Assessment of Energy Efficiency and Contribution of Climate Change Impacts via Room Air conditioners, Refrigerators and Deep Freezers in Pakistan

By

Waqas Ali

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Session 2017-19

Supervision of

Dr. Muhammad Bilal Sajid

A Thesis Submitted to U.S. – Pak Centers for Advance Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE in

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THESIS ACCEPTANCE CERTIFICATE

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Regards,

Waqas Ali

Dedication

Dedicated to leaders who struggle for peace, harmony and mutual respect.

Abstract

Pakistan constitutes the region where summers have high temperatures with a long duration. Consequently, the demand for cooling equipment is very high in most parts of the country. To meet such high demand, increasing the efficiency of cooling air conditioners, refrigerators and deep freezers are the best solution to reduce peak load, energy consumption, and environmental impacts. Ministry of Water and Power established the Minimum Energy Performance Standard (MEPS) compliance for room air conditioners (RACs). Due to the lack of market data, there are barriers for the assessment of cooling systems efficiencies and refrigerants used. The objective of this study is to assess the on-sale RACs, refrigerators and deep freezers energy efficiency, energy consumption, energy-saving potential and indirect CO_2 emissions reduction. The performance gap between the current MEPS EER 3.2 and the market on sale ACs with average EER 3.4 have also been analyzed and the efficiency is much lower when compared with the best available contingent in the world. Before the market saturates, leapfrogging to efficient appliances is more reasonable when ownership is very low. The consumption from these three appliances in 2030 will reach 74.7 TWh in BAU while in CIS and BAT the consumption will be 64.5 and 36.55 TWh, which 86% and 49% respectively. The accumulative electricity savings of CIS and BAT are equal to 204.08 TW h and 793.38 TW h, with shares of 12 % and 47% of the accumulative BAU scenario electricity consumption for 2020-2040 and shows the reduction in CO_2 emission is 167.46 and 488.22 Mt for CIS and BAT scenario This study will also provide the direction for the next standards and labeling (S&L) implementation in Pakistan.

Key Words: Air conditioners, MEPS, EER, Refrigerant, Emissions, Climate change impact, Refrigerators, Deep Freezers, Energy Saving

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Conference paper

Waqas Ali, Muhammad Bilal Sajid, **"Assessment of Energy Efficiency and Contribution of Climate Change Impacts via Room Air Conditioners in Pakistan"** International Conference on Management Research in the Field of Sciences and Engineering, 28-29 November 2019, Superior College Lahore, Pakistan

List of Acronyms

Chapter 1
INTRODUCTION

Energy is one of the essential and basic tools for the economy of the country. As with technology advancement, the energy sources are also evolving with time renewable energy sources are entering with new feature and capabilities which are more environmentally friendly. Parallel with the renewables sources energy efficiency is also a new source of energy.

1.1 Background, Scope, and Motivation

In ancient time the cooling method shading hand fans and orientation of the building were design so that it cooling demand is minimum. But the advent of electricity provides multiple ways for cooling and preserving the food. Today the most common ways of cooling are electric fans, evaporative electric coolers, and air conditioners. For food preservation refrigerators and deep freezers are use. The air conditioner is providing a range of temperature control as compared to electric fan and evaporative cooler. Air conditioners can be operated by a range of sources, but electricity is the most commonly used source. It depends on the cooling need from room ACs to large central units are available with a verity of features and capabilities. But the power consumption and associative costs make it harder for developing countries which have low economic conditions. Most of the developing countries are lie in the region where summer is long with hot and humid conditions.

The study is conducted for the Pakistan room air conditioners (RACs), refrigerators and deep freezers market. RACs are generally consisted of window type and splits. But 95% of the RACs in Pakistan are splits[1]. And splits are further classified in inverter and fixed frequency one. In this study we collected most of the data is about the splits room ACs.

Cooling Systems consume 20-40 % of the total energy in the building. The Cooling system is energy-intensive equipment. In summer, most of the peak demand is because of the RACs which is operated in the same period while refrigerators are the source of baseload in a household. The 70 % of the peak demand in the US is because of cooling[2]

The energy efficiency is the main parameter that directly affects the energy consumption, peak load demand, cost of cooling and the environmental impacts of ACs.

1.2 Common HVAC Systems Use for Cooling

The cooling systems are divided in three main types

1.2.1 Packaged ACs

Packaged ACs: In packaged ACs the evaporator and condenser are packed in one frame or box also known as Unitary Systems. It can be further divided into four types

a. Window Type ACs
b. Packaged Terminal ACs
c. Packaged Portable
d. Package Rooftop

1.2.2 Splits ACs

Splits ACs Systems: It is used range for a small room to large buildings. In the Splits system, the condenser and evaporator are connected through pipes. Indoor units are placed inside the conditioned space and outdoor units are installed outside anywhere in the building. Its subtypes are

a. Single Splits AC
b. Ductless Multi Split System (VRF System)
c. Ductless Mini Splits
d. Central Ducted Splits

1.2.3 Chillers

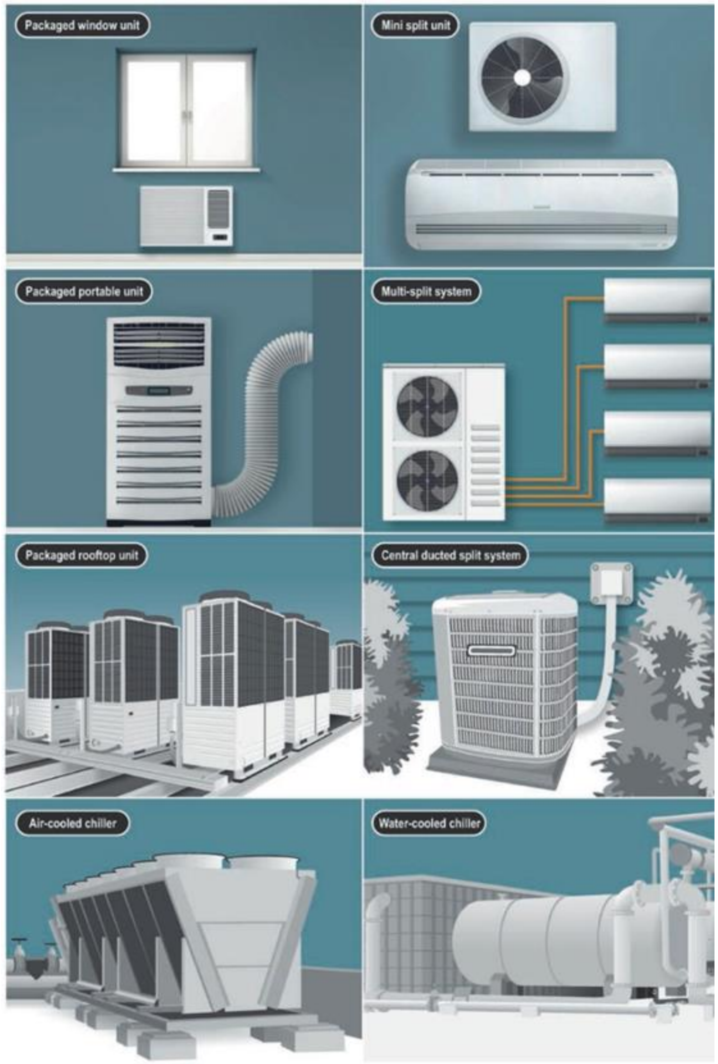

Figure 1-1.Types of HVAC Systems (Source:IEA)

Chillers are used for the large building where proper duct systems are installed and chiller use is more feasible than other systems. Chillers can be further divided into the following categories depending upon the condenser cooling medium

a. Water Cool Chillers

b. Air Cool Chiller

c. Evaporative-cooled chillers

These systems are commonly used for residential and commercial. 20 % of the RACs are used in the commercial and the rest are used in the residential sector (1).

The selection of a system for the specific application is also important for the energy-saving and cost-effectiveness of the overall cost.

1.2.4 Cooling Need and Its Future Aspects

According to the World Bank reports that cooling is no more luxury in some hot and humid climate zone like Karachi, Mumbai, Lahore where heatwaves have threatened many people's lives because of no cooling facilities. In the Kigali amendment to the Montreal protocol, that cooling is the need for such a situation. Billions of dollars' vaccines are spoiled due to the unavailability of preservation. According to the research that the Indoor Air Quality (IAQ) has a strong effect on the productivity of students, researchers, and labors[3].

The 5% of Pakistani own the AC means that a lot of potentials is for growth as compared with the developed countries which have the 90% ACs ownership[4].

Increase population, households, income, urbanization, and urban temperature are the influencing factors for the increase in RACs, refrigerators and deep freezers demand in the future. The government should ensure sustainable cooling by making policies that provide green and efficient cooling by working on efficiency and technology improvement.

