 2000). Similarly, Muga and Mihelcic developed a set of indicators that incorporate environmental, societal, and economic sustainability and used it to investigate the sustainability of different wastewater treatment technologies (Muga and Mihelcic 2008).

While sustainability has several meanings in different contexts, it is essential to determine the type of sustainability that would best suit the objectives and requirements of this research. The type of sustainability capitals used for water heater selection are stated in section T1.4 (Methodology section) below.

3.3 Goals and Objectives

The main goal of this research is to improve the sustainability of residential hot water infrastructure. Particularly, the goal of this chapter is to create the skeleton of a DST for selection of residential water heaters in the U.S, using an integrated evaluation of sustainability assessment factors. In order to achieve this goal, various specific objectives have to be accomplished.

These specific objectives include:

- To create the DSTS Exoskeleton comprising of the tool structure, based on an underlying principle that satisfies the main research goal of assisting in water heater selections
- To create the DSTS Endoskeleton by establishing a coding methodology and integrating the resultant 'codes' with the multi-attribute decision making (MADM) process, to generate a list of attributes
- To integrate and assemble the individual components (Exoskeleton and Endoskeleton) into the Final DSTS

Other objectives include:

- To address gaps and shortcomings from existing DSTs (from Chapter 2)
- To gather extensive information on residential water heater selection in the U.S. through collection of market reports
- To establish validity of the outcomes by performing various cycles of coding, i.e. recoding
- To identify opportunities for further research

3.4 Research Design and Methodology

In this section, the various objectives listed above are fulfilled by following a step by step process of accomplishing tasks, created using the Multi-Attribute Decision Making (MADM) approach on the development of the Decision Support Tool Skeleton (DSTS). A schematic of the research design is shown in Figure 3.1.

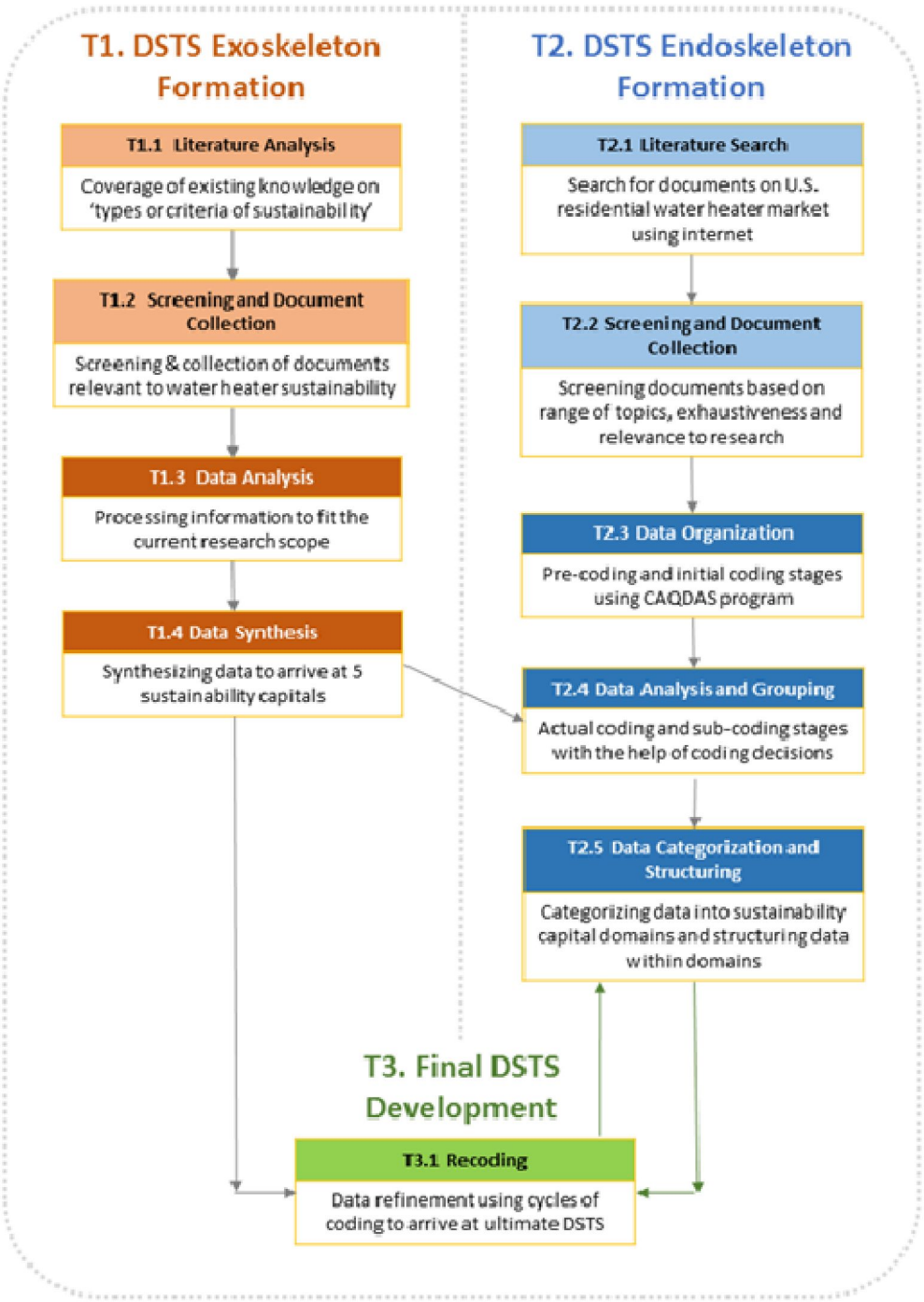

Figure 3.1: Research design for development of DSTS using MADM approach

The methodology for creating the DSTS has been segregated into three main tasks (based on the three main objectives), each having multiple task components. As mentioned earlier in section 3.2.2.2, the DSTS has been divided into two segments: Exoskeleton and Endoskeleton. The three main tasks are:

- T1. Formation of DSTS Exoskeleton
- T2. Formation of DSTS Endoskeleton
- T3. Final DSTS Development

T1. Formation of DSTS Exoskeleton

The DSTS Exoskeleton can be defined as 'the core principle or fundamental basis on which the actual tool is developed'. It involved the use of an approach or strategy towards developing the DST body, for acceptance by potential users. By adopting a principle or an idea, addressing other factors that could affect its outcome, such as target population, level of complexity, and understanding, could be made easier, simpler, and more straightforward. In order for this strategy, principle or idea to be effective, it is important that it be represented through a veritable design and/or structure.

T1.1 Literature Analysis

For the residential water heater market, 'sustainability' was used as the underlying theme to meet the objective of creating a DSTS that would provide users with explicit information and aid in rational decision making on sustainable water heater choices. The search for documents and existing literature on sustainability was performed using the Internet. While web-based eDSTs (collected earlier in Chapter 2) could be examined to identify any explicit, discrete or recurring sustainability themes in them, it was easier to identify theoretical documents that explained the subject in greater detail. Hence, the search was directed at obtaining sustainability theme based literature.

The coverage of existing knowledge on 'types or criteria of sustainability' was performed using specific keywords such as 'types of sustainability', 'sustainability for decision support tool', 'sustainability framework for decision support tool' and 'sustainability criteria' among others. The search was concluded when documents already identified were found to be repeatedly appearing in new searches.

T1.2 Screening and Document Collection

While the search for literature revealed a multitude of results on sustainability criteria and classification, there were no documents found on sustainability assessment framework for decision support tools (DSTs) on water heaters. Moreover, many of the documents were domain-specific such as sustainability in urban water management, water treatment, forest management, etc. and were targeted at addressing specific problems. These documents were screened to collect documents that had direct or indirect relevance to residential water heaters.

T1.3 Data Analysis

The third step in the methodology of DSTS exoskeleton development was analyzing the documents in greater detail to extract sustainability variables. The aim was to develop a greater understanding of sustainability and its criteria so that it could be refined or redefined to best fit the scope of this research. Such an approach would help create a structure that broadly represents major sustainability themes identified in the documents. The collected documents which were analyzed, are given below in Table 3.1:

Table 3.1: Documents that were analyzed for 'Types of Sustainability'

(Hellstrom et al. 2000)	(Goodland 2002)	(Makropoulos et al. 2008)	(Balkema et al. 2002)	(Goodwin 2003)
Set of Sustainability Criteria:	**Types of Sustainability:**	**Types of Sustainability Capitals:**	**Set of Sustainability Indicators:**	**Types of Capital for Sustainable Development:**
Health & Hygiene Socio-Cultural Environmental Economic Functional & Technical	Human Social Economic Environmental	Environmental Economic Social Technical	Functional Socio-Cultural Environmental Economic	Financial Natural Produced Human Social

The sustainability variables within these documents were examined to check for correlation to the residential water heating industry in the U.S. This was performed by analyzing the definitions, context and examples of the sustainability variables. The next task involved synthesizing and customizing the sustainability variables for this study.

T1.4 Data Synthesis

The methodology developed in this research deals with a specific type of problem: the residential water heater (technology) option selection problem. "*It relates to the decision problem of choosing the most suitable technology given case-specific conditions and constraints with respect to technical, environmental, social and economic objectives*" (Balkema et al., 2002). As mentioned earlier, sustainability variables will be used to define the structure of the DSTS as a means to encourage informed decision making and eventually, to contribute towards improving the sustainability of the residential water heater industry. Moreover, defining each component of sustainability distinctly may help organize the action required to approach global sustainability in real life (Goodland 1995).

Hence, the last step in the development of DSTS exoskeleton after analysis of existing literature was to redefine, compile and synthesize data to produce the 'sustainability criteria' for the purpose of this research. As a result, the term 'sustainability capital' has been used as the underlying approach. The five sustainability capitals obtained after data synthesis are namely: economic, environmental, technical, human and social capital, as shown in Figure 3.2. They have been explained in separate subsections below.

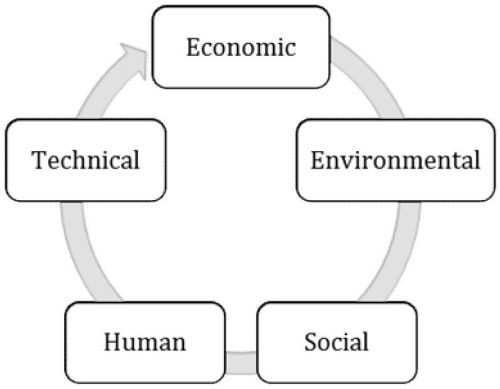

Figure 3.2: The 'Sustainability Capitals' used in the MADM approach of DSTS development

Types of Sustainability Capital used:

Economic (Sustainability) Capital: "*Economic sustainability implies paying for itself, with cost not exceeding benefits*" (Balkema et al. 2002). Though in principle it should include all resources, in practice economic sustainability is measured in terms of financial costs and benefits, i.e., financial sustainability (ibid). While purchasing a water heater, it would be represented as analyzing the life-cycle costs in addition to others.

Environmental (Sustainability) Capital: Environmental sustainability means that humanity must learn to live within the boundaries of the environment while maintaining natural capital, i.e., natural resources. (Goodland 2002). In other words, the interaction of humans and the technology should have minimal negative impact on the surroundings. For example, the amount of carbon-dioxide released as a result of daily water heater usage should be minimum.

Technical (Sustainability) Capital: Technical sustainability defines the minimal technical requirements of the solution (Balkema et. al. 2002). It refers to the attributes of a technology or a product that can enhance or maintain human well-being. In this case, the technology or product could demonstrate optimum performance in addition to high levels of durability, reliability, robustness, longevity and adaptability (Makropoulos et al. 2008).

Social (Sustainability) Capital: Social capital is a measure of social sustainability. "*Social capital is investments and services that create the basic framework of the society*" (Goodland 2002). "*It is most often referred to characteristics of the society that encourage cooperation among groups of people"* (Goodwin 2003). Among other things, public knowledge of energy-efficient water heater technologies and awareness of risk of infection from hot water systems form social sustainability.

Human (Sustainability) Capital: *"Maintaining human capital ensures human sustainability. Human capital is a private good of individuals, rather than between individuals or societies. The health, education, skills, knowledge, leadership and access to services constitute human capital"* (Goodland 2002). In the context of water heater purchases, human sustainability could be aesthetics, comfort and personal brand preferences.

Capital-Criteria-Indicator Structure in MADM Approach

While there are several definitions of sustainability, it is beneficial to use sets of criteria to make the concept of sustainability more operational and practically useful (Hellstrom et al. 2000). Quantifying or 'operationalizing' sustainability is, more often than not, a debatable concept and an ambiguous process to be handled with considerable attention to the particular characteristics of the problem at hand (Natsis et al. 2006). For this purpose, a capital-criteria-indicator approach was used as shown in Figure 3.3. It is the selection of appropriate criteria linked to specific indicators. Moreover, the assessment of sustainability through the use of sustainability indicators is a well-established and documented approach (Makropoulos et al. 2008).

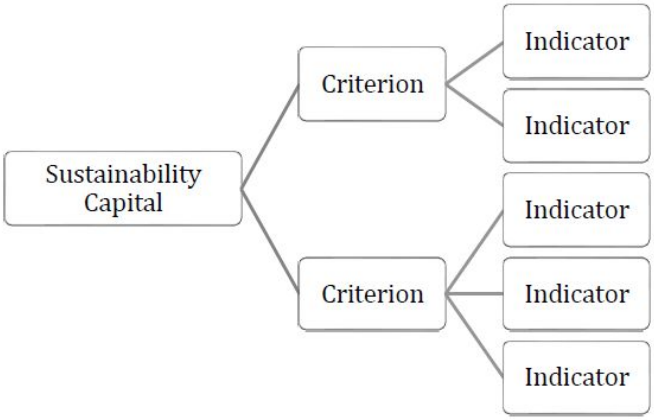

Figure 3.3: Graphical representation of sustainability capital, criteria and associated indicators

- ***Capital:*** Capital can be viewed as stocks that have the capacity to produce flows of a desirable outcome (Goodwin 2005). *"Each capital contains a set of (quantitative or qualitative) indicators enabling assessment"* (Makropoulos et al. 2008).
- ***Criterion:*** *"A criterion can be defined as a measure against which option performance is assessed along with the degree to which stated objectives are achieved"* (ibid).
- ***Indicators:*** *"Indicators constitute a means of measuring the level to which criteria are satisfied"* (ibid).

T2. Formation of DSTS Endoskeleton

The DSTS Endoskeleton on the other hand, can be defined as the 'set of variables used to represent the capital'. In this research, these sets of variables are termed as 'Attributes'. Attributes is a generic term used to denote criteria, sub-criteria and indicators against which the corresponding sustainability capital will be assessed. The methodology below explains the formation of the DSTS endoskeleton in greater detail.

T2.1 Literature Search

The search for literature for the endoskeleton of the DSTS began with the objective of collecting documents that specifically focused on the U.S. water heater market. This was based on the assumption that these documents contain 'attributes' of/related to residential water heaters as well as the water heater decision making process in the U.S. The aim of this task was to collect attributes, which would eventually be used to create a comprehensive list of criteria and indicators. In similarity to section T1.1, an Internet search was performed to collect the documents using keywords, shown in Table 3.2. The search was however, limited to what was accessible via the Internet.

Table 3.2: Keywords for literature search using Internet

Keywords:	
U.S. Residential Water Heater Market Report	Residential Water Heater Market Technical Report
U.S. Water Heater Market Profile	U.S. Residential Water Heater Market Status
Technical Report on Residential Hot Water Systems	U.S. Residential Water Heater Market Profile
Research and Development on Residential Water Heating	U.S. Residential Hot Water Technologies
	Residential Hot Water Systems Report

T2.2 Screening and Document Collection

A preliminary analysis of the documents from the Internet search results revealed several water heater market reports that may not be necessarily related to the topic at hand. These included documents such as consumer blogs, detailed product specifications, reports on commercial or industrial water heaters, etc.

Thus, the documents were screened to identify and select those based on multiple factors such as the range of topics covered, exhaustiveness of the document and relevance to the U.S. residential water heating market sector. In addition, it was observed that many of the documents either contained a DST within its content or were representative of a DST themselves. These included additional information on water heater characteristics, guidance to purchase decisions and consideration of critical factors during selection. These reports were the ideal documents to analyze for attributes and were finally collected. The gathered documents came in several forms, namely technical reports, white papers, publications, academic journals, etc. It should be noted that certain documents though relevant to this research, were not accessible as they could not be purchased online. After screening and collection, the documents were organized for qualitative data analysis via 'coding'.

T2.3 Data Organization

In this research, 'Coding' was used a qualitative data analysis (QDA) technique, to identify and capture analytic information from existing documents. More information on coding and its cycles has been given below.

Coding as a Qualitative Data Analysis (QDA) Technique

Charmaz describes coding as "the 'critical link' between data collection and the interpretation of their meaning" (Charmaz 2001). Its definition is given below:

- ***Coding:*** In the context of this research, coding is defined as *'an interpretive act of identifying, analyzing and capturing analytic information from existing data, on the basis of predefined research goals and objectives'*. The data can consist of journals, documents, reports, drawings, etc. Here 'coding' refers to the process and 'code' refers to the outcome of that process.

- ***Code****:* In qualitative data analysis, a code is defined as *"a researcher-generated construct that symbolizes and thus attributes interpreted meaning to each individual datum for later purposes of pattern detection, categorization, theory building and other analytic processes"* (Saldana 2013).

Majority of qualitative researchers will code their data both during and after collection as an analytic tactic, for coding is analysis (Miles and Huberman 1994). The qualitative analytic process is cyclic rather than linear (Saldana 2013). Various cycles of coding (iterations) may be performed till the researcher is satisfied with the desired outcome(s). Rarely is the First Cycle of Coding data perfectly attempted. The Second Cycle (and possible the Third and Fourth Cycles and so on) of Coding further manages, filters, highlights, and focuses the salient features of the qualitative data record for generating categories, themes, concepts, grasping meaning, and/or building theories (ibid).

Cycles of Coding:

- ***First Cycle of Coding:*** They are processes that happen during the initial coding of the data. The portion of data to be coded during the First Cycle of Coding processes can change in magnitude from a single word to a full paragraph to an entire page of text (ibid).

- ***Second Cycle of Coding:*** They are a bit more challenging because they require analytic skills such as classifying, prioritizing, integrating, synthesizing, abstracting, conceptualizing and theory building (ibid). In Second Cycle Coding Processes, the portions coded can be the exact same units, longer passages of text, analytic memos about the data and even a reconfiguration of the codes themselves developed thus far.

The documents that were collected in T2.2 had to be organized even before the actual coding process could begin. This was accomplished by using a Computer Aided Qualitative Data Analysis Software (CAQDAS) explained in detail below:

Coding using CAQDAS

CAQDAS is *"a software program that efficiently stores, organizes, manages and reconfigures your data to enable human analytic reflection"* (Saldana 2013). However, it must be noted that CAQDAS itself does not actually code the data; the task is still the responsibility of the researcher (Saldana 2013). For this research, a CAQDAS called 'ATLAS.ti' has been used for code development and coding process. Table 3.3 shows the various stages of coding employed in data organization using ATLAS.ti.

Table 3.3: Stages of coding in data organization

Stages of Coding	Coding Method	Code Development
T2.3.1 Pre-Coding	Structural Coding	***Structural Code:*** *"What are the factors in the selection of residential water heaters in the United States?"*
T2.3.2 Initial Coding	Attribute Coding	***Attribute Codes:*** *Name of the document, Year of publication, Author/publishing entity and Type of document*

T2.3.1 Pre-Coding Stage

The pre-coding stage is the stage before the actual use of ATLAS.ti (CAQDAS) where tasks whose outcomes can affect the coding process significantly, are taken into account and performed. In this study, structural coding has been used in the pre-coding stage:

Structural Coding: It is the process of generating a question-based code that "acts as a labelling and indexing device, allowing researchers to quickly assess data likely to be relevant to a particular analysis from a larger data set" (Saldana 2013). In this context, structural coding refers to process of identifying the problem and framing a central research question(s), the answer to which can be obtained by coding the collected documents. Hence the structural code for the development of the decision support tool skeleton was framed as: *"What are the factors in the selection of residential water heaters in the United States?"*

T2.3.2 Initial Coding Stage

The initial coding stage occurs immediately after the pre-coding stage, in which the researcher performs tasks in preparation for coding such as code creation, code development and the coding process to be employed for further analysis of documents. The task used for this research in the initial coding stage is given below.

Attribute Coding: It is the notation, usually at the beginning of a data set rather than embedded within it, or basic descriptive information such as literature characteristics, demographics, data format, time frame and other variables of interest for qualitative and quantitative analysis (Adapted from Saldana 2013). The attribute codes developed in this task are related to the data

format of the collected documents, such as *name of the document, year of publication, author or publishing entity and type of document* (shown in Appendix C).

T2.4 Data Analysis

The next step in the methodology of development of the DSTS endoskeleton was the analysis of data in the collected documents for 'attributes' (generic term for criteria, sub-criteria and indicators). The data was analyzed and processed using ATLAS.ti, a powerful CAQDAS tool which enables management of qualitative data. In this task, the third and fourth stage of coding were implemented, as explained in Table 3.4 below.

Table 3.4: Stages of coding in data analysis using ATLAS.ti

Stages of Coding	Coding Method	Code Development
T2.4.1 Coding (Actual)	Magnitude Coding	***Magnitude Codes:*** *Attribute(s), Attributes in Image, Attributes in Tabs*
T2.4.2 Sub-coding	Descriptive and In-vivo Coding	***Descriptive Codes*** ***In-vivo Codes***

T2.4.1 Coding (Actual) Stage

The coding stage is the most important stage in the process of generating attributes to be used in the MADM approach to develop the DSTS endoskeleton. The coding method used in this stage is called as Magnitude Coding, as explained below:

Magnitude Coding: It is a coding method where the codes applied can consist of words or abbreviations that suggest intensity or frequency, as well as such continua as weight or importance (Saldana 2013). Since the subsequent steps in the methodology involved collecting 'attributes' ('attributes' is a generic term to represent criteria, sub-criteria and indicators for the MADM approach), these codes would be created with the keyword 'attribute' in their names. The magnitude codes were created on the basis of the data layout as it appears in the document. As a result, three simple codes created were:

- *Attribute(s)* – These will be assigned to data appearing as text in paragraph or headings
- *Attributes in Image* – These will be assigned to data appearing as text in images or figures
- *Attributes in Tabs* – These will be assigned to data appearing as text in tables or columns

<u>Coding Decisions</u>

Before magnitude coding can be performed on the data, it was important to consider and understand how the coding decisions would take place. The act of coding requires one to see things from a researcher's analytic lens. The researcher's perceptions and interpretations depends on what type of filter covers the lens. The data set obtained after coding could change depending on the addition or subtraction of these filters. Hence, coding is an interpretative and heuristic act where the researcher's cognitive skills such as induction, deduction, abduction, synthesis, evaluation or logical and critical thinking will come into play (ibid).

Coding results and the actual number of codes generated for each document, will vary, and they depend on many contextual factors such as nature of the data, coding methods used for analysis and the level of details (ibid). Also, depending on the coding methods chosen, some codes may appear more frequently in selected type of data than the others (ibid). As a result, several assumptions and system boundaries were implemented to ensure a uniform coding methodology.

System Boundaries for Coding:

- Coding for attributes containing information on residential water heater selection was limited to what appeared on the documents. For example, detailed information on distribution system such as the piping material, etc. was not included as it did not appear in the document sections that were analyzed.
- In terms of residential water heaters, only information on individual water heaters was analyzed for coding. Multi-family central systems and combined systems were excluded from analysis.
- Condensing, non-condensing and light duty water heaters have not been included because they are relatively new in the market (DOE 2012b).
- Wood as an energy source has been excluded from analysis, because of its relatively low percentage of market share as a fuel for residential water heaters.
- Only post-manufacturing considerations were included in the analysis unless explicitly specified in the decision support tool skeleton (DSTS).
- All documents were analyzed using ATLAS.ti and grouped in a single family.
- Attributes may be repetitive when they appear in two or more codes during simultaneous coding (such as in a figure or a table) of the same document.
- Since the number of codes can accumulate quite quickly and change as analysis progresses (Saldana 2013), the codes were organized by maintaining a separate compilation.

Assumptions for Coding Decisions:

- The 'Table of Contents' page of the document under analysis was reviewed first, so as to avoid inspecting sections which were not relevant to the structural code generated (central research question).
- It must be noted that attribute coding (T2.3.2) is different in meaning from assigning codes to generate attributes.
- During the coding process, necessary personal attributes for coding such as perseverance and patience, dealing with ambiguity when countering contrasting data, flexibility via various cycles of coding, and the need to be ethical were exercised to ensure optimum results.
- It should be noted that the selection of data as attributes within the document and assigning codes to it, were performed as per the researcher's cognitive skills, discretion, and judgment.
- Some of the documents in the analysis (Balkema et al. 2002; Hellstrom et al. 2000; Makropoulos et al. 2008) had direct mention of criteria and indicators as attributes, which made the coding process easier.

- When encountering a DST within the document, a reverse strategy was adopted wherein the structure or framework of the tool was studied to identify attributes.
- There was the potential risk of portions being excluded from data analysis, which was countered by performing various iterations of coding.
- The analysis also helped identify potential sections within the document which would later be assessed in further detail.

T2.4.2 Sub-coding Stage

Before the sub-coding stage could begin, the results from magnitude coding (explained above in T2.4.1) were generated in the form of a list of primary attributes through ATLAS.ti. These results appeared in sequence in the order in which the codes were assigned to the data. Next, second-order tags were assigned to primary attributes to detail or enrich the entry, depending on the volume of data that exists or may be needed for categorization and data analysis (Miles and Huberman 1994). This stage of coding is thus called 'sub-coding'. There were two coding methods adopted for data analysis at the sub-coding stage, as given below.

Descriptive Coding: It is a coding method which summarizes the primary codes in a word or a short phrase, most often as a noun representing the basic topic of the qualitative data under analysis (Saldana 2013). This type of coding was mainly used to generate a secondary attribute list, in alignment with the current research interests.

In-vivo Coding: Also known as 'literal coding', in-vivo coding refers to producing a "word or short phrase from the actual language found in the qualitative data record" (ibid). This was primarily used when the word or short phrase was in direct relevance with the research objective and could be used directly or modified slightly as per the researcher's requirements.

Figure 3.4 summarizes tasks T2.3 Data Organization and T2.4 Data Analysis d as a flowchart.

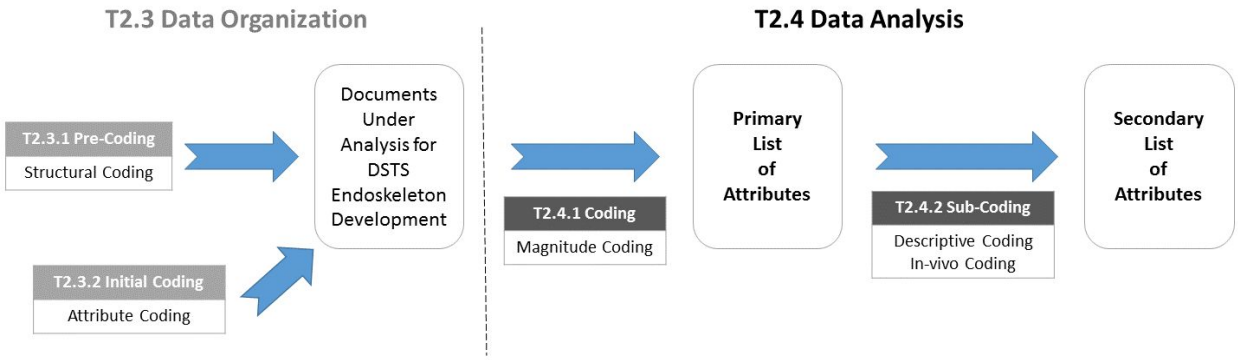

Figure 3.4: Flowchart of tasks T2.3 'Data Organization' and T2.4 'Data Analysis'

T2.5 Data Categorization and Structuring

The last task in the development of the DSTS endoskeleton using the MADM approach involved analysis of the 'secondary attribute list' generated after the sub-coding process. This task involved the following sub-tasks, which are explained in detail below:

- Categorization of data as per the definition of sustainability capitals, synthesized from task T1.4 of development of DSTS exoskeleton
- Classification of attributes from the attribute list as criteria, sub-criteria or indicator

T2.5.1 Data Categorization into Sustainability Capital Domains

The list of secondary attributes were analyzed and simultaneously categorized into the sustainability capitals namely: environmental, economic, technical, social and human, synthesized (T1.4), during the DSTS exoskeleton development. After the attributes (secondary) were categorized, they were stored under their corresponding sustainability capitals in an excel spreadsheet in a non-hierarchical manner.

