LIFE CYCLE AND ENERGY ANALYSIS OF PRODUCTS AND HOSPITAL SYSTEMS

A Dissertation by

Fadhel Yousef Alshqaqeeq

Master of Science, St. Mary's University, 2012

Bachelor of Science, Jubail Industrial College, 2009

Associate of Science, Jubail Industrial College, 2006

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The following faculty members have examined the final copy of this dissertation for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Doctor of Philosophy with a major in Industrial Engineering.

Janet Twomey, Committee Chair

Michael Overcash, Committee Member

Ehsan Salari, Committee Member

Eylem Asmatulu, Committee Member

Ward Jewell, Committee Member

Accepted for the College of Engineering

Royce Bowden, Dean

Accepted for the Graduate School

Dennis Livesay, Dean

DEDICATION

To my father, for his support and love for the family;
to my mother, for her infinite love;
to my wife, my sisters, and my brothers, for their support and encouragement

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisors, Professor Janet Twomey and Professor Michael Overcash, for the opportunity to carry out this research and for their continuous support, patience, and guidance. I would also like to thank my Ph.D. committee members, Dr. Ehsan Salari, Dr. Eylem Asmatulu, and Dr. Ward Jewell, for their insightful questions, which helped to improve my work. Finally, a very special thanks to my parents—without their support and encouragement, none of my achievements would have ever been possible.

ABSTRACT

There is a relationship between the healthcare sector and treatment of the patient in the delivery of service. During the process of this relationship, waste and CO_2 are generated, which increases over time. Compared to other industries, very little information is available with which to make science-based decisions in order to reduce waste and CO_2 emissions while still maintaining quality patient care. This research investigates three areas to assess the environmental impact of healthcare: nutrition, hospital materials, and radiology. This research applies critical literature analysis techniques, life cycle assessment, and energy analysis to identify the aspects of sustainability improvement of healthcare services and products with an emphasis on hospitals.

In order to provide solutions, one area of study is assessing the amount of food waste in hospitals by quantifying and analyzing food consumption, waste, and energy use in a hospital food system so that environmental impacts may be avoided. Therefore, quality and quantity are important factors in hospitals, whether producing high quality with instruments (reusable and disposable [single-use] products), on the one hand, or overproducing food or items, on the other. Life cycle cradle-to-grave studies are widely used to understand the environmental consequences of reusable and disposable products.

The hypothesis of this study in the area of radiology focuses on imaging modalities. With the energy data from quantitative imaging, we can establish the role of healthcare teams in lowering the hospital energy footprint and thus contributing to hospital sustainability. Lower energy means less electricity, less power plant emissions (SO_x, smog, CO_2) into the air and water, and ultimately less impact on public health.

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LIST OF ABBREVIATIONS

ACR	American College of Radiology
BTUs	British Thermal Units
CO2eq	Carbon Dioxide Equivalent
CT	Computed Tomography
CTA	Computed Tomography Angiography
GHG	Greenhouse Gas
GWP	Global Warming Potential
HHI	Healthy Hospitals Initiative
HP	Horsepower
JACR	*Journal of the American College of Radiology*
kWh	Kilowatt Hour
lb	Pound
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MJ	Megajoule
MRA	Magnetic Resonance Angiography
MRI	Magnetic Resonance Imaging
MSKCC	Memorial Sloan Kettering Cancer Center
NRE	Natural Resource Energy
oz	Ounce
PET	Polyethylene Terephthalate
SOx	Sulphur Oxides

therm	Thermal
US	Ultrasound
WSU	Wichita State University

CHAPTER 1

INTRODUCTION

1.1 Scope and Introduction

This research uses the critical analysis techniques of life cycle and energy analysis to better understand aspects of sustainability improvement of healthcare products and services, with an emphasis on hospitals. The areas of study include food systems, product selection, and imaging. The food and product topics are new areas in the Wichita State University (WSU) effort at a hospital-wide understanding of energy and waste improvement, while imaging is a new extension of earlier work in this area.

1.2 Dissertation Organization

This dissertation is organized into four sections that at the conclusion of the research resulted in four papers. Each chapter is self-contained in that each includes a literature review, research objective, data, and conclusion. The final chapter provides a summary of findings and future work.

Chapter 2— Literature Review of Hospital Food Waste: The objective of this research is to assess the amount of food waste in hospitals and provide solutions to reduce it. The research is based on published hospital studies of food waste. In contrast to similar hospital food reviews, this study includes articles published up through September 2015 and quantifies improvements.

Chapter 3—Case Study of Hospital Food System: The objective of this research is to quantify and analyze food consumption, waste, and energy use in one large hospital food system so that environmental impacts may be avoided. In a healthcare facility, food waste comes from many processes and from overproduction. Any food left on patient trays indicates dissatisfaction or nutrition inadequacy and will affect the patient's nutrition. Some food waste, such as vegetable and fruit peels, cannot be avoided under normal circumstances. This case study takes place at Via Christi Hospital St. Francis in Wichita, Kansas.

Chapter 4—Comparison of Reusable to Disposable Products: Life Cycle Analysis: The objective of this study is to examine the major recurring factors that determine whether reusable or disposable product alternatives have a lower environmental footprint across all such reported studies. Some of the materials addressed in these studies are in the healthcare sector, and some are not.

Chapter 5—Choice of Imaging Modalities with Lower Environmental Impact to Meet Patient Needs. The objective of this research is to provide an opportunity to reduce hospital energy use and the public health impact through changes in radiology decision-making rather than changes in technology. This modest improvement would be a direct contribution to healthcare sustainability by the radiology community without any change in technology.

CHAPTER 2

LITERATURE REVIEW OF HOSTPIAL FOOD WASTE

2.1 Introduction and Objectives

Food waste can occur anywhere in the world and may result during each of the following steps in the food process: transportation, storage, preparation, cooking, and consumption. In order for hospitals to save money and improve sustainability goals, focusing on food waste is important. For example, the annual cost of edible plate waste has been estimated at 5.625 million Saudi riyals ($1.5 million) for regular meals [1]. Most hospital food waste is that which is thrown away, with only a small portion being recycled or composted. Preparing food that eventually results in waste is considered mismanagement of our natural resources. One review by Williams and Walton [2] in 2011 covered published articles from 1963 up to March 2011 and revealed 32 studies in hospitals that recorded the percentage of food waste and mentioned the reasons and strategies to reduce waste. This dissertation study covers published articles from 1945 to September 2015 and addresses solutions with real improvements in terms of percentages. The objective of this literature review is to show the percentage of food waste in hospitals and provide solutions to reduce it, based on previous hospital studies on food waste during these past several years.

2.2 Abstract

Uneaten food, whether it is uneaten by hospital patients or simply prepared but not served, is considered food waste. Plate waste is the remaining uneaten food after being served to hospital patients. This article reviews publications regarding these two aspects of hospital food waste. In the reviewed papers, most food waste occurs because of portion size, serving time, service system, method of food preparation, or medical status of the patient, as discussed in one review article covering published articles from 1963 to March 2011. Food waste was measured either by weight

or visual estimation. Understanding patients' needs and the food service system may help to reduce food waste. This literature review reveals the percentage of food waste and solutions to reduce it. These percentages range from 6% to 65% but more typically are between 15% and 35%, with a median food waste of 31%. This literature review also shows the number of studies on food waste in hospitals during previous years until September 2015. A summary of the five articles that quantified food waste solutions showed an improvement range from 4.2% to 49%. From these improvements, hospitals could reduce their food waste to at least about 21%. Therefore, the median food waste of 31% as reported above could be reduced to about 24%. From previous studies, the main factor involving a reduction in food waste was menu and the type of food or preparation procedure. This review does not cover bio waste, or avoidable or unavoidable food. Also, it does not report calories or energy wasted, and does not cover liquid or food that has been used in tube feeding. Also, unserved food waste was not considered here.

2.3 Methods

Research efforts were focused on publications that provided information about food waste associated with hospitals. Related journals from electronic reference databases were identified from 1945 to September 2015 using combinations of key words and titles. The key words "food waste" and "plate waste" in a hospital and in only English language journals were chosen for this study. The following search engines were used to extract information: PubMed, ScienceDirect, and Web of Science (formerly Web of Knowledge). The total number of relevant titles and abstracts resulting from searches was 37 from PubMed, 639 from ScienceDirect, and 84 from Web of Science, for a total of 760 from all search engines. From that number, about 103 articles, which occurred in more than one database, were identified and removed with the help of endnote. A flowchart showing the search engines used in the initial pooling of the literature is shown in Figure 2.1.

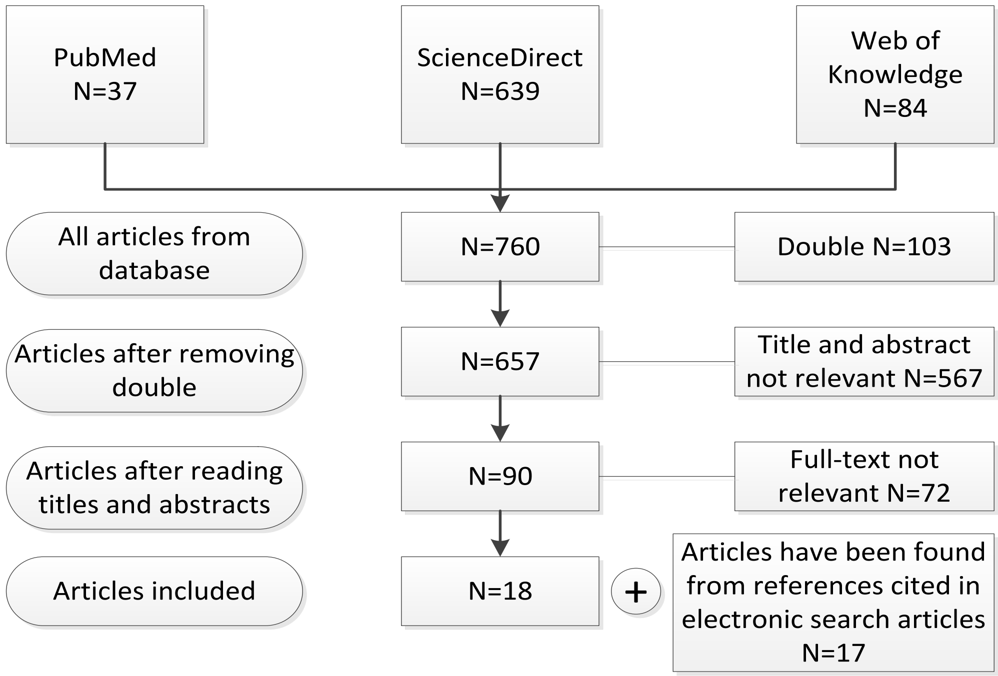

Figure 2.1: Flowchart of selected studies indicating hospital food waste.

After excluding the duplicated articles, it was determined that 567 articles had titles and abstracts not relevant to the main study, so they were also excluded. Of the remaining 90 articles, 72 full texts were eliminated because they talked about calorie waste, solid waste, treatment of food waste, supply of chain management, hazardous waste in hospitals, and other waste such as chemicals, which were not included in this study. The remaining 18 articles, in addition to 17 articles found from the references, were included in the study.

2.4 Results and Solutions

After reviewing many studies on food or plate waste in hospitals, the resulting 35 articles provided percentages for food waste, and the remaining articles provided solutions to reducing waste. Other studies relative to waste in terms of energy value or protein content were not covered here. Table 2.1 shows the percentages of food waste from patients in different hospitals, ranging from 6% to almost 65%. As shown, the median food waste was about 31%. These differences among hospitals depend on the patient situation, services, and menus. Table 2.1 summarizes most studies in many countries during the past years until September of 2015.

TABLE 2.1

LITERATURE SUMMARY OF FOOD WASTE

Facility Hospitals	**Weight Percent of Food Waste From Patient Trays**	**Explanation**	**Reference**
1 university hospital in US	22, 19, 13	measured, different diets selective	[3]
152 hospitals in UK	10 ± 0.4	measured	[4]
1 Kansas teaching hospital in US	21.3	measured	[5]
Royal Victoria Hospital in Canada	38.3 ± 48.9	visual estimation	[6]
1 hospital in the Netherlands	42.7	measured	[7]
18 hospitals in Saudi Arabia	30	measured	[1]
3 hospitals in Taiwan	21.51, 16.61, 6.36	measured	[8]
1 Missouri hospital in US	45	measured	[9]
11 UK hospitals	9.9, 16.2, 15.5	measured, breakfast, lunch, dinner	[10]
Queen’s Medical Center in UK	31, 34, 35, 42	measured, four wards	[11]
4 hospitals in UK	23.1, 39.66, 42.35	measured, breakfast, midday, evening	[12]
Tickhill Road Hospital in UK	49.0–11.8	measured (average plated and bulk)	[13]
4 hospitals in UK	25.3, 27.8	measured (plated and bulk)	[14]
1 university hospital in UK	35	measured	[15]
1 university rehabilitation ward in UK	32	measured	[16]
1 general hospital in UK	33.5–14.5	measured (plated vs. bulk)	[17]
1 hospital in Brazil	36–61	measured	[18]
7 community hospitals in UK	18	five-point visual estimation	[19]
1 general hospital in UK	11.6 ± 3.0, 5.9 ± 1.9	measured (plated and bulk)	[20]
2 military hospitals in US	42.3–45.5	measured	[21]
1 general hospital in UK	65 ± 3.8, 17 ± 5.9	measured (plated and bulk)	[22]

TABLE 2.1 (continued)

Facility Hospitals	Weight Percent of Food Waste From Patient Trays	Explanation	Reference
4 hospitals in Sivas, Turkey	17	measured	[23]
1 North Texas acute care hospital in US	42	average of six categories of estimated waste—baseline	[24]
1 North Texas acute care hospital in US	32	average of six categories of estimated waste—food changes	[24]
Hvidovre University Hospital in Denmark	28–48	measured	[25]
1 university hospital in Brazil	22	measured	[26]
1 Indiana hospital in US	40	plate assessment	[27]
1 university hospital in Switzerland	22–30	not stated	[28]
1 general hospital in Korea	23.2	measured	[29]
1 hospital in the Netherlands	38	measured	[30]
256 hospitals in 25 European countries	18	four-point visual estimation	[31]
10 hospitals in Tabriz, Iran	46.87	measured	[32]
3 hospitals in UK	24–39	measured	[33]
1 university hospital in Amsterdam	38	measured	[34]
1 university hospital in Denmark	11–18	measured (lunch and supper)	[35]
Overall Food Waste	Median 31 (6–65) N = 45		

Table 2.2 provides some solutions and improvements to reduce food waste. Approximately 37 studies discussed these issues, but only five of them included the percentage of improvement to reduce food waste. One of the solutions to the problem of food waste is portion size, which was mentioned in some studies. Table 2.2 includes only articles with the recorded percentage of improvement and their solutions, but other papers discussed solutions with no percentage of improvement recorded; these are shown in Figure 2.2.