1.3 Problem Statement

Energy efficiency improvement is one of the key elements for sustainable development. In the developed world, they have done a lot of research and achieved the highest efficiency level. In developing countries, that face the energy shortfall haven't addressed the issues. According to IEA, energy use for space-cooling is more rapidly increasing than other end-use in the building sector. To estimate the energy-saving and CO_2 emission reduction potential by improving the efficiency of air-conditioners, refrigerators and deep freezers in Pakistan by using the LEAP energy model.

1.4 Research Objective

- To assess the current energy efficiency performance of room air conditioners, refrigerators and deep freezers in Pakistan
- Energy-saving potential in RACs, refrigerators and deep freezers under different energy policies scenarios in Pakistan.
- CO_2 emission reduction potential in 22 years period of studies

1.5 Thesis Outlines

A brief review of purpose and work performed in each the remaining chapter is given as follows

Chapter 2

Chapter 2 provide the literature, the previous studies findings, government policies, involvement in efficiency improvements, how international energy agency highlights the importance of the issues we have energy-saving potential.

Chapter 3

This chapter is an introduction to numerical parameters to measure the performance of room air-conditioners, how they can be defined and calculated. What are the significance of these parameters in defining the standard for appliances? It also compares different world standards for RACs

Chapter 4

This chapter focuses on the methodology and data sources, how the scenarios are generated with assumptions and growth rated are calculated, energy modeling in LEAP, energy consumption calculation for different appliances are discussed.

Chapter 5

Chapter 5 discusses the market characteristics of Pakistan's RACs, refrigerators and deep freezers, the leading players of the market and their share. And direct emissions are calculated for the RACs and the annual increase in energy consumption due to RACs are analyzed.

Chapter 6

This section presents the finding of the study, shipment growth, retirements, increase in ownership and energy-saving potential, reduction of emissions under different scenarios for these compressor base appliances are discussed. Different policies case implications are evaluated.

Chapter 7

In this section, the study is concluded. The energy-saving and CO_2 emission reduction are figured out for RACs, refrigerators and deep freezers with numerical figures. And policies recommendation is given for implications.

Summary

Improvement of energy efficiency has a lot of potential for energy saving in domestic cooling sector in developing countries like Pakistan. Cooling is need and no more luxury in heat wave hit areas. There are different types of system for domestic cooling but in Pakistan's market splits is very common. Cooling contribute to peak load demand stress our grid system in summer.

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Chapter 2
LITERATURE REVIEW

2.1 Introduction

Pakistan is the sixth most populous country in the world. More than 50% of total electricity is consumed by the domestic sector which shows the growth of 8 CAGR [1]. And most of the domestic and residential is consumed by the cooling systems, refrigerators and deep freezers. Among the end-use of energy in the residential sector, cooling show a greater increase than other activities energy consumptions[2].

Pakistan is faced with huge demands in terms of air conditioning units for residential and commercial cooling. As a result, it is very important to propose a solution that will address the core issues related to the increase in cooling types of equipment. The increase in demand for cooling appliances will eventually increase energy consumption and consequently increase environmental emissions. The improvement in the energy efficiency of these systems will reduce energy consumptions and indirect emissions. Before addressing the core issues the assessment of the current RACs, refrigerators and deep freezers market is very essential to show how core parameters are interlinking with each other. Pakistan is a developing country and the ACs demand in developing countries will reach 1.5 billion in 2030 due to their hot and humid climate zone with an increasing population [3]. The cooling requirement of Pakistan is increasing due to population growth and the urbanization in Pakistan ACs demand is increasing more rapidly than 5.95% per year(2011-2012) [4]. As the economic prosperity increase, RACs utilization and volume also increase [5]. Domestic cooling is the need in the heatwave hit cities of Pakistan in which the death tolls up to 2000 in 2015 mostly in Karachi. The cooling requirements for Pakistan are estimated 10TWh for 2018 [6]. Pakistan has CDD 2810 with a population of 197 million which 553.570 total cooling demand potential in billion person degree day which is 1.984 time that of USA[3]. Energy use for space cooling is more rapidly increasing than other end-use in the building sector, it contributes an average 16% peak load in summer and 70% in the US [2]. According to the Daily Times the AC production increase 24% July-Feb 2017-2018 and 37,554 units more produce than the previous year. Pakistan estimated ACs annual production is 600,000-650,000 units for 2017[7]. MEPS implementation in developing countries shows a 16% improvement in the average efficiency of ACs in China and a reduction in carbon dioxide emission[8].

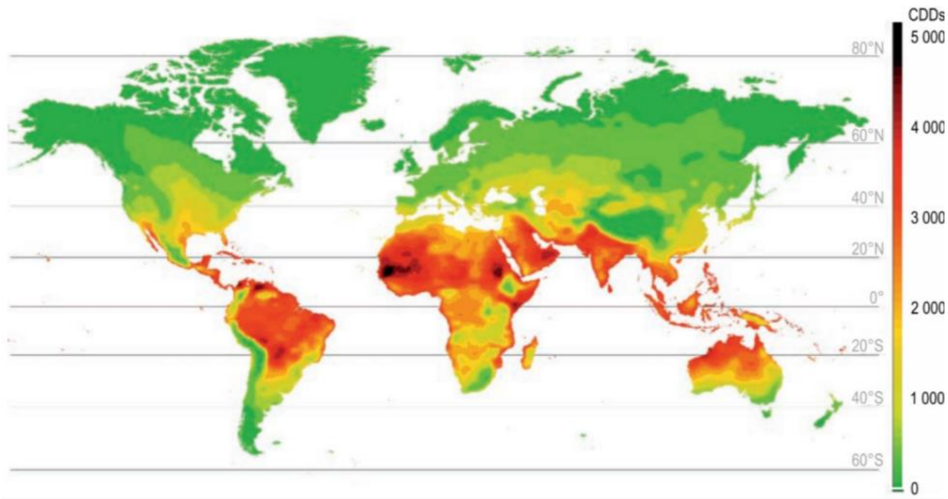

Figure 2-1. World Cooling Degree Days Distribution (Source:IEA)

Adaptation of ACs in developing is increasing with the increase in income, a decrease in the prices of ACs and due to their climate zone temperature because most of the developing countries lie in the hot and humid climate zone figure 2-1.[9]. This will put more strain on the energy supply side and indirect emissions but the prices of electricity are uncertain which is a prime parameter along with energy efficiency to determine the energy consumption and future growth in ACs[10].

In developing countries like South Africa, the refrigerator accounts for 15% of the electricity, which mostly comes from low-income households. The slow pace S & L cant accelerated through the incentive programs and the barriers can be eliminated quickly by achieving efficient refrigerators adoption[11]. In 2009 Pakistan 46% of domestic is due to consumption of cooling equipment which include the 33% fan which is replacing by air conditioners. In the remaining 7% is consume by refrigerators and 5% by ACs[12].

The ownership increase from 12 to 40% with the 50 % increase per capita consumptions from 2001 to 2011[13]. As shown in figure. 2-2.

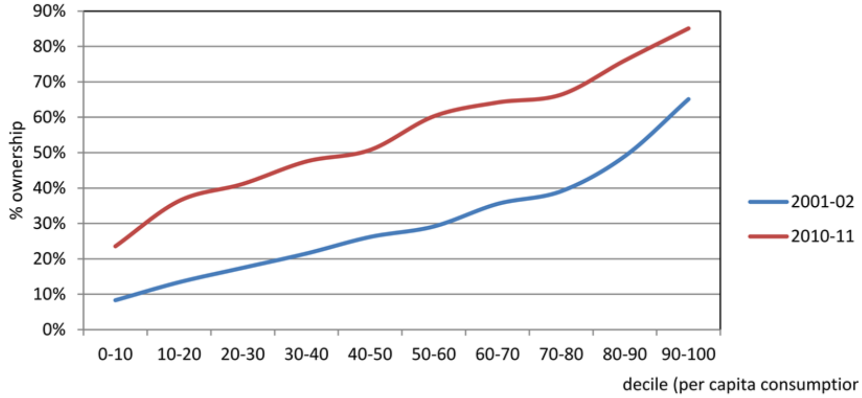

Figure 2-2 Refrigerators ownership per capita consumption decile(Source:IBA,Karachi)

Pakistan has the energy-saving potential from 1.2 to 2.9 GW(gigawatt) alone focusing on improvement of energy efficiency about 30% of the baseline and by the transition to low global warming, refrigerants will also increase the efficiency of about 5% avoiding 0.21-0.48GW [14][15].

Hydrofluorocarbons (HFCs) absorption in atmosphere is increasing from 10-15% each year[16]. In Pakistan, the government is also decreasing the CFCs import and HFCs taking place in this transition.[17]. By adopting the best available technology(BAT) we can reduce the total emission of 373.0 GtCO_2e[15].