The definitions of sustainability (obtained from T1.4) provided the fundamental basis on which the data was categorized into the capitals. In addition, sorting of water heater selection attributes developed by Brazeau (2012) in her Ph.D dissertation, as shown in Figure 3.5, provided a starting point for the categorization. In her document, the interrelationships between the various attributes and the domains under which they were outlined, were studied. She also stressed that while water heater selection is probably most driven by consumer drivers (i.e., costs, availability, and consumer comfort reports), environmental impacts, local factors, and public health (Figure 3.5) could play a larger role if more reliable, practical assessment were readily available (ibid).

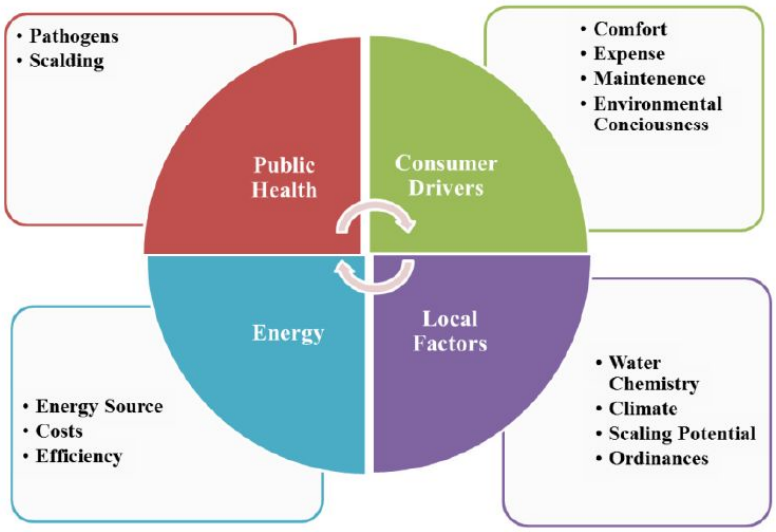

Figure 3.5: Factors for selection of residential hot water infrastructure (Brazeau 2012)

Moreover, such sorting of data occurred in other documents (Makropoulos et al. 2008, etc.) which served as examples of strategies to evaluate the comprehensive list of attributes and sort them. Additionally, one of the advantages of using ATLAS.ti was its ability to trace the code back to its source or origin. As a result, the section, subject or the context in which the code occurred helped make the decisions on data categorization.

In case of uncertainty in deciding the category, the attributes were placed under all relevant categories until further analysis was performed. Also, if two similar attributes were encountered during this task, they were placed under the relevant group(s) for subsequent evaluations. It must be remembered that for all of the above functions, the researcher's cognitive skills and knowledge were used to make the distinctions.

T2.5.2 Data Structuring within Sustainability Capital Domains

The last sub-task in this process was the structuring of attributes within their respective sustainability capital domains. At first, the sequence for each of the capital domains was established by the researcher to arrange the attributes, which in turn would give it significance and meaning. It must be noted that the sequences were created at the stage in the methodology where the researcher had developed a notion of the overall data that was captured and collected in the earlier tasks.

The established sequences are given below in the order in which they appear in the DSTS:

- ***Environmental Capital Domain:*** Contains information on existing water heater (such as its physical environment and current usage profile) followed by environmental considerations for the new water heater and finally environmental impacts and ways to prevent it
- ***Economic Capital Domain:*** Contains information on site costs, followed by water heater costs, economic analyses techniques and available economic resources
- ***Technical Capital Domain:*** Contains information on water heater properties (technicalities, functionalities, etc.) followed by system properties including water quality to and from the system and finally the setbacks due to the technologies
- ***Social Capital Domain:*** Talks about the market factors, its boundaries, knowledge and awareness of the market actors
- ***Human Capital Domain:*** Contains two main criteria: non-energy benefits to individuals and their psychographic factors during selection of water heaters

Once the attributes were placed in their respective sequence in the capital domains, each attribute was classified as a criterion, sub-criterion or indicator, whose formulation was based on the capital-criteria-indicator approach (from T1.4). This was a very important step as it involved sequencing and arranging attributes within each domain, to give it meaning and fulfill the overall objective of the DSTS.

The 'interconnection between codes', 'orientation of the codes towards the research objective' and the researcher's cognitive skills were primarily used to classify and structure the attributes within the domains. As mentioned earlier, sorting of some attributes appeared directly in documents previously analyzed (Makropoulos et al. 2008, etc.), which helped to classify them as criterion, sub-criterion and indicator. In addition, the attributes from the codes could be traced back to its origin in ATLAS.ti, where classification was performed by looking at the subject, section or the context in which it appeared in the documents.

In some cases, two or more attributes were grouped together and labeled as a new criterion. This new criterion would embody the sub-criteria which was represented by indicators. Simultaneously, the indicators were organized based on their connection with their respective criterion and sub-criterion. Also, it must be noted that the occurrence of a particular attribute in different forms was solved by giving it a common identity or term. For example, the attributes 'water savings' and 'reduced water usage' were combined to be 'water conservation'. Several attributes occurred in more than one location within the decision support tool skeleton (DSTS). The inclusion or exclusion of these attributes was based on the researcher's discretion, knowledge and skills to identify the sustainability capital in which it was best applicable to suit the research interests.

T3. Final DSTS Development

The final step in the development of DSTS was to perform 'recoding' of the result obtained in T2 (Formation of DSTS Endoskeleton) so that the multi-attribute decision making (MADM) approach can be represented in a manner that successfully achieves the objective of providing a DSTS to enable informed decision making.

T3.1 Recoding

The recoding of data was achieved through various 'cycles of coding' as explained earlier in section T2.3. For the purpose of this research, three cycles of coding were performed to refine the results and to arrive at the ultimate DSTS. This can be assumed as a 'quality control' process, as explained below:

The ***first cycle of coding*** was performed manually using paper and pen. It involved analysis of text based qualitative data analysis followed by creating jottings of various codes. While the number of codes generated as a result of this process were small compared to the ultimate list of codes, this step was important to learn the basics of coding and qualitative data analysis.

The ***second cycle of coding*** was performed electronically using ATLAS.ti, a CAQDAS program to perform coding. In this process, existing documents were coded simultaneously with the complex instructions and multiple functions of CAQDAS programs. This cycle resulted in the generation of a long list of attributes, which were organized in a capital-criteria-indicator approach without any sub-criteria.

The ***third and final cycle of coding*** was performed using ATLAS.ti, similar to the second cycle, but was much more meticulous and detailed in approach. Care was taken to ensure that all relevant attributes were included. In addition to the inclusion of sub-criteria, a fifth and sixth column on unit of measurement and notes/comments were added respectively. This was in direction with the research objective of creating a DSTS that had its data structured to ensure significance, meaning and context.

For potential users of the DSTS, it is important to make use of the indicators in the most effective manner to assist in the decision making process. These indicators measure the economic, environmental, technical, human and social sustainability of residential water heaters

in U.S. However, readers should understand that the selection and interpretation of these indicators is context specific and based on the judgement of the researcher.

Indicators could be represented quantitatively, either through measurements, cost calculations or enquiries (Balkema et al. 2002). In order to quantify qualitative indicators, they could be rated on a scale of 0 to 5 with 0 being the worst score and 5 being the best score (Makropoulos et al. 2008). These indicators could also be used to assess the influence of a technology on a certain indicator (Balkema at al. 2002). For example, a potential advantage of using demand water heaters could be the smaller space it occupies in the house. However, size could be a disadvantage if it is incapable of providing continuous supply of hot water in large volumes. For users to assess these tradeoffs, it would be more meaningful to use indictors as go or no go decision variables in optimization (Balkema et al. 2002)

3.5 Results

In all, 535 codes were generated using the coding process in ATLAS.ti as shown in Figure 3.6.

Id	Name	Media	Quotations
P 1	ACEEE 2012.pdf~	PDF	71
P12	ASSE 2012.pdf	PDF	22
P11	Balkema et al. 2002.pdf	PDF	22
P 2	Bartels et al. 2001.pdf~	PDF	22
P 3	DOE 2010.pdf~	PDF	57
P 4	DOE 2012a.pdf~	PDF	20
P16	DOE 2012b	PDF	45
P13	FSC 2014.pdf	PDF	9
P15	Hellstrom et al. 2000.pdf	PDF	7
P 5	Maguire 2009.pdf~	PDF	31
P10	Makropoulos et al. 2008.pdf	PDF	4
P 6	NREL 2013.pdf~	PDF	50
P 7	ORNL 2011.pdf~	PDF	52
P 9	PERC 2011.pdf~	PDF	60
P 8	PG&E 2012.pdf~	PDF	36
P14	PNNL 2013.pdf	PDF	27

Figure 3.6: A snapshot from ATLAS.ti showing the documents used for the coding process and the number of codes generated

Attributes induced from these codes were categorized into sustainability capital, criteria, sub-criteria and indicators, the final result being (see Table 3.5 below):

- No. of Sustainability Capitals -5
- No. of Criteria – 27
- No. of Sub-Criteria – 94
- No. of Indicators - 364

Table 3.5 shows the resultant decision support tool skeleton containing capital, criteria, sub-criteria and indicators in a sustainability assessment framework (Adapted from Hellstrom et al 2000; Goodland 2002; Makropoulos et al. 2008; Balkema et al. 2002; Goodwin 2003 and synthesized from ACEEE 2012; ASSE 2012; Balkema et al. 2002; Bartels et al. 2001; Brazeau 2012; DOE 2010; DOE 2012a; DOE 2012b; FSC 2014; Maguire 2009; NREL 2013; ORNL 2011; PERC 2011; PG&E 2012; PNNL 2013).

Table 3.5: The final Decision Support Tool Skeleton (DSTS) showing sustainability capitals (environmental, economic, technical, social, and human), criteria, sub-criteria, and associated indicators

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
Environment	Physical Environment	Geographic Criteria	Climate Zone	*(select one)*	[Cold/Very Cold/Subarctic,Marine,Mixed Humid,Hot/Dry/Humid-Mixed/Dry] Resistance heating in heat pump water heaters depends on climate (both due to inlet water and evaporator inlet air) (DOE 2012b)
			Altitude	ft. above sea level	
			Site Solar Resource		For solar hot water systems
			Inlet Water Temperature	°C, °F	
			Outdoor Air Temperature	°C, °F	
			Outer Humidity Ratio	(ratio)	
			Shielding From Forces of Nature		For example, seismic strapping may be required for areas prone to earthquakes such as California, Oregon, etc. Other forces of nature include floods, hurricanes, etc.
		Household Characteristics	Building Type	*(select one)*	[Single-Family, Multi-Family, Mobile Homes, etc.]
			Water Heater Location	*(select one)*	Installation Locations - [Garages, Basements, Crawlspaces, Utility Rooms or Other] (DOE 2010)
			Orientation/Tilt of Collector	θ	For solar hot water systems
			Weight of Water Heater	lbs	To ascertain the ability of the structure to hold the water heater
		Space Considerations	Room/Location Height	ft. or inches	Heat pump water heaters are typically taller than conventional storage units and should not be placed in tight spaces like closets (PERC 2011)
			Room/Location Volume	ft^3	
			Type of Conditioning	*(select one)*	[Conditioned or Unconditioned space] The cooling effect of a heat pump water heater can assist in cooling a home during the summer, but adds to the heating load in the winter (PERC 2011)
			Ambient Air Temperature	°C, °F	
			Ambient Humidity Ratio	(ratio)	
			Changes to Existing Walls		For upgrades, gas line upsizing, etc.
		Venting Accomodations	Provision of Venting	*(select one)*	[Yes/No]
			Type of Vent	*(select one)*	[Direct, Power or Other]; Different venting strategies (e.g. Power Venting, Sealed Combustion) (PERC 2011)
			Type of Venting	*(select one)*	Horizontal, Vertical or Other
			Venting Material	*(select one)*	Plastic, Stainless Steel or Other
			Length of Vent	ft.	The power vented design also allows for side venting, which can greatly reduce the required length of the exhaust vent. (NREL 2013)
		Drainage/Trenching Requiremen	Presence of Drain	*(select one)*	[Yes/No]
			Air Gap	inches	Typically, there is a 6" air gap between drain pipe outlet and drain
			Drain Pan Pipe		
			Condensate Drain		
			Provision of Trenching	*(select one)*	[Yes/No]; May be required only in few cases
			Other Requirements		
		Local/Regional Code Considerations	Plumbing Codes	UPC codes in place?	It is the responsibility of the installing contractor to insure that all national and local codes are complied with (DOE 2012b)
			Air Quality Emission Regulations		Most efficient water heaters in California because of ultra-low NOx air emissions requirements (DOE 2012a)
			Other Ordinances		For example, building codes in Oregon require different clearance for the various water heating technologies.
	Water Heater Usage Profile	Existing Water Heater Specifications	Type of Unit	*(select one)*	[Storage, Tankless/On-Demand, Heat-Pump, Solar, Tankless Coil & Indirect, Others] This is used for replacement purposes only
			Equipment Make and Model		This is used for replacement purposes only
			Residential Fuel/Energy Type	*(select one)*	[Electricity, Fuel Oil, Geothermal Energy, Natural Gas, Propane, Solar Energy]
		Use Quantities & Patterns	Type of Draw	*(select one)*	[Low, Medium or High]; [Close Together or Spread Out]
			Average Daily Draw Rate	gal/day	
			Peak Period	(time)	Time of Draw
			Total Peak Hour Demand	gal	
			Water Use Intensity	gal/ft^2	
	Hot Water Load Estimation	Demographic Data	Number of Occupants/Users	no.	
			Number of Bedrooms and Bathrooms	no.	
			Number of Hot Water Fixtures	no.	Include dishwasher, clothes washer, shaving, hand dishwashing in addition to showers
		Peak Hour Demand	Average Consumption per Usage per F	gal	Consumption may vary on season. Include the highest of summer and winter consumption.
			Number of Usages in 1 hour	no.	
			Gallons Used in 1 hour	gal	
			HW Load Based on Occupants & Clima	*(select one)*	[Low, Moderate, Average, Above Avg, High]
	Energy Considerati	Optimal Resource Allocation	Fuel Availability	*(select one)*	[Yes/No]; Due to regional differences

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
		Fuel Requirements	Primary Fuel Type	*(select one)*	[Electricity, Fuel Oil, Geothermal Energy, Natural Gas, Propane, Solar Energy]
			Secondar Fuel Type		Some advanced technologies such as heat pump and solar hot water systems use a secondary fuel
			Fuel Input Rate	Btu/hr	
	Resource Utilization	Water	Use of Fresh Water	gal/year	
			Loss of Water	gal/use or gal/year	
		Energy	Residential Energy Source		Source of Fuel Generation such as fossil fuels, natural gas, solar, etc.
			Use of Fossil Fuels	MJ/year	
			Annual Energy Consumption	[kWh,gal,therm	Depends on heating/cooling seasons and the impact of water heater on space heating/cooling (NREL 2013)
			Base Case Energy Use	kWh	
			New Measure Energy Use	kWh	
			Summer Demand	kW	
			Winter Peak Demand	kW	
		Land	Use of Available Land	ft^2	
		Other	Chemical Usage	gal/year	Postmanufacturing usage of chemicals for maintenance, repair, etc.
			Material Usage	kg/year	Postmanufacturing usage of materials for installation, maintenance, etc.
	Environmental Impa	Contribution to Water Pollution	Toxicity of Leakage/Condensate	pH value	
			Flooding	gal	In some cases, a catastrophic failure of the water heater can lead to flooding and/or loss of hot water (ORNL 2011)
		Contribution to Acidification	Level of H+ -eqv	mol/year	
		Contribution to Global Warming	Level of CO2 -eqv	kg/year	The CO2 emissions from water heaters can be calculated from "emissions factors" from the U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID). These emission factors provide a multiplier to estimate the emissions which result from the production of a unit of electricity (PERC 2011)
		Emissions	Level of NOx emissions	ppm/year	
			Level of COx emissions	ppm/year	
			Level of SOx emissions	ppm/year	
			Level of Particle emissions	ng/J	
		Noise Pollution	Noise		HPWHs generate some noise from the operation of the heat pump (PERC 2011), which is similar to that of a dishwasher (DOE 2010)
		Undesirable Consequences of Resource Conservation	Increase in Usage	gal/day, gal/yr	Some sustainable water heaters may provide amenities such as endless supply of hot water, etc. This could inadvertently increase its usage and result in increase in energy consumption; Moreover both scale and corrosion increase with water usage and temperature (PNNL 2013)
			Health Risks		Reducing the energy consumption associated with hot water use in the home can pose substantial health problems if the health risks associated with lower water temperatures are not taken into account (FSC 2014)
		Undesirable Cosmetic Characteristics	Color/Visual Appeal		Discoloration of water
			Odor		
			Taste		
	Resource Conservat	Water Conservation			
		Prevention of Leakage/Spillage	Volume of Leakage/Spillage	mL, gal	
			Use of Drain Pans	*(select one)*	[Yes/No]
		Groundwater Preservation	Groundwater Level Maintenance	ft. from ground level	
			Judicious Use of Water	gal/use or gal/year	
		Energy Conservation			
		User Behavior	Optimal Energy Utilization	kWh	For example, propane and oil-fired storage water heaters can utilize electric ignition systems for combustion instead of standing pilot lights (PERC 2011)
			Weatherization Practices		
			Understanding Domestic Hot Water Usage Patterns and Profiles		
		Energy Savings	Lifetime Energy Cost Savings	$	
			Lifetime Fuel Savings	[kWh,gal,therm]	
			Smart-Grid Integration		
		Material Conservation	Reuse Potential		
		Other	Other Environmental Benefits		
Economic	Site Specific Cost Estimates	Fuel Costs	Relative Residential Pricing of Electricity to Natural Gas	(ratio)	
			Cost of Energy/Fuel Production	$, $/Btu	

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
			Cost of Fuel Switching	$	Fuel Switching is for replacment purposes only
			Local Utility Rate	$/unit	Energy rates can be derived from market data which is regularly collected and made available by the U.S. Energy Information Administration (EIA) (PERC 2011)
			Retail Fuel rates	$/mil Btu, $/MWh	
		Space Associated Costs	Cost for Venting Requirements	$	
			Electrical Circuit Upgrade Cost	$	
			Gas Line Upsizing Cost	$	Cost associated with larger piping
			Cost for New Electric Oulets	$	Cost Associated with electric outlets for fans, propane systems, etc.
	Life Cycle Costing	First Cost	Cost of Equipment	$	Upfront Cost
			Price Premium	$/equipment	
		Investment Costs	Investment Cost	$	
			Return on Investment (ROI)	$	
			Total Loan Amount	$	Loan Provision for water heaters takes into account the debt to income ratio and the credit score
			Amortization Factor	$/amor. period	
			Loan Interest Rate	%	
			Term of Loan	years	Duration of loan
		Installation Costs	Material Cost	$	
			Labor Hour		In some cases, R.S. Means can be used to develop a cost for a particular installation item not covered in other analysis, such as the cost to install a dedicated electric circuit (PERC 2011)
			Labor Hour Cost	$/labor hour	It is added for more complex installations (PERC 2011)
			Labor Markup	$/hour	It can be obtained from R.S. Means
			Associated Incremental Cost	$	These include provision of drain, space associated costs, cost associated to address constarints on HPWH location (PERC 2011)
		Operating Costs	Fuel Rate Factor	(ratio)	[ElecFactor, GasFactor]; Based on local average fuel rate and nominal fuel rate, it is used to reflect local retail prices (DOE 2012b)
			Nominal Annual Operating Cost	($/kWh,$/therm)	
			Base Case Annual Water Heating Cost	$	Based on Nominal Annual Operating Cost vs Load ($/kWh,$/therm) and Fuel Rate Factor; Only for electric and gas storage water heaters (DOE 2012b)
			Advanced System Operating Cost	$	Based on Nominal Annual Operating Cost ($/kWh,$/therm) and Fuel Rate Factor (DOE 2012b); For advanced technologies such as heat pump water heaters, energy star water heaters, advanced gas water heater systems, etc.
			Estimated Incremental Cost	$	Incremental costs are based on site factors, new construction, retrofit, etc.
			Water Cost	$/1000 gal	
			Annual Operating Cost		Monthly energy consumption was used to determine annual operating costs, taking into account seasonal variations in energy costs (NREL 2013)
		Insurance Costs	Cost of Insurance	$/year	
		Maintenance Costs	Cost of Maintenance	$	
			Cost of Upgrades	$	
			Annual Maintenance Cost	$	All maintenance costs should be annualized by multiplying the cost by the likelihood that it would be performed and dividing by the maintenance period (NREL 2013)
		Repair/Retrofit Costs	Supplementary Cost/Potential Cost Iss	$	Costs for water softner systems, expansion tanks, etc. and other variable costs
		Replacement Costs	Removal/Replacement Cost	$	
			Residual Value	$	Scrap, Resale or Salvage Cost
		Taxes	Amount of Taxes	$/year	Fedral and State tax
			Incentive Amount	$	Tax Credits, Rebates
		Other Costs	Non-Fuel Operating, Maintenance and Repair Costs	$	
			Cost of Source Energy	$	
			Fuel Switch Cost	$	
			Miscallaneous Costs	$	
	Cost -Effectiveness Analysis (CEA)	Cost-Effectiveness for New Construction	Annual Savings	$/year	
			Amortization Factor	$/amor. period	
			Incremental Cost	$	
			Incentives	$	Incentive amount
			Cost-Effectiveness Ratio	(ratio)	Calculated using Equivalent Annual Cost (EAC), i.e. the annual cost of owning an asset over its entire life.
		Cost-Effectiveness for Retrofit	10 Year Savings	$	
			Estimated Incremental Cost	$	
			Incentives	$	Incentive amount

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
			Fuel Switch Cost	$	Only for replacements
			Calculated Savings	$	
	Break-Even Analysis	Total Cost of Ownership	Annual Cost of Ownership (ACO)	$	It is the sum of annual energy cost in a year, annual principal, interest on system's first cost amortized over the equipment's rated service life. The "ACO" essentially estimates the cost for buying a water heater and paying for its annual energy bills, spread out over the system's rated service life (PERC 2011)
			Base Case Capital Costs	$	
			Base Case Operating Costs	$	For example, solar water heater has minimum water heating costs
			Base Case Maintenance Costs	$	
			Additional Water Heater Operating Co	$	
			AdditionalWater Heater Maintenance	$	
			Expected Water Heater Lifetime	years	The expected lifetime ofa water heater in a given installation can dramatically influence the cost-effectiveness and savings potential of a water heater (PNNL 2013)
		Projected Savings	Annual Consumption	therms	
			Annual Savings	therms	
			Annual Savings	$	
			Lifetime Savings	$	
			Percentage of Savings	%	
			Earnings from Return on Investment	$	
			Cost of Saved Energy (CSE)	$/[kWh,gal,ther	Factor of Cost-Benfit Analysis
		Payback Period	Time of Payback	Years	
	Present Value Method	Recurring Costs	Uniform Present Value (UPV)	$	The present value methods are used to bring all future costs, which may occur in different years, back to today's value of money.
			Fuel Consumption	[kWh,gal,therm]	
			Maintenance Cost	$	
		Non-Recurring Costs	Single Present Value (SPV)	$	
			Fuel Consumption	[kWh,gal,therm]	
			Maintenance Cost	$	Non-recurring costs for heat pump water heaters and residual value
	Other Economic Ana	Feasibility Analysis	Sensitivity Analysis		
			Material Flow Analysis		
			Percentage of Feasibility	%	
		Risk Analysis	Financial Risk Analysis		
	Economic Resources	Incentives	Availability of Incentives		Public beneficial incentives
			Type of Incentives-1	*(select one)*	[Rebate, Tax Credit, Discount, Grant or Loan]
			Type of Incentives-2	*(select one)*	Fedral, State or Local
			Incentive Amount		Average and range of incentive amount
			Mode of Incentives	*(select one)*	[Online applications, Mail-in applications or Point of Sale (POS) Rebates] (DOE 2012a)
			Green Incentives		Based on renewable energy or energy-efficiency criteria
			Other Financial Incentives		For example, grants, etc.
		Financial Assistance	Leasing Arrangements		
			Loans		
			On-bill Financing Programs		Used mainly by utilities; It allows a buyer of specific efficient equipment to pay off a no- or low-interest loan with the cost savings yielded from monthly utility bill. (ORNL 2011)
Technical	Water Heater (Appliance)	Product Speficications	Type of Equipment	*(select one)*	[Storage, Tankless/On-Demand, Heat-Pump, Solar, Tankless Coil & Indirect, Others]
			Equipment Make and Model		Detailed specifications on model
			Quantity of Equipments	no.	
			Rated Storage Volume	gal	For active solar water heating systems, the size of the solar storage tank increases with the size of the collector - typically 1.5 gallons per square foot of collector
			Rated Power	Btu/hr	
			Capacity	kW	
			Tank Height	inches	
			Other Diimesnions	inches, ft.	
			Tank Weight	kg/ft^2	
			Rated Service Life	years	Rated Service life is generally 8 to 20 years, with the variance based on a number of factors including water heater type, water quality, and maintenance practices (PNNL 2013)
			Input Rating	Btu/hr	
			Input to Volume Ratio	Btu/hr/gal	

