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Life cycle assessment and economic analysis of residential air conditioning in Saudi Arabia

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ABSTRACT

Buildings consume 79% of Saudi electricity, of which 70% is consumed by air conditioning (AC) systems as a result of the high ambient temperatures during the long summer season and heavily subsidized cost of electricity. Fossil fuels are burned as the primary energy source in power plants causing environmental impacts. A cradle-to grave regional life cycle assessment (LCA) of residential building air conditioning has been performed to evaluate these impacts. The results show that the use phase is responsible for largest share of the environmental impacts, and that the type of primary fuel used influences the magnitude of the impacts in each region. Copper and steel production dominate the manufacturing phase impact and the end-of-life (EOL) phase results in environmental benefits by reduction in the need for virgin materials. The overall contribution of transportation is minor. Economic considerations influence decisions more than environmental concerns in a developing country like Saudi Arabia. To evaluate the relationship of economics to environmental effects, life cycle cost (LCC), and payback period (PBP) are included with the use of Monte Carlo simulation (MCS) to model the effect of the variability in input prices on the uncertainty associated with the final results.

1. Introduction

In Saudi Arabia, there is extensive use of indoor air conditioning systems as a result of the high ambient temperatures during the long summer [1]. The Electricity & Cogeneration Regulatory Authority annual report (2012) reports the proportion of electrical energy consumed by various sectors in Saudi Arabia, as is shown in Fig. 1. The figure shows that 50% of the Kingdom's electricity is consumed by the residential sector [2]. Furthermore, the demand for electricity in the Kingdom is increasing an average of 8% per year, due to a heavily subsidized cost structure [3] and population growth (2.34% annually). In response of this population growth there are plans to construct 1.65 million new homes over the next few years [4]. Table 1 shows the actual increase in and demand for power generation by comparing the major Saudi Electricity Company (SEC) indicators between 2000 and 2012 [5]. Because of the hot climate, electricity consumption increases substantially during the summer (June–September) [3]. The summer peak-period electricity usage occurs between 13:00 and 17:00 each day [6].

Seventy-nine percent of Saudi electricity is consumed in the operation of buildings (residential, commercial and government) [3], compared with 30–40% worldwide [7,8]. Air-conditioning (AC) consumes 70% of the country's total electricity during summer season [1]. Moreover, 70% of total residential consumption is for AC [3], which is considered high compared to other regions of the world as shown in Table 2 [8]. This huge demand for electricity increases fossil energy consumption. Table 3 shows that natural gas and crude oil were the primary energy sources for most of the electricity produced (74%), with the balance produced from diesel and heavy fuel oil for the timeframe of this study, 2012 [5]. The proportion of natural gas reached its highest level in 2007, but has fallen over the following years as shown in Table 3. This decrease in natural gas consumption is a result of a royal decree in 2006 stating that the largest power plants in the country would be fueled by crude oil in the future. A switch back to natural gas might take place if large gas reserves are discovered or the country decides to import gas [9]. Therefore, the amount of gas used in power plants is expected to remain constant and its proportion of overall fuel mix will decrease over time as new plants fueled by crude oil come online.

The burning of fossil fuels has an adverse impact on the environment and public health [15] and is largely responsible for the greenhouse gas emissions driving global climate change [16,17]. Moreover, as in other developing countries, the Kingdom has

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Table 1
Comparison of SEC major indicators for two years [5].

	2000	2012	Growth %
Generation capacity (MW)	24,083	53,588	122.5
Transmission networks lengths (km)	29,166	51,881	77.9
Distribution networks lengths (km)	219,076	438,130	100
Number of customers (million)	3.5	6.7	91.3
The number of cities, villages and settlements electricity reaches	7406	12,450	22.3

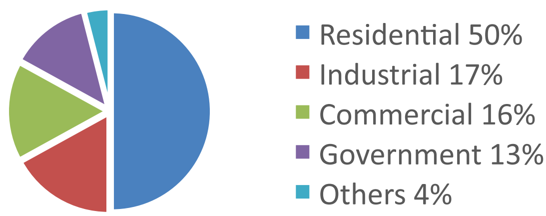

Fig. 1. Distribution of Saudi electricity consumption by sector in 2012 [3].

Table 2
Residential building energy consumption and its space conditioning share for comparison purpose [8].