Policies play a crucial role in the reduction of environmental emissions and improving efficiency. Japan and South Korea are taking the lead due to their energy-efficient strategies like Japan Top Runner program started in 1997, which is mandatory in 2004, bring a 7.2% improvement in efficiency per year. Similarly, South Korea also launched the Energy Frontier Program in 2011 for key appliances which also include the ACs who bring 12% improvement in efficiency per year [18].

The study assesses the current RACs, refrigerators and deep freezers energy efficiency, improvement potential, energy-saving, and CO_2 emissions reduction. The EERs are compared with the current MEPS to show the implication of the current policies and future directions for RACs while refrigerators and deep freezers are compared with the world best available technology. The increase in energy consumption, peak load and total emissions related to new induction of ACs is annually evaluated. The results, challenges, and policy recommendations are presented are after the assessment.

2.2 Overview of Pakistan MEPS and Energy Star

In December 2014 ministry of water resources power division propose ES&L for some electric appliances which include room air conditioners and fans through NEECA (National Energy Efficiency and Conservation Authority) with help of UNOP and GEF[19]. The sample is shown in figure 1. For ACs which have the capacity under 14000 watts are covered in the ES&L program whose compliance is voluntary base [4]. MEPS for window types and split ACs with air cooling condenser, close motor compressor and operate in climate zone of T1 and T3 as shown in table 2.1.

Table 2.1 PAKISTAN MEPS 2014 (Source: NEECA)

Table 1.Type	Cooling Capacity (CC) W (BTU)	Energy Efficiency (EER) W/W
Window	3517-4499 (558.86-714.91)	2.90
Split	≤ 4500 (715.07)	3.20
	4500 -≤ 7100 (715.07-1128.22)	3.10
	7100 -≤ 14000 (1128.22-2224.67)	3.00

The test should be conducted according to PS: ISO: 5151 in a certified laboratory but in Pakistan, there is no such facility available for ACs, refrigerators and deep freezers. The three energy star labels RACs are provided after qualifying the test criteria, but it still lacks the details of stars assigning and customers can’t identify the efficient product among the labeled products[19].

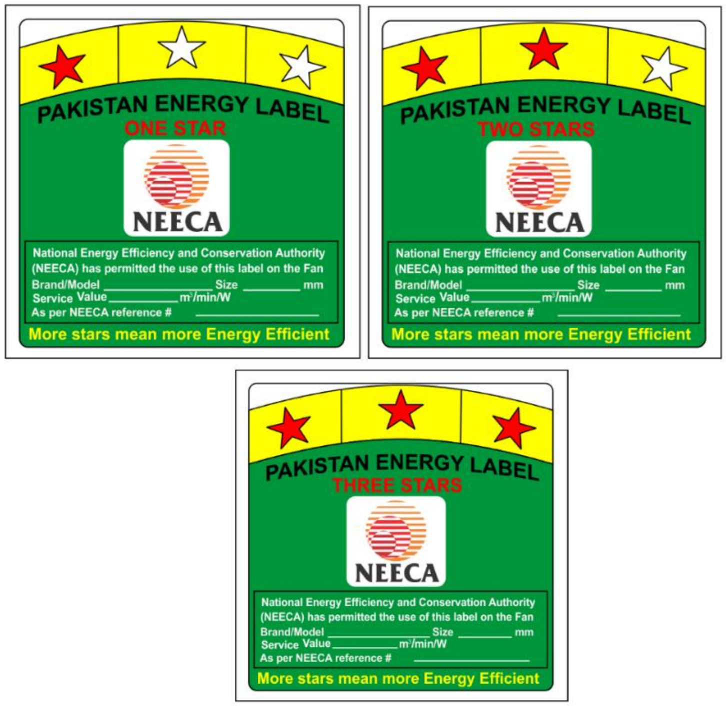

Figure 2-3 Pakistan Energy Star Label for Fans (Source: NEECA)

2.2.1 Environmental Emissions

The cooling appliances are using refrigerants with some specific thermodynamic properties. Refrigerants releasing into the environment have some negative effects on environments in the form of Ozone depletion and global warming. They are also consuming the electricity which is generated with the combustions of fossil fuel which emit emissions to the environment. So, the emissions are divided into direct and indirect emissions.

2.2.1.1 Direct Emissions of RACs

Direct emissions are the one which are released in the form of refrigerant leakage, refrigerant loss and other emissions which directly deteriorate the natural ecological system and environment in form of global warming and ozone depletion. During the life cycle of cooling equipment, it needs multiple times to refill the system with refrigerant. After the Montreal Protocol, the use of CFCs is restricted but this triggers the increase of

HFCs which have global warming potential of 1900 of CO_2 although its zero-ozone depletion potential. And CFCs replacing with high GWP HFCs in the cooling industry is alarming.

2.2.2 Indirect Emissions of RACs

The indirect emissions are related to the use of electricity, all around the globe, most of the electricity is generated from thermal power plants which are the main source of emissions which include CO2, NOx, SOx and some other. In Pakistan, 70% of our power is generated with the thermal power plants which means that indirect emissions are significant[1]. Pakistan emission factor is 0.615374995 kg CO_2/KWh which show how much CO_2 emission is emitted per Kilowatt of electricity[20].

Summary

This chapter estimates the Pakistan future cooling demand with population growth. Pakistan RACs ownership will increase due to high cooling degree days, increase in population and economic stability. Pakistan MEPS and energy labels are summarized. The types of emission associated with cooling systems are categorized.

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Chapter 3

PERFORMANCE PARAMETERS AND STANDARDS (ACs)

3.1 Nominal Performance Metrics

All parameters are using the input energy to out cooling effect made through that energy but operating conditions like temperature, operation hours and change in cooling load consideration made them different from each other in term application.

3.1.1 Coefficient of Performance (COP)

The COP is the ratio of cooling or heating in watt divide by the output cooling in watt

$$COP = \frac{Cooling\ Output}{Power\ Input}$$

Cop instantaneously measure the performance of equipment the higher the COP the higher the more efficient is AC. The COP is a dimensionless number because both input and out have the same unit of power. From Carnot's theorem, we can calculate the maximum COP which is the function of indoor and outdoor temperature

$$COP = \frac{Tc}{Th - Tc}$$

T_c is indoor temperature while T_h outdoor ambient temperature.

As the COP instantly measure the performance so it is not worthy of saving estimation.

3.1.2 Energy Efficiency Ratio (EER)

Like COP it is the ratio of cooling effect taken in British thermal unit per hour (BTU) to electrical power in watt-hour(Wh).

$$EER = \frac{Cooling\ Effect\ in\ BTU/Hour}{Power\ Input\ in\ \ Wh}$$

This unit is not dimensionless because of the power to energy ratio in different units. EER are calculated over a specific period at some specific operating conditions like which is shown in Table 3.1 below[1].

Table 3.1. EER Measuring Conditions (Source:P. K. LLC)

	Dry bulb temperature	Wet-bulb temperature	Relative Humidity	Dew Point
Outdoor conditions	95°F (35°C)	75°F (24°C)	40%	67°F (19)
Indoor conditions	80°F (27°C)	67°F (19°C)	51%	60°F (16°C)

COP and EER are the conventional performance evolution metrics for room air conditioners which shows the performance of units when they are operating at the specific conditions. In real life, performance is a function of outdoor temperature, humidity, operating temperature, and consumer behaviors.

With time to time efficiency parameters were modified to evaluate the real performance of ACs which include on-off, changes in outside temperature, humidity, inside temperature requirement and load. The variable-frequency ACs(VFACs) bring more challenges to calculate their performance on these nominal parameters. VFACs performance is to be considered in part-load operation. So fixed and variable frequency RACs evaluating on same performance metrics is not a good solution. A more feasible metrics which estimates the performance over the whole heating or cooling season is seasonal evaluation metrics.

3.2 Seasonal Evaluation Metrics

So to cover long-range operation conditions and wide types of technologies like fixed and variable frequency cooling equipment, engineers and policymakers adopt more comprehensive metrics to map the exact performance of ACs.

Different country standards and labels (S&L) use different seasonal efficiency parameters. But most important one are seasonal evolution metrics are SEER, SCOP, CSPF, APF, which are used by some developed countries which are leading in cooling industry technology.

In seasonal metric, the indoor condition is fixed like EER but outside temperature changes with the cooling season so in terms of percentage the outside temperature is distributed along the cooling season. The operation hours are also distributed with the temperature so that gives a clear picture of overall performance.

$$SEER = \frac{Cooling\ Effect\ over\ Season}{Electrical\ Power\ consumed\ over\ Season}$$

3.3 Standard Use in World

Table 3.2 World Standards

Summary of international RAC standards.