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
			Insulation of Water Heater	R-value	
			Collector Area	ft^2, m^2	Only for Solar Water Heating System; Contractors usually follow a guideline of around 20 sq. ft. of collector area for each of the first two family members. For every additional person, add 8 sq. ft. if you live in the U.S. Sun Belt area or 12-14 sq. ft. if you live in the northern United States (DOE 2013).
	Energy Efficiency	Rating Metric: Energy Star Specifications	Energy Factor		Energy Factor is the federally mandated performance metric for the vast majority of residential water heaters (DOE 2012b); It is a measure of a water heater's overall energy efficiency, based on the amount of hot water produced per unit of fuel consumed over a typical day (DOE 2010); Energy Factor is dependent on Recovery Efficiency, Standby Losses and Cycling Losses; Light Duty Water Heaters have not been included because they are relatively new and performance is defined in terms of thermal efficiency; It is available only for high efficiency storage(electric, gas, heat pump), whole home tankless(gas) and solar water heaters.
			Solar Energy Factor(SEF) or Solar Factor(SF)		It is defined as the amount of energy delivered to the storage tank by the solar collector divided by the total energy input into the tank. (NREL 2013)
			First Hour Rating		The first-hour rating is the amount of hot water in gallons the heater can supply in the first hour starting with a tank full of hot water (DOE 2010); It depends on the tank capacity, source of heat (burner or element), and the size of the burner or element. (DOE 2013)
			Maximum Flow Rate/ Gallons Per Mintue		Maximum Flow Rate (GPM) - Hot water delivery from tankless water heaters is not measured by first-hour rating, but rather by the maximum flow rate that the heater can achieve while maintaining a particular temperature rise (DOE 2010)
			Warranty		
			Safety Standards		The American National Standards Institute (ANSI) assists other organizations in developing safety standards for many different appliances, including gas water heaters; Electric water heaters, such as heat pump water heaters, are tested under Underwriters Laboratories (UL) 174 (DOE 2010); SRCC's OG-300 standard outlines minimum quality and operational requirements for solar water heaters (DOE 2010)
			Test Improvements		Energy Factor test Improvements - climate specific, category specific, add water waste/usage to test (ORNL 2011)
		Rating Metric: Home Energy Rating System	HERS Index		The Home Energy Rating System (HERS) Index is the industry standard by which a home's energy efficiency is measured.
		Efficiency Specifications and Losses	Energy Guide Label		The EnergyGuide label lists the first hour rating in the top left corner as "Capacity (FHR)"; The Federal Trade Commission requires an EnergyGuide label on all new conventional storage water heaters but not on heat pump water heaters (DOE 2013).
			Source Efficiency		Site-to-source energy rate; The source efficiency takes into account all the primary energy that is consumed to provide electricity or natural gas to a home (NREL 2013)
			Conversion Efficiency		For a gas water heater, the conversion efficiency is the combustion efficiency of the water heater (Maguire 2009)
			Steady State Efficiency		For tankless water heaters mainly
			Recovery Efficiency		It is defined as how efficiently a unit of fuel can heat up water (PERC 2011)
			Solar Fraction		Based on the Solar Rating and Certification Corporation's (SRCC) conversion formula: Solar Fraction = 1 – (EF/SEF), assuming a 0.6 or 0.9 EF for gas or electric backup, respectively (DOE 2010)
			Standby Losses		It is the % of heat loss per hour from stored water compared to the water's heat (DOE Website); It occurs with storage water heaters, regardless of demand because of tank losses and pilot energy (DOE 2012b)
			Cyclic Losses		They are thermal losses experienced as water circulates through a water heater tank (PERC 2011)
			Other Losses		Firing losses
			Efficiency Improvement Potential		Other factors for improvement of efficiency levels
			Heat Rate	Kbtu/kWh	Inverse of Efficiency; It is a factor of conversion efficiency
			Tank Loss Coefficient	Btu/hr-ft2-F	
		Basis of Efficiency Level	Standard Efficiency (Federal Minimum)		Base level efficiency; National Appliance Energy Conservation Act (NAECA) standards
			Typical Efficiency		Market data is used to characterize typical EF values for the electric and propane tankless (condensing) units; The solar hot water system efficiency specifications are based on typical efficiency metrics for the solar collectors, with the tankless back-up system meeting the relevant ENERGY STAR criteria (PERC 2011)
			High Efficiency		
			Mode of Operation		Resistance only, hybrid or other
	Performance	Water Temperature Stability /Control	Set Point Temperature	°C, °F	
			Tank Temperature	°C, °F	
			Desired Output Temperature	°C, °F	
			Heat Flow Rate	kW, kJ/s	
			Overall Heat Transfer Coefficient	$W/m^2K°$	It is based on recovery efficiency, EF, average storage tank temperature, ambient air temperature, thermal load delivered by the water heater and its rated power (Maguire 2009); For walls, heat-exchanger in storage water heater
			Capacitance	uf	Ability of the tank and water in the tank to store heat energy

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
			Coefficient of Performance (COP)	(ratio)	For heat pump water heaters, the efficiency is typically measured and reported as COP, defined as the amount of energy delivered by the unit divided by the amount of energy consumed (NREL 2013)
		Delivery of Hot Water	First Hour Rating (FHR)	gal/hr, gal/min	Only for storage units
			Water Heater Flow Rate	gal/min	For tankless units and others
			Maximum Flow Rate	gal/min	Defined by heating capacity, setpoint, and inlet water temperature (DOE 2012b)
			Actual Output Temperature	°C, °F	
			Daily Average Recovery Load	Btu/day	
			Annual Average Recovery Load	Mbtu/year	
	Water Heater System Properties	Distribution System	Configuration of Distribution System		Open, recirculation system or other
			Control Type of Recirculation System		
			Distance of Installation from Use Point		Savings can be increased by encouraging installations closest to where hot water is required (DOE 2010)
			System Efficiency		Takes into account an enhanced system approach incorporating advanced, low thermal loss distribution networks and minimization of hot water usage/loads, and that is cost effective and easy to install (ORNL 2011)
		Distribution System Impacts	Impact on Heating/Cooling Equipment		The tank losses in low use cases in cooling-dominated climates led to increased cooling energy consumption and higher source energy consumption (NREL 2013)
			Impact on Other Fixtures in Homes		
		Ancillary Devices	Low-Flow Sensors		
			Short Draw Sensors		If plumbed into a single-lever faucet, it should be able to delay current flow and heating to minimize energy use when activation was inadvertent (ACEEE 2012)
			Freeze Protection Sensors		
			Noise Control Features		
			Flue Damper		
			Learnable/Intelligent Controls		These controls learn use patterns and adjust set points (ORNL 2011)
			Water Heater Jacket/ Blanket	R-value	
			Drain/Catch Pan		
			Sedimentation Trap		
			Heat Trap		
			Noise Control Features		
			Vibration Control Measures		
			Other Devices/Strategies		Other auxiliary systems inputs include drain heat recovery devices, flue gas recovery and desuperheaters (DOE 2012b)
		Safety Devices	Anti-Scald Device		
			Thermal Expansion Tank		
			Pressure Relief Valve or Regulator		
			High Temperature Safety Switch		
			Check Valve		
			Temperature Actuated Mixing Valve		
			Automatic Compensating Mixing Valve		
			Temperature Limiting Device		
			Anti-Scale Device		
			Self-Cleaning Device		
			Other Safety/Service Parameters		For condensate management, air filters, diagnostics, and freeze protection (ACEEE 2012)
	Robustness of the System	Durability	Periodic Maintenance		
			Water Treatment	(yes/no)	Water treatment is done to prevent rusting or corrosion; Water softner is used as a last resort
			Auxillary System Inputs		
			User Handling of Water Heater	(yes/no)	
		Longevity	Service Life	Years	Water heater performance and longevity depends on scale build up and corrosion.
			Sustained Performance		
		Flexibility	Flexibility		
		Resilience/Adaptability	Adaptable to Local Conditions		It is defined as the possibility to extend the system in capacity, or with additional treatment (Balkema et al. 2002)
			Endurance of Seasonal Effects		
		Reliability/Security	Long Term Product Reliability		Reliability is the sensitivity of the system to malfunctioning of equipment and instrumentation (Balkema et al. 2002); Reliability must be proven to at least match that of current HW systems. (ORNL 2011)
			Length of Warranty	Years	
			Product Guarantee	(yes/no)	

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
		Maturity	Maturity		
	Water Quality	Physical, Chemical and Biological Characteristics			
		Incoming Water	Quality of Incoming Water		To confirm if it is within acceptable standards; Local water quality is the primary cause of premature failure of water heaters (PNNL 2013)
			Density	lb/in^3	
			ph Level	ph level	
			Water Temperature	°C, °F	
			Hardness of Water	Mg/L, ppm	Soft or hard water; Soft water will rust and eat away at ferrous (iron-containing) components in the water heater resulting in leaks and premature failure (PNNL 2013) whereas hard water causes water heater failure due to scale build up.
			Presence of Dangerous Heavy Metals		Compunds of lead, arsenic, mercury, etc.
			Presence of Impurities	*(select one)*	[Yes/No]
		Outgoing Water	Hotness of Water	°C, °F	
			Presence of Harmful Bacteria		For example, Legionella
	Technology Setback	Water Quality Impacts	Corrosion, Rust and.or Scale Buildup		Two main terms describe water quality with regard to its propensity to produce scale or corrosion in water distribution systems or equipment—carbonate hardness and alkalinity; Specifically, highly alkaline water will lead to the accumulation of scale, which will impact the efficiency of tankless and gas storage water heaters and can lead to decreased equipment life; Soft water increases the risk of corrosion, which can decrease equipment life by more than half if not properly mitigated (PNNL 2013)
		Water Heater Failure	Damage to Water Heater		Extreme cases include tank bursting
			Damage to Furniture/Home		A survey by the Insurance Institute for Business & Home Safety (IBHS 2007) found that water heater failures are one of the top five "water loss" claims, or claims in which monetary compensation is sought as a result of water damage to furniture, equipment, or the home itself. Of the 700 water-heater-related water loss claims analyzed, 69 percent were due to leaks in the water heater or to the tank bursting. (PNNL 2013)
			Loss of Water		
		Growth of Pathogens	Presence of Sediment at Bottom of the Heater	*(select one)*	[Yes/No]
			Amount of Sediment	(volume)	
			Amount of Microbial Growth	CFU/mL	
		Health Hazards	Microbial Diseases		Legionella bacteria are commonly found in potable water supplies and they can multiply in warm, nutrient-rich domestic hot water systems and can spread to humans when breathed in. (ASSE 2012)
			Scald Hazards	°F >120, °C >49	Temperatures over 120 degrees F (49 degrees C) at the points of use are considered a hazard, with extremely higher temperatures causing serious second and third-degree scald burns upon contact with adult skin (ASSE 2012); Especially prone to older people, infants, etc.
			Indirect Effects		Use of hot water can indirectly control Asthama in human beings
Social	Market Acceptance	Market Penetration	Product Availability		Products need to be available for immediate delivery to meet emergency demands of most water heater customers (DOE 2012); Regional product availability (ex: Ultra -low NOx, Southern California); Limited model availability at retailers – special order is required (DOE 2012a)
			Product Acceptability		Socio-cultural acceptance of the product; In different cultures, people will have a different perception of hot water heating and usage, resulting in different habits (Balkema et al. 2002)
			Demand for Water Heater in Consideration		
			Affordability/ Willingness to Pay		Situations may arise causing the buyer to modify, postpone or avoid the final decision. These could be sticker shock (affordability) among others (DOE_2012); Any new technology or system developed must be cost competitive with today's technologies, offering an acceptable payback period (ORNL 2011)
			Promotion		Education and Referral, Geo-targeted Promotions
			Association with Rebate Program		
		Service Parameters	Service Infrastructure Availability	*(select one)*	[Yes/No]
			Expertise and Assistance		The selected technological solution requires a certain level of expertise for installation, operation and maintenance. If the expertise is not locally available it may be gained through import or training (Balkema et al. 2002)
			Plumber/Installer Familiarity with Technology		
			Plumber/Installer Capability?	*(select one)*	[Yes/No]
			Institutional Requirements		Different regulations and control mechanisms that fit in the existing institutional infrastructure of the country or region (Balkema et al. 2002)

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
		Installation Considerations	Installation Feasibility		One key decision variable is installation feasibility, with systems like the heat pump water heater (HPWH) having unique space and location requirements, which in some cases could eliminate it as a viable option (PERC 2011)
			Manufacturer's Installation Instructions		It is the responsibility of the installing contractor to insure that all manufacturer's installation instructions are complied with (DOE 2012b)
			Ease of Installation		
			Ease of Upgrades		
	Sociographic Boundaries	Social Inclusion	Competence/Information Requirements of Stakeholders		
			Connectedness Between Stakeholders		[Low to High]; To assess how often do they come in contact
			Existence of Information Asymmetry		
			Retail Channel Engagement		Program Participation - To inform customers about limited time opportunities to participate in a program
			Collaboration (Market Focused Programs)		A market-focused program design has to provide benefits to all participants in the water heater value chain. It is expected that channel partners will contribute resources that will drive sales of qualified products, such as product discounts, store associate training, and coordinated advertising (DOE 2012a)
		Social Impacts	Provision of Social Benefits	*(select one)*	[Yes/No]
			No. of jobs created	No.	Ability of manufacturers and other stakeholders to create new jobs depening on economic and social factors
			Local Development		
			Other Social Impacts		
	Knowledge	User Interactions	Understanding User Behavior	*(select one)*	[Yes/No]
			Start-up Delay		
			Preventive Maintenance Strategies		For example, heat pump water heater requires a condensate drain and periodic air filter cleanings (DOE 2010); Other strategies include regularly (every year) draining tank to remove sediment (PNNL 2013); Annual flushing, de-liming for HPWH and backup tank annual flush for solar gas water heaters (NREL 2013)
		Technological Awareness	Temperature Control	*(select one)*	[Yes/No]; To ensure health, safety and energy codes are in place
			Pressure Control	*(select one)*	[Yes/No]; Temperature/Pressure Relief Valve
			Cold Water Sandwich	*(select one)*	[Yes/No]; Also Known as Stacking/ Thermal Layering /Stratification; Layers of varying temperature hot water in the storage tank, created by the intermittent actuation of the water heater thermostatic control caused by short and frequent draws of hot water from the storage tank at the point of use (ASSE 2012)
			Minimum Flow Rate	*(select one)*	[Yes/No]
			Combustion Air, Venting	*(select one)*	[Yes/No]; Why Venting is Important? - If the flue gas were allowed to cool to a temperature where the water vapor condenses out of the flow, the sulfur odorizer added for safety reasons could combine with the condensed water to make sulfuric acid, corroding the flue and destroying the water heater (NREL 2013)
			Backdrafting	*(select one)*	[Yes/No]
			Other Tech. Awareness Factors		For example, product quality
		Public Health and Safety	Water Quality Impacts		Physical, chemical and biological characteristics of water can impact humans, especially immunocompromised people
			Exposure to Toxic Compounds		Spreading of toxic compounds from water
			Scalding Awareness		Improper design and use of hot water delivery systems can lead to scalding and other health and safety related effects. There is a general misconception that the water heater thermostatic control is capable of delivering a constant, safe water temperature. Temperatures at the point of use over 120F (49C) are considered a hazard. Without further temperature controlling downstream of the outlet of the water heater, the potential to experience dangerous scalding water temperatures at the point of use increases greatly (ASSE 2012)
			Understanding of Associated Threats or Allergies		Hot water washing has been identified as a necessary activity to help control the asthma epidemic that is now facing the United States. The availability of hot water is critical to the control of dust mites as a causal source of both the development and exacerbation of asthma (FSC 2014)
			Risk of Infection		Microbial Risk Analysis/Assessment
			Carbon Monoxide (CO) Poisoning		
			Growth of Mold/Mildew		
			Combustion Safety		
			No of accidents (if any)	no.	To know the causes of water heater failures
	Awareness and Confidence	Decision-Making Aspect	Information Search for Product Availability		During information search, the potential buyer learns about retailers or contractors who supply the products as well as the features of water heater brands. The outcome of this phase is typically a short list of product purchase options and suppliers (DOE 2012a)
			Promote Early Replacement		
			Understanding Costs to Benefits		
			Understanding Non-Energy Benefits		
		Stimulation of Sustainable Behavior	Awareness		For example, consumers must be aware of the benefits of energy efficiency when faced with a choice between an efficient product and the alternative (DOE 2012a)
			Participation		

Capital	Criteria	Sub-Criteria	Indicator	Unit	Notes /Comments
			Responsibility		It is the user's responsibility to use hot water judiciously; The behavior of a building's occupants is a significant determinant of total water use and hot water demand (ORNL 2011)
			Utility Bill Weather Normalization		
			Weatherization Practices		Weatherization practices include a wide range of energy efficiency measures and technologies for retrofitting homes and apartment buildings, including water heater replacements (DOE 2010)
			Outreach and Training		Seek quotations for supply, installation and plumbing work
Human	Non-Energy Benefits	Amenities	Shorter Waits for Hot Water		
			Continuous Supply of Hot Water		
			Adequate Endless Hot Water		A potential disadvantage is that this could contribute to longer showers, resulting in reduced energy savings (DOE 2012b)
			Control of Temperature - Safe Temper:	^{o}C, ^{o}F	A safe temperature depends on age, skin condition and health of the bather (ASSE 2012)
		Other Benefits	Regain of Floor Space		Use of Tankless water heaters for example
			Longer Service Life Benefits		
	Stakeholder/User Psychographic Criteria	Satisfaction	Comfort		
			Convenience		
		Interests	Technology Reputation		
			Curiosity to Try Newer Technologies		
			Vendor/Supplier Reliability		In some cases, there may be uncertainity of vendor or supplier reliability
		Preferences	Aesthetics	*(select one)*	[Color, Shape, Design, etc.]
			Image		Value of the water heater
			Technology Preference		Based on fuel, model type or other classifications
			Personal Preference		
			Uniqueness of Technology		
			Brand Name		
			Goodwill		Brand Value
			Reputation of Supplier		
			Other Emotional Drivers		
		Personality/Lifestyle	Lifestyle		
			Social Class		
			Personality Characteristics		

3.6 Discussion and Conclusions

In this study, the final Decision Support Tool Skeleton (DSTS) developed consisted of two main components: endoskeleton and exoskeleton. The DSTS exoskeleton was created using sustainability assessment factors: sustainability capitals namely: economic, environmental, technical, social and human. Use of sustainability capitals ensured that it could be operationalized to suit the main research goal, i.e., selection of residential water heaters. The capital-critera-indicator approach was well documented in various other studies on sustainable infrastructure, and fitted perfectly with the established research goals.

On the other hand, the DSTS endoskeleton was developed incorporating a coding methodology, created in ATLAS.ti, a Computer Aided Qualitative Data Analysis Software (CAQDAS), which helped in the analysis and subsequent data extraction. The resultant 'codes' were then integrated using Multi-Attribute Decision Making (MADM) process, to generate a comprehensive list of attributes in an excel document. The various iterations, i.e., cycles of coding the DSTS ensured that the final outcome achieved some level of validity. Through the cycles of coding, any additional information encountered, was added to strengthen the list of attributes.

It had been shown earlier that there were several gaps and/or shortcomings in existing Decision Support Tools (eDSTs) on residential water heater selection, such as, inadequate and/or inconsistent information, inequality to important factors, ignorance on health/social factors, no transparency in assumptions, improper coverage of different water heater systems, and others. The final DSTS developed addressed all these shortcomings by providing a detailed list of attributes, categorized as capital, criteria, sub-criteria and indicators, along with providing notes/additional information on each attribute.

In all, the DSTS developed had the following count of components and sub-components:

- No. of Sustainability Capitals -5
- No. of Criteria - 27
- No. of Sub-Criteria - 94
- No. of Indicators - 364

Using a common coding methodology for all documents ensures that the results are consistent in information, obtained from the codes. Moreover, the source documents were detailed market reports by industry trade groups or government agencies, adding to the credibility of the outcomes. Important factors which may have been ignored by eDSTs, were included in the list of attributes such as, health/safety factors, installation considerations, post-installation considerations (repair, retrofit, operation and maintenance), ancillary devices on improving performance of water heaters, life cycle analysis tools, factors for public education and awareness, and others.

Moreover, within the sustainability capitals in the DSTS, the various criteria, sub-criteria and indicators were organized taking into consideration their inter-relationships and relevance. This ensured that all related factors appeared alongside, which added to the ease with which the DSTS could be read and understood. While, the eDSTs may provide results that vary, the DSTS

provides a thorough list of attributes, use of which would contribute to informed decision making in the selection of residential water heaters in the U.S.

Human sustainability capital has been introduced as a relatively new concept, which empowers people to make choice based on psychographic criteria such as interests, preferences, satisfaction, personality, social class and lifestyle. It has been purposively incorporated, as it contributes to the flexibility with which the DSTS could be used by various populations: an individual, specific target groups or the masses in general.

In the end, the use of sustainability capitals in the capital-criteria-indicator approach, and data integration using MADM approach, also added another dimension in addition to selection, where all water heaters could be evaluated or measured in sustainability variables and eventually, encourage a shift in decision making process towards more sustainable options. This could also be used as a starting platform for improving the overall sustainability of the residential hot water infrastructure.

References

American Council for an Energy Efficient Economy (ACEEE). (2012). *Emerging Hot Water Technologies and Practices for Energy-Efficiency as of 2011*, No. A112, Washington, D.C.

American Society of Sanitary Engineering (ASSE). (2012). *Understanding Potential Water Heater Scalds*, Westlake, OH.

Balkema, A. J., Preisig, H. A., Otterpohl, R. and Lambert, F. J. D. (2002), "Indicators for the Sustainability Assessment of Wastewater Treatment Systems." *Urban Water*, 4: 153–161.

Bartels, R., Fiebig, D. G. and Soest, A. V. (2001). "Consumer and Experts: An Econometric Analysis of the Demand for Water Heaters." No. 2003-26, Center for Economic Research, University of Tilburg, Netherlands.

Brazeau, R. H. (2012). "Sustainability of Residential Hot Water Infrastructure: Public Health, Environmental Impacts, and Consumer Drivers." Ph.D Dissertation, Department of Civil and Environmental Engineering, Virginia Tech., Blacksburg, VA.

Canada Mortgage and Housing Corporation (CMHC). (2004). "Decision Making Framework." Annex 31 - Energy-Related Environmental Impact of Building, *Energy Conservation in Buildings and Community Systems*, Ontario, Canada.

Charmaz, K. (2001). *Contemporary Field Research: Perspectives and Formulations*, R. M. Emerson (Ed.), 2nd Edition, 335-352, Prospect Heights, IL.

Fisher, Sheehan & Colton (FSC). (2014). "Energy Conservation for Hot Water May be in Tension with Public Health Outcomes." *FSC's Law and Economic Insights*, 14(2), 1-7.

Georgilakis, P. S. (2005). "State of the Art of Decision Support Systems for the Choice of Renewable Energy Sources for Energy Supply in Isolated Regions." *International Journal of Distributed Energy Resources*, 2(2), 129-150.

Goodland, R. (1995). "The Concept of Environmental Sustainability." *Annual Review of Ecology and Systematics*, 26: 1-24.

Goodland, R. (2002). "Sustainability: Human, Social, Economic and Environmental." *Encyclopedia of Global Environmental Change*, John Wiley & Sons, Ltd., Hoboken, N.J.

Goodwin, N. R. (2003). "Five Kinds of Capital: Useful Concepts for Sustainable Development." No. 03-07, Global Development and Environment Institute, Tufts University, Medford, MA.

Hellstrom, D., Jeppsson, U. and Karrman, E. (2000). "A Framework for Systems Analysis of Sustainable Urban Water Management." *Environmental Impact Assessment Review*, 20: 311–321.

Hepting, D. H. and Maciag, T. (2005). "Consumer Decision Support for Product Selection." Department of Computer Science, University of Regina, Regina, Canada.

Kengpol, A. and O'Brien, C. (2001). "The Development of a Decision Support Tool for the Selection of Advanced Technology to Achieve Rapid Product Development." *International Journal of Production Economics*, 69: 177-191.

Kalbande, D. R. and Thampi, G. T. (2009). "Multi-attribute and Multi-criteria Decision Making Model for Technology Selection using Fuzzy Logic." *International Journal of Computing Science and Communication Technologies*, 2(1), 377-383.

Keysar, E. and Pearce, A. R. (2007). "Decision Support Tools for Green Building: Facilitating Selection Among New Adopters on Public Sector Projects." *Journal of Green Building*, 2(3), 153-171.

Maguire, J. B. (2009). "A Parametric Analysis of Residential Water Heaters." M.S. Thesis, Department of Mechanical Engineering, University of Colorado, CO.

Makropoulos, C. K., Natsis, K., Liu. S., Mittas, K. and Butler, D. (2008). "Decision Support for Sustainable Option Selection in Integrated Urban Water Management." *Environmental Modelling & Software*, 23: 1448-1460.

Miles, M. B. and Huberman, A. M. (1994). *Qualitative Data Analysis*, 2nd Edition, Sage Publications, Thousand Oaks, CA.

Muga, H. E. and Mihelcic, J. R. (2008). "Sustainability of Wastewater Treatment Technologies." *Journal of Environmental Management*, 88: 437–447.

Natsis, K., Makropoulos, C., Liu, S., Butler, D. and Memon, F. (2006). "A Fuzzy Logic Multi-criteria Assessment in Urban Water Management Decision Support." *Proceedings of the Seventh International Conference on Hydroinformatics*, 4: 2725–2732.

National Renewable Energy Laboratory (NREL). (2013). *Comparison of Advanced Residential Water Heating Technologies in the United States*, No. NREL/TP-5500-55475, Denver, CO.

Oak Ridge National Laboratory (ORNL). (2011). *Research and Development Roadmap for Water Heating Technologies*, Oak Ridge, TN.

Pacific Gas and Electric Company (PG&E). (2012). "Market Focused Program Design to Accelerate Penetration of ENERGY STAR Water Heaters." *PG&E's Emerging Technologies Program*, No. ET12PGE3191, San Francisco, CA.

Pacific Northwest National Laboratory (PNNL). (2013). *Impacts of Water Quality on Residential Water Heating Equipment*, No. 22921, Richland, WA.

Propane Education and Research Council (PERC). (2011). *Comparing Residential Water Heaters for Energy Use, Economics, and Emissions*, Washington, D.C.

Riddle, W. E. and Williams, L.G. (1987). "Technology Selection: An Educational Approach." *IEEE Transactions on Software Engineering*, SE-13(11), 1199-1206.

Saldana, J. (2013). *The Coding Manual for Qualitative Researchers*, 2nd Edition, Sage Publications, Thousand Oaks, CA.

Swann, K. and O'Keefe, W. D. (1990). "Advanced Manufacturing Technology: Investment Decision Process, Part II." *Management Decision*, 28 (3), 27-34.

U.S. Department of Energy (DOE). (2010). *Energy Star Water Heater Market Profile - Efficiency Sells*, Washington, D.C.

U.S. Department of Energy (DOE). (2012). "Building America Program - Water Heating Standing Technical Committee." *Residential Energy Efficiency Stakeholder's Meeting*, Austin, TX.

U.S. Department of Energy (DOE). (2012). *Strategy Guideline: Proper Water Heater Selection*, Washington, D.C.

U.S. Department of Energy (DOE). (2013). "Energy Saver 101." *Water Heating Infographic*, <http://energy.gov/sites/prod/files/2013/04/f0/waterHeaters101-final.png> (Dec. 27, 2013).

Yurimoto, S. and Masui, T. (1995). "Design of a Decision Support System for Overseas Plant Location in the EC." *International Journal of Production Economics*, 41: 411-418.

Chapter 4: Analysis of U.S. Residential Water Heater Stakeholder System and Decision-Making Process

4.1 Abstract

With the large number of water heaters presently in service in existing homes being regularly replaced, there is the potential for significant energy savings, if advanced and high efficiency water heaters are adopted in the market. In order to fully understand the purchase process, it is essential that the relationship between the various stakeholders and their decision making process be analyzed. This study aims to create a stakeholder system map encompassing the supply-chain of residential water heater market as well as analyze the decision making process in addition to market trends and barriers. This will be achieved by qualitative data analysis using coding and corresponding data extraction, integration and interpretation using meta-synthesis. The resulting map contains the entire stakeholder system with three main channels of communication and supply: utility, retail and wholesale. Moreover, most decisions occur as emergency replacements where the immediate need of the consumer is to maintain the constant supply of hot water.

4.2 Introduction

This section provides a current market overview on residential water heater purchases, followed by information on the various actors and players within the stakeholder system and their functions, and lastly, the different stages of decision making by the market actors. The introduction of these topics in this section will make subsequent chapters simpler to comprehend.

4.2.1 U.S. Market Overview on Water Heater Purchases

Nationally, about eight percent of households replace their water heaters annually (DOE 2009), amounting to between 7 million and 7.8 million water heaters replacements in the United States each year. Another 1.2 million to 2 million units are installed in new homes (ibid). The recession had deflated the water heater market, with sales falling 20 percent since their peak in the mid–2000s, driven mostly by a 72-percent decline in new construction (NEEA 2012). Voluntary purchases have also fallen modestly. These declines have increased the prominence of emergency replacements in the overall market, and may have made manufacturers and major retailers more guarded about sharing sales figure (ibid). Moreover, water heaters are typically out of the scope for most retrofit programs (DOE 2010).

Water heaters are replaced on average every 13 years, although product lifetime depends on a variety of factors including the type of unit, hardness of water and how the water heater is maintained (ibid). Considering the age of water heaters in the installed base and their average lifetime, approximately 37 million water heaters will be replaced starting from 2010, till the end of 2015 (ibid). Most of these water heaters just met the original federal standards in 1990, creating an opportunity for large savings compared to the installed base of the water heaters today (ibid). From the above statistics, it is evident that there is enormous potential in the U.S. residential water heater industry for environmental and economic savings.