	Residential energy consumption (%)	Space conditioning share (%)
Saudi Arabia	50	70
USA	22	53
UK	28	62
Spain	15	42
European Union	26	68

Table 3
Fuel types percentages in energy production over the last seven years [5,10–14].

Year	Natural gas	Crude oil	Diesel	Heavy fuel oil
2007	52	11	18	19
2008	45	20	22	13
2009	38	34	22	6
2010	34	40	22	4
2011	37	37	21	5
2012	39	35	20	6

experienced rapid industrial growth in recent years. This rapid development drives increased emissions. It is expected that the consumption of primary energy will almost double by 2030 with concomitant environmental impacts [6]. It is important that the emissions in the Kingdom be managed effectively for the purpose of helping mitigate global climate change.

A survey conducted by Proctor Engineering group and AMAD Technical Consultation and Laboratories estimates that more than 95% of air conditioners in Saudi Arabia are one of two types: window and split units [18]. A window AC is one in which all the components exist in one single unit that is mounted in a window of the room. In contrast, the split AC consists of two units: an indoor unit (cooling coil, blower and air filter) and an outdoor unit (compressor, condenser coil and expansion tube), with tubing connection. A comprehensive assessment of a residential AC system's resource use intensity, electricity consumption and environmental impacts requires life cycle assessment and life cycle cost perspectives.

An attributional life cycle assessment (ALCA) framework for evaluating air conditioning systems manufactured according to two energy efficiency standards is applied in this study. ALCA gives a good understanding of the systems' energy and environmental performance and is appropriate for benchmarking studies. This cradle-to-grave assessment includes manufacturing, transportation, use phase and end of life (EOL) recycle or disposal of the AC unit itself. As in most developing countries, economic aspects generally have greater influence on decisions than concern for the environment [19]. To understand these trade-offs, life cycle cost (LCC) assessment, payback period (PBP), net present value (NPV) and internal rate of return (IRR) analyses from the perspectives of a customer and government are included in this study. This study investigates the environmental burdens of residential cooling systems in Saudi Arabia, identifies the activities that are responsible for the greatest impacts on the environment, and recommends possible changes that should improve the environmental performance of the entire system.

2. Methodology and data sources

The goal of this study is to investigate the environmental performance of the residential cooling systems in Saudi Arabia through life cycle assessment. LCA is a methodology that evaluates the potential environmental burdens of products and processes and can be used to assess opportunities for environmental improvements. The function of an air-conditioning system is to keep a house comfortable. The functional unit of this study is the climate control of 1 m^2 of living area (the residential buildings' characteristics are described by Algarni [4]) maintained at 75 F of each type of residential building for one year, which allows the comparison of different types of buildings in different regions. For the cradle-to-grave life cycle assessment, the system needed to provide the functional unit was divided into several subsystems: AC manufacturing phase (includes materials extraction and production), transportation phase, fossil fuel production (fuel extraction, refinery and natural gas plants), power plant electricity production, the cooling or climate control phase, and the EOL disposal phase as illustrated in Fig. 2. Thus the system boundary extends from raw material extraction through end-of-life disposal of used AC units. Each sub-system was modeled to estimate its energy and materials requirements. The study was performed with the use of software SimaPro 8 [20]. Ecoinvent v3 database [21] was used for modeling the entire system and ImpactWorld+ method [22] was applied for the impact assessment. ImpactWorld+ is a regionalized method that assesses and differentiates emissions occurring in different geographical locations across the globe, which leads to a regionally specific understanding of potential impacts. Twelve midpoint categories are included in this study. Human health related categories that include global warming, respiratory inorganics, carcinogens and non-carcinogens and ozone layer depletion. Ecosystem quality related categories that include global warming, acidification, eutrophication and ecotoxicity. Resources include fossil energy use and mineral resources use impacts. The method does not have normalization or weighting [22].

Algarni [4] has calculated the cooling energy consumption for common residential buildings, which are apartment, traditional house and villa, in all the 13 provinces of Saudi Arabia. The buildings' characteristics include double-glazed windows, concrete slab roof and floor with concrete block wall with cement mortar outside and inside with an *R*-value of 1.62 m^2K/W. Full details of buildings are clearly described in Algarni's work [4], and energy consumption is based on the weather data of every provinces they were simulated. The efficiency of the AC significantly