Standard category	Test method standard	Performance calculation method standard	Energy efficiency standard	Energy efficiency index
China	GB/T 7725-2004	GB/T 7725-2004	GB 12021.3–2010(CFRACs) GB 21455–2013(VFRACs)	SEER, HSPF, APF
Japan	JISC 9612: 2013 JRA 4048: 2006 JISB 8615	JISC 9612:2013 JRA 4046	JRA 4046 Top Runner Program	CSPF, HSPF, APF
America	AHRI 210/240: 2008	AHRI 210/240–2008	Energy Star (Endorsement) DOE	SEER, HSPF, APF
EU	EN 14511-2011	EN 14825-2012	(EU) No 206/2012 (EU) No 626/2011 G/TBT/N/EEC/362G/TBT/N/EEC/363	SEER, SCOP
Australia	AS/NZS 3823.1.1 AS/NZS 3823.1.2	AS/NZS 3823.2-2013	AS/NZS 3823.2-2013	AEER, ACOP, SRI
ISO	ISO 5151-2017	ISO 163581-2013(CSPF) ISO 16368-2-2013(HSPF) ISO 16358-3-2013(APF,TAPF)	——	CSPF, HSPF, APF, TAPF

Pakistan is using ISO 5151-2010 standard category which the old version of (the above mention in table 3.2.

Summary

Different types of numerical metrics are used for the evaluation of cooling systems performance. Among them the COP is used in Pakistan's MEPS standard. In developed countries the seasonal performance indicators are used which comprehensively evaluate the performance as compared with COP.

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Chapter 4
Methodology

The methodology of this study consists of two sections i.e. the Pakistan energy assessment of RACs, refrigerators and deep freezers and the second is modeling the energy consumption under different policies scenario of these three types of appliances.

4.1 Energy performance assessment of RACs refrigerators and deep freezers

4.1.1 Data Sources

The information is collected from brands' official online databases that are available for customers. While Some from retailer shops like daraz.pk. The specification of the ACs, refrigerators and deep freezers collected as per manufacturers are given. For shipment, sales, production and shares of different brands data, the official reports of ministries like Pakistan Economic Survey, Pakistan Bureau of Statistics, the world bank study reports and research articles are used. The world's best technology of these appliances is taken from the European top ten database[1][2].

4.1.2 Collected Data

The collected information includes manufacturers, model names, type of system, cooling capacity, EER, refrigerant type, charge, rated power, and prices. After data collection, the data is analyzed through excel for comparison, in the analysis we use only EERs and Capacity for the performance evaluation.

The EER used in this study is the ratio of cooling capacity in watt to rating power in watt, which is given on the manufacturers' database in the product specification.

4.1.3 Survey Sample Size

For ACs 193 types of different models, EERs are considered. For refrigerators 200, while for deep freezers models 21 models of different brands are considered. The refrigerators and deep freezers are divided into range capacity to give the accurate range of energy intensity for the LEAP energy model. The collected data from main brands in Pakistan Dawlance, Orient, PEL, Hair cover 80 percent of the market shares of these three types of home appliances.

4.2 Energy Modeling in LEAP

Assessment provides the basic parameters for LEAP modeling. The LEAP (Long-range energy alternative planning) is used for energy modeling in this study. The bottom-up approach enables us to go to the details of each appliance by dividing them into subcategories and with energy intensity. LEAP gives us access to give all the related details like share in stock, sale share, vintage percentage, the useful life of the equipment. The vintages life of ACs, fridges and deep freezers are different. The nature of fridge and deep freezer is the same, so the service life of these appliances is the same which is 16 years. For RACs, service life is 10 years because the new technology adaptation will more feasible in the future as come to assume a shorter life of the equipment.

The research main steps for the assessment of energy efficiency and future forecast with different approach scenarios are shown in figure 4.

4.2.1 Stock Analysis

In the stock analysis, the sales growth is projected for the future years, subtracting the retirement from the shipment estimated the increase in new ACs, Refrigerators and Deep Freezers ownership**.**

$$Shipments\ =\ Increase\ in\ Ownership\ +\ Retirement \qquad (1)$$

An increase in ownership is shipment due to the increase in population, household, urbanization, economic growth and improvement in lifestyle. Retirement function is the shipment growth of a service life period ago than the base year that means the first ACs (service life10 years) retirement batch in 2019 is the shipment of

2009. Similarly, for refrigerators and deep freezers (service life10 years), the first retirement in 2019 is the shipment of 2004.

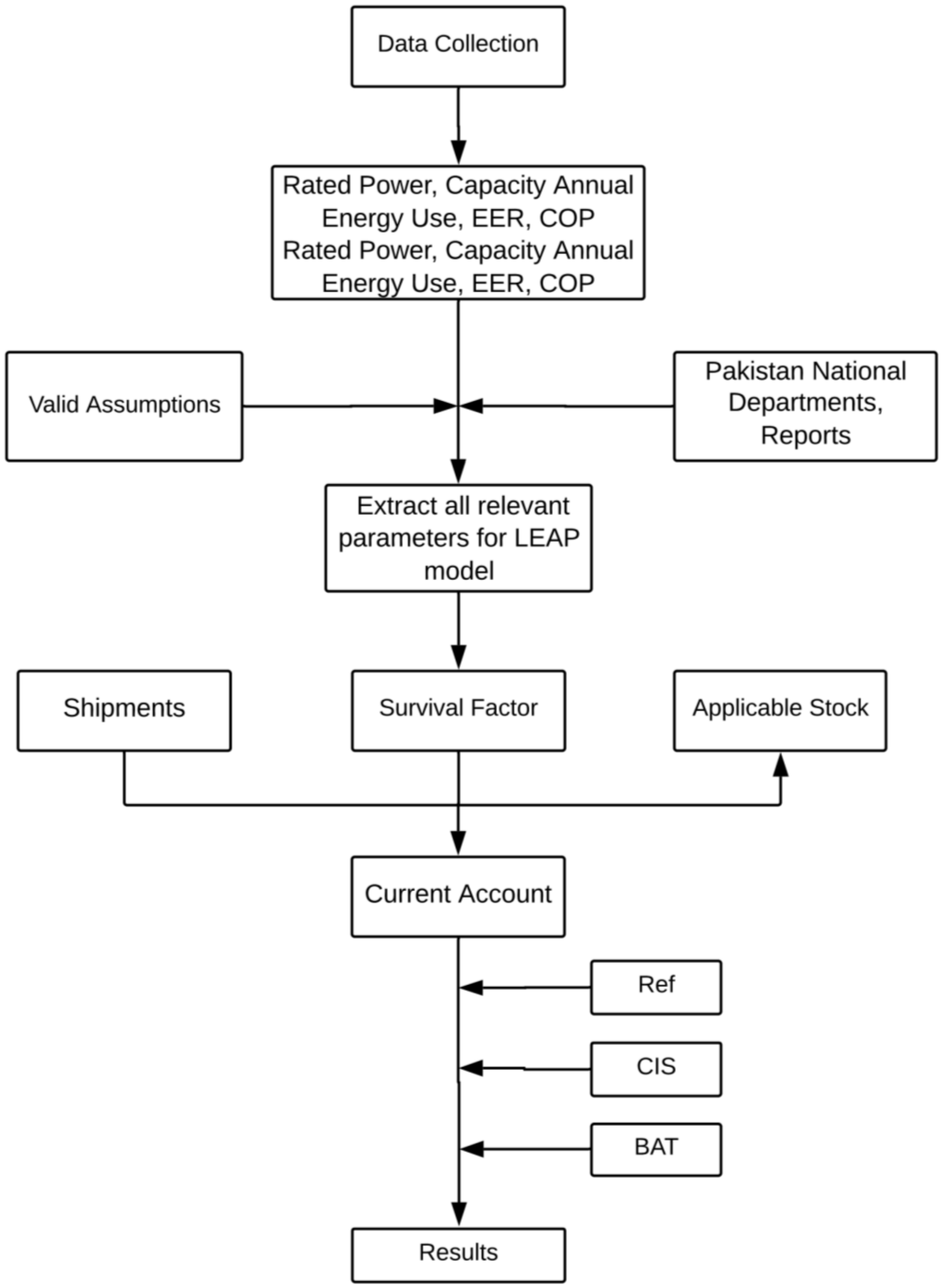

Figure 4-1 Assessment outline for RACs, refrigerators and deep freezer.

4.2.2 Total Stock Calculation

The total stock of the equipment is the summation of all previous shipments over the life service of each equipment.

$$Stock = \sum_{i=1}^{l} Sh_i \qquad (2)$$

In the equation Sh_i is the shipment of year i, the l is the life cycle of each type of equipment. For ACs, l is 10 years while for refrigerators and deep freezers the l is 15 years.

4.2.3 Energy Consumption Estimation

4.2.3.1 For ACs

The annual energy consumption of We use the capacity wise formula, assume the operation time in a day, the summer season which the ACs are used

$$E = 210\ days \times 8\ h \times \frac{Cooling\ capacity(kw)}{EER_{Average}} \qquad (3)$$

Where $E(KWh)$ is annual energy consumption for each RACs capacity. $EER_{Average}$ is the average EER of the applicable stock.