4.2.2 Residential Water Heater Stakeholder System

Decision Support Tools (DSTs) inform the decision-making process by helping actors understand consequences of different choices (CMHC 2004). However, these tools may lack the ability to engage all stakeholders due to their focus on selective decision makers. For a tool to be effective, it must take into account the knowledge base as well as other concerns of all potential actors/users (ibid).

Actor: An actor is defined as a person involved in the decision making process. The actor may use a tool for selection himself, or he may consult a specialist (ibid). Actors must juggle many conflicting criteria and assess tradeoffs to arrive at a satisfactory solution.

The actors and other market players together form the stakeholder system. Each actor or player may has different roles or responsibilities to perform, as shown (adapted from CMHC 2004):

- Consumers - Choice of products or technical solutions
- Architects - Improvement of overall environmental building performance
- Authorities - Providing environmental information to customer / authorities
- Retailers/Wholesalers - Marketing / product comparison
- Manufacturers - Labelling / certification
- Policy Makers - Meeting standards

The U.S. residential water heater stakeholder system is considerable with various actors and key players in the fray (DOE 2012; NEEA 2012; PG&E 2012) as mentioned in Table 4.1. Information asymmetry affects the transmission of knowledge between these stakeholders, complicating the decision making process (Bartels et al. 2001). The United States Department of Energy (DOE)'s Building America Program highlights that "*information transfer both to and from stakeholders is critical in moving the marketplace toward the implementation of preferred high efficiency solutions for a given application*" (DOE 2012).

Table 4.1: A sample of water heater stakeholders in the residential sector (DOE 2012; NEEA 2012; PG&E 2012)

Water Heater Stakeholders:			
Regulatory Bodies	Wholesalers	Remodelers	Homeowners
Trade Groups	Retailers	Utilities/Programs	Consumers
Manufacturers	Builders	Suppliers	Building Occupants
Mfr. Representatives	Contractors	Plumbers	Promotional Partners
Distributors	Property Owners	Installers	

The value chain or market structure connects the manufacturer of a water heater with the ultimate end user (PG&E 2012). An example of the residential water heater market structure from PG&E's Emerging Technologies Program has been shown in Figure 4.1. There are two main channels that bring the water heater products from the manufacturer to the consumer, the retail channel and the wholesale channel (ibid). The wholesale channel, plumbing contractors and builders, serves replacement as well as new construction demand (ibid). However, several

other major stakeholders have not been included such as architects, utilities, contractors, policy makers, etc. Moreover, statistics on market share as well as the inter-relationship between the stakeholders is limited.

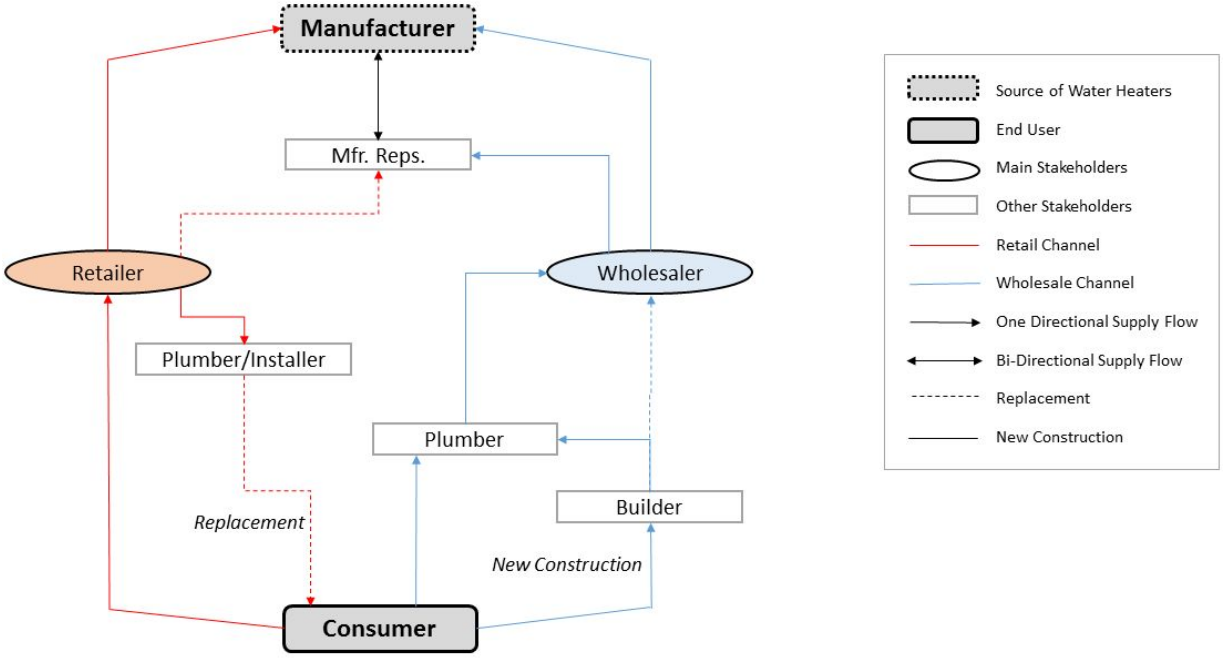

Figure 4.1: Supply chain of U.S. water heater market (adapted from PG&E 2012)

4.2.3 Decision Making Stages

In the U.S. residential water heater market, there could be various market actors involved in the decision making process for the selection of water heaters, and a critical factor to understand is this purchase process (PG&E 2012). The fundamental buying process, defined by Kotler (1988) more than two decades ago, defines five decision making stages: problem recognition, information search, evaluation of alternatives, the purchase decision, and post-purchase behavior (Kotler 1988; PG&E 2012). For water heaters, as with most products, the potential customer moves through all stages of the process as explained (ibid):

- ***Problem Recognition*** - The phase in which the problem occurs can have major impact on the decision making process. A home owner or someone in the household typically notices one or more of five issues with their water heater: lack of or inadequate hot water, noise, discolored water, leaks and odor (ibid).

- ***Information Search*** - After the home owner identifies the problem, the next stage is to more actively search for information to help diagnose the problem and look for a solution (ibid). Water heater problems usually need to be addressed in a hurry as they often break down at the most inconvenient time and there is little time to research solutions and to identify all product options (ibid).

- ***Evaluation of Alternatives*** - When potential buyers have gathered information about different options for water heater replacement, they evaluate options against their needs (ibid). The evaluation depends largely on the starting point such as "need hot water now" or "need to take care of my old water heater" among others, and involves assessing various factors (ibid).

- ***The Purchase Decision*** - After the evaluation of alternatives, and with input and recommendations from the retailer or contractor, the homeowner forms purchase intentions (ibid). Situations may arise causing the buyer to modify, postpone or avoid the final decision such as sticker shock (affordability), availability, or uncertainty about product or vendor reliability (ibid).

- ***Post-Purchase Behavior*** – The interaction between the supplier and the buyer continues with the customer's concerns such as satisfaction with the purchase, installation process and the product performance (ibid). Dissatisfaction will lead to product returns or complaints, while satisfaction can result in word of mouth promotions and repeat business (ibid).

Since, the aim of this chapter is to understand and interpret the dynamics of the U.S. residential water heater market, it was essential to know background information on the market and its various players. Moreover, realizing the various stages of decision making, will help shape the final research product of a stakeholder map, comprising of the supply chain and the stakeholder system. It will also help to understand the actual decision making process.

4.3 Goals and Objectives

In order to implement the DSTS and maximize the diffusion of eDSTs into the market, it is fundamentally important to understand the dynamics of the U.S. residential water heater supply chain, stakeholder system as well as the decision making process.. Hence, the main goal of this chapter is to create a stakeholder map using meta-synthesis of exiting market documents, incorporating the supply-chain and stakeholder system. The various system elements such as market actors, players, decision making process, decision influences, and market barriers will also be expressed in further detail in this chapter.

Specific objectives include:

- To gather extensive information on the stakeholder system and decision making process on selection of residential water heaters in U.S., through screening and simultaneous collection of market reports
- To analyze the collected documents for by establishing a coding methodology using manual coding
- To perform relevant data integration using meta-synthesis
- To represent the data as a stakeholder map, comprising all stakeholders (actors and players), their relationships and, the supply-chain
- To provide extensive information on market trends/barriers, decision making process during selection, and the significance of touch points in the market

Other objectives include:

- To establish validity of the outcomes by performing recoding
- To identify opportunities for further research

4.4 Research Design

The research design is a flowchart showing the methodology used to arrive at the results, by diving them in tasks corresponding to the above stated objectives. Here, five main tasks: literature search, screening and document collection, qualitative data analysis, data interpretation, and recoding have been incorporated, as shown in Figure 4.2.

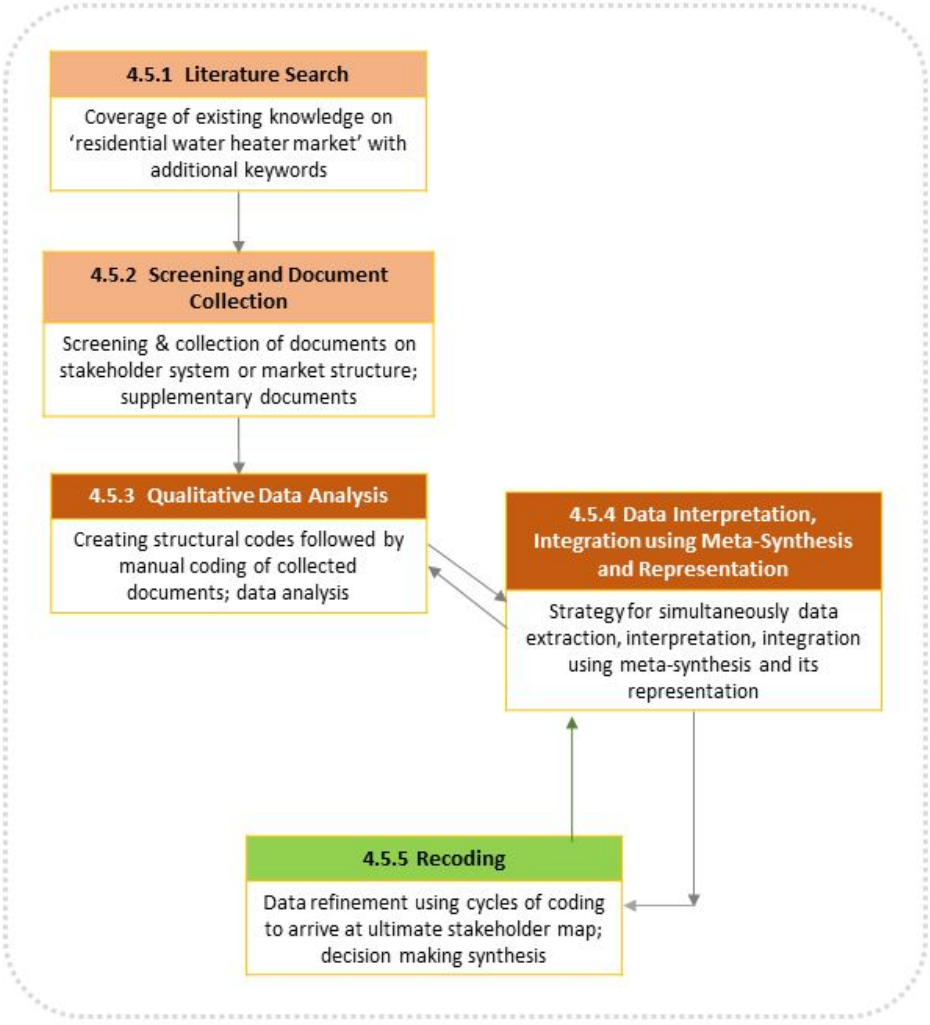

Figure 4.2: Research design for analysis of U.S. residential water heater stakeholder system and decision making process

4.5 Methodology

An important aim of this research is to set the stage to educate members of the public on the principles of decision making. The analysis of the U.S. residential water heater market will help understand the dynamics of supply value-chain, the transfer of technology between various stakeholders and the complete stakeholder system with touch (leverage) points where the DSTS (developed in Chapter 3) could be introduced. The tasks (Figure 4.2) explain the steps taken towards the analysis of the U.S. residential water heater market, described in the following subsections.

4.5.1 Literature Search

It is important to identify intended readers or stakeholders i.e. target audiences of guidance documents (Bosch & Pearce 2003). Some key players from the residential water heater stakeholder system have already been identified (DOE 2012; NEEA 2012; PG&E 2012) and mentioned earlier in the document (Table 4.1).

In similarity to section T2.1 from chapter 3, the search for documents and existing literature on U.S. residential water heater market was performed using the Internet. The search strategy was similar to that of the task T2.1, using keywords shown earlier in Table 3.2 from chapter 3. Additional keywords such as ‘market structure’, ‘supply-chain’, ‘decision makers’, ‘decision-making’, ‘stakeholders’, etc. were included in the search strategy to filter the search results to obtain documents that spoke about the research topic at hand. However, it must be noted that the search was limited to whatever was accessible via the Internet and was concluded when convergence was noted in the search results.

4.5.2 Screening and Document Collection

Using a similar approach from section T2.2, a preliminary analysis of the documents from Internet search was conducted to reveal documents that may be irrelevant and not necessarily related to the U.S. residential water heater market structure or stakeholder system. These included documents such as reports on water heating in other countries, reports on stakeholders in commercial or industrial water heating industry, etc.

Thus, these documents were screened to identify and collect those that specifically mentioned information on the market structure or stakeholder system. Some documents collected at the end of task T2.1 from chapter 3, that fit the current search description for documents, were also analyzed and collected. The literature from the search results were screened by reviewing the table of contents, market structure, purchasing and supply-chain sections.

Consequentially, six main documents remained after screening that were consistent with the study goals and, most importantly, had a supply-chain map in them. Other supplementary documents were also collected based on their exhaustiveness, relevance and importance. The gathered documents mainly came in the form of reports or publications. Documents that could not be obtained online or through interlibrary loan were not included in the study.

4.5.3 Qualitative Data Analysis (QDA) using Manual Coding

The third step in the creation of the U.S residential water heater stakeholder map and system analysis to understand the decision making process, involved qualitative data analysis of the collected documents, obtained from task 4.5.2. Similar to the development of the DSTS Endoskeleton (T2.3 in Chapter 3), 'Coding' was used to capture crucial information from the documents.

At first, structural coding method was used to develop structural code, before the coding process could begin. As mentioned earlier in chapter 3, structural coding refers to process of identifying the problem and framing a central research question(s), the answer to which can be obtained by coding the gathered documents. The structural codes developed (Table 4.2) were:

Table 4.2: Topic-wise structural codes before the 'Coding' process

Topic	Structural Codes
Stakeholder System	▪ Who are the market actors? ▪ Who are the other players in the stakeholder system? ▪ How is the technology transferred in the supply-chain? ▪ What are the inter-relationships between all the stakeholders? How do they interact? ▪ What are the significant touch points for intervention in the stakeholder system?
Decision-Making Aspect	▪ What are the main decisions in choosing a water heater for new construction as well as replacement purposes? ▪ How are decisions made in emergency and planned replacements? ▪ What are the actors' preferences during decision making? ▪ Who are the final decision makers? ▪ Are there any decision influences?
Other Market Information	▪ What are the various market barriers to adoption or penetration of water heaters? ▪ Are there any remarkable trends in the market?

After establishing the structural codes, the qualitative data analysis of the gathered document began. The coding approach taken in this task was however, different from that in section T2.3 from chapter 3. The coding methodology has been explained below along with coding system boundaries and assumptions.

Manual Coding: Manual coding was used as the coding process for this task. Manual coding was preferred over coding using CAQDAS because data interpretation and stakeholder map creation was performed simultaneously, as data was being coded. This approach in a CAQDAS program would have been much more complex. Manual coding method involved analysis of text based qualitative data analysis followed by creating jottings of various codes. A mix of manual/pen as well as Microsoft Word application was used to analyze codes, created for the stakeholder map and the decision-making aspect respectively. Important quantitative data was

also being recorded in the process. Coding and its simultaneous analysis would help answer the questions highlighted in this research.

System Boundaries for Coding

- Coding for informative data is limited to the water heater market structure and stakeholder system (including supply chain memberships and processes). It does not include supply chain management or integration.
- Various manufacturing processes such as material production, component/part manufacturing, system integration, etc. have not been included for coding processes.
- Exports and mobile homes have not been pursued in detail in the stakeholder system analysis.
- Imports have been completely excluded from the analysis.
- An important consideration in the coding was to see how the product as a whole influences the stakeholders in the process and their interactions.
- Plumbing contractors as distributors also do an active business in parts service and repair that was not pursued due to complexity.

Manual Coding Assumptions

- The 'Table of Contents' page of the document under analysis was reviewed first, so as to avoid inspecting sections altogether, which were not relevant to the structural codes generated (central research questions).
- Speed reading was performed to identify relevant sections in the document from where information would be coded.
- In-vivo coding was used throughout the process. No separate codes were assigned to the data in the documents.
- 'Indexing' of data was used to code and link chunks of data. It is a process that is used to quickly locate the data without having to read every word in the document.
- During the coding process, necessary personal attributes for coding such as perseverance and patience, dealing with ambiguity when countering contrasting data, flexibility via various cycled of coding and the need to be ethical were exercised to ensure optimum results.
- It should be noted that the coding decisions were based on the researcher's cognitive skills, discretion and judgment.
- The analysis also helped identify potential sections within the document which would later be assessed in further detail.

4.5.4 Data Interpretation, Integration using Meta-Synthesis and Representation

The last steps in the methodology for development of stakeholder map and analysis on decision making aspect, were the interpretation of data from the codes followed by data integration and final representation of the findings. Additional steps were taken to ensure that the findings be situated in a larger interpretive context, and were presented in an accessible and usable form (Sandelowski et al. 1997).

Beyond the practical issue of accessing data from codes for the review, there is a question about the prospective nature of the search strategy (Walsh and Downe 2004). The assumption in classic meta-analysis is that the strategy is fully formed before formal searching (for data from codes) begins. The search strategy involved extracting useful information that would help answer the research questions, justified with examples, instances, or other credible sources of information. Repetitive data was not extracted from the codes. The aim was to extract meaningful information and organize it to represent it as an individual entities that would answer the research queries.

The codes obtained from manual coding were analyzed for information that could help solve the research questions described earlier. Also, extracted datum from the codes was being represented simultaneously in a separate manual as the coding process continued. Once these extracted data were individually represented (in graphical forms for stakeholder system and written forms for decision making aspect), they were analyzed again for themes, patterns, and other analytic information. This information was then integrated or synthesized to produce interpretative results.

For the next step, qualitative meta-synthesis was used to integrate the data, as it seeks to understand and explain phenomena through interpretation, rather than deduction (ibid). The next two paragraphs give a brief introduction to the concept of meta-synthesis.

Meta-Synthesis

Meta-synthesis attempts to integrate results from a number of different but inter-related qualitative studies (Walsh and Downe 2004). The technique has an interpretive, rather than aggregating, intent, in contrast to meta-analysis of quantitative studies (ibid). It is an important technique for qualitative researchers and can deepen understanding of the contextual dimensions of the residential water heater market.

Sandelowski and co-authors define meta-synthesis as *"the theories, grand narratives, generalizations, or interpretive translations produced from the integration or comparison of findings from qualitative studies"* (Sandelowski et al. 1997). Moreover they acknowledge three different approaches to meta-synthesis, namely:

- Integration of findings of one investigator's multiple studies in a related field. This approach may be regarded the 'purest', as it acknowledges this central tenet of constructed knowledge. The disadvantage is that it does not allow for the exploration of multiple viewpoints (Sandelowski et al. 1997; Walsh and Downe 2004).
- Synthesis of studies by different investigators in a related field. The second is the most commonly adopted approach to date (ibid).
- Quantitative summary of key elements across qualitative studies. The third is actually a methodological rather than a heuristic point and, arguably, this technique could be used in any meta-synthesis, although it would be a superficial one (ibid).

The technique used in this research study for data integration using meta-synthesis was to assemble the individual findings by one investigator (graphical forms for stakeholder system and written forms for decision making aspect) and synthesize them to produce more meaningful

results. It was performed keeping in mind central research goal of developing a stakeholder map, as well as a market analysis for the decision making process.

The qualitative meta-synthesis was not a trivial pursuit, but rather "*a complex exercise in interpretation: carefully peeling away the surface layers of studies to find their souls in a way that did the least damage to them*" (Sandelowski et al. 1997). The data was analyzed in sufficient detail to preserve the integrity of each study and at the same time, produce a usable synthesis (ibid).

The last step in this task involved representing the data in a manner is clear, consistent, easy to comprehend and that fulfills the various research objectives. As mentioned earlier, the stakeholder map was represented in a graphical form with individual representations of major actors, players, their relationships and the direction of flow of information between them. For the decision making aspect, the representation was divided into two major components: decisions for new construction and replacement. The final task involved perfecting this technique through carious cycles of coding, to ensure that the findings were managed, filtered, highlighted, and focused.

4.5.5 Recoding

'Recoding' is an analytic technique and refers to the various cycles of coding that were performed to generate the final result.

- The *first cycle of coding* was mainly performed to get acquainted with the process of manual coding as a qualitative data analysis (QDA) technique.
- The *second cycle of coding* was much more meticulous and resulted in the generation of a complete stakeholder map with inter-relationships between various stakeholders, their functions, their importance in making selection decisions and other qualitative/quantitative data. This process required several analytical skills such as prioritizing, integrating, synthesizing, and conceptualizing.
- Lastly, the *third and final cycle* of coding was mainly performed for refinement of results, addition of relevant information, editing unwanted information, and synthesizing it to appear more meaningful.

In total, three cycles of coding were performed to generate the stakeholder map whereas one cycle of coding was performed to generate a synthesis of the decision-making aspect and other market factors such as market barriers, and touch points among others, as shown in the next section.

4.6 Results

This section has been divided into five main subsections: stakeholder map, decision making process and preferences, market barriers, market trends, and significant touch points in the stakeholder system. This is in line with the main research goal of providing a comprehensive analysis on the U.S. residential water heater market.

4.6.1 U.S. Residential Water Heater Stakeholder Map

The U.S. residential water heater stakeholder map (Figure 4.3) is a description of the various stakeholders who can impact the source, supply and purchase of water heaters in the residential construction sector in the United States. An understanding of how these different players interact with one another to create a water-heater industry stakeholder system is useful in promoting and marketing new and energy-efficient water-heater technology (ORNL 2004). The stakeholder map includes key types of processes such as informational, financial, and physical interactions or transfers between the stakeholders.

Summary of Key Findings:

- The water heater market is highly variable depending on regional factors, climate and fuel availability (DOE 2010).
- This industry is highly fragmented with states having varying levels of market maturity. These largely depend on the incentive levels and market adoption (Navigant 2010).
- Different documents with supply-chain maps represented different facets of the system, but none captured all the facets in a single map.
- None of the documents that were analyzed had a detailed stakeholder system.
- Only one document mentioned exports, imports and mobile homes in the water heater supply chain (ORNL 2004).
- During the analysis contrasting opinions in the supply-chain were discovered.
- Plumbers install about 60% of all water heaters (DOE 2010). Moreover, installations done in remodels, new homes and multifamily residences are also most likely to be done by plumbers (ibid).
- Water heater replacements make up only 10-20% of a plumber's business (ibid).
- Some findings from the analysis spoke about the link or relationship between two stakeholders without any supporting data. For example, one document mentioned that distributors and wholesalers sell water heaters directly to the public, without substantial proof or evidence (NEEA 2012).
- Based on the interview conducted by Northwest Energy Efficiency Alliance (NEEA) it was found that installers resell more than 91% of the water heaters they install (ibid).
- In most cases, component manufacturers take the role of a wholesaler or distributor and sell the product directly to installers (Navigant 2010).
- The residential water heater market is dominated by a small number of manufacturers
- There were differences in the way the stakeholders appeared in the supply chain. For example one stakeholder was identified by different titles in different documents such as installation specialists, installer, plumber (installer), system installer, etc.
- Customers for replacement residential water heaters are homeowners and rental property owners and managers; builders are the primary customers in new construction markets (PG&E 2012).
- Trucking was the only mode of transport explicitly identified in the documents that was used in the supply-chain (ORNL 2004).

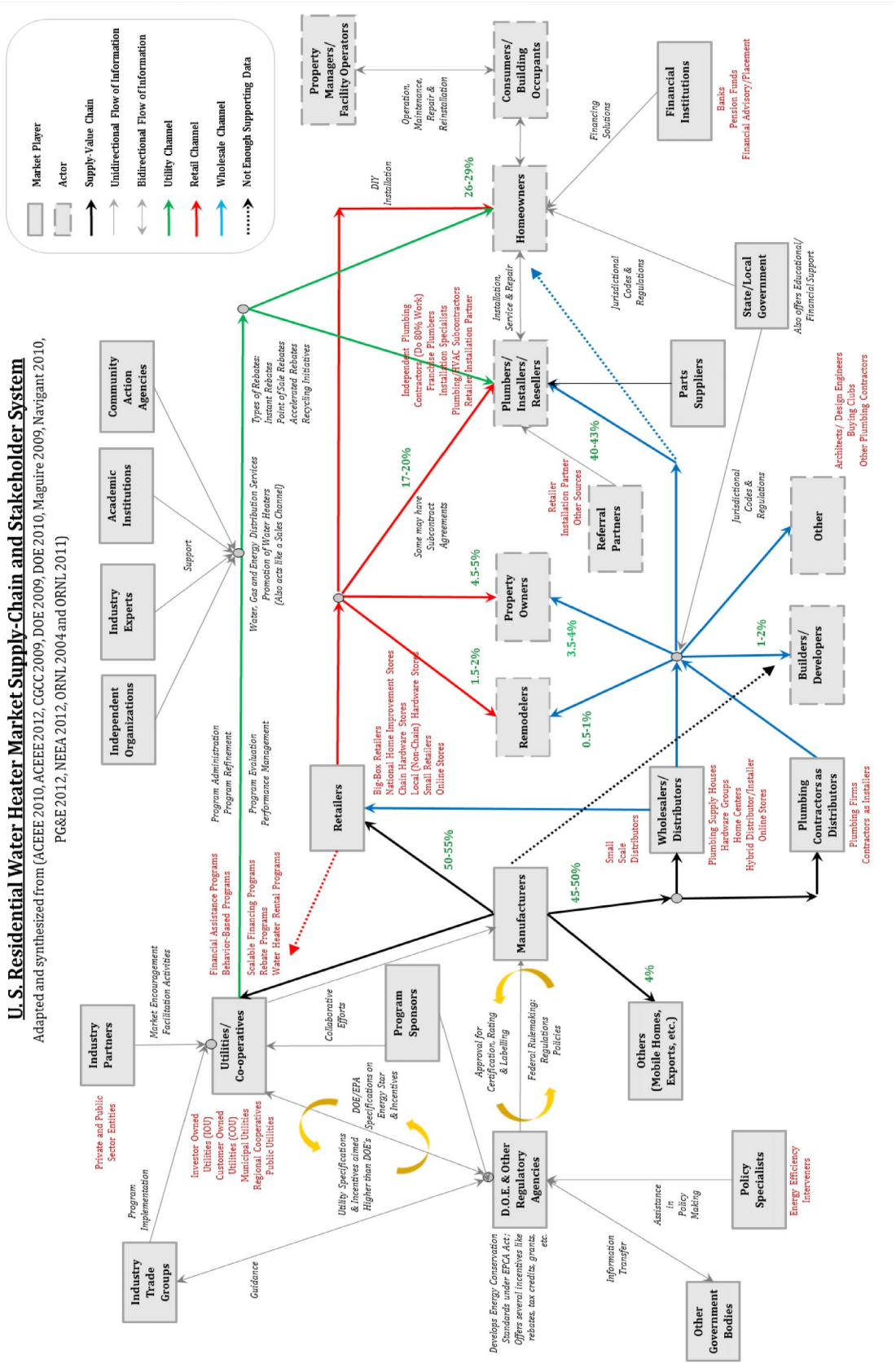

Figure 4.3: U.S. residential water heater stakeholder map

At a national level, the ***Department of Energy (DOE)*** is the most significant stakeholder and is charged with developing energy conservation standards for residential water heaters under section 325(e) (4) (B) of the Energy Policy and Conservation Act (EPCA) (PG&E 2012). The most recent standards for residential water heaters were issued March 31, 2010 and were applied starting April 16, 2015 for residential water heaters (ibid). In addition, government incentives will make purchasing ENERGY STAR qualified water heaters more attractive to consumers (DOE 2009). The federal energy efficiency tax credit and other financial incentives are targeted at motivating the buyers.