TABLE 2.2

SUMMARY OF FIVE ARTICLES QUANTIFYING FOOD WASTE SOLUTIONS AND IMPROVEMENT (37 ARTICLES PROVIDED QUALITATIVE IMPROVEMENTS)

Reference	Percent improvement	Solutions for hospital food system improvements
McLymont et al. [36]	Before program implementation, 39% of patients surveyed consumed greater than 50% of their main entrée; after program implementation, 88% of patients surveyed consumed greater than 50% of their main entrée (49% improvement)	Policies and procedures were developed, and menu items were tested
Ewalt et al. [37]	Average decrease of 27.4% in food waste per tray	Menu and system changes positively impacted food waste
Marlette et al. [38]	15% of food waste from students who did not purchase competitive food items and 30% of food waste from students who did purchase (15% improvement)	Analysis of food wasted by type led to school waste reduction by changing preparation or types of food
Connors and Rozell [24]	Percentage of food waste reduced from 42% to 32% during first phase (August 2001) and second phase (August 2002), respectively (10% improvement)	Changes in food offered were based on detailed observation of what was wasted and led to reduction in waste
Frakes et al. [5]	Mean percentage waste of all food served was 21.3% and for pre-plates was 25.5% (4.2% improvement)	Cook-freeze restaurant menu system in a hospital led to low waste

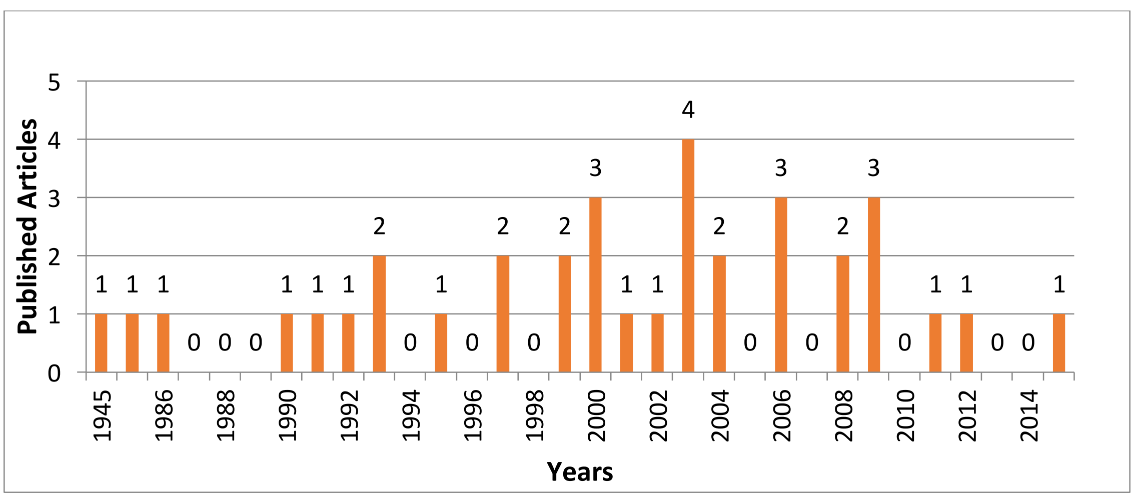

Figure 2.2: Published articles from 1945 until September 2015.

As can be seen in Table 2.2, in the five articles that quantified food waste solutions, the improvement range was between 4.2% and 49%. Reasonable improvement, addressed by McLymont et al. [36] was determined by using the Memorial Sloan Kettering Cancer Center (MSKCC) STRAIGHT-A process to facilitate performance improvement. After applying the rules and changing the menus, improvement increased from 39% to 88%, a 49% improvement. Ewalt et al. [37] found an average of 27.4% decrease in food waste per tray after modifying the menu and making system changes, and they determined that the minimum improvement of 4.2% could be achieved by using a cook-freeze restaurant menu system, as mentioned by Frakes et al. [5]. Most of these improvements involved the menu as well as type of food or procedure that might be involved in reducing food waste. From these improvements, hospitals could reduce at least about 21% of their food waste. Therefore, if hospitals develop and improve their menus, service system, and training staff, then food waste would be reduced to about 24%. These percentages relative to improving food waste have different scales of measurement. For example, Dubois [6] used a six-point visual estimation scale developed by Comstock. As shown in Figure 2.2, food waste might not have been the focus of researchers because collecting the data consumed too much time, as mentioned in the introduction section. Most of these studies were done between 1999 and 2009.

Figure 2.3 shows that 25 European countries had the most hospitals, or 256, performing food waste studies in previous years [31]. The United Kingdom and Saudi Arabia alone had 188 and 18 hospitals, respectively, involved in food waste studies. An overlap in these studies involves the UK, Denmark, and Switzerland, which are considered European countries, and the study by Hiesmayr et al. [31] did not mention which 25 countries participated in those studies. The United States and Iran both having 10 hospitals that studied food waste seems low compared to the rest of the world. Overall, the total number of hospitals involved in food waste studies is 496 hospitals in different countries. This figure indicates that those countries interested in publishing hospital food waste articles realize that this is an issue, whether financial or environmental, that must be solved.

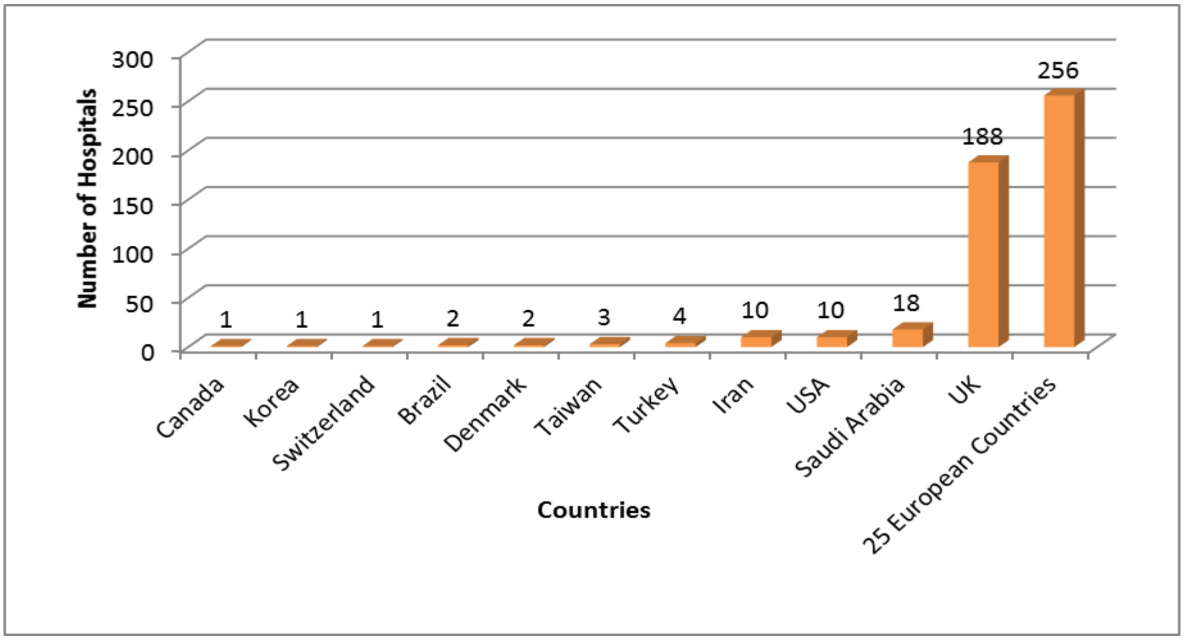

Figure 2.3: Number of hospitals versus countries studied.

Figure 2.4 shows the five improvement categories whereby food waste can be reduced, and how frequently these are reported the in literature:

- Patients' condition, which includes their appetite and needs, such as flavor and diets.
- Food and menu, which includes portion-size options, ordering, more menu choices, quality of food, and food style.
- Service system, including packaging, assistance in ordering meals, delivery system, and meal time.
- Developing and training staff, which includes knowing the meaning of food waste, polices, and rules; quantity of food cooked by monitoring, observing, and recording; and improving catering practices and communication.

- Environment, including the eating location and surrounding noise.

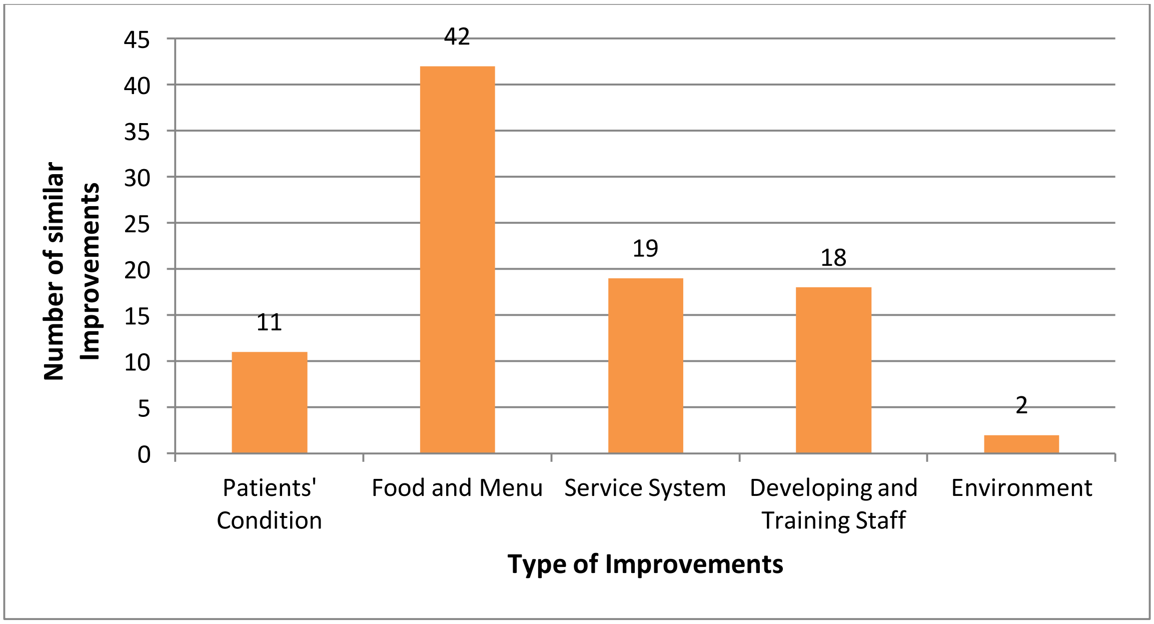

Figure 2.4: Number of similar improvements versus type of improvements.

Most improvements involved food and a menu that patients prefer. The second most frequent improvement suggested was in the service system, and developing and training staff. Patients' condition was repeated 11 times in the literature review, and finally environmental conditions were mentioned twice in the literature review. Hartwell and Edwards [20] reported the improvement in the delivery system and how patient satisfaction improved, but food waste increased because there was poor communication between patients and kitchen staff. Some papers mentioned two or more categories for improvement at the same time.

2.5 Conclusion

Food waste is considered an important issue that hospitals can use to improve sustainability. Analyzing food wasted and by changing the way food is prepared leads to waste reduction. High percentages were recorded in many of the literature review studies, suggesting more research and support to improve the reduction of food waste. However, it might be impossible to achieve zero waste because of complex reasons for why waste happens, especially when dealing with sick patients. The number of hospitals that have been included in the studies is considered low based on the number of hospitals in the world. Countries should pay attention to their sources of food and keep track of the food waste that has been increased in some hospitals. Food waste should be monitored and controlled for each meal that has been served to a patient. Monitoring and improving hospital facilities may help to reduce food waste. Also, knowing the reasons for food waste and applying all possibilities to change whether the service system, menus, serving time, patients' needs, training staff, communications, quality of food, and food preparation can lead to a reduction in food waste.

2.6 References for Chapter 2

[1] Al-shoshan, A. A. (1992). Study of the regular diet of selected hospitals of the Ministry of Health in Saudi Arabia: Edible plate waste and its monetary value. *The Journal of the Royal Society for the Promotion of Health*, *112*(1), 7-11.

[2] Williams, P., & Walton, K. (2011). Plate waste in hospitals and strategies for change. *e-SPEN, the European e-Journal of Clinical Nutrition and Metabolism*, *6*(6), e235-e241.

[3] Hageman, M. I. (1945). A study of plate waste as a directive measure in food conservation. *Journal of the American Dietetic Association*, *21*(10), 685-689.

[4] Platt, B. S., Eddy, T. P., & Pellett, P. L. (1963). *Food in hospitals. A study of feeding arrangements and the nutritional value of meals in hospitals*. London: Oxford University Press.

[5] Frakes, E. M., Arjmandi, B. H., & Halling, J. F. (1986). Plate waste in a hospital cook-freeze production system. *Journal of the American Dietetic Association, 86*(7), 941-942.

[6] Dubois, S. (1990). Accuracy of visual estimates of plate waste in the determination of food consumption. *Journal of the American Dietetic Association, 90*(3), 382-387.

[7] Deutekom, E. J., Philipsen, H., Ten Hoor, F., & Abu-Saad, H. H. (1991). Plate waste producing situations on nursing wards. *International Journal of Nursing Studies, 28*(2), 163-174.

[8] Li, C. S., & Jenq, F. T. (1993). Physical and chemical composition of hospital waste. *Infection Control*, *14*(03), 145-150.

[9] Holdt, C. S., Sitter, K., & Gates, G. E. (1993). Comparison of plate waste estimation measures in a pediatric hospital1.*Foodservice Research International*, *7*(2), 81-91.

[10] Hong, W., & Kirk, D. (1995). The analysis of edible plate waste results in 11 hospitals in the UK. *Foodservice Research International*, *8*(2), 115-123.