4.2.3.2 **Refrigerators and Deep freezers**

The assumption of 300-day operation in a year. The annual energy consumption is calculated from the rated power given brands online database

$$E = 300\ days \times \frac{Rated\ KWh}{day} \qquad (4)$$

Where $E(KWh)$ is annual energy consumption for each capacity range, $Rated\ KWh$ is per day consumption as per manufacturers specification.

4.2.4 Energy-Saving and Indirect CO_2 Emission Reduction

The energy-saving is calculated from the difference between business as usual scenario (BAU) vs continues improvement scenario (CIS) and best available technology (BAT) cases

$$AES_{CIS} = BAU_i - CIS_i \quad (5)$$

$$AES_{BAT} = BAU_i - BAT_i \quad (6)$$

In the equations AES is the energy-saving BAU is the reference scenario. The emissions reduction for each case is calculated from the equation

$$ER_{CIS} = AES_{CIS} \times EF \quad (7)$$

$$ER_{BAT} = AES_{CIS} \times EF \quad (8)$$

ER is the emission reduction and EF is the grid emission factor of Pakistan which 0.615 kilogram per kilowatt-hour[3].

4.3 Scenarios and Data

4.3.1 Scenarios

In this study, three scenarios are considered for the energy forecasting of RACs, refrigerators and deep freezers in Pakistan. The business as usual (BAU), continuous improvement scenario (CIS) and best available technology (BAT). In the previous study by World Bank, South Asia Climate Change Unit take the stock EER of 2.6 in 2016 due to large sale and average EER of 3.4 on sale market for two year, so it is feasible assumption take stock EER 2.8 that is 7.7% more than the World Bank study[4].In the CIS case after 2020, the five interval 10% improvement is considered for the next 15 years and then 5% for the next 10 years due to giving more relax improvement. while in BAT the European best ACs is adopted for the next 15 year and the 5 % improve to that occur in 2035.

4.3.2 Data

In Pakistan 96% of the RACs are single splits and share of window type units is decreasing[5]. The share of production and sale are shown in table 1. The ACs ownership is very low so the share of the respective capacities share are the same for all years. The service life for the ACs is 10 years which is taken from previous studies. The tables 4.1 to 4.3 are the data extracted from the survey along with some valid assumptions.

Table 4.1 Production and sales share of room air conditioners in Pakistan

Rated cooling capacity in KW(Ton)	Sales & stock share	Pakistan's EER	World BAT EER
$C \leq 3.51685$ (≤ 1 Ton)	20%	2.8	5.15
$3.51685 < C \leq 5.27528$ ($1 < C \leq 1.5$)	70%	2.8	4.95
$5.27528 < C \leq 7.03371$ ($1.5 < C \leq 2$)	7%	2.8	3.94

Table 4.2 Survey table for refrigerators

Capacity Range (Liters)	No of models	Sales & stock share	Pakistan (KWh)	World BAT (KWh)
above 540	7	3.40%	1200	264
400-540	52	25.87%	1080	230
Above 200 to 380	118	58.70%	828	159
Up to 200	24	11.94%	500	121

Table 4.3 Survey data table for deep freezers

Capacity Range (Liters)	No of models	Sales & stock share	Pakistan (KWh)	World BAT(KWh)
200 to 300	9	41%	360	130
312 to 400	8	36.30%	750	160
412 to 515	5	22.70%	980	195

Summary

The methodology of the research is discussed thoroughly. The survey data information is used in LEAP energy model. LEAP model working principles are explained by using energy formulas. Different scenarios are considered along with assumptions and future trends which gives the energy consumption and savings.

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Chapter 5

Pakistan’s ACs and Refrigerators Market

5.1 Pakistan ACs and Refrigerators Market Brands Survey

Pakistan is among the six most populous countries in the world. Most of the population of Pakistan especially the big cities of Pakistan situated in a hot and humid region where ACs affordability is also high as compared to other regions, make a potential market for ACs. To cover this market large a large number of local and international companies are manufacturing, assemble and market the ACs products.

The most well-known brands are

1. Haier
2. Gree
3. Orient
4. Dawlance
5. Kenwood
6. PEL
7. Changhong Ruba
8. Samsung
9. Sabro
10. LG
11. Daikin
12. Toshiba
13. Acson (Malaysia)
14. Panasonic
15. Green Air
16. Waves
17. General
18. Sharp(Japan)
19. Electrolux(Sweden)
20. Mitsubishi Electric
21. Success
22. Enviro
23. Gaba Nation
24. Fashion hawk
25. Hyundi
26. Singer
27. Midea
28. Panatron
29. Euromax
30. Bosch
31. Top Mark
32. Aux –Daikool
33. TCL
34. O General

The above mention companies have launched their different models. So to assess the overall market the share of the companies and their performance level is crucial. Some manufacturers have cover most of the market share here their discussion is important.

Pakistan assembles and manufactures 90% of their demand and 10% are imported[1].

5.2 Local Manufacturing RACs and Refrigerators Brands in Pakistan

5.2.1 Haier

Haier is one of world- leading Chinese home appliance based company who's headquartered is in Qingdao China. It is the world's largest home appliance market share from the last six years[2]. Haier established a manufacturing facility in Pakistan in 2000. In 2002 the Haier start the first production with 2000 units in the Lahore facility. In 2009 first DC inverter technology was launched in Pakistan. Haier also has started the VRF system by successfully installing it in Quetta[3]. Haier is also one of the leaders in the refrigerator industry.

5.2.2 Gree

Gree Electronics is Chinese base home appliance company which was founded in 1991 in Zhuhai in China which specialized in ACs production. In residential ACs sale, it ranks number one since 2005. In Pakistan Gree is working with the DWP group which provides the distribution services to their common venture with the name of Eco-Star. In 2006 the Gree start local assembling in Lahore which is the second overseas production setup of Gree. It is also providing the VRF systems, centrifugal water chiller for commercial application[4].

5.2.3 Orient

Orient Group of companies was established in 2000 in partnership with Japanese Mitsubishi. In 2005 increase in taxes and duties on the imported product they decide to locally manufacture the ACs units. In 2009 they started the production of refrigerators. In 20013 they sign dealership with Midea Chinese largest home appliances brand[5]. Now they have a good share in Pakistan ACs industry.

5.2.4 Dawlance

Dawlance is Pakistan indigenous home appliance companies which established in 1980 in Karachi. The company is a well-known brand for Refrigerators and ACs in Pakistan with three manufacturing units two in Karachi one in Hyderabad. It was acquired by Arceilik in 2016. Now it works as the subsidiary company for ARcelik which is Turkey base company[6].

5.2.5 PEL

PEL is a Pakistani based company that produce electrical equipment and home appliances especially the Air conditioners and refrigerators for more than 20 years. PEL and General Corporation start collaboration in 1981 by launching window types ACs. In 1995 the PEL and General covered 75% of Pakistan ACs market [7]. But with time the market share was decreased due to adaptation of new technology and lack of R&D in the product improvement.

5.2.6 Kenwood

It is a home appliances manufacturer that start an assembly plant in Karachi in 2004. Now its refrigerators and ACs market have some share in Pakistan.

5.2.7 Sabro

Pakistani base Sabro specializes in the HVACR industry. It provides a verity of cooling equipment like Chillers, VRF, DC inverters, and air handling units not only for the local customers but also have branches working abroad.

5.2.8 Waves-Singer

Waves start split AC production in 2002 in Lahore. In 2017 it merges with the singer to form Waves- Singer Pakistan Limited.

5.2.9 Daikin

Mia is assembling Daikin ACs in Islamabad, the same group is also working for Acson company in Pakistan.

5.3 Pakistan RACs and Refrigerators Markets Shares by Brands

Haier, Gree, Orient, Dawlance, Kenwood, and PEL are major market players which manufacture and assemble in Pakistan. Chinese brands like Haier, Gree and Chonghong comprise the major markets shares of more than half because some other Chinese brands like Midea have marketed their residential and commercial air conditioners with the help of Green leaves in Pakistan share in the market [8].

The imported ACs units have more of Chinese manufacturers as primary contingent [9][10]. Pakistan's market share is shown in figure 5-1.

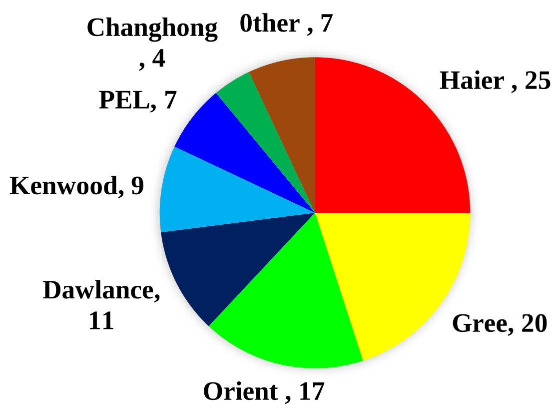

Figure 5-1.Pakistan's RACs Market Share 2018 (Source:World Bank Report)

The refrigerators and deep freezers market shares are also shown in fugue 5-2 [1]. In the refrigerators and deep freezers market the local brands cover 62% of shares[11]. All these appliances have some commons components like condenser, evaporators, compressor and use the same vapor compression cycle.