Other ***regulatory agencies*** oversee energy efficiency programs and offer guidance related to the implementation of potential relevant program design elements that may be incorporated to a new water heater programs (PG&E 2012). ***Policy specialists*** assist the government in current and future policy decision making. ***Program sponsors*** can boost savings by leveraging current federal tax credits for high-efficiency water heaters (DOE 2009).

Market structure, or value chain, connects the manufacturer of a water heater with the ultimate end user (PG&E 2012). Though, there are only two main channels that bring the products from manufacturer to the consumer, the ***retail channel*** and the ***wholesale channel***, a third channel called ***utility channel*** has also been included as they play a critical role in promotion of advanced technologies. The wholesale channel, plumbing contractors and builders, serves replacement as well as new construction demand (ibid).

Utilities and other ***program sponsors*** are gaining experience in developing strategies to promote energy efficient water heaters (DOE 2010). More than two dozen utility sponsored programs and 37 state programs are promoting ENERGY STAR qualified water heaters (ibid). Some utilities, including a number of regional energy-supply cooperatives, also sell specific energy efficient units to homeowners and/or plumbing contractors/water-heater installers (ORNL 2004). These sales are often subsidized, providing additional profit to the installer and subsequent savings to the homeowner (ibid).

As was seen for many ENERGY STAR products, when DOE sets an appropriately strong specification the utilities will rally around it and often offer significant incentives (ibid). These incentives are also an attempt to make it worthwhile for manufacturers to invest in new production lines and for distributors to stock products they would not ordinarily stock (ibid).

While previously, water heater sales were split roughly 50/50 between the retail and wholesale markets, declines in housing construction and the sputtering national economy between 2008 – 2012 led to retail sales gaining prominence in the overall supply chain, particularly the big box retailers (NEEA 2012). Manufacturers supply 50-55% of water heaters to retailers, 45-50% to wholesalers/contractors, 4% to mobile homes & exports and a small portion to the utilities (DOE 2010; NEEA 2012; ORNL 2004).

While component manufacturing is mainly done abroad, water heater assembly is mainly done in the U.S by the ***manufacturers*** (CGGC 2009). As of 2008, A.O.Smith, Rheem Manufacturing and Bradford White made 96% of all residential water heaters in the U.S., with the remainder manufactured by several smaller companies, many of which are solar water heater manufacturers

(DOE 2010). A.O. Smith and Rheem distribute their products through retail and wholesale channels whereas Bradford White products are sold exclusively by wholesalers (PG&E 2012). Meanwhile, manufacturers provide most of the in-store signage and collateral materials found in national retailers (DOE 2010).

Retailers sell directly to consumers who do the installation themselves (52-58%) or use one of the retailer's ***installation partners*** (34-40%), with whom they may have subcontract agreements (NEEA 2012; PG&E 2012). The Home Depot and Lowe's are the leading big-box retailers of residential water heaters. They also include chain department stores such as Sears, and chain hardware stores such as Ace Hardware, True Value Hardware, and others (NEEA 2012). These retailers also sell to ***property owners*** (9-10%) and ***remodelers*** (3-4%) (DOE 2010). According to interviews by Northwest Energy Efficiency Alliance, bigger retailers place more emphasis on price as a selling point whereas smaller retailers compete on service (NEEA 2012).

The wholesale channel contains two main players, ***distributor/wholesaler*** and ***plumbing contractor (as distributor)*** who receive and store products from the manufacturers, provide limited technical support, store spare parts and provide limited training (Navigant 2010). There are nearly 100 distributors of water heaters with the largest being Ferguson, Johnstone Supply and Winnelson (DOE 2010). Plumbing contractors that act as distributors include George Morlan, Grover, Rush, and others (NEEA 2012).

About 87% of water heaters from the distributors and contractors go to the plumbers, with an additional 7-8% to property owners, 2-4% to builders/developers, 1-2% to remodelers (DOE 2010) and a small percentage to other market players such as buying clubs. Many distributors and wholesalers (known as plumbing supply houses) sell directly to the public and/or offer installation services (NEEA 2012). There are also small-scale distributors who represent about 5% of the water heater market, supplying to both wholesalers and retailers, as well as occasionally to builders and plumbers, i.e., installers (ORNL 2004). Distributors determine what products are available to plumbers and are an efficient way to reach plumbers (DOE 2010).

Plumbers/Installers obtain products from distributors and perform site assessment, system installation and maintenance (Navigant 2010). Plumbers can be strategic partners for water heater rebate programs because they directly purchase or influence the purchase of about 60% of all water heaters (DOE 2010). They often make recommendations to the consumer based on the consumer's characteristics and needs, and their own interests, in terms of expected profits revenues, the chances of getting the job, a lasting relationship with the client, and their reputation in general (NEEA 2012).

This group consists of independent plumbing contractors (approximately 80 % of the market) who install water heaters as part of their services, and installation specialists (e.g., Fast Water Heaters) (NEEA 2012). Installers usually work with a limited number of suppliers, generally ones with whom they have long-standing relationships (Navigant 2010).

Installers resell more than 91% of the water heaters they install, as ***resellers*** (NEEA 2012). ***Parts suppliers***, plumbing contractors, and installers also do an active business in parts service and repair. (ORNL 2004)

The ***state/local government*** provides educational and/or financial support for the adoption of energy-efficient residential water heaters (ORNL 2004) In addition to consideration of jurisdictional codes and regulations (NEEA 2012), rebates may be available from government entities in some parts of the country due to funding provided through the American Recovery and Reinvestment Act of 2009 (DOE 2009) and other types of legislation. ***Facility managers/operators*** as well as other ***building occupants*** play an important role in post-installation phase of residential water heaters.

4.6.2 Decision Making Process and Preferences

The analysis of documents has given detailed insights into the decision making process for the selection of residential water heaters in U.S. Here, the synthesis of results has been divided into three major subsections: decision making in new construction, decision making in replacement situation, and finally, preferences in selection.

4.6.2.1 Decision Making in New Construction

Of the total water heater sales, 18% are for new construction whereas the 82% of majority sales are for replacement purposes (DOE 2010). In the new construction segment, building construction decisions are influenced by a number of factors, including a variety of information sources (PNNL 2003). Water heater technology selection occurs primarily in the construction phase for residential building construction, with contractors or subcontractors making the primary decision (ibid) in addition to builders (ORNL 2004). Building contractors/subcontractors give preference to products with which they are familiar and that are easy to install, as this requires the minimum amount of training for their crews and enables them to minimize their time per unit install (PNNL 2003).

Architects involved in customized new home construction as well as owners may also be responsible for model selection (ORNL 2004). Changes can be made through the permitting phase, up to the point at which materials have actually been purchased and/or installed. (PNNL 2003). Other residential construction players such as design engineers, and others may influence the building technology adoption decisions at different stages of the design and construction process.

4.6.2.2 Decision Making in Replacements: Emergency vs Planned

In the replacement segment, homeowners replace water heaters for three major reasons (DOE 2009) given below (Figure 4.4):

- The unit fails completely, i.e., emergency situation (39%).
- The performance of the unit becomes unacceptable, i.e., poor performance issues (26%).
- The homeowner decides it’s time for a new one, i.e., planned replacement (35%)

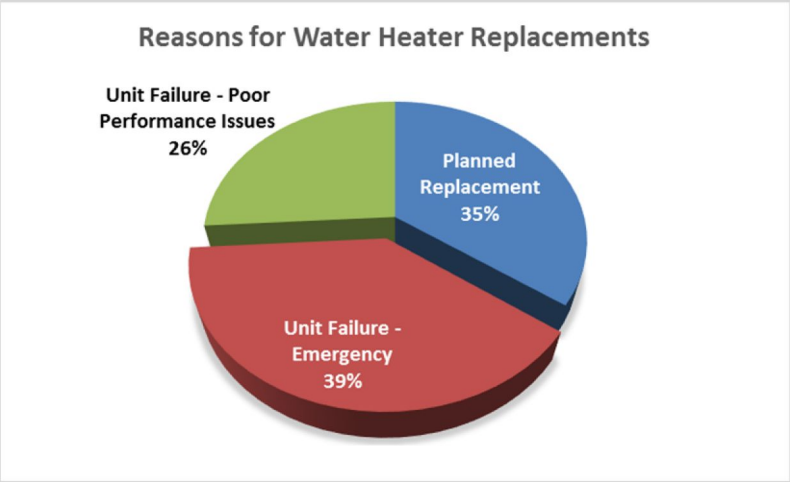

Figure 4.4: Reasons for replacing residential water heaters (DOE 2009)

The speed of the water heater purchase decision depends on whether the decision is an emergency or planned (DOE 2010; NEEA 2012; PG&E 2012). Nationally, only 29 percent of water heater purchases are planned replacements (DOE 2010). Most residential water heater replacements occur as emergency sales where immediate availability is essential to maintain comfort and function (ORNL 2011; PG&E 2012). The majority of water heater replacements occur on failure (DOE 2010; ORNL 2011). Since consumers are generally unwilling to be without hot water for more than a few hours, consumers put a premium on water heaters that can be delivered quickly (ORNL 2011). This creates an emergency situation where the consumer rarely performs an extensive search for an efficient water heater and instead takes whatever is 'on the truck' from the contractor or plumber.

Reasons for Emergency Replacements

The economy determines whether consumers plan water heater purchases or not (NEEA 2012). Planned replacements drop when purse strings tighten, making planned purchases in the next five years difficult to predict (ibid). This change in consumer attitude around spending and financing has a big impact on water heater purchases (PG&E 2012). It causes consumers to defer water heater replacement until they need to make an emergency decision and as a result select lower priced, less efficient options (ibid).

Another important factor is that the water heating appliance is often chosen by someone other than the primary occupant (CGGC 2009). For example, a home builder will purchase the unit for new homes but the energy cost savings would accrue to the homeowner. Similarly, a rental unit owner may not see the financial savings of an energy efficient unit if the utilities are paid by the renter (Murtishaw & Sathaye 2006)

Interviews conducted by Northwest Energy Efficiency Alliance showed that 28% of the consumer respondents purchased the existing unit directly from the plumber (NEEA 2012). As mentioned earlier, since emergency replacements are unplanned expenses, consumers prefer low cost bids from plumbers. This in turn may reinforce a notion among plumbers that all consumers

value the lowest cost water heaters possible, which may mean that plumbers do not take the time or effort to try to sell consumers on more efficient water heaters with higher initial cost (ACEEE 2010).

Surprisingly, consumer interviews also found that a majority of homeowners, many of whom had purchased their water heaters within the previous year, could not name the brand of water heater that was currently in their home (NEEA 2012). This and other pieces of evidence suggest that consumers are disengaged from water heater decisions (ibid).

According to expert and manufacturer interviews conducted by Northwest Energy Efficiency Alliance, when homeowners do think about their water heaters, they think of them as a plumbing fixture, not an appliance (NEEA 2012). Thus, homeowners may be less likely to do extensive research to determine the cost effectiveness of different water heating options prior to purchase of a replacement (Murtishaw and Sathaye 2006).

Furthermore, water heaters are "low touch" or "out of sight – out of mind" products, unlike refrigerators and other durable goods with which customers interact regularly. These factors have implications on customer purchasing behavior related to energy efficient water heaters and related marketing strategies (PG&E 2012).

4.6.2.3 Preferences

Consumers are interested in, but skeptical about efficient models (NEEA 2012). Consumers find that energy efficiency and ENERGY STAR rankings are significant selling points, rating them as the first and third most important factors respectively when purchasing a water heater in consumer interviews (ibid). For cost-conscious consumers, efficiency rebates and incentives are powerful motivations for buying efficient water heaters. Yet many consumers (26%) appear skeptical about claims of utility bill savings and are willing to pay only a modest premium for energy efficiency (ibid). This skepticism is reinforced by installers, some of whom have had poor experiences with heat pump water heaters in particular (ibid).

Of mention, consumers who do purchase advanced water heating technologies, such as tankless water heaters, often do so for the amenities they provide (shorter waits for hot water, continuous hot water, etc.) (ACEEE 2012). These technologies are likely to be chosen for these tangible benefits, and may also help save energy (based on various factors such as use patterns, etc.). Depending on the fuel source, additional costs may be incurred to increase electrical service capacity or to install gas supply infrastructure.

4.6.3 Market Barriers

The analysis of the collected documents also revealed various market barriers, which are synthesized (CGGC 2009; DOE 2009; NEEA 2012; ORNL 2004; PG&E 2012) below:

- High upfront/first cost including installation costs
- Regulation-driven costs
- Poor public awareness of the product
- Perception of poor and inadequate product reliability

- Insufficient installation and maintenance infrastructure
- Limited availability and selection of advanced and/or efficient products, since distributors do not want to stack the products until the market is developed.
- Limited interest in advanced water heating technologies
- High proportion of emergency replacements, since most purchase decisions are emergency decisions.
- Complicated code requirements
- Lack of objective sources of information
- Channel (wholesale and retail) indifference to high efficiency products
- Plumber/installer reluctance and technology perceptions
- Skepticism about performance of high efficiency water heater models
- High fuel prices
- Lack of specialized/customized service
- Confusion about the purpose of the product, e.g., some people think of heat pump water heaters as a space-conditioning heat pump.
- Lack of confidence with the product
- Lack of appropriate marketing skills or tools by installers
- 'Out of sight' purchases, since once a water heater is purchased, there is seldom any interaction with the occupants.

4.6.4 Market Trends

The U.S. residential water heater market is buffeted by two trends. On one hand, during periods of economic downturn, water heater sales tend to diminish and consumers become more skittish about major purchases (NEEA 2012). On the other hand, a growing imperative for energy conservation is expanding manufacturers' offerings of high efficiency water heaters (ibid). These two trends create both, a need and an opportunity to bridge the gap between cash-conscious consumers, and the money-saving opportunities offered by the incoming and new generation of high-efficiency water heaters (ibid).

Manufacturers have indicated that retail sales are weighted towards electric water heaters while wholesale/distributor sales are weighted towards gas, with a roughly 60-40 split in both cases (DOE 2010). This is consistent with the data on who buys water heaters through each channel, as it is reasonable to expect that homeowners purchasing and installing a water heater themselves are more likely to install an electric water heater than a gas water heater (ibid).

The distribution, sale and purchase of a water heater technology depends a lot on the region, climate and fuel availability (ibid). Gas is the predominant water heating fuel in the West, Midwest and Middle Atlantic, while in the Pacific Northwest and the South (with the exception of Texas), most water heaters are electric (ibid). A minority of homes in New England and Middle Atlantic continue to use fuel oil (ibid).

4.6.5 Significant Touch Points in the Stakeholder System

Touch points are points of power in the stakeholder system where a small shift in one factor can produce large changes in other factors. A well established and detailed stakeholder map can help identify places to intervene (Meadows 1999), to influence market actors, and other players in cognitive decision making.

In the supply chain, the most influential touch point lies with plumbers/installers, as they represent the supply chain group most trusted by consumers (NEEA 2012). If they have the education, training, and access to high efficiency inventory, they will effectively discuss high efficiency options with buyers (ibid). Resellers who disclose as much information as soon as possible about the installation, operation, and maintenance of high efficiency water heater options will help consumers feel more informed and confident about choosing a high efficiency water heater (ibid).

The other significant touch point lies with manufacturers. Manufacturers must decrease the costs of high efficiency units to shorten their payback period, by setting standards and creating supply to meet changing consumer needs (ibid). Streamlining the number of products on the market and calling out the products best suited for one's climate zone will also make it easier for salespeople and installers to improve the sales and marketing of high efficiency water heaters (ibid).

Lastly, online campaigns and consumer publication advertising facilitate consumer confidence, but relationships with utilities and installers present the greatest potential to improve consumer education and have them consider high efficiency units first (ibid).

4.7 Discussion and Conclusions

Through this research study, extensive information on the U.S. residential water heater stakeholder system and decision making process on selection of water heaters, was gathered, through screening documents and simultaneously, collecting them. It provided a detailed insight into the intricacies of decision making and several other aspects.

Earlier in this document, the literature review of collected documents on U.S. residential water heater market revealed that they did not possess adequate information on the various stakeholders. However, at the end of this study, several stakeholders were identified and represented in a stakeholder map, as actors and major players. This helped in the search for more detailed information on the major decision makers as well as their decision influences.

As mentioned earlier, one of the important aims of this research was to establish a coding methodology for qualitative data analysis, a method that is increasingly gaining momentum. This study established a manual coding strategy to analyze, extract and interpret data from the documents. Meta-synthesis was then used to integrate and represent the results.

In order to implement the DSTS and maximize the diffusion of eDSTs into the market, it was fundamentally important to understand the dynamics of the U.S. residential water heater supply chain and stakeholder system. This was achieved by creating a stakeholder map. The map comprised the supply-chain and the complete stakeholder system, development of both of which, were the primary goals of this study. While six different market reports had a supply chain on the water heater market in the U.S., it was inconsistent and ignored several stakeholders. The stakeholder map produced at the end of this study gave a detailed insight into the various actors, market players, their interrelationships and position. Subsequent participants under each stakeholder category were also provided.

Moreover, there was a need to perform a synthesis of the various documents, in order to fully understand how the selection decisions on residential water heaters were being made. This was satisfied by performing manual coding and using meta-synthesis, to integrate information from various documents, in a written form. As a result, a complete analysis of the decision making process was performed.

The statistics, facts and other facets of the decision making process were represented in two components: decision making in new construction and replacement situation. While, one of the research questions referred to who the major decision makers were, this analysis provided the corresponding decision makers for both, new construction and replacement.

This research also helped in synthesis and understanding of other system elements such as decision influences, selection preferences, market trends/barriers, and the significance of touch points in the market. Overall, a thorough analysis of major elements of the U.S. residential water heater market proceeded to realize opportunities for further research.

Lastly, in similarity to the previous chapter, various cycles of coding were performed to develop the stakeholder map, as a means of validation. The cycles of coding resulted in a stakeholder map as well as an analysis of the U.S. residential water heater market, after continuous improvement and refinement.

References

American Council for an Energy Efficient Economy (ACEEE). (2010). “Working Together to Transform the Market for Water Heaters.” *ACEEE Summer Study on Energy Efficiency in Buildings*, 9: 321-330, Washington, D.C.

American Council for an Energy Efficient Economy (ACEEE). (2012). *Emerging Hot Water Technologies and Practices for Energy-Efficiency as of 2011*, No. A112, Washington, D.C.

Bartels, R., Fiebig, D. G. and Soest, A. V. (2001). “Consumer and Experts: An Econometric Analysis of the Demand for Water Heaters.” No. 2003-26, Center for Economic Research, University of Tilburg, Netherlands.

Bosch, S. J. and Pearce, A. R. (2003). "Sustainability in Public Facilities: Analysis of Guidance Documents." *Journal of Performance of Constructed Facilities,* 17(1), 9-18.

Canada Mortgage and Housing Corporation (CMHC). (2004). "Types of Tools." Annex 31 - Energy-Related Environmental Impact of Building, *Energy Conservation in Buildings and Community Systems,* Ontario, Canada.

Center on Globalization, Governance & Competitiveness (CGGC). (2009). "Electric Heat Pump Water Heaters." *Manufacturing Climate Solutions - Carbon-Reducing Technologies and U.S. Jobs*, Chapter 6, Duke University, N.C.

Kotler, P. (1988). *Marketing Management: Analysis, Planning, Implementation, and Control*, 6th Edition, 194-203, Prentice Hall, N.J.

Maguire, J. B. (2009). "A Parametric Analysis of Residential Water Heaters." M.S. Thesis, Department of Mechanical Engineering, University of Colorado, CO.

Meadows, D. (1999). "Leverage Points – Places to Intervene in a System." The Sustainability Institute, Hartland, VT.

Murtishaw, S. and Sathaye, J. (2006). "Quantifying the Effect of the Principal-Agent Problem on US Residential Energy Use." Lawrence Berkeley National Laboratory, Berkeley, CA.

Navigant (2010). *Solar Water Heating Supply Chain Market Analysis,* Burlington, MA.

Northwest Energy Efficiency Alliance (NEEA). (2012). *2011 Water Heater Market Update,* No. 12-234, Portland, OR.

Oak Ridge National Laboratory (ORNL). (2004). *Heat Pump Water Heater Technology: Experiences of Residential Consumers and Utilities,* Oak Ridge, TN.

Pacific Gas and Electric Company (PG&E). (2012). "Market Focused Program Design to Accelerate Penetration of ENERGY STAR Water Heaters." *PG&E's Emerging Technologies Program*, No. ET12PGE3191, San Francisco, CA.

Pacific National Northwest Laboratory (PNNL). (2003). *Characterizing Building Construction Decision Processes to Enhance DOE Program Design,* No. 14507, Richland, WA.

Sandelowski, M., Docherty, S. and Emden, C. (1997). "Qualitative Metasynthesis: Issues and Techniques." Focus on Qualitative Methods, *Research in Nursing & Health,* 20: 365–371.

U.S. Department of Energy (DOE). (2009). *Water Heater Market Profile,* Washington, D.C.

U.S. Department of Energy (DOE). (2010). *Energy Star Water Heater Market Profile - Efficiency Sells,* Washington, D.C.

U.S. Department of Energy (DOE). (2012). “Building America Program - Water Heating Standing Technical Committee.” *Residential Energy Efficiency Stakeholder’s Meeting*, Austin, TX.

Walsh, D. and Downe, S. (2004). “Meta-synthesis Method for Qualitative Research: A Literature Review.” Methodological Issues in Nursing Research, *Journal of Advanced Nursing*, 50(2), 204–211.

Chapter 5: Conclusions and Summary

The conclusions from the various chapters of this research study and their corresponding summaries have been provided in this chapter, as shown below.

5.1 Chapter 1 - Introduction to the U.S. Residential Water Heater Market

This chapter discussed that residential water heating is an important energy use in homes with potential for significant savings. While the majority of water heaters in use today are of low efficiency, the market adoption of high efficiency technologies such as tankless, heat pump, and others, is increasing. Manufacturers are slowly beginning to produce these units in larger quantities and retailers and plumbers are offering these units on a more frequent basis. However, the market barriers to these technologies such as high first costs, lack of awareness, and others still remain.

Preliminary investigation has revealed that independent of energy or heat source, water heater design and operation are major determinants of public health risk and energy consumption in water heaters. The impacts of water quality on the water heating equipment and the associated health risks such as Legionella, carbon monoxide poisoning, among others, have to be considered in life cycle analyses. Correspondingly, public awareness of these issues may be limited and requires objective sources of information dissemination.

5.2 Chapter 2 - Analysis of Existing Web-based Decision Support Tools (eDSTs) on Selection of Residential Water Heaters

Chapter 2 evaluated Decision Support Tools (DSTs) on selection of residential water heaters in the U.S., to highlight any shortcomings and/or missing information in them. While, no direct literature that discussed inadequacies in water heater DSTs could be found, the collection and subsequent analysis of a small sample population of market reports showed several gaps that existed in current tools. Some of the reports which had DSTs within them, retorted several inconsistencies in their structure and functionality such as improper format, lack of comprehensive information, non-inclusion of all prevalent water heating technologies and factors for their selection, and limited stakeholder targets and involvement, among others.

For more detailed analysis on the state of existing tools and to establish their credibility, a new study was conducted to gather web-based existing Decision Support Tools (eDSTs) using a rigorous Internet search strategy and collection method. A preliminary tool screening was performed before collection, followed by development of a typology of eDSTs based on tool category, type and, other criteria, and finally stored as an Existing Tool Inventory (ETI) for further characterization. In total, 203 tools were collected. The evaluation of findings based on an algorithm developed by the researcher showed an equal proportion of tools specifically designed for selection purposes (42%), and purely educational purposes (41%). However, information on water heater sizing, which is a preliminary estimate of household hot water requirements before the purchase of new water heaters, appeared in only 27% of the tools.

An overwhelming majority of eDSTs collected were websites and publications with almost unrestricted access. The characterization of ETI, performed to access the effectiveness of existing tools, revealed startling results. 87% of tools did not mention any health and/or safety factors in their content, in addition to the about 50% of tools that did not mention installation and post-installation considerations. Trends from these tools show that tankless water heaters are becoming popular but storage water heaters are still an important consideration. Just over half of the total tools explicitly mentioned any goals in them.

From the above analysis, it can be concluded there the eDSTs may not be consistent in providing information on selection of residential water heaters. Several important factors that could have potential implications such as health and/or safety, operation and maintenance, and others were ignored. Moreover, several eDSTs did not cover advanced water heating technologies such as heat pump and solar, and may not have been transparent in their assumptions.

5.3 Chapter 3 - Development of Multi-Attribute Decision Support Tool Skeleton (DSTS) for Selection of Residential Water Heaters

As a result, Chapter 3 concentrated efforts on gathering relevant information on factors or parameters affecting residential water heater selection, with the aim of creating a DST in future that encompassed all selection factors and addresses all important stakeholders. This comprehensive set of factors and parameters was organized in a Decision Support Tool Structure (DSTS) through the Multi-Attribute Decision Making Approach (MADM). In order to enable true MADM to reach a clear and unambiguous solution, five sustainability capitals,:- economic, environmental, technical, human and social, were used as the underlying theme in DSTS Exoskeleton.

The use of sustainability capitals in the capital-criteria-indicator approach, and data integration using MADM approach, also added another dimension in addition to selection, where all water heaters could be evaluated or measured in sustainability variables and eventually, encourage a shift in decision making process towards more sustainable options. This could also be used as a starting platform for improving the overall sustainability of the residential hot water infrastructure.

On the other end, the formation of the DSTS Endoskeleton began by analyzing documents using electronic coding in ATLAS.ti, a Computer Aided Qualitative Data Analysis Software (CAQDAS) program. Attributes were generated from theses codes in a data extraction process and were organized in a Capital-Criteria Indicator approach to fulfill the MADM approach. Various cycles of coding were also performed in a process called recoding, for data refinement and as a form of validation.

The resultant DSTS addressed all the gaps and/or shortcomings mentioned earlier, by providing a detailed list of attributes, categorized as capital, critera, sub-criteria and indicators, along with providing notes/additional information on each attribute. Using a common coding methodology for all documents ensured that the results were consistent in information that was obtained from the codes. Moreover, the source documents were detailed market reports, prepared by industry trade groups or government agencies, adding to the credibility of the outcomes.

Important factors which may have been ignored by eDSTs, were included in the list of attributes such as, health/safety factors, installation considerations, post-installation considerations (repair, retrofit, operation and maintenance), ancillary devices on improving performance of water heaters, life cycle analysis tools, factors for public education and awareness, and others. While, the eDSTs may provide results that vary, the DSTS provided a thorough list of attributes, use of which could contribute to a marketplace shift towards adoption of more sustainable residential water heaters.

5.4 Chapter 4 - Analysis of U.S. Residential Water Heater Stakeholder System and Decision-Making Process

Lastly, Chapter 4 understood the interests and concerns of the various stakeholders for strategic and effective DSTS execution. In order to implement the DSTS and maximize the diffusion of eDSTs into the market, it was fundamentally important to understand the dynamics of the U.S. residential water heater supply chain and stakeholder system. This was achieved by creating a stakeholder map. While six different market reports collected in this study, had a supply chain (component of stakeholder map), it was inconsistent and ignored several stakeholders.