[11] Stephen, A. D., Beigg, C. L., Elliott, E. T., Macdonald, I. A., & Allison, S. P. (1997, January). Food provision, wastage and intake in elderly hospital patients. In *Proceedings of the Nutrition Society of London*, *56*(2), 220A-220A. Cambridge University Press.

[12] Edwards, J., & Nash, A. (1997). Catering services. Measuring the wasteline. *The Health Service Journal*, *107*(5579), 26-27.

[13] Kelly, L. (1999). Audit of food wastage: differences between a plated and bulk system of meal provision. *Journal of Human Nutrition and Dietetics*, *12*(5), 415-424.

[14] Edwards, J. S., & Nash, A. H. (1999). The nutritional implications of food wastage in hospital food service management. *Nutrition & Food Science*, *99*(2), 89-98.

[15] Barton, A. D., Beigg, C. L., Macdonald, I. A., & Allison, S. P. (2000). High food wastage and low nutritional intakes in hospital patients. *Clinical Nutrition*, *19*(6), 445-449.

[16] Barton, A., Beigg, C., Macdonald, I., & Allison, S. (2000). A recipe for improving food intakes in elderly hospitalized patients. *Clinical Nutrition*, *19*(6), 451-454.

[17] Wilson, A., Evans, S., & Frost, G. (2000). A comparison of the amount of food served and consumed according to meal service system. *Journal of Human Nutrition and Dietetics*, *13*(4), 271-275.

[18] Mattoso, V. D., & Schalch, V. (2001). Hospital waste management in Brazil: A case study. *Waste Management & Research*, *19*(6), 567-572.

[19] Hamilton, K., Spalding, D., Steele, C., & Waldron, S. (2002). An audit of nutritional care delivered to elderly inpatients in community hospitals. *Journal of Human Nutrition and Dietetics*, *15*(1), 49-58.

[20] Hartwell, H. J., & Edwards, J. S. (2003). A comparative analysis of “plated”and “bulk trolley” hospital food service systems. *Food Service Technology*, *3*(3-4), 133-142.

[21] Dilly, G., & Shanklin, C. (2003). Reply. *Food Service Technology*, *3*(1), 29-35.

[22] Marson, H., McErlain, L., & Ainsworth, P. (2003). The implications of food wastage on a renal ward. *British Food Journal*, *105*(11), 791-799.

[23] Altin, S., Altin, A., Elevli, B., & Cerit, O. (2003). Determination of hospital waste composition and disposal methods: a case study. *Polish Journal of Environmental Studies*, *12*(2), 251-255.

[24] Connors, P. L., & Rozell, S. B. (2004). Using a visual plate waste study to monitor menu performance. *Journal of the American Dietetic Association*, *104*(1), 94-96.

[25] Freil, M., Nielsen, M., Bitz, C., Gut, R., Mikkelsen, B. E., & Almdal, T. (2006). Reorganization of a hospital catering system increases food intake in patients with inadequate intake. *Scandinavian Journal of Nutrition*, *50*(2), 83-88.

[26] Nonino-Borges, C. B., Rabito, E. I., Silva, K. D., Ferraz, C. A., Chiarello, P. G., Santos, J. S. D., & Marchini, J. S. (2006). Food wastage in a hospital. *Revista de Nutricao*, *19*(3), 349-356.

[27] Kandiah, J., Stinnett, L., & Lutton, D. (2006). Visual plate waste in hospitalized patients: Length of stay and diet order. *Journal of the American Dietetic Association*, *106*(10), 1663-1666.

[28] Iff, S., Leuenberger, M., Rösch, S., Knecht, G., Tanner, B., & Stanga, Z. (2008). Meeting the nutritional requirements of hospitalized patients: An interdisciplinary approach to hospital catering. *Clinical Nutrition*, *27*(6), 800-805.

[29] Sohn, C. M., & Yeom, H. S. (2008). Effects of nutrition service improvement activities for reducing plate waste of the diabetic mellitus diet in a general hospital. *Korean Journal of Community Nutrition*, *13*(5), 674-681.

[30] van Bokhorst-de van der Schueren, M. A. E., Brouwer, I. A., Weijs, P. J. M., & Langius, J. A. E. (2009). Patients waste high amounts of food provided by the hospital kitchen. *Clinical Nutrition Supplements*, *4*(2), 98.

[31] Hiesmayr, M., Schindler, K., Pernicka, E., Schuh, C., Schoeniger-Hekele, A., Bauer, P., & Team, T. N. A. (2009). Decreased food intake is a risk factor for mortality in hospitalised patients: The NutritionDay survey 2006. *Clinical Nutrition*, *28*(5), 484-491.

[32] Taghipour, H., & Mosaferi, M. (2009). Characterization of medical waste from hospitals in Tabriz, Iran. *Science of the Total Environment*, *407*(5), 1527-1535.

[33] Sonnino, R., & McWilliam, S. (2011). Food waste, catering practices and public procurement: A case study of hospital food systems in Wales. *Food Policy 36*(6), 823-829.

[34] Roosemalen, M. M., Weijs, P. J., & Langius, J. A. (2012). High waste contributes to low food intake in hospitalized patients. *Nutrition in Clinical Practice*, *27*(2), 274-280.

[35] Ofei, K. T., Holst, M., Rasmussen, H. H., & Mikkelsen, B. E. (2014). How practice contributes to trolley food waste. A qualitative study among staff involved in serving meals to hospital patients. *Appetite*, *83*, 49-56.

[36] McLymont, V., Cox, S., & Stell, F. (2003). Improving patient meal satisfaction with room service meal delivery. *Journal of Nursing Care Quality*, *18*(1), 27-37.

[37] Ewalt, G. E., Rogers, E., Bishop, J., & Dickman, P. (2011). The effect of room service-style food service on inpatient plate waste. *Journal of the American Dietetic Association*, *111*(9), A61.

[38] Marlette, M. A., Templeton, S. B., & Panemangalore, M. (2005). Food type, food preparation, and competitive food purchases impact school lunch plate waste by sixth-grade students. *Journal of the American Dietetic Association*, *105*(11), 1779-1782.

CHAPTER 3

A STUDY OF FOOD WASTE IN ST. FRANCIS HOSPITAL

3.1 Introduction

Food waste comes from many processes and also from overproduction. Any food left by a patient indicates dissatisfaction or nutrition adequacy and will affect the patient's nutrition. Under normal circumstances, some separate food waste cannot be avoided, such as vegetable and fruit peels.

The food system at Via Christi Hospital St. Francis in Wichita, Kansas, is a multi-customer structure, not unlike other hospital food facilities. The major customers are the following:

- Patients
- Retail customers
- School catering
- Special events catering

Patients and retail clients are the major customers. These are served by a food supply network, which is 90% the Sysco Corporation and a series of about 15 smaller, specialized suppliers. Some emphasis is placed on locally produced foods. This food is delivered to St. Francis, and any unacceptable items are returned for credit. Sysco allows a return and credit of any purchases deemed unusable. Through an education system, St. Francis has become representative of an efficient, low-return client. In 2014, returns were about $4,200.

At the beginning stage of the food system, food has the necessary primary packaging (surrounding the food, like a can for tomatoes) and secondary packaging (surrounding multiple primary containers, like a plastic case for 20 cans). Between the St. Francis warehouse and the food preparation area, some of the secondary packaging is removed but is not considered in the boundary of this food waste study. The profile of food demand in food preparation is established by the St. Francis staff of dieticians and chefs, based on expected needs of the four customer groups. From food preparation, the food, beverages, and condiments are used to meet the customer system, as shown in Figure 3.1.

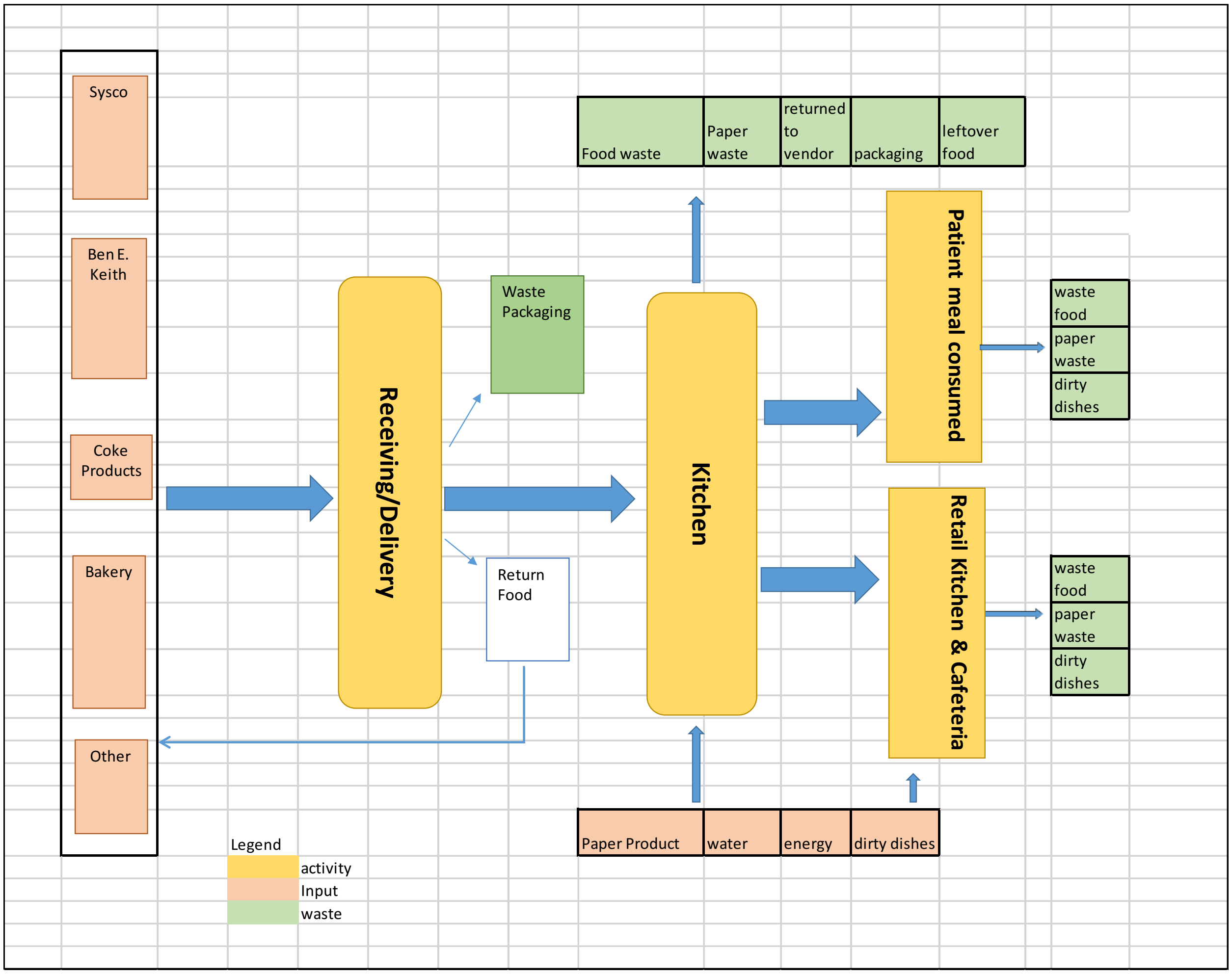

Figure 3.1: Process flow diagram of St. Francis food system.

As the specific foods are prepared, there are also energy and mass flows needed to meet the needs of St. Francis. Energy is used in storage, other continuously running equipment (like drink machines), food preparation, food cooking, serving, and lighting. Mass or weight flow measurements separately tracked packaging, unused foods from preparation and consumption, and patient tray waste.

Thus the food system is a three part structure involving food/beverage, energy, and mass. To be effective, a primary base or functional unit would be customers served (such as 1,000 customers who are in each of the four groups). Information systems are also present to help with the main goals of meeting customer requirements for food, beverages, and condiments. Examples are the information flow between supplier and St. Francis, and patient menu system of ordering. The Sysco system is sophisticated and meets these specific needs. The staff were supportive and instrumental in this study. Another information system reports all food, beverage, and condiment items that go to the patients, again comprehensive and useful. These two information systems focus on providing high-quality nutrition to St. Francis customers. However, when the full food system assessment is the focus, these computerized systems were found to not use the same basis, nomenclature, or food codes. In addition, the mass or weights of the system is incomplete and difficult to relate to the functional unit of 1,000 customers. Therefore, the overall goal of this phase of the integrated analysis and improvements program for the St. Francis nutrition system is currently limited, and this study has begun to provide some integration. A whole analysis is necessary to ensure that all three areas (customer nutrition, energy, and mass) are evaluated together. A major need is to better integrate existing information systems with these three areas. Without more integration tools or measurements, improvements become difficult to formulate and implement in the nutrition system. That is, "if it cannot be measured, it is difficult to improve."

This study covers a number of areas of the St. Francis nutrition system that have been completed as of December 31, 2014.

3.2 Abstract

This overall study involves one hospital food system that supports meals for patients, retail customers, school catering, and special event catering. The estimated food prepared is 90% for

patients and retail customers, and hence these are covered in this life cycle analysis report. The goal is to quantify food purchase, consumption, and waste, as well as energy use in the food system. These new data would then serve as metrics and benchmarks toward reducing energy, waste, and cost.

Input to the overall food system was estimated to be 90% from Sysco, which translates to a total of about 1,200 food item codes (Sysco codes) per year and weighing about 1,200,000 pounds (lbs). This in turn translates to 3,300 lbs of food/day (1.6 tons) at an approximate average purchase cost of $2.20/lb. The first step is to unpackage and prepare the food (referred to here as only retail and patient meals). Waste in the kitchen where food preparation and patient meals are handled consists of solids (peels, seeds, tops, etc.), liquids (pickle juice, canned fruit liquid, etc.), and fully prepared food kept warm but for which no patient requests are made and so are declared as leftover waste. There would appear to be little room for reducing the preparation waste, while there might be room for improvement for reducing the leftover waste (about 8 tons/yr). This study addressed the food waste per tray and per patient, whereby the average waste per tray was 0.17 lb (164 lbs/day for a patient population of about 320). The study also addressed the retail waste (unused leftovers), which averaged 132 lbs/day. The total average food loss during the food preparation stage was about 149 lbs/day: about 70 lbs/day from solid food (uncooked), about 34 lbs/day from liquid (not water), and about 44.7 lbs/day from leftovers. The actual hospital food waste is about three-fold higher than the patient tray waste, which is the most studied aspect of the hospital food system. Thus, this study provides a new perspective on hospital food waste because it measures food waste and energy use in the kitchen, patient, and retail areas for improvement. Suggested recommendations are also made to reduce waste from packaging, unconsumed food, and food preparation, all of which contribute to lowering the cost of landfilling.