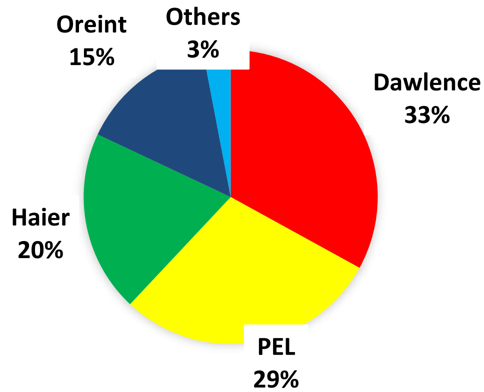

Figure 5-2.Pakistan's Refrigerators Market (Source:Asghar Reza)

5.4 Pakistan's RACs, Refrigerators, and Deep Freezers Demand

According to the Japan refrigeration and air conditioning industry association (JRAIA), the annual average growth for five years (2012-2017) is 4.2% and for 2016-2017 the growth is 7.5% [16]. As the population increase, the requirement of home appliance increases. The number of units required for each year is shown in figure 5-3[12]. The growth for refrigerators and deep freezers are observed at 4.46% and 2% respectively.

The growth is affected in 2019 with rupees devaluation because the manufacturers in Pakistan import most of the ACs parts from China, Malaysia, and Thailand[12]. The parts include the compressor, motors, capacitors, valves aluminum foils and galvanized iron sheets. As the imported parts become more expensive the manufacturers decrease the production of the demand for 2018 and 2019 is the same for RACs because the dollar reached the highest level of 160 Pakistani rupees.

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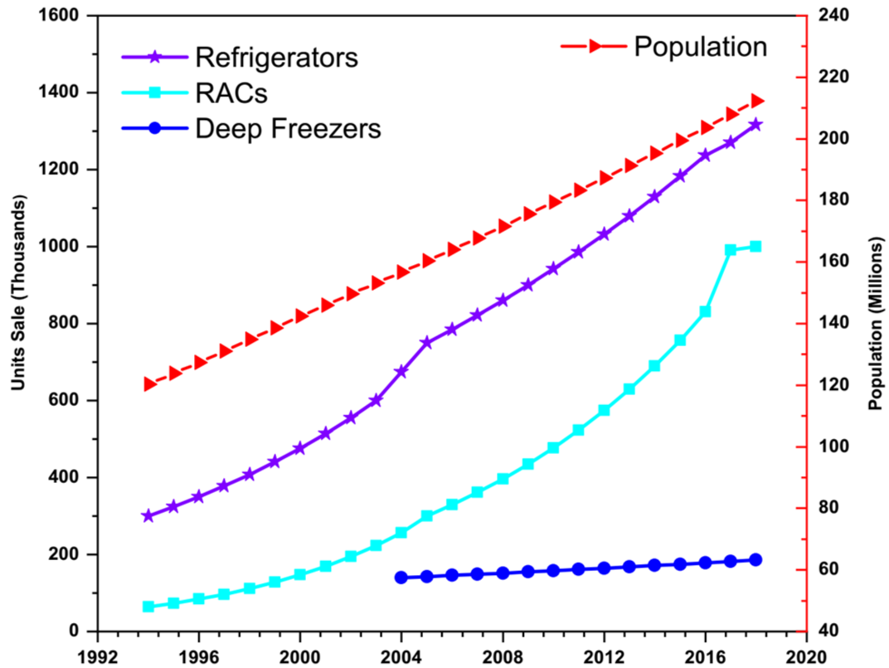

Figure 5-3 RACs, Refrigerators and Deep Freezers Sale from 1994 to 2018 along with Populations Growth (Sources: Pakistan Bureaus of Statistics, News Reports, Pakistan Gallup*)*

5.5 Annual increase in environmental impact due to RACs in Pakistan

5.5.1 Direct Emissions from Room ACs

Direct emissions are associated with refrigerant loss and leakage from the ACs equipment. There is no proper recovery of refrigerant at the end life of ACs in Pakistan but here we consider leakage only. In Pakistan leakage is high, there is a lack of awareness in technicians and customers which causes mishandling during refilling and installation. The annual leakage for split ACs is 10% of charge [13], [14]. In Pakistan manufacturers and assemblers using R410a which have no ozone depletion but high GWP of 2088. Some imported models are using R407C. A small number of manufacturers are still using R-22 which will be phase out in 2020 according to the Kyoto Protocol.

Refrigerant can be estimated from annual Demand units. To show the growth in the refrigerants demand for RACs. We will take 2016 as the base year instead of 2018. In 2016 estimated total production is 800000 units as shown in figure 5-3.

Before estimation, we assume on industrial experience that half of the units produced are 1.5-ton, 30% are 1-ton, 15% 2-ton remaining 5% are 4-ton units also depicted in table 5.1. The refrigerant charge per unit in table 5.1 is the average of R410a of the Haier, Gree, and Orient in each capacity unit.

Table 5.1 Refrigerant Estimation for 2016

Capacity type	Production %	Number of Units	Charge per unit	Tons Refrigerant R410a
1.5 Ton	50	400000	1.4 kg	560
1 Ton	30	240000	0.8 kg	192
2 Ton	15	120000	2.0 kg	240
4 Ton	5	40000	4.0 kg	160
Total	100	802857	4.6 kg	1152

For 2016 the estimated volume for the R410a is 1152 metric ton. The leakage emission can be calculated as

$$E_m = V_a \times L_r \times GWP \qquad (9)$$

Where E_m is emission leakage, V_a is annual refrigerant volume and L_r is leakage rate. Using the above formula direct emission for each year can be calculated. Direct emission for 2016 is calculated as 240.53760 $KtCO_2e$. (Kilotons of carbon dioxide equivalent). Similarly, the refrigerant quantity can be calculated for 2017 and 2018 is 1490.4 and 1987.2 metric ton. The direct emissions associated with this refrigerant can be calculated by using equation (9). The refrigerants direct emissions which is shown in the graph of emissions figure 5-4.

5.5.2 Indirect Emission and Annual Increase in Energy due to Room ACs in Pakistan

Indirect emissions are associated with the use of electricity by equipment. Power plant generates electricity and produce emissions. As the electrical appliances use electrical power it also indirectly releases the emission which is produced because of the generation of consumed electricity shown in figure 5-4. Cooling AC is an energy-intensive appliance and its indirect emissions are more than the direct ones. Annual power consumption for inverter and fixed ACs are calculated by using equation 10 and 12[15].

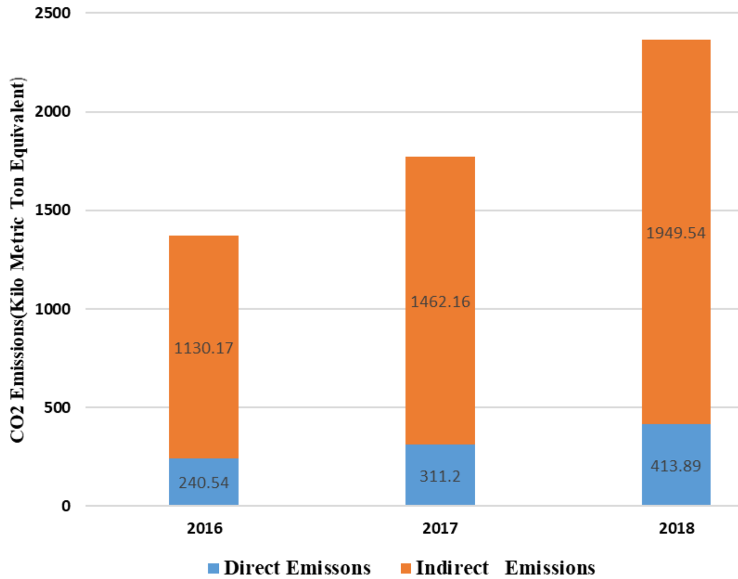

Figure 5-4 Annual Increase in Room ACs Emissions

Fixed frequency ACs Annual Power Consumption (APC)

$$APC(Fixed) = No\ of\ days \times \frac{hours}{day} \times R_{AC} \times N \tag{10}$$

Inverter ACs Annual Power Consumption

$$APC_{in} = No\ of\ days \times \frac{hours}{day} \times \{(0.4 \times R_{AC}) + (0.6 \times HR)\} \times N \tag{11}$$

Where R_{ac} is rate power of AC, N is the number of units sold. APC_{in} is APC inverter and HR are half rated power. Assume 8 hours operation of ACs for seven months because most populated cities in Pakistan the summer season is long up to seven months. 1843.11462 GWh energy is consumed by this new entry. The grid emission for Pakistan is 0.615374995 kg CO_2/KWh[16].