Thus, the final phase of the document examines existing residential water heater market documents, to develop a synthesis of the stakeholder map, current trade, and practices using meta-synthesis. An important aim of this chapter was to address the information asymmetry and potential differences in preferences between stakeholders at various decision stages in the market supply chain, which complicated the decision making process. The stakeholder map comprised the supply-chain and the complete stakeholder system, development of both of which, were the primary goals of this particular study. It gave a detailed insight into the various actors, market players, their interrelationships and position. Subsequent participants under each stakeholder category were also provided.

Moreover, there was a need to perform a synthesis of the various documents, in order to fully understand how the selection decisions on residential water heaters were being made. This was satisfied by performing manual coding and using meta-synthesis, to integrate information from various documents, in a written form. As a result, a complete analysis of the decision making process was performed.

The statistics, facts and other facets of the decision making process were represented in two components: decision making in new construction and replacement situation. While, one of the research questions referred to who the major decision makers were, this analysis provided the corresponding decision makers for both, new construction and replacement.

This research also helped in synthesis and understanding of other system elements such as decision influences, selection preferences, market trends/barriers, and the significance of touch points in the market. Overall, a thorough analysis of major elements of the U.S. residential water heater market proceeded to realize opportunities for further research.

Contributions

This research takes a holistic view of the water heater selection problems in the U.S. residential construction sector and offers solutions that address these barriers. The specific contributions have been listed below in two subsections.

Major Contributions:

1. While, there was no direct literature that provided an analysis of web based existing Decision Support Tools (eDSTs) on selection of residential water heaters in the U.S., several gaps and/or shortcoming were found to exist in the current pool of eDSTs. Thus, this research created a database of eDSTs known as Existing Tool Inventory (ETI), where 203 tools were collected. These eDSTs were stored in a hybrid organizing framework based on tool type, tool category, cost, source, and change of web link (URL), in a step called 'typology of eDSTs'. Next, they were parametrically analyzed based on several factors such as goals, water heater model type, fuel source, health/safety factors, and installation and post-installation considerations, in a step called 'characterization of ETI'. This comprehensive analysis and results of eDSTs resulted in the following contributions:

- An inventory of web-based eDSTs on selection of residential water heaters, stored in a hybrid organizing framework in a excel database
- A list of current gaps in existing body of knowledge on water heater eDSTs
- Detailed analysis of the findings from typology of eDSTs and characterization of ETI
- A record of current trends on eDSTs in the market

2. Just as in the earlier chapter, there was no direct literature found on the development of a Decision Support Tool Skeleton (DSTS) that comprises of an extensive list of selection factors for residential water heaters in U.S. Hence, this research study developed a detailed methodology to create a multi-attribute DSTS of criteria, sub-criteria and indicators, to enable rational and informed decision making, and which addresses the requirements of the various stakeholders. The specific contributions are:

- Establishment of a qualitative data analysis technique using electronic coding, in a Computer Aided Qualitative Data Analysis Software (CAQDAS) program called ATLAS.ti.
- A procedure for analysis of attributes generated from codes, on the basis of sustainability assessment capitals: economic, environmental, technical, human, and social, and subsequent organization in a capital-criteria-indicator approach
- A multi-attribute DSTS consisting of a comprehensive list of selection factors, integrated using Multi-Attribute Decision Making (MADM) approach, and classified as: five sustainability capitals, 27 criteria, 94 sub-criteria, and 364 indicators; It included additional information for several attributes for easier understanding
- Ultimately, a foundation or starting point of knowledge on residential water heater selections, from which several DSTs can be created

3. Though previous studies and reports on the U.S. residential water heater market structure had been established in sufficient detail, it missed several key components like a complete supply-chain, inclusion of various stakeholders, relationship between the stakeholders, among others. Through this study, a stakeholder map (comprising of the supply-chain and the stakeholder system) was created to integrate the findings from various individual studies using meta-synthesis and subsequently, interpret the results. A stakeholder map encompasses all stakeholders in a single system, consisting of major actors, players, their inter-relationships and a supply chain. The specific contributions of this study are:

- Establishment of a manual coding methodology for data analysis from water heater market reports, interpretation and integration using meta-synthesis, and finally representation in graphical form.
- Development of a stakeholder map comprising of several stakeholders, categorized as market actors and players, organized and represented through their inter-relationships; Includes mention of participants under each stakeholder category
- A detailed supply-chain analysis starting from the manufacturer to the various end users through three main channels: wholesale, retail and utility

4. The analysis of the various U.S. residential water heater market documents provided detailed insights into various facets of the market such as the decision making process, preferences of water heater types, market trends, barriers, and significant touch points for intervention. The last leg of this research study, integrated all the findings from the various individual studies using meta-synthesis to give an extensive coverage of each facet. Specifically, a detailed analysis of the major decision makers, influencers, stages, and the process of decision making were studied and synthesized, to establish a starting point for future research initiatives on the subject.

Other Contributions:

5. Throughout the course of this research, about 70 documents on U.S. residential water heater market were collected. This compilation was represented as an important database of U.S. residential water heater market documents, collected at various phases of research and that has the potential to make data collection and analysis for successive research studies easier.

Implications

Implications for Research:

The findings from this study have important implications for both knowledge development and the utilization of qualitative research in the water heating industry. Firstly, this research served as a starting point for evaluation of existing web-based decision support tools on selection of residential hot water heaters in the United States. It could help create awareness among fellow academicians about the impending importance to the decision support tools in the residential water heater market. Additionally, it has the potential to serve as a reference for evaluation of decision support tools in general, that undergo parametric analysis. Also, the extensive use of coding, both manual and electronic using CAQDAS program will serve as a methodological guide for future ethnographers on the steps and processes in coding in the built environment domain. Since the coding process heavily relied on the cognitive skills of the researcher to make classifications and judgement, the resultant interpretations may vary when performed by others. This could possibly lead to other noteworthy results.

Implications for Practice:

This research study has numerous implications for practitioners and stakeholders of the residential water heating market in the United States. In addition to contributing to the existing body of knowledge, this research provided a starting point to raise public awareness, and attempts to positively influence the decision making process towards adoption of more sustainable options. Existing web-based DSTs can be used by tool users such as homeowners, plumbers, architects, contractors, builders, and others, to sort and finally select water heaters, enabling more informed decision making. Moreover, one or more tools can be filtered from a multitude of tools to suit their present needs and requirements.

The bodywork of factors, i.e., Decision Support Tool Skeleton (DSTS), can serve as a tool in itself and can take the following forms:

- An educational tool for plumbers, installers and other contractors on the current market profile, spectrum of water heaters available in the market, and their associated benefits as well as disadvantages.
- An awareness tool for public health and safety, identifying potential adverse health outcomes associated with hot water usage, impact on water quality and proper maintenance on the longevity/durability of water heaters, along with stimulation of more sustainable behavior, etc.
- An informative tool for all stakeholders of the residential water heater market to ensure information symmetry among them, as well as to empower decision makers to make their own choices as much as possible.

Lastly, the stakeholder map can positively impact the stakeholders in ensuring information symmetry, cognitive decision making skills and knowledge of existing stakeholder relationships which will consequentially enable true market transformation.

Limitations

This research study looks at a very important topic, that of residential water heating in the U.S., which has enormous pragmatic implications. Through the course of this study, several limitations were experienced, that are given below.

The existing web based Decision Support Tools (eDSTs) on residential water heater selection, collected at the beginning of chapter 2, were all searched using the Internet. The Internet is a powerful resource and is assumed to be available to most members of the society. This means that only tools that were accessible on the internet were analyzed in this research, whereas, several DST forms exist such as audio notes, video tapes, CD-ROMS, among others.

During the characterization of Existing Tool Inventory (ETI) at the end of chapter 2, a major assumption was that the parameters has to be explicitly mentioned as titles, headings, sub-headings or text highlights, in order to enable the researcher to identify relevant information during speed reading of the tools. A major limitation to the analysis was that there could be a possibility of tools mentioning parameter(s) within the body of content, rather than explicitly shown as a sub-headings or text highlights.

Another key limitation was that the data set (and thus, the conclusions from it) included documents resulted from the Internet search, from a particular point in time. This particular point in time included a major recession in the construction industry, which may have yielded different types of results, compared to a boom period. This was evidenced by some of the discussions on market trends and barriers (in chapter 4).

The qualitative data analysis (QDA) performed using electronic and manual coding in chapter 3 and chapter 4 respectively, was based on the researcher's cognitive skills, judgement and discretion. Since coding is an interpretive act, there is a possibility of varying results from coding methods and processes when performed by other ethnographers. As a result, the final interpretations, synthesis and results may slightly vary too.

Moreover, various cycles (iterations) of coding were adopted at the end of the coding processes, to manage, filter, highlight and focus the salient features of the qualitative data record for generating themes and concepts. However, the iterations were performed using the same coding methods and processes used previously, at the end of the first cycle of coding. Other coding methods could be used to arrive at other possible outcomes.

Future Research Needs

Residential water heating in the U.S. is a vast topic. The recent growth of the industry, coupled with arrival of advanced water heating systems and new market trends call for investigations and/or new research studies. This particular study too, could be performed in other ways, as described:

The typology of existing tools on residential water heater selection, and its subsequent characterization, could be performed on other tool forms such as brochures, manuals, video tapes, CD-ROMS, etc. This could help strengthen the existing tool results or offer new insights into the current state of the tools. In addition, the characterization of web based existing Decision Support Tools (eDSTs) could be performed using other parameters such as demographic factors, household type, type of distribution system, and others. This would again offer more detailed insights into the pool of tools.

A significant contribution of this research was the collection and storage in a database, of about 70 documents on U.S. residential water heater market, through the course of this study. While the methodology involved screening and subsequent analysis of the documents, those discarded could be analyzed to check if it impacts the current outcomes. Moreover, all the documents were collected using an Internet search, whereas other document forms could exist as manual publications, and others which could be assessed for results.

The Decision Support Tool Skeleton (DSTS) developed at the end of chapter 3, could be further categorized into secondary and tertiary criteria and so on, to decrease the complexity and increase the ease of usage. The DSTS could also be created on other principles or fundamentals other than sustainability, to offer varying results. Also, there is a need for detailed investigation into the most appropriate medium for implementation of the DSTS, as a database of critical or essential factors, into the marketplace.

As mentioned before, residential water heating in the U.S. has enormous practical implications. The dissemination of information from the DSTS is possible by creating several Decision Support Tools (DSTs) with varying complexity levels, to suit the stakeholders being targeted. For example, the DST could be used for selection, education or awareness. By portraying a priority criteria set with associated indicators could enable informed decision making. In other sense, the success of tool implementation at leverage points in the market could help validate the existing DSTS. Other validation methods could also be adopted.

Predominantly, the DSTS was developed through analysis of U.S. residential water heater market documents, some of which had DSTs within them. The final DSTS criteria or sub-criteria could be used as the basis for evaluation or further characterization of eDSTs (from chapter 2), to establish a detailed and thorough analysis of the current pool of tools.

Lastly, the stakeholder map, comprising of the supply-chain and the stakeholder system did not take some elements into consideration such as imports, exports, and supply to mobile homes, due to lack of relevant data. Its investigation would be an important future need to establish a detailed stakeholder map and its complete analysis. Also, a key limitation to the development of the stakeholder map was the particular point in time in which it was yielded. Thus, this study could be expanded to include a broader time frame to see whether the conclusions are consistent over time. While coding cycles were included during development, as a form of validation, other techniques such as inter-rater reliability test and expert reviews, could be adopted to strengthen the conclusions.

Appendix A: Typology of eDSTs in a Hybrid Organizing Framework

No.	Tool Category	Decision Support Tool Title	Source	Tool Type	Description	Cost	Web Link Changed?	Web Link
1	Selection & Sizing	Residential Water Heater Selection Guide	A.O. Smith	Publication	Residential Product C	Free	No	http://www.hotwater.com/resources/literature/catalogs/residential
2	Sizing	Apartment Building Sizing	A.O.Smith	Software	ProSize - Water Heate	Free	No	http://www.hotwatersizing.com/ApplicationData/Apartment.aspx
3	Selection	Hot Water Tank Vs. Tankless Water Heater	Action Auger	Website		Free	No	http://actionauger.com/hot-water-tank-vs-tankless-water-heater
4	Educational	Water Heaters: Choosing a New Water Heater	Advantage Airtech Ltd.	Website		Free	No	http://www.advantageairtech.com/water-heaters
5	Selection	Choosing a Water Heater	Air Conditioning, Heating and Refrigeration Institute	Website	Water Heaters	Free	No	http://www.ahrinet.org/site/579/Homeowners/Indoor-Comfort-Syst
6	Other	Indirect Water Heaters	Air Conditioning, Heating and Refrigeration Institute	Website		Free	Yes	http://www.ahrinet.org/site/840/Certification/AHRI-Certification-Pro
7	Educational	Tankless Water Heaters	Air Conditioning, Heating and Refrigeration Institute	Website		Free	Yes	http://www.ahrinet.org/site/581/Homeowners/Indoor-Comfort-Syst
8	Selection & Sizing	Tankless	Air Conditioning, Heating and Refrigeration Institute	Publication	A Primer for Contract	Free	Yes	http://www.ahrinet.org/App_Content/ahri/files/Homeowners/tankle
9	Educational	Storage Water Heaters	Air Conditioning, Heating and Refrigeration Institute	Website		Free	Yes	http://www.ahrinet.org/site/580/Homeowners/Indoor-Comfort-Syst
10	Educational	Heat Pump Water Heaters	Air Conditioning, Heating and Refrigeration Institute	Website		Free	Yes	http://www.ahrinet.org/site/582/Homeowners/Indoor-Comfort-Syst
11	Educational	Indirect-Fired Water Heaters	Air Conditioning, Heating and Refrigeration Institute	Website		Free	Yes	http://www.ahrinet.org/site/583/Homeowners/Indoor-Comfort-Syst
12	Selection & Sizing	The Alaska Consumer Guide to Water Heating	Alaska Housing Finance Corporation	Publication		Free	Yes	http://www.cchrc.org/sites/default/files/docs/Consumer_Guide_Ho
13	Selection	Electric Storage Tank Water Heater	Ameren	Publication	Ameren Missouri Resi	Free	Yes	http://www.ameren.com/-/media/missouri-site/Files/UEfficiency/Fo
14	Selection	Advanced Gas Water Heaters	American Council for Energy Efficient Economy	Publication	Emerging Technologie	Free	No	http://aceee.org/files/pdf/2006_AdvGasWH.pdf
15	Selection & Sizing	Water Heating	American Council for Energy Efficient Economy	Checklist/Matrix		Free	No	http://www.aceee.org/consumer/water-heating
16	Selection & Sizing	Domestic Water Heating Design Manual	American Society of Plumbing Engineers	Publication	2nd Edition	$209.95	No	https://aspe.org/node/1404
17	Educational	Understanding Potential Water Heater Scald Hazar	American Society of Sanitary Engineering - Scald Awar	Publication		Free	No	http://www.asse-plumbing.org/WaterHeaterScaldHazards.pdf
18	Educational	Scald Hazards Associated with Low-Flow Showerhe	American Society of Sanitary Engineering - Scald Awar	Publication		Free	No	http://www.map-testing.com/assets/files/ASSE%20Scald%20Hazard
19	Sizing	Residential Sizing Guide	American Water Heaters	Checklist/Matrix		Free	No	http://www.americanwaterheater.com/support/resSizing.aspx
20	Sizing	Product Sizing	Amtrol	Software	Choose a Calculator	Free	No	http://www.amtrol.com/support/sizing.html
21	Educational	Choosing the Right Minneapolis Tankless Water He	Aqua City	Website		Free	No	http://www.aquacityplumbing.com/Minneapolis-Plumbing/heating/
22	Selection & Sizing	Hot Water Heater Buying Guide	BGE Home - A Constellation Company	Checklist/Matrix		Free	No	https://www.bgehome.com/water_heaters_buying.php
23	Sizing	Water Heater Selection Guide	Blue Ridge Electric Membership Corp.	Checklist/Matrix	Greensmart	Free	No	http://www.blueridgeemc.com/water-heater-selection-guide
24	Sizing	General Sizing Formula	Bock Water Heaters	Checklist/Matrix		Free	No	http://www.bockwaterheaters.com/Portals/0/Engineering%20Manu
25	Selection & Sizing	2011 Residential Water Heating Solutions	Bosch	Publication		Free	No	http://www.prowaterheatersupply.com/PDFS/Bosch_Therm_Reside
26	Selection & Sizing	Tankless Water Heating Solutions	Bosch	Publication	Residential and Comn	Free	No	http://www.prowaterheatersupply.com/PDFS/Bosch_Tankless_Prod
27	Sizing	Tank Water Heater	Boulden Brothers	Website		Free	No	http://bouldenbrothers.com/water-heaters/tank-water-heater/
28	Educational	Tankless Water Heaters	Boulden Brothers	Website		Free	No	http://bouldenbrothers.com/water-heaters/tankless-water-heater/
29	Educational	Hybrid Water Heaters	Boulden Brothers	Website		Free	No	http://bouldenbrothers.com/water-heaters/hybrid-water-heaters/
30	Educational	Solar Water Heaters	Boulden Brothers	Website		Free	No	http://bouldenbrothers.com/solar-water-heaters/
31	Selection & Sizing	RightSpec® Residential Water Heater Sizing	Bradford White	Software	Everhot® Tankless Wa	Free	No	http://rightspec.bradfordwhite.com/Sizing/EverhotRes.aspx
32	Sizing	RightSpec® Residential Water Heater Sizing	Bradford White	Software	Energy Saver Tank-Ty	Free	No	http://rightspec.bradfordwhite.com/Sizing/Residential.aspx
33	Selection & Sizing	Water Heaters	California Energy Commission - Consumer Energy Cen	Website		Free	No	http://www.consumerenergycenter.org/residential/appliances/wate
34	Sizing	Residential Water Heater Sizing Guide	Center Point Energy	Checklist/Matrix	Home Energy Plus	Free	No	http://www.centerpointenergy.com/hsp/products/heatingandcoolin
35	Sizing	Gas Tankless Water Heaters - Choosing The Correct	Chilipepper Appliance	Website		Free	No	http://www.chilipepperapp.com/Artcls38-tankless-size.htm
36	Educational	Solar Water Heating Buyer's Guide	City of Richland, WA.	Publication		Free	No	http://wa-richland.civicplus.com/DocumentCenter/Home/View/72
37	Educational	Water Heaters	City of Rochester, Minnesota	Publication		Free	No	http://www.rochestermn.gov/departments/bldgsafety/brochures/R
38	Educational	Tankless Hot Water - Demand Water Heaters	Climate Works - Heating & Cooling	Website		Free	No	http://climateworks.ca/water-heaters/tankless-hot-water/
39	Sizing	Water Heater Buying Guide for Homeowners in Ha	Constellation Home	Website		Free	No	http://www.constellationhome.com/water-heater-buying-guide/
40	Educational	How EF Should Factor Into Your Water Heater Deci	Cool Power LLC.	Website		Free	No	http://blog.coolpowerac.com/2012/08/02/water-heater-decision/
41	Selection & Sizing	Water Heaters: Tank or Tankless?	Dave Yates	Publication	Make the right choice	Free	No	http://cloud.chiefarchitect.com/1/pdf/magazine-articles/water-heat
42	Selection	Water Heating	DBEDT - State of Hawaii	Publication	Hawaii Homeowner's	Free	No	http://energy.hawaii.gov/wp-content/uploads/2011/10/Hawaii-Hom
43	Selection	The Complete Buyer's Guide to Water Heaters	Deer Valley Plumbing Contractors Inc	Website		Free	No	http://deervalleyplumbing.blogspot.com/2014/04/how-to-pick-best-
44	Selection	What Water Heater is Best for You?	Denham's Plumbing & Drain Service	Website		Free	No	http://denhamsplumbing.com/magna-suspendisse-eleifend-at-nulla/
45	Educational	Guidelines for Earthquake Bracing of Residential W	Department of General Services, Division of the State	Publication		Free	No	http://www.seismic.ca.gov/HOG/waterheaterbracing_08-11-04.pdf
46	Sizing	Water Heater Sizing and Type	Direct Energy	Checklist/Matrix		Free	No	http://www.directenergy.com/ontario/home-services/water-heater/
47	Sizing	Tankless Electric Water Heater Sizing Guide	Eemax	Checklist/Matrix		Free	No	http://www.grainger.com/ec/pdf/Tankless-Electric-Water-Heater-Siz
48	Educational	ENERGY STAR Qualified Water Heaters — Which Ty	Energy Star - USODE, ESEPA	Website		Free	No	http://www.energystar.gov/index.cfm?c=water_heat.pr_help_me
49	Selection	Residential Water Heating Program	Gas Technology Institute - California Energy Commissi	Publication	Facilitating the Marke	Free	No	http://www.etcc-ca.com/sites/default/files/reports/ET11PGE1111%2
50	Educational	Heat Pump Water Heaters	Green Riverside	Website		Free	No	http://www.energydepot.com/RPUres/library/HPwaterheater.asp
51	Selection	Replacement Electric Water Heater	Green Riverside	Website		Free	No	http://www.energydepot.com/RPUres/library/REwaterheater.asp
52	Educational	Replacement Gas Water Heaters	Green Riverside	Website		Free	No	http://www.energydepot.com/RPUres/library/RGwaterheater.asp
53	Educational	Solar Water Heating	Green Riverside	Website		Free	No	http://www.energydepot.com/RPUres/library/Swaterheater.asp
54	Educational	Tankless or On-Demand Water Heaters	Green Riverside	Website		Free	No	http://www.energydepot.com/RPUres/library/TLwaterheater.asp
55	Educational	Water Heaters (Traditional)	Heat Relief - Heating and Cooling	Website		Free	No	http://www.heatrelieftoday.com/water-heaters/
56	Educational	Tankless Water Heaters	Heat Relief - Heating and Cooling	Website		Free	No	http://www.heatrelieftoday.com/water-heaters-tankless/
57	Selection	Demand (Tankless or Instantaneous) Water Heater	Home Innovation Research Labs. www.toolbase.org	Website		Free	No	http://www.toolbase.org/Building-Systems/Plumbing/demand-wate
58	Educational	Tankless Water Heaters	Home Innovation Research Labs. www.toolbase.org	Website		Free	No	http://www.toolbase.org/TechInventory/techDetails.aspx?ContentD
59	Educational	Heat Pump Water Heaters	Home Innovation Research Labs. www.toolbase.org	Website		Free	No	http://www.toolbase.org/TechInventory/TechDetails.aspx?ContentD

No.	Tool Category	Decision Support Tool Title	Source	Tool Type	Description	Cost	Web Link Changed?	Web Link
60	Educational	Hot Water Recirculation Systems	Home Innovation Research Labs. www.toolbase.org	Website		Free	No	http://www.toolbase.org/TechInventory/TechDetails.aspx?ContentD
61	Educational	Water Heaters with Space Heating Capacity	Home Innovation Research Labs. www.toolbase.org	Website		Free	No	http://www.toolbase.org/ToolbaseResources/level4TechInv.aspx?Co
62	Educational	Solar Water Heaters	Home Innovation Research Labs. www.toolbase.org	Website		Free	No	http://www.toolbase.org/Technology-Inventory/Plumbing/solar-wat
63	Selection	Choosing the Right Water Heater Replacement	Indy Renovation	Website		Free	No	http://www.indyrenovation.com/plumbing/water-heater-installation
64	Selection & Sizing	Even Flow: The Smart Consumer's Guide to Water H	Jack Mason	Publication		$0.99	No	http://www.amazon.com/Even-Flow-Smart-Consumers-Heaters-ebo
65	Educational	Water Heater Installation	LifeLine Plumbing	Website	Water Heater	Free	No	http://www.lifelineplumbing.com/water-heater.html
66	Educational	Residential Customers Guide to Solar Hot Water	Long Island Power Authority	Publication		Free	No	http://lipower.org/pdfs/cei/solar/shw-fact.pdf
67	Selection	Water Heater Buying Guide	Lowe's	Website		Free	No	http://www.lowes.com/cd_Water+Heater+Buying+Guide_57898949
68	Educational	Tankless Water Heater Guide	Lowe's	Website		Free	No	http://www.lowes.com/cd_tankless+water+heaters_1312372735_
69	Educational	Considering Water Heater Replacement	MAST Heating & Cooling	Website	Decision Making Tips	Free	No	http://www.mastheating.com/index.php/component/rsblog/view/7
70	Selection	Electric Water Heater vs. Gas Water Heater – Whicl	More Vent	Website		Free	No	http://www.moreventservices.com/blog/bid/74389/Electric-Water-H
71	Selection	Water Heaters	National Association of Realtors www.houselogic.com	Website	Appliance Buying Gui	Free	No	http://www.houselogic.com/home-advice/water-heaters/hot-water-
72	Educational	Is a Tankless Water Heater Right For You?	National Association of Realtors www.houselogic.com	Website		Free	No	http://www.houselogic.com/home-advice/water-heaters/tankless-w
73	Educational	Is Solar-Thermal Hot Water for You?	National Association of Realtors www.houselogic.com	Website		Free	No	http://www.houselogic.com/home-advice/solar-energy/is-solar-ther
74	Selection & Sizing	Water Heater Guide	Natural Resources Canada	Publication		Free	Yes	http://publications.gc.ca/collections/collection_2013/rncan-nrcan/M
75	Selection	Tank vs Tankless - The Big Decision	Navien Review	Website		Free	No	http://www.navienreview.com/index.php/component/content/articl
76	Selection & Sizing	Finding The Right Water Heater Pays Off	Neri & Russo	Website	Water Heaters	Free	No	http://www.neriandrusso.com/water-heaters/
77	Selection	Water Heaters	New Jersey Clean Energy Program	Website		Free	No	http://www.njcleanenergy.com/water-heaters
78	Educational	Homeowner Guide	Noritz	Website	Version 2	Free	No	http://www.noritz.com/wp-content/uploads/2013-Homeowner-Guic
79	Educational	Water Heaters, Tankless Water Heaters	North Texas Air	Website	Residential Heating ar	Free	No	http://www.northtxair.com/water-heaters.php
80	Educational	Solar Water Heating Systems	Orlando Utilities Commission	Publication	Residential Solar Ener	Free	No	http://www.ouc.com/docs/customer-brochures/solar_energy_guide
81	Selection	Impacts of Water Quality on Residential Water Hea	Pacific Northwest National Laboratory - USDOE	Publication		Free	No	http://www.pnnl.gov/main/publications/external/technical_reports/
82	Selection	Deciding Between A Traditional or Tankless Water H	Pippin Brothers - Home Services	Website		Free	No	http://www.pippinbrothers.com/blog/article/deciding_between_a_t
83	Educational	Water Heaters	Pompeii's Plumbing & Heating	Website	Water Heaters in Clev	Free	No	http://pompeiis.com/water-heaters-in-cleveland/
84	Selection	Tank Water Heater vs. Tankless Water Heater: Whi	Poole's Plumbing	Website		Free	No	http://www.poolesplumbing.com/blog/tank-water-heater-vs-tankles
85	Selection	Choosing the Best Water Heater	Power House - Alliant Energy	Website		Free	No	http://www.powerhousetv.com/energy-efficientliving/waterheating
86	Selection & Sizing	Water Heaters	Prime Plumbing Inc.	Website	REPLACING YOUR WA	Free	No	http://www.primeplumbinginc.com/water-heaters.html
87	Selection	Water Heater Buying Guide	PSNC Energy	Publication		Free	No	http://www.psncenergy.com/NR/rdonlyres/3645D2CC-1140-48A7-B
88	Sizing	DHW First Hour Rating	Residential Energy Dynamics Innovative Software Solu	Software	Red Calc Tool User Gu	Free	No	http://www.residentialenergydynamics.com/REDCalcFree/Help/DHV
89	Educational	Tankless Water Heaters	Rheem	Website	Condensing Tankless	Free	No	http://www.rheem.com/group/tankless-gas-water-heaters-condensi
90	Sizing	What Size of Water Heater do you Need?	Rheem	Website		Free	No	http://www.rheem.com/products/tank_water_heaters/how_to_size
91	Selection & Sizing	Selecting a Water Heater	Rheem	Website		Free	No	http://www.rheem.com/products/water_heating/selection
92	Educational	Water Heating Solutions for Home Owners	Rheem	Website		Free	No	http://www.rheem.com/products/tank_water_heaters/homeowners
93	Cannot be Ascertair	Rheem Tankless Water Heater Selection and Install	Rheem	Website		Free	Yes	http://www.rheem.com/products/water_heating/tankless/how_to_i
94	Sizing	Sizing Of A Residential Water Heater	Rheem - RUUD	Checklist/Matrix		Free	No	http://www.cpi.coop/wp-content/uploads/2012/12/Marathon_sizin
95	Sizing	Gas Water Heater Selection Guide	Richmond - The Water Heater Experts	Checklist/Matrix		Free	No	http://cdn.globalimageserver.com/FetchDocument.aspx?ID=48698d
96	Sizing	Electric Water Heater Selection Guide	Richmond - The Water Heater Experts	Checklist/Matrix		Free	No	http://cdn.globalimageserver.com/FetchDocument.aspx?ID=d5f0d25
97	Sizing	Rinnai Sizing Calculator	Rinnai	Software		Free	No	http://calc.rinnai.us/residentialapp.aspx?&SID=cxadmfi35uwi3gi0bj0
98	Selection	Energy Efficient Tankless Water Heaters	Rinnai	Publication		Free	No	http://www.directenergy.com/images/pdf/tankless-rinnai.pdf
99	Selection	Residential Tankless Water Heater Guide	Rinnai	Publication	The Beginning of Endl	Free	No	http://www.alpinehomeair.com/related/Rinnai_R_Series_Brochure.F
100	Selection	#5 Water Heating	Rocky Mountain Institute	Publication	Home Energy Briefs	Free	No	http://www.rmi.org/Knowledge-Center/Library/2004-17_HEB5Wate
101	Selection & Sizing	Choose the Right Water Heater for your Needs	Rona	Website	Water Heaters	Free	No	http://www.rona.ca/en/projects/Water-heaters
102	Selection & Sizing	Buying a Water Heater	Sears	Website	Water Heaters	Free	No	http://www.sears.com/en_us/sears-knowledge-center/home-appliar
103	Selection	How to Select a Water Heater	Sears	Website	Water Heaters	Free	No	http://www.sears.com/en_us/sears-knowledge-center/home-appliar
104	Sizing	A Guide to Selecting and Installing a Solar Hot Wate	SOLARH(2)OT, LTD.	Publication		Free	No	http://www.solarhotusa.com/support/literature/files/Guide.pdf
105	Selection	Tips for Buying a New Water Heater	State of Illinois	Publication	Domestic Hot Water E	Free	Yes	https://www.illinois.gov/KeepWarm/Documents/hotwaterheating.p
106	Educational	The Dish on Residential Hot Water Heaters	Sylla International, LLC.	Website		Free	No	http://syllainternational.com/modern-architects-blog/2014/03/prim
107	Selection & Sizing	Sizing Heaters and Steam Requirements for Domes	The Alstrom Corporation	Publication		Free	No	http://www.alstromcorp.com/PR/SHSRDHWSHOTELS.pdf
108	Selection	Model Considerations Before You Buy	The Home Depot	Website	Water Heaters	Free	No	http://www.homedepot.com/c/water_heater_buying_guide_HT_BG
109	Selection	Point of Use Water Heaters and Recirculating Pump	The Home Depot	Website		Free	No	http://www.homedepot.com/c/selecting_the_right_water_heater_H
110	Educational	Inspiration: Tankless Water Heaters	The Home Depot	Website		Free	No	http://www.homedepot.com/c/how_tankless_water_heaters_HT_BC
111	Educational	Electric VS Gas Hot Water Heaters	The Home Fixers	Website		Free	No	http://www.thehomefixers.com/plumbers/waterheaters/electric-vs-
112	Educational	ECM: Domestic Water-Heating Systems	U.S. Department of Housing and Urban Development	Website	W5. Replace Inefficier	Free	No	http://portal.hud.gov/hudportal/HUD?src=/program_offices/public_
113	Educational	Domestic Hot Water System Recommendations for	U.S. Department of Housing and Urban Development	Website	Energy Efficient Rehal	Free	No	http://rehabadvisor.pathnet.org/sp.asp?id=10771
114	Educational	Solar Hot Water Heaters	U.S. Department of Housing and Urban Development	Website	Energy Efficient Rehal	Free	No	http://rehabadvisor.pathnet.org/sp.asp?id=17845
115	Selection	Domestic Hot Water - Single Family Housing	U.S. Department of Housing and Urban Development	Website	Energy Efficient Rehal	Free	No	http://rehabadvisor.pathnet.org/sp.asp?id=9712
116	Selection	Energy Efficient Homes: Water Heaters	University of Florida	Publication		Free	No	http://edis.ifas.ufl.edu/pdffiles/FY/FY102500.pdf
117	Selection & Sizing	Choosing a New Water Heater	University of Georgia	Publication		Free	No	http://spock.fcs.uga.edu/ext/pubs/hace/HACE-E-60-06.pdf
118	Selection	Estimating Costs and Efficiency of Storage, Demanc	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/estimating-costs-and-efficier
119	Educational	Heat Pump Water Heaters	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/heat-pump-water-heaters