3.3 Data Collection and Methods

This study covered the kitchen that served patients, retail areas, and the cafeteria at Via Christi Hospital St. Francis. The kitchen served approximately 1,200 patient meals daily. After analyzing and observing the work habits and employee shifts in the kitchen, data collection was initiated randomly over two days, three times a day. Twenty trays were gathered and weighed, and the wasted food and non-food were recorded separately. After that, data were collected for two weeks randomly, including weekends. Each day was divided into three shifts: morning, afternoon, and evening. There were 42 shifts, and the collected data covered 25% of all shifts, which included approximately ten random shifts for a two-week period. The kitchen had more than ten carts with which to collect trays from patients' rooms. Patient trays from different wards were included in this procedure, but liquids were not included. After the carts were delivered to the cleaning area, the trays were counted, the waste food was separated from non-food and placed in different bags, the bags were weighed separately on a scale, and the data were recorded. This procedure was done for all data collected. Leftover food that could not be used the next day and waste from the preparation food were measured and recorded. The scale calibration involved a full 2-liter Pepsi bottle indicating a weight of 5 lbs, but this actually weighed about 4.8 lbs on our scale. The six 2-liter Pepsi bottles indicating a weight of about 30 lbs actually weighed about 28.4 lbs on the same scale. Therefore, a 1.056 factor was used for all weights that were recorded.

3.4 Discussion

This discussion covers six sections including the St. Francis food system, food preparation, patient nutrition, patient non-consumed material, retail food, and energy use in the Via Christi Hospital St. Francis in Wichita, Kansas.

3.4.1 Approximate Total of St. Francis Food System

The Sysco Corporation and the Ben E. Keith food distributor were asked to provide food purchasing data. Sysco responded, and the St. Francis staff estimated that the company provides 90% of the total food supply. Sysco was very cooperative in providing all purchases from July 1, 2013, to June 30, 2014. Included were about 1,200 individual items, each with a code number that included information on all purchases (food weight per item, total weight per item, and number of items per year). In that year, about 1,200,000 lbs of food, beverages, and condiments were purchased (about 3,300 lbs/day or about 1.6 tons/day) at an overall average purchase cost of about $2.20/lb. These items were rank-ordered, and about 380 items constituted 85 wt% of the total food, beverages, and condiments used in that year at St. Francis. The weight of the 380 total food items was about 8,500 lbs, with food content at 7,700 lbs and packaging at 800 lbs.

3.4.2 Food Preparation

The system between the purchased warehouse-stored food and the customer is referred to as the food preparation stage, or kitchen, as shown previously in Figure 3.1. Waste included packaging and unused food (outer lettuce leaves, bones, peels, etc.). The food preparation involved not only patient meals but also retail food distribution and catering. At this stage, the losses during preparation were assigned to only patient and retail, which Christi estimated to be 90 wt% of the total nutrition system. Food preparation waste was measured by direct collection for the following three categories:

- Weight of solids from food preparation (potato peels, fruit peels, bones, etc.).
- Liquid from containers (pickle juice, liquid from canned fruit and vegetables not used in cooking, etc.).
- Prepared food kept warm until the end of a shift or end-of-the-day discarded food.

Packaging was not included in the food processing waste.

Results from a continuous 16-day measurement study are provided in Table 3.1. Variability in the solids and liquids that are disposed of is often due to preparation of some foods on the same day but used for cooking on subsequent days. The total waste over a 16-day period helped to average these measurements. These food processing wastes are the first stage between the arrival of food from the supplier and the delivery to patients. Casual observation indicated that the largest food preparation waste was from cantaloupes, pineapples, onions, tomatoes, and lettuce. The largest cooked materials that were thrown away as leftovers were potatoes and other vegetables such as carrots and corn, eggs, etc.

TABLE 3.1

FOOD LOSSES DURING FOOD PREPARATION STAGE OF HOSPITAL FOOD SYSTEM

Day	**Solids, not cooked (lbs)**	**Liquids, not water (lbs)**	**Leftovers (lbs)**	**Total waste per day (lbs/day)**
1	72.0	64.7	39.8	176.5
2	70.0	36.8	62.6	169.4
3	0.0	26.5	32.2	58.8
4	26.9	26.5	25.9	79.3
5	144.3	37.7	41.1	223.1
6	124.1	41.9	36.2	202.2
7	57.9	37.5	54.3	149.7
8	51.0	28.4	54.8	134.1
9	110.4	23.8	32.2	166.4
10	62.6	36.0	37.5	136.0
11	0.0	36.4	49.5	85.9
12	99.9	26.7	64.2	190.9
13	110.6	27.6	62.3	200.5
14	61.7	32.0	52.2	146.0
15	51.2	46.1	23.8	121.1
16	84.1	15.8	46.3	146.2
Total	1126.8	544.4	714.9	2386.0
Average per day	70.4	34.0	44.7	149.1
Total per year (average per day X 365 days)	25,704	12,418	16,308	54,430

Over the 365 days of that year, the food preparation loss was 54,430 lbs/yr or about 4.5 wt% of the food purchased from Sysco (Table 3.1). Leftovers were about 30% of this stage of waste production (about 1.4 wt% of purchased food) and most like the patient non-consumed material because the foods were prepared but not ordered in a timely fashion by the patients.

3.4.3 Patient Nutrition

A substantial improvement in reducing unconsumed food was implemented by St. Francis some time ago and is referred to as the menu system. Here, patients select food, beverage, and condiment items from an extensive list, and if these meet their medical clearances, then the order is filled and delivered. There are regular meal times, but other patient schedules can also be accommodated. At St. Francis, there are about 940 patient meals/day, seven days/week (343,000 meals/yr).

An information system at St. Francis catalogues all the patient food, beverages, and condiments using a name for each item (like apple pie, one slice; beef broth, one bowl; diet coca cola, 12 oz; etc.) The patient meal data from this information system were provided as a paper copy for the week of 6/24/14 to 6/31/14. Based on patient requests, approximately 550 food items were entered into the system for that week. Most of these food items are listed by the amount, such as ounces or cups, while others are listed more generally (like one parfait, one Philly steak sandwich, etc.). All items also list the number ordered per week. After converting the food items to an Excel spreadsheet, the total weight of each item in the week was compiled. A designation of food, beverage, or condiment was assigned. This covered all food items, in which item weight, number of items per week, and weight/week were provided. The patient meal database and the use of food names illustrates the current multiple information categories since the names of food ordered by patients are not the same as those of the Sysco food-purchasing system.

From the current data on patient meals, the average weight of items per patient meal is about 28 oz (790 g), as shown in Table 3.2. Of this, food and condiments comprise 467 g and beverages comprise 322 g. An average of eight items is served on each tray. The average patient tray weight is subsequently used to assess the percent unconsumed material. As a preliminary estimate using 6,640 meals/week (based on the year 7/1/13–6/30/14), 1.74 lbs/tray, and 52 weeks/yr, the patient nutrition system consumes about 600,000 lbs/yr or 50 wt% of the total food purchased from Sysco.

TABLE 3.2

SUMMARY OF PATIENT MEALS SERVED BETWEEN JUNE 24 AND JUNE 30, 2014

	Weight (lbs)	Patient meal based on 5,047 meals (lbs/tray)	Patient meal based on 5,047 meals (g/tray)	Percent of total
Food (lbs)	5,025	0.996	452	63.9
Beverages (lbs)	3,580	0.709	322	45.6
Condiments (lbs)	165	0.033	15	2.1
Total served (food + beverages + condiments)	8,771	1.738	789	
Number of food items requested: 42,106 (8.3 per tray)				

3.4.4 Patient Non-Consumed Material

For a two-week period, patient tray waste was measured at specific times each day. These times were selected on a random basis so as to represent all patient trays. About 2,400 trays, or about 25% of all trays, were measured, as shown in Table 3.3. On each tray, the food and non-food (plastic container and paper) wastes were separated; then the food wastes were combined, and the number of trays recorded. Similarly the combined non-food waste was measured, but beverages were not measured.

TABLE 3.3

ANALYSIS OF FOOD AND NON-FOOD WASTE FROM PATIENT TRAYS
(PATIENT POPULATION ABOUT 320)

	Number of trays per observation period	Food weight (lbs)	Non-food weight (lbs)	Food waste per tray (lbs)	Non-food waste per tray (lbs)	Total average waste per tray (lbs)
	202	33.2	21.4	0.16	0.11	0.27
	172	30	24	0.17	0.14	0.31
	196	37	29	0.19	0.15	0.34
	198	43.6	24	0.22	0.12	0.34
	146	23.8	23.6	0.16	0.16	0.32
	331	51.8	46.4	0.16	0.14	0.30
	194	35.2	34.6	0.18	0.18	0.36
	353	56	43.4	0.16	0.12	0.28
	184	32.6	33.8	0.18	0.18	0.36
	391	59.2	34.4	0.15	0.09	0.24
Total	2,367			1.74	1.39	3.13
Average waste per tray				0.17	0.14	0.31
Annual waste (average lbs per tray X number of trays per year)				45,558	36,465	

From this two-week period, the food waste per tray was about 0.17 lb (2.7 oz, or 75 g). Compared to the weight of food given to the patients, this waste is about 16 wt%. From the literature studies, most reported wastes are in the 25% to 40% range, so St. Francis is at the very low waste level. Scaling this up to 6,640 patient meals per week, the annual patient food waste at St. Francis is about 59,000 lb/yr (29 tons). Of the total annual food purchased (for all customer groups) the patient food waste is about 4.9 wt%. However, what the patients do not consume also creates a food preparation waste to give a life cycle perspective. Adding the food processing annual waste of 54,400 lbs/yr to the patient waste (59,000 lbs) gives a total of about 9.5 wt% loss from the purchased food. Thus, the benefit of reducing all food waste is greater than the actual food lost because it includes actual landfill costs. In addition, these food wastes are a potential economic value stream if used by composting and other reuse firms.

3.4.5 Retail Food

The hospital's retail facility receives food from the preparation kitchens and also cooks some food directly for customers. The retail (behind the counter) waste study included three sources for these materials:

- Food that is cooked and kept warm but, at the end of a shift or the end of a day, is thrown out as leftovers.
- Food that is prepared for customers but is rejected and thrown out.
- Waste from the cooking of food.

Results from the retail food waste study are given in Table 3.4.

TABLE 4.4

RETAIL FOOD WASTE

Day	Waste Category Weight (lbs)			Total
	End-of-shift + end-of-day (leftovers)	**Customer-rejected food**	**Food preparation**	
1	145.3	0.0	3.3	149
2	107.2	0.0	0.0	107
3	167.5	2.5	0.0	170
4	94.1	0.0	0.0	94
5	117.3	0.0	0.0	117
6	106.8	0.0	0.0	107
7	181.2	0.0	0.0	181
8	115.6	0.0	0.0	116
9	156.5	0.0	0.0	157
10	128.3	0.0	0.0	128
11	72.2	0.0	0.0	72
12	174.2	0.0	0.0	174
13	144.3	0.0	0.0	144
Average waste per day	131.6	0.2	0.3	132
Annual total (average X 365 days)	**48,027**	**70**	**94**	**48,191**

Casual observations of the major leftover food losses show items such as mashed potatoes, roast beef, burgers, spaghetti, and turkey. The combined food losses from preparation, use by patients, and retail behind-the-counter activities yields a total of 54,400 + 59,000 + 48,200, respectively, for a total of 161,000 lbs/yr or about 13 wt% of the food purchased. Interestingly, about 64,000 lbs/yr (32 tons/yr) of food is prepared and cooked, but then discarded before patients or customers can consume them (retail and patient food leftovers). In addition, traditional hospital studies of patient tray waste underestimate the hospital food waste by about 300%.

This study did not include retail food and containers disposed of by customers. These containers and resulting food waste in retail have an impact on the following:

- Weight of the materials trucked and landfilled from St. Francis.
- Large methane release from waste food in the anaerobic landfill environment.

The retail system was also analyzed for an alternative concept, namely, replacing the disposable containers with reusable plates, cutlery, and a cleaning system for those dining in the retail area. This is a partial conceptual analysis and not a full economic analysis. The concept here is to estimate an equivalent number of full meals at the retail location that are equivalent to patient meals. This was done using the annual retail sales (all locations at St. Francis in 2013) and the estimated meal cost. For an entrée, two vegetables, salad, desert, and drink, the meal cost is about $11.50 in the retail facility. The average retail sale (total sales divided by total transactions) is $4.10, which is expected because many transactions are small snacks, etc. Using the midpoint of the average transaction and a full meal yields a lower price of $7.80. These two costs ($7.80 + $11.50) and the annual sales give a range of about 260,000 to 390,000 meals per year. The retail staff estimated that about 40% of the purchases are consumed in the retail area, so this reduces the meals to 105,000 to 165,000 per year, which is about 30% to 50% of the number of patient plated meals.

If these retail meals were served on plates with utensils, instead of disposable containers, then there would be potential benefits: a reduction in disposable packaging that is landfilled and a shift of food wastes to aerobic wastewater treatment (City of Wichita) instead of landfill anaerobic treatment and the resultant methane impact on the atmosphere. Each current meal is assumed to be comprised of one 9”x 9”x 3” Styrofoam® shell for the entrée and two vegetables; one 5” x 5” x 3” Styrofoam® shell for the salad; one 5” x 5” x 3” Styrofoam® shell for the desert; one knife, spoon, and fork set; and one medium cup for a drink. These weigh 18 g, 6.2 g, 6.2 g, 10.8 g, and 7.8 g, respectively, for a total of 49 g. Their costs are approximately, $0.07, $0.038, $0.038, $0.074, and $0.042, respectively, for a total of $0.26 per meal. Therefore, for the potential meals consumed in the retail facility, the annual reduction in container weights is 5,100–8,100 kg (6–9 tons) and a savings of $28,000–$43,000. A collection system for plates and utensils would need to be installed. However, the 30%–50% increase in utensils over current patient meals may allow the kitchen’s current cleaning system to be utilized.