Then the indirect emissions associated with this energy are 1130.1664 KtCO2e per year increase occur due to RACs as shown in table 5.2.

Table 5.2 For RACs in 2016

Capacity (Tons)	Type AC	Share	Total No. of Units	Avg. Power rated	Energy (MWh)
1.5	Inverter	80%	320000	1650	620928.00
1.5	Fixed	20%	80000	1650	221760.0
1	Inverter	80%	192000	1160	261918.72
1	Fixed	20%	48000	1160	93542.40
2	Inverter	80%	96000	2500	282240.0
2	Fixed	20%	24000	2500	100800.0
4	Inverter	80%	32000	5000	188160.00
4	Fixed	20%	8000	5000	67200.00
Total			8000000		1836549.12

The emission increasing rate is 29-33% per year. The indirect emissions are 82.5% of the total which means it consume a lot of energy which is coming from thermal power plant because of Pakistan thermal electrical power share is 75.7%[17]. The direct emission can be controlled through controlling the leakage of the refrigerants, follow proper procedure during installation and maintenance.

The transition of high GWP refrigerants R410a (2088) to low GWP refrigerants like R-32(677) and R-290(3) can mitigate the direct emissions from ACs but the low GWP refrigerants have safety issues because of their flammability which restrict their charge to 150 gram [18]. The study found that low GWP refrigerants show better performance with high ambient temperatures than R410a[19].

ACs using R-32 and R-290 are manufactured in China and India[20]. Emissions can be controlled through the aggregate approach by increasing efficiency and transitioning to low GWP refrigerants.

Pakistan experiences the shortfall of electricity in the summer season because of the increase in cooling demand. The annual sale of ACs also takes place in the summer season so the new ACs sold are almost contributed to peak load demand. The power use for these units can be calculated by using the equations (10) and

(11). The annual energy consumption increases due to ACs have been shown in figure 10 for 2016.

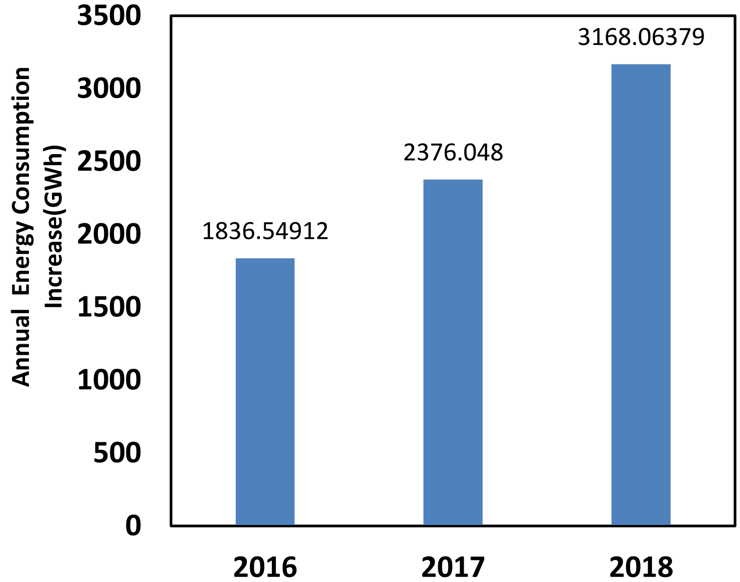

Figure 5-5 Annual Energy Consumption Increase (GWh) due to New RACs

The increase in power consumption occur 29% for 2016-217 and a 33% increase from 2017 to 2018 is highest due to RACs coming into stock. The previous study estimate 1500-3000 MW peak load can be avoided by improving efficiency 30% and transitioning to low GWP refrigerants in Pakistan by 2030[14].

Summary

This chapter covers the Pakistan's RACs and refrigerators market shares by different manufactures. Pakistan's market is largely dependent on Chinese base manufactures. The direct emission of RACs is also calculated along with increase in annual energy due to new RACs sale.

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Chapter 6

Chapter 6

Results and Discussion

The results of this study are divided into two portions the first one is the assessment of cooling equipment while the second one shows the energy forecasting and saving potential.

6.1 Current Energy Efficiency Performance

The assessment section of the study compares Pakistan's energy performance parameters with world best efficient ACs, Refrigerators and deep freezers. Pakistan’s minimum energy performance standards (MEPS) compliance is voluntary, which means MEPS has no impact on the performance of ACs. The EER of 194 different type RACs models are displayed of the current market in figure (average EER). The market on sale average EER black line of fixed and inverters ACs combine is 3.40 which is more than 3.20 the highest limit MEPS red line. As shown in figure 6-1 that most of the EER are below the redline of MEPS.

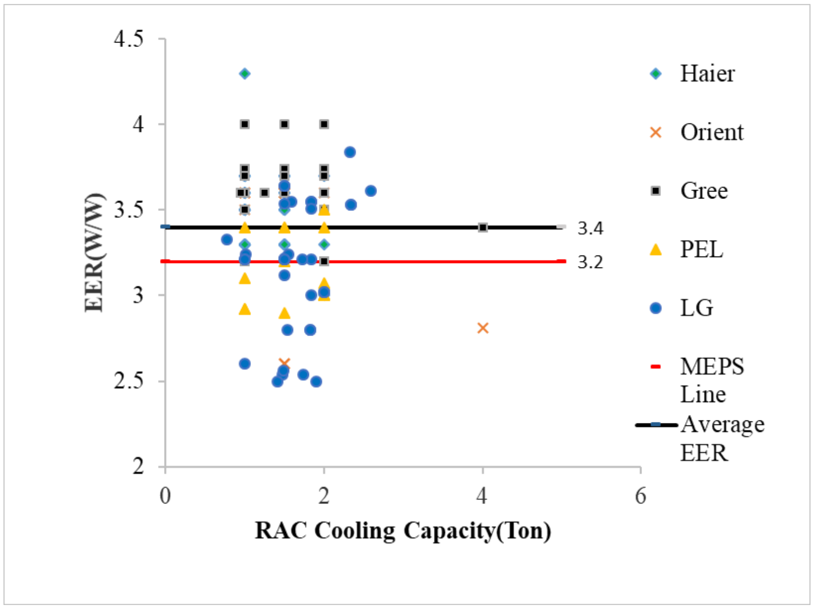

Figure 6-1 Pakistan's MEPS Line vs Average EER

6.1.1 Air Conditioners

The best available ACs in the European market are with EER 5.63 which is much higher than our best one and some Chinese models are more efficient than European models [7] as shown in the figure 6-2. In Pakistan, there is no proper implemented MEPS and S&L for ACs, so we compare it with the world's best available technology to show the improvement opportunities in the current ACs market.

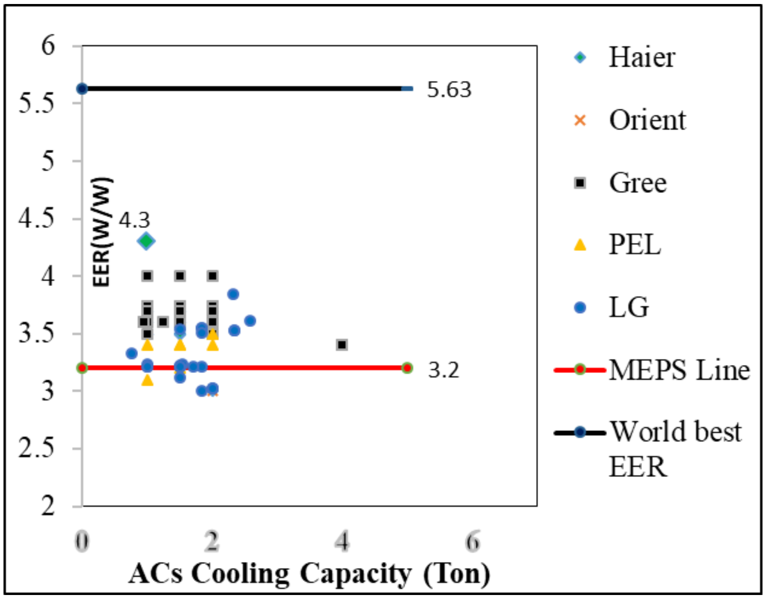

Figure 6-2. Pakistan Inverters RACs EER vs World best

Pakistan is an unregulated market for refrigerators and deep freezers in terms of policy guideline. And most of the manufacturer's brands are local, and multinational brands product are rare. Due to a lack of technology, local brands focus on durability rather than efficiency. The market on sale rated annual energy consumptions are compare with world best available refrigerators and deep freezers as shown in figure 6-3 and 6-4.