No.	Tool Category	Decision Support Tool Title	Source	Tool Type	Description	Cost	Web Link Changed?	Web Link
120	Selection	Selecting a New Water Heater	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/selecting-new-water-heater
121	Selection & Sizing	Sizing a New Water Heater	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/sizing-new-water-heater
122	Educational	Solar Water Heaters	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/solar-water-heaters
123	Educational	Storage Water Heaters	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/storage-water-heaters
124	Educational	Tankless Coil and Indirect Water Heaters	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/tankless-coil-and-indirect-wa
125	Educational	Tankless or Demand-Type Water Heaters	USDOE	Website	Energy Saver	Free	No	http://energy.gov/energysaver/articles/tankless-or-demand-type-wa
126	Selection	Water Heating -	USDOE Energy Efficiency and Renewable Energy	Publication	Energy Savers - Tips o	Free	No	http://energy.gov/sites/prod/files/2013/06/f2/energy_savers.pdf
127	Selection	Water Heating	USDOE Energy Efficiency and Renewable Energy	Publication	Technology Fact Shee	Free	No	http://apps1.eere.energy.gov/buildings/publications/pdfs/building_a
128	Selection	Residential Gas Storage Water Heaters	USDOE Energy Efficiency and Renewable Energy	Website	Federal Energy Manag	Free	No	http://energy.gov/eere/femp/covered-product-category-residential-
129	Educational	Residential Heat Pump Water Heaters	USDOE Energy Efficiency and Renewable Energy	Website	Federal Energy Manag	Free	No	http://energy.gov/eere/femp/covered-product-category-residential-
130	Selection	Energy Cost Calculator for Electric and Gas Water H	USDOE Energy Efficiency and Renewable Energy	Software	Federal Energy Manag	Free	No	http://energy.gov/eere/femp/energy-cost-calculator-electric-and-ga
131	Educational	Heat Your Water With the Sun	USDOE Energy Efficiency and Renewable Energy	Publication	A Consumer's Guide	Free	No	http://www.nrel.gov/docs/fy04osti/34279.pdf
132	Educational	Gas Storage Water Heaters	USDOE Energy Efficiency and Renewable Energy	Publication	Federal Energy Manag	Free	No	http://www.nrel.gov/docs/fy10osti/48285.pdf
133	Educational	Solar Water Heating	USDOE Energy Efficiency and Renewable Energy	Publication	Federal Energy Manag	Free	No	http://www.nrel.gov/docs/fy99osti/26013.pdf
134	Selection	Water Heating	Virginia Dept. of Mines, Minerals and Energy	Publication	Chapter 6	Free	No	https://www.dmme.virginia.gov/DE/LinkDocuments/HandbookWate
135	Cannot be Ascertair	Electric Water Heaters	Wabash County REMC	Publication		Free	D	http://www.wabashremc.com/media/water_heater.pdf
136	Selection & Sizing	A Retrofit Decision-Making Tool	WAPTAC	Other	Water Heater Guide	Free	No	http://www.waptac.org/Field-Standards-and-Guides/Water-Heater-(
137	Selection	Purchasing a New Electric Water Heater	Washington State University	Publication	Energy Efficient Wate	Free	No	http://www.energy.wsu.edu/documents/AHT_Efficient%20Water%2
138	Selection	Choosing the Right Tankless Water Heater	Washington Water Heaters	Website	Tankless Hot Water H	Free	No	http://www.washingtonwaterheaters.com/tankless_select.html
139	Selection	Purchasing & Installing Guide	Water Heater Leaking Hero	Database		Free	No	http://www.waterheaterhero.net/category/purchasing-guide/
140	Selection	How to Compare Water Heaters	Water Heater Reviews - www.watersbe.com	Website	Compare Water Heat	Free	No	http://watersbe.com/compare-water-heater-by-ratings/
141	Educational	A Hands-on Guide to Water Heaters	Weingarten, Larry & Suzanne	Publication	The Water Heater Wc	$35	No	http://www.abebooks.com/servlet/SearchResults?sts=t&tn=The+Wa
142	Educational	Buying a Hot Water Heater	Western Mechanical	Website		Free	No	http://www.western-mech.com/water-heaters/
143	Selection & Sizing	Buyer's Guide	Whirlpool	Website		Free	No	http://www.whirlpoolwaterheaters.com/buyers-guide/
144	Selection	Water Heaters	White's Plumbing, Inc.	Website		Free	No	http://www.whitesplumbing.net/services/water-heaters/
145	Sizing	Sizing a Tankless Water Heater	www.about.com - Bob Formisano	Website	Home Repair	Free	No	http://homerepair.about.com/od/plumbingrepair/qt/Sizing-A-Tankle
146	Sizing	Tankless Water Heaters - What You Need to Know	www.about.com - Bob Formisano	Website	Home Repair	Free	No	http://homerepair.about.com/od/plumbingrepair/ss/tankless_hwh.h
147	Educational	Compare Water Heaters to Save Energy	www.about.com - Murrye Bernard	Website	Home Renovations	Free	No	http://homerenovations.about.com/od/energysaving/a/Compare-W
148	Educational	Tankless Water Heater Basics	www.about.com - Murrye Bernard	Website	Home Renovations	Free	No	http://homerenovations.about.com/od/energysaving/a/TanklessWat
149	Educational	Your Ultimate Water Heater Buying Guide	www.bestwaterheaterreviews.org	Website		Free	No	http://bestwaterheaterreviews.org/
150	Selection & Sizing	Buyer's Guide - Natural Gas Water Heaters	www.citizensenergygroup.com	Publication		Free	No	http://www.citizensenergygroup.com/pdf/ProductGuides/waterheat
151	Selection	Water Heater Buying Guide	www.ConsumerReports.org	Website		Free	No	http://www.consumerreports.org/cro/water-heaters/buying-guide.h
152	Educational	How to Buy a Water Heater	www.consumersearch.com	Website		Free	No	http://www.consumersearch.com/water-heaters/how-to-buy-a-wat
153	Selection	Water Heater Buyers' Guide – Tankless or Tradition	www.coolray.com - Mr.Plumber	Website		Free	No	http://www.coolray.com/blog/article/tankless-vs-traditional-water-h
154	Educational	Tankless Water Heaters	www.coolray.com - Mr.Plumber	Website		Free	No	http://www.coolray.com/water_heaters/
155	Educational	Traditional Water Heaters	www.coolray.com - Mr.Plumber	Website		Free	No	http://www.coolray.com/tankless/
156	Educational	Water Heaters	www.coolray.com - Mr.Plumber	Website		Free	No	http://www.coolray.com/water-heaters/
157	Selection	What You Need to Know Before Buying a Water He	www.doityourself.com	Website		Free	No	http://www.doityourself.com/stry/hotwaterbuying#b
158	Educational	Tankless Water Heater Guide	www.ebay.com	Website		Free	No	http://www.ebay.com/gds/Tankless-Water-Heater-Guide-/1000000(
159	Selection	The Complete Water Heater Buying Guide	www.ebay.com	Website		Free	No	http://www.ebay.com/gds/The-Complete-Water-Heater-Buying-Guic
160	Sizing	What Tankless Water Heater is Right for You?	www.ebay.com	Website		Free	No	http://www.ebay.com/gds/What-Tankless-Water-Heater-is-Right-for
161	Selection & Sizing	How to Choose the Right Water Heater!	www.energyloans.org	Website	Water Heater	Free	No	http://www.energyloans.org/EnergyReference/body_waterheater.ht
162	Selection	Compare Electric vs. Gas Tankless Water Heaters	www.e-tankless.com	Website		Free	No	http://www.e-tankless.com/gas-vs-electric
163	Educational	Energy-Efficient Hot Water for Farms	www.extension.org - America's Research Based Learr	Website		Free	No	http://www.extension.org/pages/31803/energy-efficient-hot-water-
164	Selection	Choosing a New Water Heater	www.familyhandyman.com	Website		Free	No	http://www.familyhandyman.com/plumbing/water-heater/choosing
165	Selection	Tankless Water Heaters – Gas or Electric? You Deci	www.FaucetDepot.com	Website		Free	No	http://www.faucetdepot.com/resources/gas-electric-tankless-heater
166	Selection & Sizing	How To Choose The Best Energy Star Water Heater	www.funtimesguide.com	Website	Home Building/Remo	Free	No	http://homebuilding.thefuntimesguide.com/2010/03/energy_star_w
167	Selection	All About Water Heaters	www.GreenBuildingAdvisor.com	Website	Musings of an Energy	Free	No	http://www.greenbuildingadvisor.com/blogs/dept/musings/all-abou
168	Educational	Heat-Pump Water Heaters Come of Age	www.GreenBuildingAdvisor.com	Website	Musings of an Energy	Free	No	http://www.greenbuildingadvisor.com/blogs/dept/musings/heat-pu
169	Selection	Water Heating	www.GreenBuildingAdvisor.com	Website		Free	No	http://www.greenbuildingadvisor.com/green-basics/water-heating
170	Educational	Solar Water Heater	www.GreenBuildingAdvisor.com	Website	Musings of an Energy	Free	No	http://www.greenbuildingadvisor.com/blogs/dept/musings/solar-ho
171	Selection	Are Tankless Water Heaters a Waste of Money?	www.GreenBuildingAdvisor.com	Website	Musings of an Energy	Free	No	http://www.greenbuildingadvisor.com/blogs/dept/musings/are-tank
172	Sizing	New Guidelines for Multifamily Water Heating	www.homeenergy.org - Fredric S. Goldner	Checklist/Matri>	The Home Performan	Free	No	http://www.homeenergy.org/show/article/nav/water/page/13/id/1
173	Selection	Water Heaters and Energy Conservation- Choices, (	www.homeenergy.org - Larry and Suzanne Weingarte	Website	The Home Performan	Free	No	http://www.homeenergy.org/show/article/nav/hotwater/page/9/id/
174	Cannot be Ascertair	Sizing a Tankless Water Heater	www.hometips.com - Don Vandervort	Website		Free	Yes	http://www.hometips.com/buying-guides/sizing-tankless-water-heat
175	Educational	Solar Water Heaters Buying Guide	www.hometips.com - Don Vandervort	Website		Free	No	http://www.hometips.com/buying-guides/solar-hot-water-heaters.h
176	Educational	Tankless Water Heater Buying Guide	www.hometips.com - Don Vandervort	Website		Free	No	http://www.hometips.com/buying-guides/tankless-water-heater.htn
177	Sizing	Storage Water Heaters Buying Guide	www.hometips.com - Don Vandervort	Website		Free	No	http://www.hometips.com/buying-guides/water-heaters-convention
178	Educational	Point-of-Use Water Heaters Buying Guide	www.hometips.com - Don Vandervort	Website		Free	No	http://www.hometips.com/buying-guides/waterheaters-point-of-use
179	Educational	Why a Tankless Water Heater is A Great Home Ren	www.hometips4women.com - Tina Gleisner	Website		Free	No	http://www.hometips4women.com/tankless-water-heater-home-rer

No.	Tool Category	Decision Support Tool Title	Source	Tool Type	Description	Cost	Web Link Changed?	Web Link
180	Selection	Quick Guide to Buying a Water Heater	www.hotwaterfacts.com	Website		Free	No	http://www.hotwaterfacts.com/default.htm
181	Educational	How to Switch to a Tankless Water Heater	www.houzz.com	Website		Free	No	http://www.houzz.com/ideabooks/21634433/list/How-to-Switch-to-
182	Selection & Sizing	How to Choose a New Water Heater	www.howstuffworks.com - Charles W. Bryant	Website		Free	No	http://home.howstuffworks.com/how-to-choose-a-water-heater.htn
183	Selection & Sizing	Hot Water Heater Selection, Inspection, Installatior	www.InsectAPedia.com	Website		Free	No	http://inspectapedia.com/plumbing/Hot_Water.htm
184	Educational	Guide to Tankless Water Heaters	www.InsectAPedia.com	Website		Free	No	http://inspectapedia.com/plumbing/Tankless_Water_Heaters.htm
185	Educational	Solar Water Heater	www.insulationreviewed.com	Website		Free	No	http://www.insulationreviewed.com/solar-water-heater/
186	Selection	Tankless Water Heaters	www.JustTankless.com - Water Heater Experts	Website		Free	No	http://www.justtankless.com/index.htm
187	Sizing	Tankless Water Heater Buying Guide	www.plumberSurplus.com	Website		Free	No	http://www.plumbersurplus.com/Buying-Guides/Tankless-Water-He
188	Selection & Sizing	Water Heater Reviews	www.scaview.org	Website	On Water Heaters	Free	No	http://www.scaview.org/WaterHeaters.html
189	Educational	Tankless Water Heaters	www.tanklesswaterheater-reviews.com	Website		Free	No	http://www.tanklesswaterheater-reviews.com/
190	Cannot be Ascertair	Important Factors To Consider When Choosing A Ri	www.tanklesswaterheaterv.com	Website	Rinnai Tankless Wate	Free	D	http://www.tanklesswaterheaterv.com/rinnai-tankless-water-heater
191	Cannot be Ascertair	How To Choose The Right Water Heater For Your H	www.tanklesswaterheaterv.com	Website	What Kind Of Water H	Free	D	http://www.tanklesswaterheaterv.com/water-heater/
192	Cannot be Ascertair	Save Water, Energy And Money With A Tankless W	www.tanklesswaterheaterv.com	Website	Selecting The Best Tai	Free	D	http://www.tanklesswaterheaterv.com/tankless-water-heater/
193	Cannot be Ascertair	Selecting a Tankless Water Heater	www.tanklesswaterheatingguide.com	Website	Tankless Water Heate	Free	D	http://www.tanklesswaterheaterguide.com/#selecting
194	Educational	Hot Water Heaters – Answers to All of Your Questic	www.waterheaterpro.org	Website	Water Heater Resour	Free	No	http://www.waterheaterpro.org/
195	Selection	Buying an Electric Water Heater?	www.waterheaterpro.org	Website	Water Heater Resour	Free	No	http://www.waterheaterpro.org/electric-water-heater
196	Educational	Gas Hot Water Heaters	www.waterheaterpro.org	Website	Water Heater Resour	Free	No	http://www.waterheaterpro.org/gas-hot-water-heaters
197	Educational	Solar Water Heaters – How You Can Use the Sun to	www.waterheaterpro.org	Website	Water Heater Resour	Free	No	http://www.waterheaterpro.org/solar-water-heaters
198	Educational	Interested in Tankless Water Heaters?	www.waterheaterpro.org	Website	Water Heater Resour	Free	No	http://www.waterheaterpro.org/tankless-water-heaters
199	Educational	Choosing a Water Heater - The Basics	www.waterheaterrescue.com	Website	Know-How, Solutions	Free	No	http://www.waterheaterrescue.com/pages/WHRpages/English/Long
200	Educational	Water Heater Style Selection	Zoro - EZ Tips Technical Resources	Publication	Water Heater Selectic	Free	No	http://cloudfront.zoro.com/img/zoro_tips/water_heater_eZtip-1.pdf
201	Sizing	Tankless Water Heaters	Zoro - EZ Tips Technical Resources	Publication	Water Heater Selectic	Free	No	http://cloudfront.zoro.com/img/zoro_tips/water_heater_eZtip-3.pdf
202	Sizing	Standard Tank Water Heater	Zoro - EZ Tips Technical Resources	Publication	Water Heater Selectic	Free	No	http://cloudfront.zoro.com/img/zoro_tips/water_heater_eZtip-2.pdf
203	Educational	Point-of-Use and Hot Water Dispenser	Zoro - EZ Tips Technical Resources	Publication	Water Heater Selectic	Free	No	http://cloudfront.zoro.com/img/zoro_tips/water_heater_eZtip-4.pdf

Appendix B: Characterization (Parametric Analysis) of ETI

No.	Decision Support Tool Title	Source	Water Heater Type (Model)							W.H.Type	Inst. & Post-Inst. Considerations				Web Link
			Goals	Storage/ Tank	Tankless/ Demand	Solar	Heat Pump	Indirect	Other	Fuel Source	Installation/ Replacement	Repair/ Retrofit	Operation/ Maintenance	Health/ Safety	
1	Residential Water Heater Selection (	A.O. Smith	Yes	X	X		X			Electric and Gas				No	http://www.hotwater.com/resour
2	Apartment Building Sizing	A.O.Smith	Yes	X			X			Electric, Gas and Other				No	http://www.hotwatersizing.com/A
3	Hot Water Tank Vs. Tankless Water I	Action Auger	No	X	X					None			X	No	http://actionauger.com/hot-water
4	Water Heaters: Choosing a New Wat	Advantage Airtech Ltd.	Yes	X	X					None				No	http://www.advantageairtech.com
5	Choosing a Water Heater	Air Conditioning, Heating and Refrigerati	No	X	X		X	X		None			X	No	http://www.ahrinet.org/site/579/I
6	Indirect Water Heaters	Air Conditioning, Heating and Refrigerati	Yes					X		None				No	http://www.ahrinet.org/site/840/(
7	Tankless Water Heaters	Air Conditioning, Heating and Refrigerati	No		X					None	X			No	http://www.ahrinet.org/site/581/I
8	Tankless	Air Conditioning, Heating and Refrigerati	Yes		X					Electric and Gas	X			No	http://www.ahrinet.org/App_Cont
9	Storage Water Heaters	Air Conditioning, Heating and Refrigerati	No	X						Electric, Gas and Other				No	http://www.ahrinet.org/site/580/I
10	Heat Pump Water Heaters	Air Conditioning, Heating and Refrigerati	No				X			None	X			No	http://www.ahrinet.org/site/582/I
11	Indirect-Fired Water Heaters	Air Conditioning, Heating and Refrigerati	No					X		None				No	http://www.ahrinet.org/site/583/I
12	The Alaska Consumer Guide to Wate	Alaska Housing Finance Corporation	Yes	X	X				X	Electric, Gas and Other			X	No	http://www.cchrc.org/sites/defau
13	Electric Storage Tank Water Heater	Ameren	Yes	X			X			Electric				No	http://www.ameren.com/-/media
14	Advanced Gas Water Heaters	American Council for Energy Efficient Ecc	Yes	X	X					Gas		X		No	http://aceee.org/files/pdf/2006_A
15	Water Heating	American Council for Energy Efficient Ecc	No	X	X	X	X	X	X	Electric and Gas			X	No	http://www.aceee.org/consumer/
16	Domestic Water Heating Design Mar	American Society of Plumbing Engineers	Yes	X	X		X	X		Electric, Gas and Other	D	D	D	Yes	https://aspe.org/node/1404
17	Understanding Potential Water Heat	American Society of Sanitary Engineering	Yes							None				Yes	http://www.asse-plumbing.org/W
18	Scald Hazards Associated with Low-F	American Society of Sanitary Engineering	Yes							None				Yes	http://www.map-testing.com/asse
19	Residential Sizing Guide	American Water Heaters	No							Electric and Gas				No	http://www.americanwaterheater
20	Product Sizing	Amtrol	No							None				No	http://www.amtrol.com/support/
21	Choosing the Right Minneapolis Tanl	Aqua City	No		X					None				No	http://www.aquacityplumbing.cor
22	Hot Water Heater Buying Guide	BGE Home - A Constellation Company	Yes							Electric and Gas	X			No	https://www.bgehome.com/wate
23	Water Heater Selection Guide	Blue Ridge Electric Membership Corp.	Yes							None				No	http://www.blueridgeemc.com/w
24	General Sizing Formula	Bock Water Heaters	Yes					X		Electric, Gas and Other				No	http://www.bockwaterheaters.co
25	2011 Residential Water Heating Solu	Bosch	Yes	X	X		X			Electric and Gas	X			No	http://www.prowaterheatersupph
26	Tankless Water Heating Solutions	Bosch	Yes	X	X					Electric and Gas				No	http://www.prowaterheatersupph
27	Tank Water Heater	Boulden Brothers	No	X						None				No	http://bouldenbrothers.com/wate
28	Tankless Water Heaters	Boulden Brothers	No		X					None	X	X	X	No	http://bouldenbrothers.com/wate
29	Hybrid Water Heaters	Boulden Brothers	No						X	None	X	X	X	No	http://bouldenbrothers.com/wate
30	Solar Water Heaters	Boulden Brothers	No			X				None				No	http://bouldenbrothers.com/solar
31	RightSpec® Residential Water Heate	Bradford White	No		X					Gas and Other	X			No	http://rightspec.bradfordwhite.co
32	RightSpec® Residential Water Heate	Bradford White	No	X						Electric, Gas and Other	X			No	http://rightspec.bradfordwhite.co
33	Water Heaters	California Energy Commission - Consume	Yes	X	X	X	X			None			X	No	http://www.consumerenergycente
34	Residential Water Heater Sizing Guic	Center Point Energy	Yes							None				No	http://www.centerpointenergy.co
35	Gas Tankless Water Heaters - Choos	Chilipepper Appliance	Yes		X					Gas				No	http://www.chilipepperapp.com/A
36	Solar Water Heating Buyer's Guide	City of Richland, WA.	No			X				None				No	http://wa-richland.civicplus.com/D
37	Water Heaters	City of Rochester, Minnesota	Yes	X	X				X	None				No	http://www.rochestermn.gov/dep
38	Tankless Hot Water - Demand Wate	Climate Works - Heating & Cooling	No		X					None				No	http://climateworks.ca/water-hea
39	Water Heater Buying Guide for Hom	Constellation Home	Yes							Electric and Gas	X			No	http://www.constellationhome.co
40	How EF Should Factor Into Your Wat	Cool Power LLC.	No							None				No	http://blog.coolpowerac.com/201
41	Water Heaters: Tank or Tankless?	Dave Yates	Yes	X	X					Electric, Gas and Other	X			Yes	http://cloud.chiefarchitect.com/1/
42	Water Heating	DBEDT - State of Hawaii	Yes			X	X			Electric and Gas				No	http://energy.hawaii.gov/wp-cont
43	The Complete Buyer's Guide to Wat	Deer Valley Plumbing Contractors Inc	Yes	X	X	X				Electric and Gas	X		X	No	http://deervalleyplumbing.blogspc
44	What Water Heater is Best for You?	Denham's Plumbing & Drain Service	Yes		X					Electric and Gas				No	http://denhamsplumbing.com/ma
45	Guidelines for Earthquake Bracing of	Department of General Services, Divisior	No							None	X			No	http://www.seismic.ca.gov/HOG/
46	Water Heater Sizing and Type	Direct Energy	Yes							None				No	http://www.directenergy.com/ont
47	Tankless Electric Water Heater Sizing	Eemax	Yes		X					Electric				No	http://www.grainger.com/ec/pdf/
48	ENERGY STAR Qualified Water Heate	Energy Star - USODE, ESEPA	Yes	X	X	X	X			Gas				No	http://www.energystar.gov/index.
49	Residential Water Heating Program	Gas Technology Institute - California Ene	Yes	X	X				X	None	X			No	http://www.etcc-ca.com/sites/def
50	Heat Pump Water Heaters	Green Riverside	Yes				X			None	X			No	http://www.energydepot.com/RPI
51	Replacement Electric Water Heater	Green Riverside	No	X			X			Electric		X		No	http://www.energydepot.com/RPI
52	Replacement Gas Water Heaters	Green Riverside	No							Gas		X	X	No	http://www.energydepot.com/RPI
53	Solar Water Heating	Green Riverside	No			X				None	X		X	No	http://www.energydepot.com/RPI
54	Tankless or On-Demand Water Heat	Green Riverside	No		X					None				No	http://www.energydepot.com/RPI
55	Water Heaters (Traditional)	Heat Relief - Heating and Cooling	Yes	X						None				No	http://www.heatrelieftoday.com/(
56	Tankless Water Heaters	Heat Relief - Heating and Cooling	Yes		X					None				No	http://www.heatrelieftoday.com/(
57	Demand (Tankless or Instantaneous)	Home Innovation Research Labs. www.t	Yes		X					Electric and Gas				No	http://www.toolbase.org/Building
58	Tankless Water Heaters	Home Innovation Research Labs. www.t	No		X					None	X			No	http://www.toolbase.org/TechInv
59	Heat Pump Water Heaters	Home Innovation Research Labs. www.t	No				X			None	X			No	http://www.toolbase.org/TechInv