The retail unit provided about the same number of equivalent plate meals (260,000–390,000 meals per year, consumed in the retail area and elsewhere) as those of the patient meal system. The retail waste produced is about the same magnitude as that of the patent meal waste (not including what retail customers waste). The patient meal waste, leftovers from the kitchen, and leftovers from the retail are are about 123,500 lbs/yr. At the average food purchase price of $2.20/lb, this is about $270,000 per year, for these types of wastes only. When the cost of preparing these items that are then discarded as leftovers, in addition to the purchase price, are considered, then the amount of potential savings is higher.

3.4.6 Energy Use

In the St. Francis nutrition system, energy is used to transition purchased food into the food, beverage, and condiments consumed by the various customers. This energy is from a variety of equipment that uses electricity and natural gas. For the energy analysis, the equipment was divided into that operating continuously (24 hrs/day) and that used for shorter periods. Initially, the equipment that operated continuously was documented according to manufacturer, size, and power rating. This equipment is primarily cooling and freezer storage equipment, as shown in Table 3.5. The power usage was assumed to be 80% of the power rating values until direct measurements are made available. On this basis, the continuous operating equipment listed consumes about 213,706 kWh per year (770,000 MJ/yr). At $0.09/kWh, the continuous machines cost about $19,000 per year.

Non-continuous machines are also used in the food preparation and retail areas, and involve electricity and natural gas usage. These machines are used primarily for cooking and warming, as shown in Table 3.6. For non-continuous equipment, the electrical energy use is estimated at 530,000 kWh/yr, which at $0.09/kWh translates to $47,000/yr. The natural gas use is about 1 million kWh/year (9,500 therms), which at $4.50/therm is about $43,000 per year. Thus, the combined electrical energy and gas expense is about $90,000/yr.

Most of the cooking and warming equipment (14 pieces) has a power input that is much higher than 2 kW, and four pieces of equipment have a power input that is higher than 7 kW. In contrast, the continuous equipment has only two devices above 2 kW and none above 7 kW. Several of these non-continuous pieces of equipment operate more than 12 hours per day, so the non-continuous equipment represents a much higher single equipment energy use. Looking at this equipment and the hours of operation might yield some improvement (by selecting more energy-efficient equipment or by reducing the hours of operation by turning this equipment off or down when not in use).

TABLE 3.5

POWER ANALYSIS FOR KITCHEN EQUIPMENT OPERATING CONTINUOUSLY

Always in on mode 24/7			Equipment operate at 80% of peak	1 yr = 8760 hours	
Equipment name	Model	Power in kW	80% Power kW	Annual energy in kWh	Annual power at 80% power kW
Freezer #1 (BOHN)	LET2702A	6.585	5.268	57685.3	46148.3
Freezer #1 (BOHN)	LET20020	5.488	4.390	48071.1	38456.9
Walk-In 4 (BOHN)	ADT1350A	1.770	1.416	15503.9	12403.1
Walk-In 6 (BOHN)	ADT1350A	1.770	1.416	15503.9	12403.1
Freezer #1 (BOHN)		1.442	1.154	12632.8	10106.2
HOBART Refrigerator	QF1	1.440	1.152	12614.4	10091.5
Coca-Cola Refrigerator	VRD43	1.231	0.984	10779.2	8623.3
Freezer #1 (BOHN)		1.202	0.961	10527.3	8421.9
M3 Refrigerator	M3R47-2	1.058	0.846	9268.1	7414.5
Turbo Air Refrigerator	TST-60SD	1.024	0.819	8965.9	7172.7
Continental Refrigerator	DL2RI	0.984	0.787	8619.6	6895.7
Freezer#6(True Freezer)	TR-56F	0.746	0.597	6535.0	5228.0
Cooler #3 (True)	T-49	0.373	0.298	3267.5	2614.0
Cooler #4 (True)	T-49	0.373	0.298	3267.5	2614.0
Cooler #12 (True)	T-49	0.373	0.298	3267.5	2614.0
Cooler #13 (True)	T-49	0.373	0.298	3267.5	2614.0
Cooler #14 (True)	T-49	0.373	0.298	3267.5	2614.0
Refrigerator (True)	T-49	0.373	0.298	3267.5	2614.0
Continental Refrigerator	2R-HD	0.360	0.288	3149.5	2519.6
Freezer#3 (True Freezer)	T-23F	0.249	0.199	2178.3	1742.7
Freezer#4 (True Freezer)	T-23F	0.249	0.199	2178.3	1742.7
Freezer#5(True Freezer)	T-23F	0.249	0.199	2178.3	1742.7
Cooler #5 (True)	TSSU-60-24M-B-ST	0.249	0.199	2178.3	1742.7
Cooler #6 (True)	TSSU-60-24M-B-ST	0.249	0.199	2178.3	1742.7
Cooler #8 (True)	TSSU-60-24M-B-ST	0.249	0.199	2178.3	1742.7
Cooler (True)	TSSU-60-24M-B-ST	0.249	0.199	2178.3	1742.7
Refrigerator (True)	T-23	0.249	0.199	2178.3	1742.7
Refrigerator (True)	T-23G	0.249	0.199	2178.3	1742.7
Refrigerator (Turbo Air)	TGM-235DW	0.187	0.149	1633.7	1307.0
True Refrigerator	TSSU-27-08	0.149	0.119	1307.0	1045.6
Walk-In 2 (HTP)	HTA36-145B-AS	0.112	0.090	980.2	784.2
Walk-In 5 (HTP)	HTA36-145B-AS	0.112	0.090	980.2	784.2
Walk-In 7 (RUSSELL)	HTA36-145B-AS	0.112	0.090	980.2	784.2
Walk-In 1 (BOHN)	ADT139AJ	0.099	0.080	871.3	697.1
Heated Food Storage Cabinet (Traulsen)	AHF232WP-HHG	0.025	0.020	219.0	175.2
Heated Food Storage Cabinet (Traulsen)	AHF232WP-HHG	0.025	0.020	219.0	175.2
Heated Food Storage Cabinet (Traulsen)	AHF232WP-HHG	0.025	0.020	219.0	175.2
Heated Food Storage Cabinet (Traulsen)	AHF232WP-HHG	0.025	0.020	219.0	175.2
Heated Food Storage Cabinet (Traulsen)	AHF232WP-HHG	0.025	0.020	219.0	175.2
Heated Food Storage Cabinet (Traulsen)	AHF232WP-HHG	0.025	0.020	219.0	175.2
Walk-In 3 (BOHN)		N/A			
Cooler #10 (Traulsen)		N/A			
Total kW hrs per year				267,132.49	213,706

TABLE 3.6

POWER AND NATURAL GAS ANALYSIS FOR KITCHEN EQUIPMENT OPERATING NON-CONTINUOUSLY

Equipment name	Model	Power (kW)	Annual electrical energy (kWh)	Annual gas energy use rate from plate (BTU/hr)	Annual gas usage (BTU/day)	Daily use rate (hrs/day)
Self-cooking (Rational)	SCC202G	56.0		216,000	2,592,000	12
Eclipse electric braising pan (Groen)	BPM-40E	15.3	67,014			12
Eclipse electric braising pan (Groen)	BPM-40E	15.3	134,028			24
Griddle (Rankin-Delux)	RD80-36	9.4	47,923	32,000/burner	896,000	14
Griddle (Rankin-Delux)	848-E	8.8	9,627	30,000/burner	360,000	3
Hot water (Curtis)	RU-300	6.0	8,760			4
Grill (Rankin-Delux)	RB-836	4.2	23,266	14,500/burner	717,750	15
Coffee maker (Curtis)	FBALP3GT63A000 C-R	3.3	14,454			12
Thurmaduke steam table (Duke)	DC-E3CBSSM	2.9	17,082			16
Thurmaduke steam table (Duke)	DC-E3CBSSM	2.9	17,082			16
Thurmaduke steam table (Duke)	ASI3E M	2.7	15,768			16
Thurmaduke steam table (Duke)	ASI3E M	2.7	19,710			20
Thurmaduke steam table (Duke)	ASI3E M	1.8	10,512			16
Potato mixer (Metcalfe)	SP80	2.2	817			1
Convection oven (Cres Cor)	H1381834C	1.5	2,738			5
Beverage center (Vitality)	EX-48 PH	0.8208				
Beverage center (Vitality)	EX-48 PH	0.8208				
Ice maker	MII-302	0.513				
Convection steamer (Vulcan)	5KCP49JN9004AS	0.373				
Convection steamer (Vulcan)	5KCP49JN9004AS	0.373				
Convection steamer (Vulcan)	5KCP49JN9004AS	0.373				
Convection steamer (Vulcan)	5KCP49JN9004AS	0.373				
Oven (Cleveland)	24CDP10	0.1	292		1,274	8
Oven (Cleveland)	24CDP10	0.1	292		1,274	8
Oven (Cleveland)	24CDP10	0.1	292		1,274	8
Water boiler (Cleveland)	KDL-40-T				3,398	16
Water boiler (Cleveland)	KDL-40-T				850	4
Microwave (Amana)	RCS10	1.7				0.5
Microwave (Amana)	RCS10	1.7				0.5
Convection oven (Merry Chef)	E4S	6.2				13
Convection oven (Merry Chef)	E4S	6.2				13
Grill (Garland)						15
Burner (Imperial)	ISB-36	12		40,000	360,000	9
Burner (Imperial)	IR-6			28,000/burner 35,000/oven	1,785,000	15
Convection oven (Blodgett)	MARKV-100DOUBL	22	96,360	1/3 HP		12
Griddle (Star Max)	636TD			84900	339,600	4
Griddle (Star Max)	636TD			84900	1,698,000	20

TABLE 3.6 (continued)

Equipment name	Model	Power (kW)	Annual electrical energy (kWh)	Annual gas energy use rate from plate (BTU/hr)	Annual gas usage (BTU/d)	Daily use rate (hrs/day)
Frymaster (Dean)	SR42G-SLCT			105,000	1,680,000	16
Oven (Lincoln)	1116-000-U-K1837			40,000	640,000	16
Oven (Lincoln)	1116-000-U-K1837			40,000	640,000	16
Refrigerated cool pan (Duke)	ADI-1MD-N7 M	0.1492	871	1/5 HP = 0.15 kW		16
Pan prep cooler (Turbo Air)	TST-36SD	0.759	4,433			16
Refrigerated cool pan (Duke)	ADI-2MD-N7 M	0.1492	1,089	1/5 HP		20
Cooler (Duke)	DC-TST-32SS-531280 M	4.8	28,032			16
Cold food pan (Duke)	ADI-1M M	0.1492	871	1/5 HP		16
Ice cream maker (SaniServ)	A5011P	0.746	4,357	1 HP		16
Twin gas convection steamer (Cleveland)	24CGA10.2			72,000/per compartment	288,000	2
Fryer (Pitco)	SGC-S			75,000	225,000	3
Fryer (Pitco)	SGC-S			75,000	225,000	3
Heating and holding cabinet (Cres Cor)	H1381834C	1.5	2,738			5
Cooled water and ice maker/dispenser (Follett)	25CI425W-SI	4.3				
Total BTU per day					2,592,000	
Total BTU per year					946,080,000	
Total Therm per year					9,461	
Total kWh per year			**528,407**		**1,000,007**	
Annual cost		**$0.09/ kWh**	**$42,801**		**$42,574**	**$4.50/ therm**

3.5 Recommendations

Several sources were used to make recommendations for reducing St. Francis energy and waste in order to become more sustainable. A complete literature review discovered 12 articles specifically focused on aspects of hospital nutrition systems. The three primary concepts for reducing energy and waste are the following:

- For the whole food system, warehouse to customer, energy and wastes, a full-team approach (involving many people) proved to be a thorough, innovative methodology [1]. The team creates ideas that are evaluated for feasibility and cost, but the broader perspective leads to likely changes. This would be done at St. Francis.

- In cases where specific food-by-food analysis of non-consumed nutrition were conducted, solutions for change that reduced food waste were found [2-7]. These studies found that a detailed analysis of what specific foods are not consumed can lead to changes in food type, preparation method, portion size, etc., and lower food waste.
- The use of this study (and any further studies) as a quantitative baseline linking customer needs, energy use, and food waste will facilitate future change. Data-mining and integration of the several St. Francis information systems can be improved to obtain an ongoing assessment as a basis for recommended improvement. This reinforces the "if it is not measured, it is difficult to improve" principle.

From this study and observations of this hospital system, some specific alternatives to be assessed for energy and waste reduction are the following:

- Consider a modified retail packaging method. Instead of clamshell containers, which are often not full, move to a fast-food model where items are simply wrapped for the customer. If items are to be taken away, then these are put in a bag. This will potentially reduce the volume of solid waste and landfill costs.
- Promote drinking water in reusable bottles instead of bottled water (example, Santa Rosa Memorial Hospital, Santa Rosa, California), and again, a decrease in solid waste might occur.
- Conduct a critical review of the state-of-the art affordable equipment currently in use at St. Francis to benchmark any new purchases.
- Evaluate the current chemical use in sanitation to see what market alternatives that are specified as green might be substituted.

- Conduct a search for new recycling or composting businesses that service Wichita. The St. Francis waste would then become a revenue stream while reducing the cost to landfill these materials.

Peregrin [8] offered the following general recommendations for hospital food system improvement:

Food

- Install energy and water meters for accurate assessment of use and ease of reading.
- Introduce employee training on the correct use of new energy and water-saving technologies
- Perform regular energy audits and water audits.
- Replace outdated equipment.
- Perform regular maintenance.
- Schedule regular cleaning.
- Document improvements with projections over 5–10 years.
- Opt for reuse and recycling of equipment that is replaced.

Water

- Replace leaky fixtures.
- Reduce water consumption by installing new efficient fixtures with low flow and spray.
- Install improved and efficient water consuming equipment:
    - Improved water-efficient steamers.
    - Dish and laundry machines.
    - Ice machines and refrigeration units.

Energy

- Install occupancy sensors by area of use, storage, and walk-ins.
- Use energy-efficient (long-lasting) bulbs in all areas as well as refrigerators, ovens, and storage areas.
- Examine the energy efficiency of new equipment.

Recycling

- Work with kitchen staff to develop efficient procedures for separating, bagging, and removing recyclables.
- Enlist retail customers in the development of the same.

3.6 Limitations of Study

The total Sysco food supplies dominate the patient and retail customer needs at St. Francis. No data have yet been collected on school and catering needs, so opportunities for evaluating food waste or other improvements in these areas could not be made at this time. Food data from the approximate 15 other suppliers were estimated to be about 10 wt% of the total St. Francis nutrition system, and these are also not included.

3.7 Conclusion

The combined three-part analysis (nutrition, energy, and mass) will promote overall improvements since there are multiple goals and objectives. St. Francis could use the experience at other facilities to conduct an all-participants effort to develop suggestions (brainstorming) as a means to draw on the knowledge and experience of all involved. At this time, about 95% of the baseline analysis of the food system was built in this study to provide more information for change. The patient waste is below 16%, making St. Francis a highly food-efficient nutrition system, compared to others in the reported literature. The patient meal system is about 50% of the total food purchased on an annual basis. Recommendations to reduce waste from packaging, unconsumed food, and food preparation all contribute to lowering the cost of landfilling. A more detailed analysis of what exactly is not consumed has proven, in the literature, to yield more reductions and could be applied here.

3.8 References for Chapter 3

[1] Goonan, S., Mirosa, M., & Spence H. (2014). Getting a taste for food waste: A mixed methods ethnographic study into hospital food waste before patient consumption conducted at three New Zealand foodservice facilities. *Journal of the Academy of Nutrition and Dietetics*, *114*(1), 63-71.

[2] Connors, P. L., & Rozell, S. B. (2004). Using a visual plate waste study to monitor menu performance. *Journal of the American Dietetic Association*, *104*(1), 94-96.

[3] Marlette, M. A., Templeton, S. B., & Panemangalore, M. (2005). Food type, food preparation, and competitive food purchases impact school lunch plate waste by sixth-grade students. *Journal of the American Dietetic Association*, *105*(11), 1779-1782.

[4] McLymont, V., Cox, S., & Stell, F. (2003). Improving patient meal satisfaction with room service meal delivery. *Journal of Nursing Care Quality*, *18*(1), 27-37.

[5] Sonnino, R., & McWilliam, S. (2011). Food waste, catering practices and public procurement: A case study of hospital food systems in Wales. *Food Policy*, *36*(6), 823-829.

[6] Hong, W., & Kirk, D. (1995). The analysis of edible plate waste results in 11 hospitals in the UK. *Journal of Foodservice*, *8*(2), 115-123.

[7] Kandiah, J., Stinnett, L., & Lutton, D. (2006). Visual plate waste in hospitalized patients: Length of stay and diet order. *Journal of the American Dietetic Association*, *106*(10), 1663-1666.

[8] Peregrin, T. (2012). Sustainability in foodservice operations: an update. *Journal of the Academy of Nutrition and Dietetics*, *112*(5), S12-S15.

CHAPTER 4

COMPARISON OF REUSABLE TO DISPOSABLE PRODUCTS: LIFE CYCLE ANALYSIS METRICS

4.1 Introduction

The healthcare sector generates waste and carbon dioxide in its delivery of services and treatment of patients. McGain et al. [1] reported an increase since 2007 in the total of CO_2 emissions of approximately 8% from the healthcare sector in the United States. Compared to other industries, there is very little information available to make science-based decisions to lower waste and to lower CO_2. There is a significant need for new data and environmental impact information to serve as metrics and benchmarks for decision makers in reducing energy and waste in healthcare. The market is open, and there are an enormous number of products that have been produced. Part of this production is attributed to the medical industry, which is considered essential for daily life. Quality plays an important part in instruments that are used in surgery. Disposable and reusable products often have different aspects in material composition, packaging, reuse, cost, and disposal. Reusable products such as medical devices are made from high-quality materials and are intended to be used for many cycles. If the comparison between disposable and reusable items is based on one use only, then the single-use item will be the best choice for many products. But if the objective is to look for many uses and reduce the environmental impact, then the reusable product will be the best choice, based on the number of cycles and the cleaning process used. Some people prefer single-use products because they do not want to be involved with any safety issue or risk in the cleaning process for some items. The full life cycle studies that have been collected use the boundaries of life cycle assessment (LCA) from cradle to grave. These boundaries included raw material extraction, manufacturing, packaging, transportation, and use and disposal for both reusable and disposable products. Products considered in this research include laryngeal mask airways, sharps containers, drums, perioperative textiles, plastic anesthetic drug trays, medical textiles, drinking cups, coveralls, rechargeable batteries, laparotomy pads, food to-go containers, and animal cages. The objective of this study was to identify all published complete life cycle studies of reusable and disposable product comparisons and undertake a detailed comparison of the environmental benefit. The details of each study may be found in the original articles. This paper extracts specific data on life cycle results and the characteristics of these products that may define the relative environmental benefit.

4.2 Abstract

Products are designed and manufactured to meet market needs. Based on design, products can be used several times (reusable) or used only once (disposable). In order to understand the environmental consequences of single-use versus reusable products, life cycle cradle-to-grave studies are widely used. This paper is the first effort to examine the major recurring factors that determine whether reusable or disposable alternatives have lower environmental footprints across all such reported studies. In all but one unusual energy use case, the disposable alternatives had a greater impact on the environment, based on the carbon footprint, than reusables, ranging from 20% to 4,600% higher impact. In verifying the results in future studies, the manufacturing energy and weight of a single reusable product was always found to be greater than the comparable single disposable. Some products were stated to have large cycles of reuse (1,000–4,500), but no system for actually counting was described. At these large recycle rates, the environmental benefit of reusables increases slowly because the cycle of energy for reuse is only slightly lower that the energy for manufacturing a disposable.

4.3 Methods

The overall method in this study was to focus on publications that provided information about life cycle studies with journal articles or reports on reusable versus disposable (single-use) items. Related journal articles were identified from electronic reference databases using combinations of key words and titles from 1990 to March 2016. The key words were “life cycle,” “carbon footprint,” “reusable,” “disposable,” “single use” and “life cycle assessment” in any product with journal articles or reports in the English language chosen in this study. The following search engines were used in this study: PubMed, Web of Knowledge, ScienceDirect, and Scopus. The total number of titles and abstracts resulting from searches for relevance was 148 from PubMed, 20 from the Web of Knowledge, 320 from ScienceDirect, and 39 from Scopus, bringing the total to 527 from all search engines. Approximately 19 articles occurred in more than one database, and these were identified and removed with the help of Endnote. About 410 articles were excluded because of titles and abstracts that did not encompass the necessary life cycle approach and quantitative data. Of all the key words searched, “Life cycle assessment” had the most output results. Five articles found the title or the abstract only in the English language and the remaining body of articles was in different languages, so they were excluded. Of the remaining 93 articles, 83 full texts were excluded because the discussion was about cost, impact of delivery, quality, and comparison between the two systems of disposable and reusable, with no information about comparison in the life cycle and providing only one part of the life cycle that was not included in this study. The remaining ten articles, in addition to three articles found from the references and six articles reviewed in the state-of-the-art 2012 article by Dr. Overcash [2], were included in this study. A flowchart showing the search engines used in the initial pooling of this study is shown in Figure 4.1.

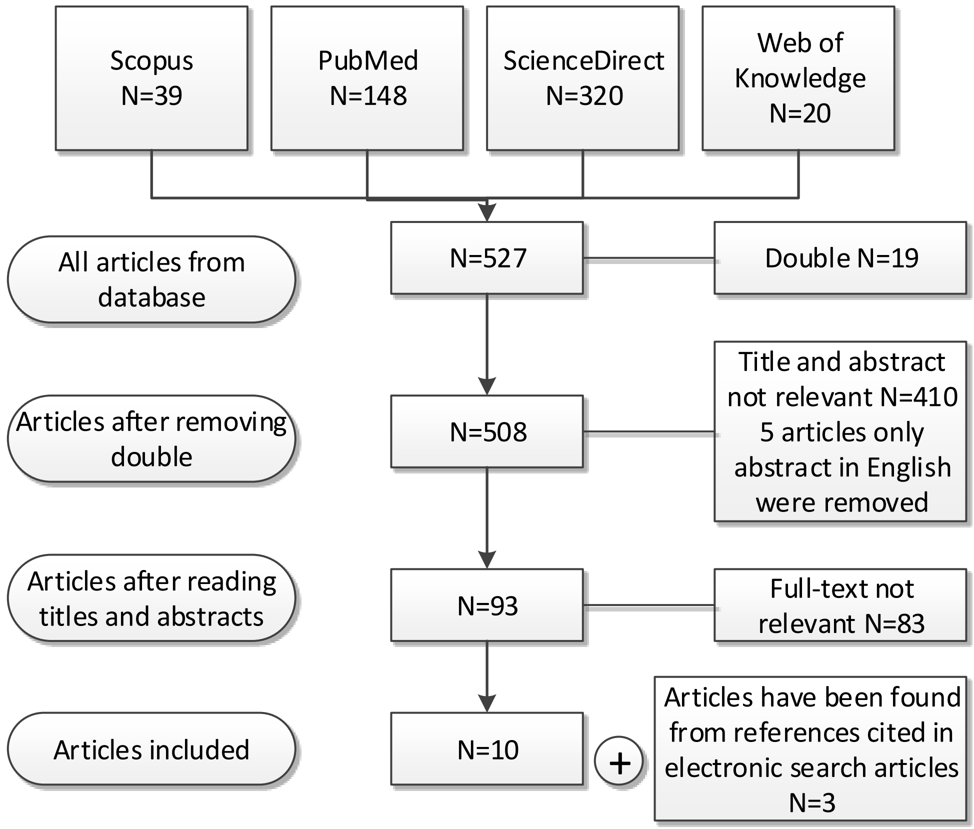

Figure 4.1: Flowchart of selected studies indicating life cycle of reusable and disposable items.

4.4 Results and Discussion

In the 13 complete articles located, there were 25 separate product comparisons of reusable and disposable alternatives, as shown in Table 4.1. The overall environmental comparison, cradle-to-gate, was expressed on a variety of bases, such as hospital uses per year, 1,000 liters of beer served, X tons of food shipped by container, etc. This resulted in a wide range of comparative results across all products, and so a common basis was selected for all comparative results. This was the use of one reusable product over the defined number of cycles until the product was finished and entered the end-of-life stage, and the comparable disposable (single-use) product to match the single reusable product. In all comparisons, the number of reusable cycles was given, although in some cases, multiple reuse cycles were quoted. In order to not over represent such studies, only one reuse rate was selected. In all cases, the reusable scenario had a lower environmental impact than the disposable scenario across these very diverse products. In one exception, the single use item was found to be better, but it was for a geographic area (South Australia) in which a particularly high carbon dioxide equivalent (CO_{2eq}) was recorded per megajoule (MJ) of electricity uses, and so this was an anomaly.

TABLE 4.1

COMPARISON OF FULL CRADLE-TO-GATE LIFE CYCLE INFORMATION ON REUSABLE VERSUS DISPOSABLE PRODUCTS

References	Comparison of Reusable vs. Disposable Products	Reusable Cycles
Raugei et al. [3]	Steel drums vs. wood fiber drums	200
McDowell [2]	PET surgical lap drape vs. 50% pulp:50% spunlace PET surgical lap drape	75
McDowell [2]	PET surgical gown vs. 50% pulp:50% spunlace PET surgical gown	75
Parsons [4]	NiMH rechargeable battery vs. NiCd alkaline battery	400
Garrido & del Castillo [5]	Polypropylene heavy reusable cups vs. polypropylene light disposable cups	10
Garrido & del Castillo [5]	Polypropylene heavy reusable cups vs. polypropylene light disposable cups	14
UniTech [2]	Nuclear plant nylon coverall vs. nuclear SMS PET and polypropylene coverall	100
Albrecht et al. [6]	Polypropylene/polyethylene fruit crates vs. wood fruit crates	50
Albrecht et al [6]	Polypropylene/Polyethylene fruit crates vs. cardboard fruit crates	50
Grimmond & Reiner [7]	Sharp containers	12.6
MnTAP [2]	Woven PET surgical gown vs. polypropylene/SMS PET surgical gown	50
ETSA [2]	Woven PET/polyurethane surgical gown vs. nonwoven PET/wood pulp surgical gown	75
Kümmerer et al. [8]	Cotton six-layer laparotomy pads vs. cotton four-layer laparotomy pads	15
Copeland et al. [9]	Polypropylene to-go food container vs. polystyrene to-go food container	30
D'Incognito [10]	Polysulfone plastic animal cages vs. PET plastic animal cages	310
RMIT [2]	Woven PET/cotton surgical package vs. nonwoven polypropylene surgical gown	127

TABLE 4.1 (continued)

References	Comparison of Reusable vs. Disposable Products	Reusable Cycles
Vozzola et al. [11]	Woven PET cleanroom coverall vs. high-density nonwoven polyethylene	50
Vozzola, et al. [12]	Knit PET/expanded polytetrafluoroethylene surgical gown vs. nonwoven PET/polypropylene surgical gown	75
Eckelman et al. [13]	Silicone/polycarbonate/polypropylene laryngeal mask airway (LMA) vs. polyvinly chloride/ polycarbonate/polypropylene laryngeal mask airway	40
Vozzola et al. [14]	Woven PET hospital isolation gown vs. nonwoven polypropylene hospital isolation gown	60

In 20 comparisons, data from these literature sources were available to calculate the energy as MJ or GWP kg CO_{2eq} needed to manufacture a single reusable product and a single disposable product. An approximate conversion factor of 0.060 kg CO_{2eq} /MJ natural resource energy was used to obtain all results on a CO_{2eq} basis for manufacturing the single products. It is interesting to note that not all articles stated the actual weight of these comparative products since the mass and material are major factors in the life cycle cradle-to-gate analysis. The manufacturing and weight data of reusable vs. disposable products are found in Table 4.2.