No.	Decision Support Tool Title	Source	Water Heater Type (Model)							W.H.Type	Inst. & Post-Inst. Considerations				Web Link
			Goals	Storage/ Tank	Tankless/ Demand	Solar	Heat Pump	Indirect	Other	Fuel Source	Installation/ Replacement	Repair/ Retrofit	Operation/ Maintenance	Health/ Safety	
60	Hot Water Recirculation Systems	Home Innovation Research Labs. www.t	No						X	None	X			No	http://www.toolbase.org/TechInv
61	Water Heaters with Space Heating C	Home Innovation Research Labs. www.t	No						X	None	X			No	http://www.toolbase.org/Toolbas
62	Solar Water Heaters	Home Innovation Research Labs. www.t	No			X				None	X			No	http://www.toolbase.org/Technol
63	Choosing the Right Water Heater Re	Indy Renovation	No		X					Electric and Gas	X	X		No	http://www.indyrenovation.com/
64	Even Flow: The Smart Consumer's Gi	Jack Mason	Yes	X	X	D	D	D	D	Electric, Gas and Other	X	D	D	Yes	http://www.amazon.com/Even-Fl
65	Water Heater Installation	LifeLine Plumbing	Yes							Gas	X	X		No	http://www.lifelineplumbing.com/
66	Residential Customers Guide to Sola	Long Island Power Authority	Yes			X				None				No	http://lipower.org/pdfs/cei/solar/
67	Water Heater Buying Guide	Lowe's	Yes	X	X	X	X			Electric and Gas				No	http://www.lowes.com/cd_Water
68	Tankless Water Heater Guide	Lowe's	No		X					None				No	http://www.lowes.com/cd_tankle
69	Considering Water Heater Replacem	MAST Heating & Cooling	Yes							None		X		No	http://www.mastheating.com/ind
70	Electric Water Heater vs. Gas Water	More Vent	No							Electric and Gas				No	http://www.moreventservices.cor
71	Water Heaters	National Association of Realtors www.hc	Yes	X	X	X				Electric and Gas				No	http://www.houselogic.com/home
72	Is a Tankless Water Heater Right For	National Association of Realtors www.hc	Yes		X					Electric and Gas				No	http://www.houselogic.com/home
73	Is Solar-Thermal Hot Water for You?	National Association of Realtors www.hc	No			X				None				No	http://www.houselogic.com/home
74	Water Heater Guide	Natural Resources Canada	Yes	X	X	X	X		X	Electric, Gas and Other	X		X	No	http://publications.gc.ca/collectio
75	Tank vs Tankless - The Big Decision	Navien Review	No	X	X					None				No	http://www.navienreview.com/inc
76	Finding The Right Water Heater Pays	Neri & Russo	Yes	X	X		X	X	X	Gas			X	No	http://www.neriandrusso.com/wa
77	Water Heaters	New Jersey Clean Energy Program	Yes			X	X			Gas	X			No	http://www.njcleanenergy.com/w
78	Homeowner Guide	Noritz	Yes		X					None	X			No	http://www.noritz.com/wp-conte
79	Water Heaters, Tankless Water Heat	North Texas Air	No		X					None				No	http://www.northtxair.com/water
80	Solar Water Heating Systems	Orlando Utilities Commission	Yes			X				None	X			No	http://www.ouc.com/docs/custon
81	Impacts of Water Quality on Resider	Pacific Northwest National Laboratory -	Yes	X	X					Electric and Gas	X		X	No	http://www.pnnl.gov/main/public
82	Deciding Between A Traditional or T	Pippin Brothers - Home Services	Yes	X	X					None		X	X	No	http://www.pippinbrothers.com/t
83	Water Heaters	Pompeii's Plumbing & Heating	No	X	X					None				No	http://pompeiis.com/water-heate
84	Tank Water Heater vs. Tankless Wat	Poole's Plumbing	No	X	X					Gas				No	http://www.poolesplumbing.com/
85	Choosing the Best Water Heater	Power House - Alliant Energy	No							Electric and Gas				No	http://www.powerhousetv.com/e
86	Water Heaters	Prime Plumbing Inc.	No							Electric and Gas		X		No	http://www.primeplumbinginc.cor
87	Water Heater Buying Guide	PSNC Energy	Yes	X	X					None	X			No	http://www.psncenergy.com/NR/
88	DHW First Hour Rating	Residential Energy Dynamics Innovative	Yes							None				No	http://www.residentialenergydyna
89	Tankless Water Heaters	Rheem	No		X					None				No	http://www.rheem.com/group/ta
90	What Size of Water Heater do you N	Rheem	No	X	X					None				No	http://www.rheem.com/products/
91	Selecting a Water Heater	Rheem	Yes	X	X	X			X	Electric, Gas and Other				No	http://www.rheem.com/products/
92	Water Heating Solutions for Home C	Rheem	No							Electric, Gas and Other				Yes	http://www.rheem.com/products/
93	**Rheem Tankless Water Heater Sele**	**Rheem**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**D**	http://www.rheem.com/products/
94	Sizing Of A Residential Water Heater	Rheem - RUUD	No							None				No	http://www.cpi.coop/wp-content/
95	Gas Water Heater Selection Guide	Richmond - The Water Heater Experts	Yes							Gas	X			No	http://cdn.globalimageserver.com
96	Electric Water Heater Selection Guid	Richmond - The Water Heater Experts	Yes		X	X			X	Electric	X			No	http://cdn.globalimageserver.com
97	Rinnai Sizing Calculator	Rinnai	Yes	X	X					Gas and Other				No	http://calc.rinnai.us/residentialap
98	Energy Efficient Tankless Water Heat	Rinnai	No	X	X					Electric, Gas and Other				No	http://www.directenergy.com/ima
99	Residential Tankless Water Heater (	Rinnai	Yes	X	X					Electric and Gas	X			No	http://www.alpinehomeair.com/r
100	#5 Water Heating	Rocky Mountain Institute	No	X	X	X	X		X	Electric and Gas		X		No	http://www.rmi.org/Knowledge-C
101	Choose the Right Water Heater for y	Rona	Yes	X	X		X		X	Electric, Gas and Other	X			No	http://www.rona.ca/en/projects/
102	Buying a Water Heater	Sears	Yes						X	Electric, Gas and Other				No	http://www.sears.com/en_us/sea
103	How to Select a Water Heater	Sears	Yes	X						Electric, Gas and Other				No	http://www.sears.com/en_us/sea
104	A Guide to Selecting and Installing a	SOLARH(2)OT, LTD.	No			X				None	X			No	http://www.solarhotusa.com/sup
105	Tips for Buying a New Water Heater	State of Illinois	Yes		X	X				None	X	X	X	No	https://www.illinois.gov/KeepWar
106	The Dish on Residential Hot Water H	Sylla International, LLC.	No		X	X	X			None				No	http://syllainternational.com/mod
107	Sizing Heaters and Steam Requireme	The Alstrom Corporation	No	X	X				X	None				Yes	http://www.alstromcorp.com/PR/
108	Model Considerations Before You Bu	The Home Depot	No	X	X				X	Electric, Gas and Other				No	http://www.homedepot.com/c/w
109	Point of Use Water Heaters and Reci	The Home Depot	Yes	X	X					None	X			No	http://www.homedepot.com/c/se
110	Inspiration: Tankless Water Heaters	The Home Depot	Yes		X					Electric and Gas				No	http://www.homedepot.com/c/ho
111	Electric VS Gas Hot Water Heaters	The Home Fixers	No		X					Electric and Gas			X	No	http://www.thehomefixers.com/p
112	ECM: Domestic Water-Heating Syste	U.S. Department of Housing and Urban D	Yes	X						Electric, Gas and Other		X		No	http://portal.hud.gov/hudportal/H
113	Domestic Hot Water System Recom	U.S. Department of Housing and Urban D	No							None		X		No	http://rehabadvisor.pathnet.org/s
114	Solar Hot Water Heaters	U.S. Department of Housing and Urban D	No			X				None	X			No	http://rehabadvisor.pathnet.org/s
115	Domestic Hot Water - Single Family I	U.S. Department of Housing and Urban D	Yes	X	X	X	X	X		None			X	No	http://rehabadvisor.pathnet.org/s
116	Energy Efficient Homes: Water Heat	University of Florida	No	X	X	X	X	X	X	Gas				No	http://edis.ifas.ufl.edu/pdffiles/FY
117	Choosing a New Water Heater	University of Georgia	Yes	X	X	X	X			Electric and Gas				No	http://spock.fcs.uga.edu/ext/pubs
118	Estimating Costs and Efficiency of St	USDOE	Yes	X	X		X			Electric, Gas and Other				No	http://energy.gov/energysaver/ar

No.	Decision Support Tool Title	Source	Water Heater Type (Model)							W.H.Type	Inst. & Post-Inst. Considerations				Web Link
			Goals	Storage/ Tank	Tankless/ Demand	Solar	Heat Pump	Indirect	Other	Fuel Source	Installation/ Replacement	Repair/ Retrofit	Operation/ Maintenance	Health/ Safety	
119	Heat Pump Water Heaters	USDOE	No	X	X		X		X	None	X		X	No	http://energy.gov/energysaver/ar
120	Selecting a New Water Heater	USDOE	Yes	X	X	X	X	X		Electric, Gas and Other				No	http://energy.gov/energysaver/ar
121	Sizing a New Water Heater	USDOE	Yes	X	X	X	X			None				No	http://energy.gov/energysaver/ar
122	Solar Water Heaters	USDOE	No			X				None	X		X	No	http://energy.gov/energysaver/ar
123	Storage Water Heaters	USDOE	Yes	X	X	X	X			None	X		X	No	http://energy.gov/energysaver/ar
124	Tankless Coil and Indirect Water Hea	USDOE	No					X	X	None	X		X	No	http://energy.gov/energysaver/ar
125	Tankless or Demand-Type Water He	USDOE	Yes	X	X	X				None	X		X	No	http://energy.gov/energysaver/ar
126	Water Heating -	USDOE Energy Efficiency and Renewable	Yes	X	X	X	X			None			X	No	http://energy.gov/sites/prod/files,
127	Water Heating	USDOE Energy Efficiency and Renewable	Yes	X	X		X		X	Electric, Gas and Other	X		X	Yes	http://apps1.eere.energy.gov/buil
128	Residential Gas Storage Water Heate	USDOE Energy Efficiency and Renewable	Yes	X	X	X	X	X		None				No	http://energy.gov/eere/femp/cov
129	Residential Heat Pump Water Heate	USDOE Energy Efficiency and Renewable	Yes				X		X	Electric				Yes	http://energy.gov/eere/femp/cov
130	Energy Cost Calculator for Electric ar	USDOE Energy Efficiency and Renewable	No							Electric and Gas				No	http://energy.gov/eere/femp/ene
131	Heat Your Water With the Sun	USDOE Energy Efficiency and Renewable	Yes			X				None	X		X	No	http://www.nrel.gov/docs/fy04ost
132	Gas Storage Water Heaters	USDOE Energy Efficiency and Renewable	No	X	X	X		X	X	Gas				No	http://www.nrel.gov/docs/fy10ost
133	Solar Water Heating	USDOE Energy Efficiency and Renewable	Yes			X				None	X			No	http://www.nrel.gov/docs/fy99ost
134	Water Heating	Virginia Dept. of Mines, Minerals and En	No	X	X	X	X	X		None	X		X	No	https://www.dmme.virginia.gov/D
135	**Electric Water Heaters**	**Wabash County REMC**	D	D	D	D	D	D	D	D	D	D	D	D	http://www.wabashremc.com/me
136	A Retrofit Decision-Making Tool	WAPTAC	Yes		X	X	X			Electric and Gas	X	X		Yes	http://www.waptac.org/Field-Star
137	Purchasing a New Electric Water Hea	Washington State University	No	X	X		X			Electric				No	http://www.energy.wsu.edu/docu
138	Choosing the Right Tankless Water H	Washington Water Heaters	Yes		X					Electric and Gas	X		X	No	http://www.washingtonwaterheat
139	Purchasing & Installing Guide	Water Heater Leaking Hero	No		X					Electric and Gas		X		No	http://www.waterheaterhero.net/
140	How to Compare Water Heaters	Water Heater Reviews - www.watersbe.	Yes	X	X	X	X			None				No	http://watersbe.com/compare-wa
141	A Hands-on Guide to Water Heaters	Weingarten, Larry & Suzanne	Yes	D	D	D	D	D	D	None	D	X	X	No	http://www.abebooks.com/servle
142	Buying a Hot Water Heater	Western Mechanical	Yes	X	X					Electric and Gas				No	http://www.western-mech.com/w
143	Buyer's Guide	Whirlpool	Yes							Electric and Gas			X	No	http://www.whirlpoolwaterheater
144	Water Heaters	White's Plumbing, Inc.	No		X					Electric and Gas	X			No	http://www.whitesplumbing.net/s
145	Sizing a Tankless Water Heater	www.about.com - Bob Formisano	No		X					None				No	http://homerepair.about.com/od/
146	Tankless Water Heaters - What You	www.about.com - Bob Formisano	No		X					None	X			No	http://homerepair.about.com/od/
147	Compare Water Heaters to Save Ene	www.about.com - Murrye Bernard	No	X	X	X				None				No	http://homerenovations.about.co
148	Tankless Water Heater Basics	www.about.com - Murrye Bernard	Yes		X					None				No	http://homerenovations.about.co
149	Your Ultimate Water Heater Buying	www.bestwaterheaterreviews.org	Yes							None				No	http://bestwaterheaterreviews.or
150	Buyer's Guide - Natural Gas Water H	www.citizensenergygroup.com	Yes	X	X				X	Gas			X	Yes	http://www.citizensenergygroup.c
151	Water Heater Buying Guide	www.ConsumerReports.org	No	X	X	X			X	Electric and Gas	X			Yes	http://www.consumerreports.org/
152	How to Buy a Water Heater	www.consumersearch.com	No							Gas	X			No	http://www.consumersearch.com
153	Water Heater Buyers' Guide – Tankl	www.coolray.com - Mr.Plumber	Yes	X	X					None				No	http://www.coolray.com/blog/arti
154	Tankless Water Heaters	www.coolray.com - Mr.Plumber	Yes		X					None				No	http://www.coolray.com/water_h
155	Traditional Water Heaters	www.coolray.com - Mr.Plumber	Yes	X						None				No	http://www.coolray.com/tankless,
156	Water Heaters	www.coolray.com - Mr.Plumber	Yes	X	X					None				No	http://www.coolray.com/water-he
157	What You Need to Know Before Buy	www.doityourself.com	Yes	X	X		X	X		None				No	http://www.doityourself.com/stry
158	Tankless Water Heater Guide	www.ebay.com	No		X					Electric and Gas	X		X	No	http://www.ebay.com/gds/Tankle
159	The Complete Water Heater Buying	www.ebay.com	Yes	X	X	X				Electric, Gas and Other				Yes	http://www.ebay.com/gds/The-Co
160	What Tankless Water Heater is Right	www.ebay.com	Yes		X					Electric and Gas	X			No	http://www.ebay.com/gds/What-'
161	How to Choose the Right Water Hea	www.energyloans.org	Yes							Electric, Gas and Other		X		No	http://www.energyloans.org/Ener
162	Compare Electric vs. Gas Tankless W	www.e-tankless.com	Yes		X					Electric and Gas	X	X	X	Yes	http://www.e-tankless.com/gas-v
163	Energy-Efficient Hot Water for Farm	www.extension.org - America's Researc	No		X					Electric and Gas	X			No	http://www.extension.org/pages/
164	Choosing a New Water Heater	www.familyhandyman.com	Yes	X	X		X			Electric and Gas				No	http://www.familyhandyman.com
165	Tankless Water Heaters – Gas or Ele	www.FaucetDepot.com	No		X					Electric, Gas and Other	X		X	No	http://www.faucetdepot.com/res
166	How To Choose The Best Energy Sta	www.funtimesguide.com	No	X	X	X	X	X		Electric and Gas				No	http://homebuilding.thefuntimesg
167	All About Water Heaters	www.GreenBuildingAdvisor.com	Yes	X	X	X	X	X	X	Gas				No	http://www.greenbuildingadvisor.
168	Heat-Pump Water Heaters Come of	www.GreenBuildingAdvisor.com	Yes				X		X	Electric	X			No	http://www.greenbuildingadvisor.
169	Water Heating	www.GreenBuildingAdvisor.com	No	X	X	X	X	X	X	Electric				No	http://www.greenbuildingadvisor.
170	Solar Water Heater	www.GreenBuildingAdvisor.com	No			X				None	X			No	http://www.greenbuildingadvisor.
171	Are Tankless Water Heaters a Waste	www.GreenBuildingAdvisor.com	Yes	X	X					Electric	X			No	http://www.greenbuildingadvisor.
172	New Guidelines for Multifamily Wat	www.homeenergy.org - Fredric S. Goldn	No		X					None				No	http://www.homeenergy.org/sho
173	Water Heaters and Energy Conserva	www.homeenergy.org - Larry and Suzan	Yes	X	X		X		X	Electric and Gas	X	X	X	Yes	http://www.homeenergy.org/sho
174	**Sizing a Tankless Water Heater**	**www.hometips.com - Don Vandervort**	D	D	D	D	D	D	D	D	D	D	D	D	http://www.hometips.com/buying
175	Solar Water Heaters Buying Guide	www.hometips.com - Don Vandervort	No			X				None				No	http://www.hometips.com/buying
176	Tankless Water Heater Buying Guide	www.hometips.com - Don Vandervort	Yes		X					Electric, Gas and Other				No	http://www.hometips.com/buying
177	Storage Water Heaters Buying Guide	www.hometips.com - Don Vandervort	Yes	X						Electric, Gas and Other				No	http://www.hometips.com/buying

No.	Decision Support Tool Title	Source	Water Heater Type (Model)							W.H.Type	Inst. & Post-Inst. Considerations				Web Link
			Goals	Storage/ Tank	Tankless/ Demand	Solar	Heat Pump	Indirect	Other	Fuel Source	Installation/ Replacement	Repair/ Retrofit	Operation/ Maintenance	Health/ Safety	
178	Point-of-Use Water Heaters Buying (	www.hometips.com - Don Vandervort	Yes		X					None				No	http://www.hometips.com/buying
179	Why a Tankless Water Heater is A Gi	www.hometips4women.com - Tina Gleis	No		X					None	X			No	http://www.hometips4women.co
180	Quick Guide to Buying a Water Heat	www.hotwaterfacts.com	No	X	X				X	Electric and Gas	X			No	http://www.hotwaterfacts.com/d
181	How to Switch to a Tankless Water H	www.houzz.com	Yes		X					None				No	http://www.houzz.com/ideabooks
182	How to Choose a New Water Heater	www.howstuffworks.com - Charles W. B	No	X	X	X	X			Electric, Gas and Other				No	http://home.howstuffworks.com/
183	Hot Water Heater Selection, Inspect	www.InsectAPedia.com	No	X	X					Electric, Gas and Other	X	X	X	Yes	http://inspectapedia.com/plumbir
184	Guide to Tankless Water Heaters	www.InsectAPedia.com	No		X					Electric, Gas and Other			X	No	http://inspectapedia.com/plumbir
185	Solar Water Heater	www.insulationreviewed.com	Yes			X				None				No	http://www.insulationreviewed.cc
186	Tankless Water Heaters	www.JustTankless.com - Water Heater E	No	X	X					Gas and Other				Yes	http://www.justtankless.com/inde
187	Tankless Water Heater Buying Guide	www.plumberSurplus.com	No		X					Electric and Gas	X		X	No	http://www.plumbersurplus.com/
188	Water Heater Reviews	www.scaview.org	Yes	X	X	X				Electric and Gas				No	http://www.scaview.org/WaterHe
189	Tankless Water Heaters	www.tanklesswaterheater-reviews.com	Yes		X					Electric, Gas and Other				Yes	http://www.tanklesswaterheater-r
190	**Important Factors To Consider Whe**	**www.tanklesswaterheaterv.com**	D	D	D	D	D	D	D	D	D	D	D	D	http://www.tanklesswaterheaterv
191	**How To Choose The Right Water He**	**www.tanklesswaterheaterv.com**	D	D	D	D	D	D	D	D	D	D	D	D	http://www.tanklesswaterheaterv
192	**Save Water, Energy And Money Wit**	**www.tanklesswaterheaterv.com**	D	D	D	D	D	D	D	D	D	D	D	D	http://www.tanklesswaterheaterv
193	**Selecting a Tankless Water Heater**	**www.tanklesswaterheatingguide.com**	D	D	D	D	D	D	D	D	D	D	D	D	http://www.tanklesswaterheaterg
194	Hot Water Heaters – Answers to All	www.waterheaterpro.org	Yes	X	X	X				Electric, Gas and Other				Yes	http://www.waterheaterpro.org/
195	Buying an Electric Water Heater?	www.waterheaterpro.org	No							Electric and Gas	X			Yes	http://www.waterheaterpro.org/e
196	Gas Hot Water Heaters	www.waterheaterpro.org	Yes							Gas				No	http://www.waterheaterpro.org/g
197	Solar Water Heaters – How You Can	www.waterheaterpro.org	No			X				None	X		X	No	http://www.waterheaterpro.org/s
198	Interested in Tankless Water Heater	www.waterheaterpro.org	Yes		X					Electric and Gas				No	http://www.waterheaterpro.org/t
199	Choosing a Water Heater - The Basic	www.waterheaterrescue.com	Yes		X					None				No	http://www.waterheaterrescue.cc
200	Water Heater Style Selection	Zoro - EZ Tips Technical Resources	Yes	X	X					None				No	http://cloudfront.zoro.com/img/z
201	Tankless Water Heaters	Zoro - EZ Tips Technical Resources	No		X					Electric, Gas and Other	X			No	http://cloudfront.zoro.com/img/z
202	Standard Tank Water Heater	Zoro - EZ Tips Technical Resources	No	X						Electric, Gas and Other				No	http://cloudfront.zoro.com/img/z
203	Point-of-Use and Hot Water Dispens	Zoro - EZ Tips Technical Resources	No		X					Electric, Gas and Other				No	http://cloudfront.zoro.com/img/z

Appendix C: Attribute (Initial) Coding in ATLAS.ti for DSTS Development

PD-Filter: All

HU: DSTS_Coding
File: [C:\Users\Pratik\Desktop\Final Thesis Documents\DSTS_Coding\DSTS_Coding.hpr7]
Edited by: Pratik Doshi
Date/Time: 2015-07-09 18:03:31

P 1: ACEEE 2012.pdf {71}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\ACEEE_2012.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: American Council for an Energy Efficient Economy
Name: Emerging Hot Water Technologies and Practices for Energy-Efficiency as of 2011
Year: 2012
Type: Report

P12: ASSE 2012.pdf {22}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\ASSE_2012.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: American Society of Sanitary Engineering
Name: Understanding Potential Water Heater Scalds
Year: 2012
Type: White Paper

P11: Balkema et al. 2002.pdf {22}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\Balkema_2002.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Balkema, A. J., Preisig, H. A., Otterpohl, R. and Lambert, F. J. D.
Name: Indicators for the Sustainability Assessment of Wastewater Treatment Systems
Year: 2002
Type: Journal Paper

P 2: Bartels et al. 2001.pdf {22}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\Bartels_2001.pdf] text/pdf

Families:

U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Bartels, R., Fiebig, D. G. and Soest, A. V.
Name: Consumer and Experts: An Econometric Analysis of the Demand for Water Heaters."
Year: 2001
Type: Research Paper

P 3: DOE 2010.pdf {57}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\DOE_2010.pdf] text/pdf
Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: U.S. Department of Energy
Name: Energy Star Water Heater Market Profile - Efficiency Sells
Year: 2010
Type: Report

P 4: DOE 2012a.pdf {20}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\DOE_2012.pdf] text/pdf
Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: U.S. Department of Energy
Name: Building America Program - Water Heating Standing Technical Committee
Year: 2012
Type: Presentation

P16: DOE 2012b {45}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\BTP_DOE_2012.pdf] text/pdf
Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: U.S. Department of Energy
Name: Strategy Guideline: Proper Water Heater Selection
Year: 2012
Type: Report

P13: FSC 2014.pdf {9}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\FSC_2014.pdf] text/pdf
Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Fisher, Sheehan & Colton

Name: Energy Conservation for Hot Water May be in Tension with Public Health Outcomes
Year: 2014
Type: Newsletter

P15: Hellstrom et al. 2000.pdf {7}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\HellStrom_2000.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Hellstrom, D., Jeppsson, U. and Karrman, E.
Name: A Framework for Systems Analysis of Sustainable Urban Water Management
Year: 2000
Type: Journal Paper

P 5: Maguire 2009.pdf {31}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\Maguire_2009.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Maguire, J. B.
Name: A Parametric Analysis of Residential Water Heaters
Year: 2009
Type: M.S.Thesis

P10: Makropoulos et al. 2008.pdf {4}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\Makropoulos_2008.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Makropoulos, C. K., Natsis, K., Liu. S., Mittas, K. and Butler, D.
Name: Decision Support for Sustainable Option Selection in Integrated Urban Water Management
Year: 2008
Type: Journal Paper

P 6: NREL 2013.pdf {50}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\NREL_2013.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: National Renewable Energy Laboratory
Name: Comparison of Advanced Residential Water Heating Technologies in the United States

Year: 2013
Type: Technical Report

P 7: ORNL 2011.pdf {52}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\ORNL_2011.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Oak Ridge National Laboratory
Name: Research and Development Roadmap for Water Heating Technologies
Year: 2011
Type: Report

P 9: PERC 2011.pdf {60}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\PERC_2011.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Propane Education and Research Council
Name: Comparing Residential Water Heaters for Energy Use, Economics, and Emissions
Year: 2011
Type: Report

P 8: PG&E 2012.pdf {36}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\PG&E_2012.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Pacific Gas and Electric Company
Name: Market Focused Program Design to Accelerate Penetration of ENERGY STAR Water Heaters
Year: 2012
Type: Report

P14: PNNL 2013.pdf {27}~ [Managed in My Library -> C:\Users\Pratik\Desktop\DSTS_Coding\PNNL_2013.pdf] text/pdf

Families:
U.S. Water Heater Market Documents (DST Endoskeleton)
Comment:
Document Attributes:
Author: Pacific Northwest National Laboratory
Name: Impacts of Water Quality on Residential Water Heating Equipment
Year: 2013
Type: Report