TABLE 4.2

METRIC OF ENVIRONMENTAL BENEFIT OF REUSABLE PRODUCTS AND SEVERAL LIFE CYCLE VARIABLES INFLUENCING THIS BENEFIT
(BLANKS INDICATE DATA NOT PUBLISHED)

Reusable vs. disposable products comparison	**Ratio of full life cycle cradle-to-grave ($kgCO_{2eq}$) of disposable system for specified number of reuses to full life cycle cradle-to-grave ($kgCO_{2eq}$) of one reusable system for specified number of reuses**	**Specified reusable cycles**	**Ratio of manufacturing energy (kg CO_{2eq}) of one reusable product to manufacturing energy (kg CO_{2eq}) of one disposable product**	**Weight of one reusable product/ weight of one disposable product**
Steel drums vs. wood fiber drums	46	200	3.0	3.6
PET surgical lap drape vs. 50% pulp: 50% spunlace PET surgical lap drape	31	75		5.0
PET surgical gown vs. 50% pulp: 50% spunlace PET surgical gown	23	75		8.4
NiMH rechargeable battery vs. NiCd alkaline battery	19	400		1.2
Polypropylene heavy reusable cups vs. polypropylene light disposable cups	13	10	7.0	14.1
Polypropylene heavy reusable cups vs. polypropylene light disposable cups	10	14	1.5	1.5
Nuclear plant nylon coverall vs. nuclear SMS PET and polypropylene coverall	9	100	2.2	2.4
Polypropylene/polyethylene fruit crates vs. wood fruit crates	8	50	3.8	2.2
Polypropylene/polyethylene fruit crates vs. cardboard fruit crates	7	50	7.0	14.1
Sharp containers	5	12.6	7.8	2.8
Woven PET surgical gown vs. polypropylene/SMS PET surgical gown	3	50	9.8	2.8
Woven PET/polyurethane surgical gown vs. nonwoven PET/wood pulp surgical gown	3	75	3.5	1.8
Cotton six-layer laparotomy pads vs. cotton four-layer laparotomy pads	3	15	2.7	1.9
Polypropylene to-go food container vs. polystyrene to-go food container	2	30	10.2	23.9
Polysulfone plastic animal cages vs. PET plastic animal cages	2	310		

TABLE 4.2 (continued)

Reusable vs. disposable products comparison	**Ratio of full life cycle cradle-to-grave ($kgCO_{2eq}$) of disposable system for specified number of reuses to full life cycle cradle-to-grave ($kgCO_{2eq}$) of one reusable system for specified number of reuses**	**Specified reusable cycles**	**Ratio of manufacturing energy (kg CO_{2eq}) of one reusable product to manufacturing energy (kg CO_{2eq}) of one disposable product**	**Weight of one reusable product/ weight of one disposable product**
Woven PET/cotton surgical package vs. nonwoven polypropylene surgical gown	2	127	13.5	1.5
Woven PET cleanroom coverall vs. high density nonwoven polyethylene	2	50	4.0	1.6
Knit PET/expanded polytetrafluoroethylene surgical gown vs. nonwoven PET/ polypropylene surgical gown	2	75	6.0	2.0
Silicone/polycarbonate/polypropylene laryngeal mask airway (LMA) vs. polyvinyl chloride/polycarbonate/polypropylene laryngeal mask airway	2	40	1.2	1.0
Woven PET hospital isolation gown vs. non-woven polypropylene hospital isolation gown	1	60	13.3	3.8

It was observed that the manufacturing energy of the single reusable item was always higher than the single disposable item. This is consistent with the reusable product being more robust to allowing multiple cycles of cleaning, preparation, and reuse. However, two products did not follow this trend, and upon discussion with the authors of those studies, an error was discovered that when corrected followed the trend of the other data. This suggests that in future published articles that compare reusable and disposable products, the manufacturing energy of each single product should be clearly stated as a data verification. Similarly, the weight of the reusable product was larger than that of the disposable product (range 23:1 to 1:1). When the weight of the disposable product was considerably lower than that of the reusable product, then the benefit of the reusable product decreased.

The relative environmental benefit of the reusable product was characterized as the ratio of the cradle-to-gate global warming potential (GWP), expressed as kg CO_{2eq}, of the disposable product system to the single reusable product system. This includes the manufacturing, cleaning, and preparation of the reusable item over the specified number of uses versus the number of disposable items needed for the same specified number of use cycles. This ratio is the primary metric used to examine the impact of life cycle variables on the relative environmental benefit of reusables. Some of the variables were number of cycles, ratio of manufacturing energy for a single disposable product equivalent to a single reusable product, ratio of the weight of the reusable product to the weight of the disposable product , and combinations of these variables, as shown in Table 4.2.

None of the life cycle variables individually correlated with the overall relative life cycle benefit ratio of reusable to disposable product. Correlation analysis between variables showed no correlation; therefore, more data is needed.

4.5 References for Chapter 4

[1] McGain, F., McAlister, S., McGavin, A., & Story, D. (2012). A life cycle assessment of reusable and single-use central venous catheter insertion kits. *Anesthesia & Analgesia*, *114*(5), 1073-1080.

[2] Overcash, M. (2012). A comparison of reusable and disposable perioperative textiles: Sustainability state-of-the-art 2012. *Anesthesia & Analgesia*, *114*(5), 1055-1066.

[3] Raugei, M., Fullana-i-Palmer, P., Puig, R., & Torres, A. (2009). A comparative life cycle assessment of single-use fibre drums versus reusable steel drums. *Packaging Technology and Science*, *22*(8), 443-450.

[4] Parsons, D. (2007). The environmental impact of disposable versus re-chargeable batteries for consumer use. *The International Journal of Life Cycle Assessment*, *12*(3), 197-203.

[5] Garrido, N., & Alvarez del Castillo, M. D. (2007). Environmental evaluation of single-use and reusable cups. *The International Journal of Life Cycle Assessment*, *12*(4), 252-256.

[6] Albrecht, S., Brandstetter, P., Beck, T., Fullana-i-Palmer, P., Grönman, K., Baitz, M., Deimling, S., Sandilands, J. & Fischer, M. (2013). An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe. *The International Journal of Life Cycle Assessment*, *18*(8), 1549-1567.

[7] Grimmond, T., & Reiner, S. (2012). Impact on carbon footprint: a life cycle assessment of disposable versus reusable sharps containers in a large U.S. hospital. *Waste Management & Research*, *30*(6), 639-642.

[8] Kümmerer, K., Dettenkofer, M., & Scherrer, M. (1996). Comparison of reusable and disposable laparatomy pads. *The International Journal of Life Cycle Assessment*, *1*(2), 67-73.

[9] Copeland, A. M., Ormsby, A. A., & Willingham, A. M. (2013). Assessment and comparative analysis of a reusable versus disposable to-go system. *Sustainability: The Journal of Record*, *6*(6), 353-358.

[10] D'Incognito, V. (2010). Environmental impact of disposable and reusable plastic cages. *Animal Technology and Welfare*, *9*(3), 147-150.

[11] Vozzola, E., Overcash, M., & Griffing, E. (2016). *Life cycle analysis of cleanroom coveralls: Reusable and disposable*. Reston, VA: Environmental Clarity, Inc. 87 pp.

[12] Vozzola, E., Overcash, M., & Griffing, E. (2016). *Life cycle analysis of surgical gowns: Reusable and disposable*. Reston, VA: Environmental Clarity, Inc. 80 pp.

[13] Eckelman, M., Mosher, M., Gonzalez, A., & Sherman, J. (2012). Comparative life cycle assessment of disposable and reusable laryngeal mask airways. *Anesthesia & Analgesia*, *114*(5), 1067-1072.

[14] Vozzola, E., Overcash, M., & Griffing, E. (2017). *Life cycle analysis of isolation gowns: Reusable and disposable*. Reston, VA: Environmental Clarity, Inc. 25 pp.

CHAPTER 5

CHOICE OF IMAGING MODALITIES WITH LOWER ENVIRONMENTAL IMPACT TO MEET PATIENT NEEDS

5.1 Introduction

Radiology is an important hospital department for those who have been in an accident or have a condition that needs imaging for diagnosis. In the 1990s, the American College of Radiology (ACR) recognized the need for guidelines for appropriate use of imaging technology. These guidelines became known as the ACR Appropriateness Criteria® (AC) [1]. In 1993, K. K. Wallace formally introduced this organization to the concept of eliminating misuse of radiology services [1]. Developed from this, the ACR AC are evidence-based guidelines to assist referring physicians and other providers in making the most appropriate imaging or treatment decision for a specific clinical condition [1]. Efficient use of radiology is the main concern of ACR, so they engaged the guidelines to provide more quality in healthcare. Developing the guidelines by imaging experts and specialists added greater benefits in interventional radiology, radiation oncology, and diagnostic imaging. The ACR provides free data on their websites for researchers or individuals to use the ACR Appropriateness Criteria® for scientific or other valuable information. Also, the *Journal of the American College of Radiology* (*JACR*) published the ACR AC to improve education about appropriate imaging for better patient care. There are many imaging services in the U.S. healthcare system, and the most-used modalities in the recent 15-year period are radiography (55.1%), sonography (19.1%), computed tomography (CT) scan (12.5%), and magnetic resonance imaging (MRI) (5.1%) [2]. The first objective of this paper is to review the ten ACR AC categories to determine how many variants have multiple "usually appropriate" modalities, that is, rated in the 7, 8, and 9 categories. The second objective is to compare the energy improvement of some examples of patient variants with multiple appropriate modalities that come from selecting the lower energy alternative.

5.2 Abstract

Every patient that comes to the radiology department has a different category of health problem. Based on the diagnosis, each patient gets the appropriate imaging to aid in his/her treatment. The Healthier Hospital Initiative (HHI, www.healthierhospitals.org) is an important effort on the part of healthcare providers to move toward sustainability. This initiative has raised awareness of energy utilization and provides tools for measuring hospital energy use. However, the coupling of patient healthcare teams (RN, MD, administrators) making decisions that achieve quality patient care, with a goal of lower environmental impact, has yet to be widely explored. This study examines the use of the American College of Radiology Appropriateness Criteria® as guidance for similar, "usually appropriate" imaging choices (ratings 7, 8, and 9) and then identifies the lower energy use alternative. Overall, in the ten ACR patient categories (with 162 subcategories and 810 variants), approximately 48% of patient conditions have similar "usually appropriate" ratings. The largest percentage of interchangeability is the cardiac category. Thus, the potential to choose a lower-energy imaging alternative appears to exist. As examples, six patient variants are used to illustrate the potential to reduce energy use in the radiology department. These examples provide approximate energy reduction alternatives, which, if selected, at 1% to 10% of patient cases (versus 48% of comparative "usually appropriate" imaging) would lead to an annual U.S. healthcare improvement of 24–240 million kWh per year. This modest improvement would be a direct contribution to healthcare sustainability by the radiology community without any change in technology.

5.3 Methodology

The ten categories of diagnostic patient conditions for radiology and within each the 6 to 27 subcategories are show in Table 5.1 (https://acsearch.acr.org/list).

TABLE 5.1

CATEGORIES OF DIAGNOSTIC PATIENT CONDITIONS

#	Categories	Subcategories
1	Breast	6
2	Cardiac	10
3	Gastrointestinal	17
4	Musculoskeletal	27
5	Neurologic	20
6	Pediatric	12
7	Thoracic	16
8	Urologic	21
9	Vascular	18
10	Womens	15

All ten ACR categories for imaging modalities were put in different tables and then the entire imaging choices for each variant were listed. The diagnostic patient categories have subcategories, and each subcategory has a number of variants. The overall categories contain about 810 variants. The number of variants ranges from 1 to 4 or more in each clinical condition in the subcategories. The variant is assigned a radiologic procedure and a rating scale from 1 to 9 for imaging equipment for each subcategory. Therefore, based on ACR AC rating scale, ratings of 1, 2, and 3 are "rarely appropriate"; ratings 4, 5, and 6 are "may be appropriate"; and ratings 7, 8, and 9 are "usually appropriate" (with a rating of 9 as the best imaging modality). Variants that were below the "usually appropriate" rating scale (that is, from 1 to 6) were excluded. After that, variants were eliminated if there were no alternatives for a given modality. Only those variants with more than one "usually appropriate"-rated modality were selected for a summary. As an example, the breast category is shown in Table 5.2. Across the six breast subcategories, twelve variants had multiple "usually appropriate" ratings. The analysis shown in Table 5.2 was repeated for the other nine patient conditions.

TABLE 5.2

ALTERNATIVE MODALITIES WITH SCORES IN DIFFERENT VARIANTS IN BREAST CATEGORY

Condition	Average ACR criteria - 7 to 9 range only	Variants	Modality	Score	Modality	score	Modality	Score
Breast Cancer Screening	9	Variant 1	MRI	9	DBT	9	Mammography	9
Breast Cancer Screening	8.33	Variant 2	MRI	7	DBT	9	Mammography	9
Breast Cancer Screening	9	Variant 3	DBT	9	Mammography	9		
Evaluation of Nipple Discharge	9	Variant 2	US	9	DBT	9	Mammography	9
Evaluation of Nipple Discharge	9	Variant 3	US	9	DBT	9	Mammography	9
Evaluation of Nipple Discharge	8.67	Variant 5	US	9	DBT	8	Mammography	8
Evaluation of the Symptomatic Male Breast	8.5	Variant 5	US	8	Mammography	9		
Palpable Breast Masses	9	Variant 1	DBT	9	Mammography	9		
Palpable Breast Masses	8	Variant 3	US	8	DBT	8	Mammography	8
Palpable Breast Masses	8.33	Variant 7	DBT	8	Mammography	8		
Palpable Breast Masses	8	Variant 11	US	8	DBT	8	Mammography	8
Stage I Breast Cancer: Initial Workup and Surveillance for Local Recurrence and Distant Metastases in Asymptomatic Women	8.5	Variant 9	DBT	9, 8	Mammography	9, 8		

Thus, the first analysis was based on the ACR Appropriateness Criteria® and the ten categories that were studied for patient condition and specific choice of imaging modality. If two or more modalities had the highest rating, then for those patients, there were alternative choices (e.g., Crohn's disease enterography rated 9 for CT and MRI). The second analysis was to use life cycle studies to establish a complete energy profile (electricity and consumables) for CT and MRI, as shown in Table 5.3, and then the energy savings by selecting alternatives was evaluated.

TABLE 5.3

NATURAL RESOURCES ENERGY CONSUMPTION OF FOUR IMAGING PRACTICES [2]

	MRI	CT-scan	X-ray	Ultrasound
TOTAL (nre-MJ per patient	1,046	216	39	31

5.4 Results

After all categories were listed with their variants, only those variants in which there were two or more modalities that scored 7, 8, or 9 were chosen so that these might be considered alternatives that still provide good patient information. It is recognized that for any given variant, not every modality with a "usually appropriate" rating (like a 9) can always be used. There is probably no single reason for the lack of interchangeability, but this could involve the way that radiologists are trained or the limits in technology. However, it is important to understand just how many variants have multiple "usually appropriate" modalities. Table 5.4 summarizes the total variants in each ACR category and what percent have alternative modalities with "usually appropriate" ratings. Across all ten ACR patient categories, 354 patient condition variants appear to have multiple "usually appropriate" modalities. Across the ten patient categories, the range of variants with interchangeable modalities was 23%–83% with the median of 48%, which is nearly half. The cardiac category had the highest level of potentially interchangeability, implying that there is some potential for selecting alternative modalities that achieve quality care through patient diagnosis imaging but at a lower energy demand.

TABLE 5.4

SUMMARY OF TEN DIAGNOSTIC CATEGORIES WITH PERCENTAGE OF COMPARABLE VARIANTS

No.	Category	Summary	Percentage of comparison variants
1	Breast	There were 47 variants in the breast diagnostic category, 20 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 27 variants, 15 were removed because there were no alternative modalities. The remaining 12 variants of the original 47 were compared between modalities to select the lower energy for hospital sustainability.	26
2	Cardiac	There were 24 variants in the cardiac diagnostic category, 2 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 22 variants, 2 were removed because there were no alternative modalities. The remaining 20 variants of the original 24 were compared between modalities to select the lower energy for hospital sustainability.	83
3	Gastrointestinal	There were 78 variants in the gastrointestinal diagnostic category, 3 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 75 variants, 28 were removed because there were no alternative modalities. The remaining 47 variants of the original 78 were compared between modalities to select the lower energy for hospital sustainability.	60
4	Musculoskeletal	There were 238 variants in the musculoskeletal diagnostic category, 23 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 215 variants, 117 were removed because there were no alternative modalities. The remaining 91 of the original 238 were compared between modalities to select the lower energy for hospital sustainability.	38
5	Neurologic	There were 164 variants in the neurologic diagnostic category, 12 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 152 variants, 76 were removed because there were no alternative modalities. The remaining 76 variants of the original 164 were compared between modalities to select the lower energy for hospital sustainability.	46
6	Pediatric	There were 55 variants in the pediatric diagnostic category, 29 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 26 variants, 13 were removed because there were no alternative modalities. The remaining 13 variants of the original 55 were compared between modalities to select the lower energy for hospital sustainability.	24
7	Thoracic	There were 56 variants in the thoracic diagnostic category, 7 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 49 variants, 25 were removed because there were no alternative modalities. The remaining 24 variants of the original 56 were compared between modalities to select the lower energy for hospital sustainability.	43

TABLE 5.4 (continued)

No.	Category	Summary	Percentage of comparison variants
8	Urologic	There were 48 variants in the urologic diagnostic category, 8 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 40 variants, 15 were removed because there were no alternative modalities. The remaining 23 variants of the original 48 were compared between modalities to select the lower energy for hospital sustainability.	48
9	Vascular	There were 38 variants in the vascular diagnostic category, 1 of which was excluded because it is under the appropriate rating scale of 7 to 9. Of the remaining 37 variants, 5 were removed because there were no alternative modalities. The remaining 29 variants of the original 38 were compared between modalities to select the lower energy for hospital sustainability.	76
10	Women's Imaging	There were 62 variants in the women's diagnostic category, 5 of which were excluded because they are under the appropriate rating scale of 7 to 9. Of the remaining 57 variants, 38 were removed because there were no alternative modalities. The remaining 19 variants of the original 62 were compared between modalities to select the lower energy for hospital sustainability.	31

Energy savings in radiology translates to reduced cost and lower environmental impact. To the extent that there is some interchangeability among ACR "usually appropriate" modalities, an energy savings analysis was conducted on six examples. These six variants were selected from the radiology community to demonstrate potential energy savings by selecting the modality with the lowest energy per patient while achieving similar patient imaging information. One example is from the neurologic category under the headache conditions (variant 4) in which selecting the computed tomography angiography (CTA) (ACR rating of 8) over the magnetic resonance angiography (MRA) (ACR rating of 8) saves about 800 MJ/patient (230 kWh/patient). Other examples were selected to cover other ACR patient categories for diagnostic, gastrointestinal, vascular, and urologic imaging. One example, chronic liver disease evaluation/follow-up, had a third alternative, ultrasound (US), for which the energy savings was more than 1,000 MJ/patient

(280 kWh/patient). One could also chose US versus CTA in this case for a small energy savings of 180 MJ/patient (50kWh/patient).

These are only illustrative examples, since discussion in the radiology community is needed to ascertain how many of these 354 patient conditions for which there are similar ACR "usually appropriate" modalities could be considered interchangeable with no significant difference in patient diagnostic results. However, the following broad evaluation for patient conditions (354) was made. Given the energy values provided previously in Table 5.3, the representative energy savings would be between 140 and 1,010 MJ/patient.

The hypothesis of this study is that by using the quantitative imaging energy data, it is possible to estimate U.S. hospital energy savings by selecting the imaging device with an equivalent rating (7s, 8s, or 9s) but with a lower energy use. In order to make such estimates, several sources of data on the distribution of imaging modalities and numbers of U.S. patients receiving imaging annually were located, as shown in Table 5.5, and values judged to be representative were established. The energy reduction was derived from a small sample of patient conditions, as shown in Table 5.6. For MRI substitutions, a typical energy reduction was 830 MJ/patient, and for CT, this was 140 MJ/patient. From Table 5.4, it can be determined that in all 354 patient categories, the median interchangeability was about 48%. However, a more conservative estimate that 1% or 10% of the MRI and CT might be replaced by another "usually appropriate" imaging modality was selected for this analysis. With the U.S. MRI and CT imaging numbers shown in Table 5.5, there is a median energy savings of approximately 17–170 million kWh and 7–70 million kWh, respectively, in the U.S. for decisions involving alternatives (1%–10% of possible patient conditions) with "usually appropriate" imaging. This total of 24–240 million kWh represents the modest contribution of the radiology community to healthcare sustainability improvement by changes in patient decisions.

TABLE 5.5

U.S. DATA ON RADIOLOGY IMAGING MODALITIES

	American College of Radiology and Radiology Business Management Association, 2013 [3]	**Smith-Bindman et al., 2012 [4]**	**Smith-Bindman, 2008 [5]**		**Estimates of total imaging by modality (patient images per thousand population)**					**Estimated total U.S. imaging by modality based on 2016 population of 322,762,018**	**Estimated percent distribution of imaging**
Cross-sectional imaging	Percent of cross-sectional imaging	Percent of cross-sectional imaging	Percent of cross-sectional imaging	Representative percent of total annual imaging	Mettler et al., 2009 (2006 basis) [6]	Smith-Bindman (assuming Washington State Group Health population is similar to general population, 2006 basis)	IMV, 2013 [7]	IMV, 2014 [8]	Value judged representative (2014 basis)		Percent value judged representative (2014 basis)
CT	25	34	37	12	224	181	240		180	58,097,160	12
MRI	17	14	15	5		72		110	80	25,820,960	5
U.S.	58	52	47	17		225			225	72,621,450	15
Cross-sectional imaging as percent of total imaging	29	37	33								0
Nuclear medicine as percent of total imaging	1	4	2	2		33			30	9,682,860	2
X-ray imaging as percent of total imaging	70	60	67	65	980	936			960	309,851,520	65
				100		1447			1475		100

TABLE 5.6

EXAMPLES OF PATIENT CONDITIONS FOR WHICH MULTIPLE ACR "USUALLY APPROPRIATE" MODALITIES IN WHICH ENERGY SAVINGS WOULD OCCUR ARE AVAILABLE AND PATIENT DIAGNOSTIC QUALITY WOULD BE MAINTAINED

ACR diagnostic category (variant)	**Modality ("usually appropriate" rating")**	**Modality ("usually appropriate" rating)**	**Modality ("usually appropriate" rating)**	**Energy savings (MJ)**	**Energy savings (MJ)**
Gastrointestinal (chronic liver disease evaluation/ follow-up—var.2)	MRI (8)	US (7)	CT (7)	US instead of MRI	US instead of CT
Energy use, MJ/patient	1,046	31	216	1,015	185
Gastrointestinal (Crohn's disease follow-up—var. 2)	MR enterography (9)	CT enterography (9)			CT instead of MRI
Energy use, MJ/patient	1046	216			830
Neurologic (headache—var. 4)	MRA (8)	CTA (7)			CT instead of MRI
Energy use, MJ/patient	1,046	216			830
Vascular (renovascular hypertension—var.1)	MRA (8)	CTA (8)			CT instead of MRI
Energy use, MJ/patient	1,046	216			830
Urologic (post-treatment follow-up of prostate cancer—var. 1)	MRI (7)	CT (7)			CT instead of MRI
Energy use, MJ/patient	1,046	216			830
Pediatric (head trauma-child—var. 3)	MRI (7)	CT (9)			CT instead of MRI
Energy use, MJ/patient	1,046	216			830

5.5 Conclusion

The ACR recommendations of modality choices include a significant number of conditions (48%) for which alternatives that are "usually appropriate" (scores 7–9) can be chosen. The patient category with the highest degree of possible interchangeability was cardiac. This represents an opportunity to reduce hospital energy use and public health impact through changes in radiology decision-making rather than changes in technology. That is, the selection of imaging modality can be changed to lower the environmental impact, while delivering quality patient care. These results are not meant to dictate radiology changes but rather provide information that for the first time will allow the radiology community to participate in improving hospital sustainability. The purpose here is to engage radiologists to use their ingenuity and creativity to examine procedures, patient-based decisions, and other avenues to seek cost and sustainability improvements. As healthcare evolves and reimbursement patterns change, there is a foreseeable chance that reimbursement could be in the form of an all-inclusive payment for the patient and not a specific modality-driven reimbursement. Hospitals might then utilize this in-house energy and consumables information on imaging to reduce costs.

5.6 References for Chapter 5

[1] American College of Radiology. (no date). About the ACR Appropriateness Criteria. Retrieved from https://www.acr.org/Quality-Safety/Appropriateness-Criteria/About-AC [cited September 16, 2016].

[2] Esmaeili, M. A. (2016). *New chapter in healthcare environmental impact reduction through medical treatment choices: The case of diagnostic imaging services* (Doctoral dissertation). Wichita State University, Wichita, Kansas.

[3] American College of Radiology and Radiology Business Management Association. (2013). *Capitation handbook*. Reston, VA: ACR and RBMA. 38 pp.

[4] Smith-Bindman, R., D. Miglioretti, D. E., & Johnson, E. (2012). Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996–2010, *Journal of the American Medical Association, 301*(22), 2400-2409.

[5] Smith-Bindman, R., Miglioretti, D. L., & Larson, E. B. (2008). Rising use of diagnostic medical imaging in a large integrated health system. *Health Affairs*, *27*(6), 1491-1502.

[6] Mettler Jr., F. A., Bhargavan, M., Faulkner, K., Gilley, D. B., Gray, J. E., Ibbott, G. S. & Thomadsen, B. R. (2009). Radiologic and nuclear medicine studies in the United States and worldwide: Frequency, radiation dose, and comparison with other radiation sources—1950–2007. *Radiology*, *253*(2), 520-531.

[7] IMV. (2013). *CT market outlook report*. Columbia, MD: IMV.

[8] IMV. (2014). *MRI market outlook report*. Columbia, MD: IMV.

CHAPTER 6

CONCLUSION AND FUTURE RESEARCH WORKS

6.1 Conclusion

Hospitals seek sustainability improvement by considering food waste as an issue. The reasons for food waste can be major factors in economic and environmental impacts, especially in hospitals that recorded a high percentage of food waste. Dealing with sick patients might make it difficult to reach a zero percentage. Many areas of healthcare must be addressed in further research. This dissertation covered nutrition services relative to food waste, materials used in hospitals, and radiology as a specific part of diagnostic services . The following points show the findings in the research articles covered:

- In different hospitals in many countries in the world, the food waste percentage ranges from 6% to almost 65% and the median is about 31%. After applying some suggested solutions from other studies, the improvement ranged between 4.2% and 49%. These improvements could reduce hospital waste by about 21% on average. Therefore, this reduction would translate to about 24% waste rather than the reported current median of 31% waste. The main factors involved in a reduction of food waste were menu and type of food or preparation procedure.
- The combined four-part analysis (kitchen, patient tray, retail, and equipment) will promote overall improvement since there are multiple goals and objectives in the case study research. The total food waste at Via Christi Hospital St. Francis per year was extrapolated to be 45,558 lbs plus 36,465 lbs for non-food waste. The patient meal system is about 50% of the total food purchased on an annual basis. The patient tray waste is below 16%, making St. Francis a highly food-efficient nutrition system, compared to that in the reported

literature (median 31%). Recommendations to reduce waste from packaging and unconsumed food preparation all contribute to lowering the cost of landfilling. This is the first quantitative study of a hospital food system that included tray waste, preparation area waste, retail waste, and equipment energy waste in kitchen and retail areas.

- The comparison of reusable to disposable products is the first effort to examine the major recurring factors that determine whether reusable versus disposable alternatives have lower environmental footprints across all such reported studies. In all but one unusual energy use case, the disposable products had a greater impact on the environment, based on the carbon footprint, than reusable producets, ranging from 20% to 4,600% higher impact.   At very large recycle rates, the environmental benefit of reusables increases slowly because the energy for reusing a product is only slightly lower than the energy for manufacturing a disposable.
- The ten categories of diagnostic patient conditions were collected in order to compare decisions involving imaging modalities. There is some potential for selecting alternative modalities that still achieve quality care through patient diagnosis imaging but at a lower energy demand, meaning that energy savings in radiology will reduce cost and lower the environmental impact. This modest improvement would be a direct contribution to healthcare sustainability by the radiology community without any technology change.

Recommendations to reduce energy and waste in hospitals in order to become more sustainable are mentioned in Chapter 3.

6.2 Future Research Work

Here is an agenda to seek further sustainability in the healthcare impact, based on the research results discussed in the four research articles included in this dissertation:

- Literature review studies recorded a high percentage of food waste, suggesting that more research and support are needed to improve a reduction in food waste.
- Countries might create a system for tracking the source of produced food and the outcome in order to minimize food waste in all facilities.
- A system that increases the awareness of all hospital staff—from nurses to physicians to administrators, plus suppliers and manufacturers—to be more cognizant of energy, material consumption, and the cost of environmental impact relative to sustainability is recommended.
- With more information provided from researchers to the radiology community, it would be possible to engage radiologists to use their ingenuity and creativity to examine procedures, patient-based decisions, and other avenues to seek cost and sustainability improvements.