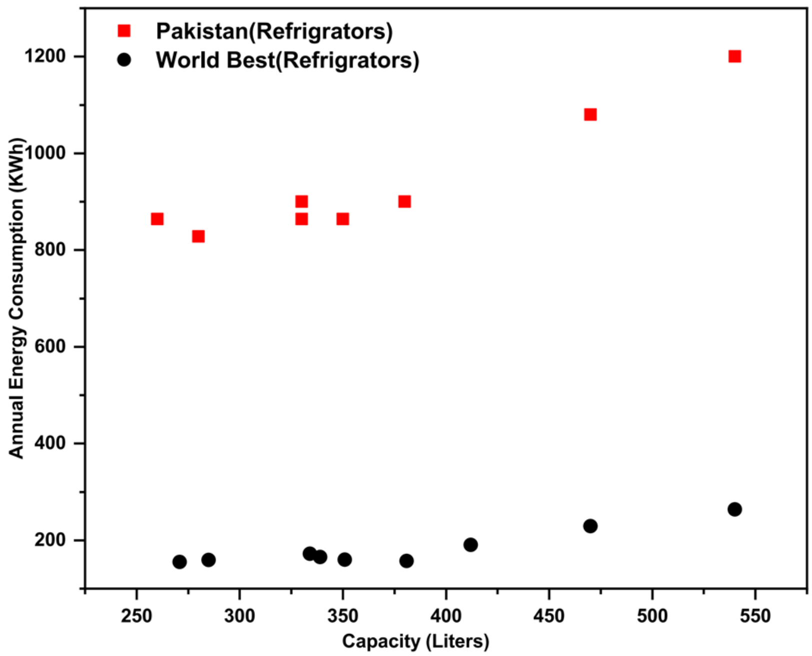

Figure 6-3 Pakistan's vs World's Best Refrigerators

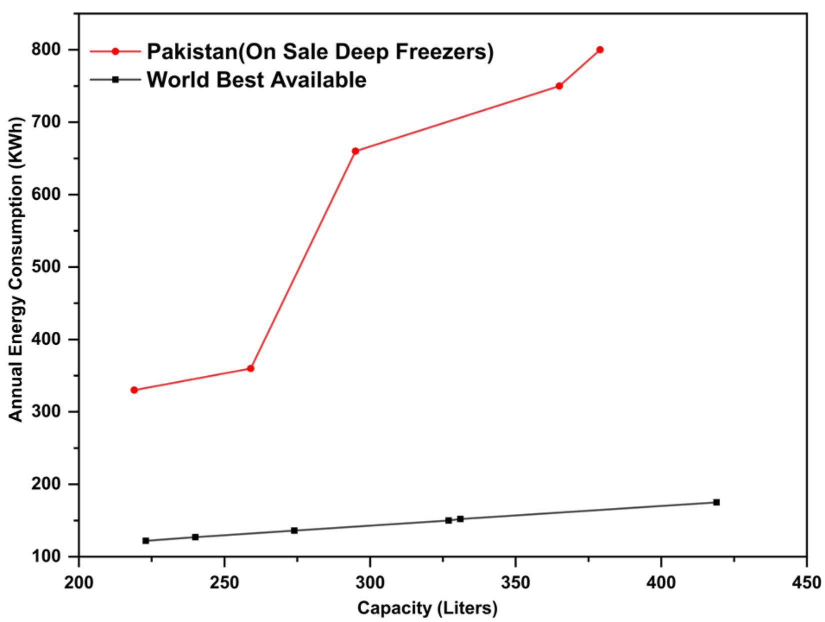

Figure 6-4.Pakistan's vs World Best Deep freezers

6.2 Energy consumption and saving potential

6.2.1 Applicable Stock

The annual shipments of RACs, refrigerators and deep freezers in 2018-2050 are calculated from the equation (1). The production and sale data of RACs, refrigerators and deep freezers are from Pakistan economic survey and world ACs demand reports [1][2]. The RACs ownership is very low 5% of the household which indicates a large potential for growth in the future without saturation as compare with the developed countries of 90%[3]. The sale growth rates for these appliances are calculated from previous two decades sale data, for RACs, refrigerators and deep freezers growth rates are 5.5%,4.66%, and 2% respectively from 2018 to 2050[4]. The annual shipments are due to the increase in ownership and retirement of previous sales after their service life completion as shown in figures. The applicable stock is a pool of appliances that are consuming the electricity. The stock is calculated from the previous sale numbers and the cycle life of each equipment by using equation (1) & (2). For RACs of service life of 10 years the shipment, stock, increase in ownership and retirement is illustrated in figure 6-5.

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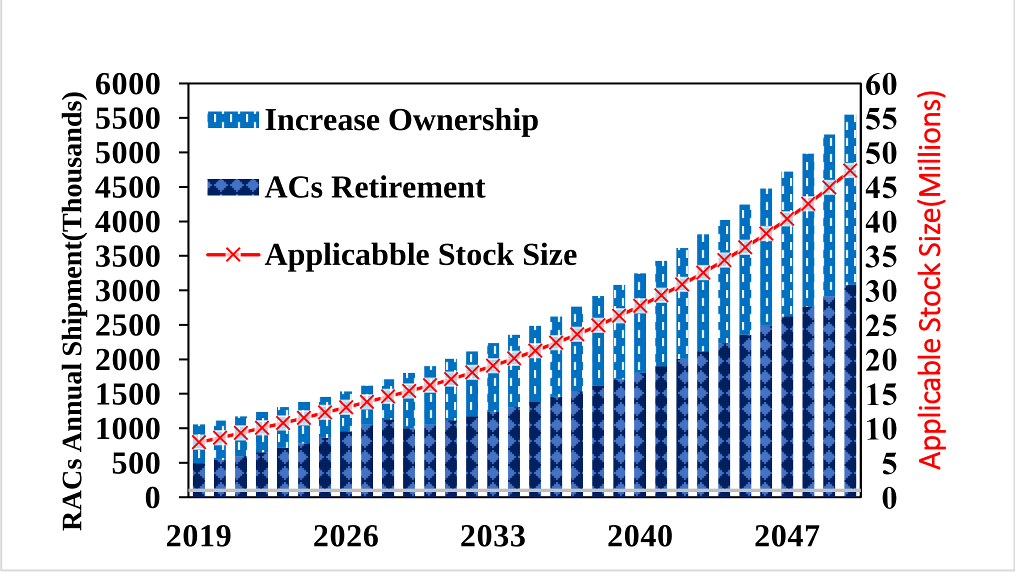

Figure 6-5 Pakistan’s RACs Annual Shipments, Retirement and Applicable Stock

In case of refrigeration and deep freezers the service life of 15 year is consider

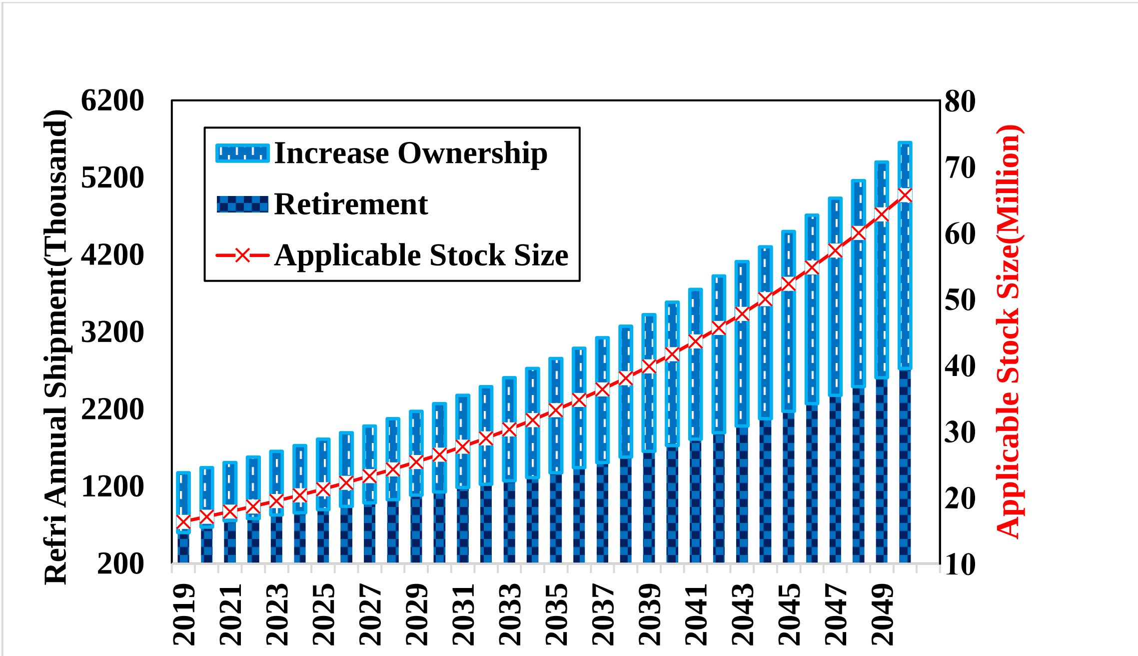

Figure 6-6 Pakistan's Refrigerators Annual Shipments, Retirement and Applicable Stock

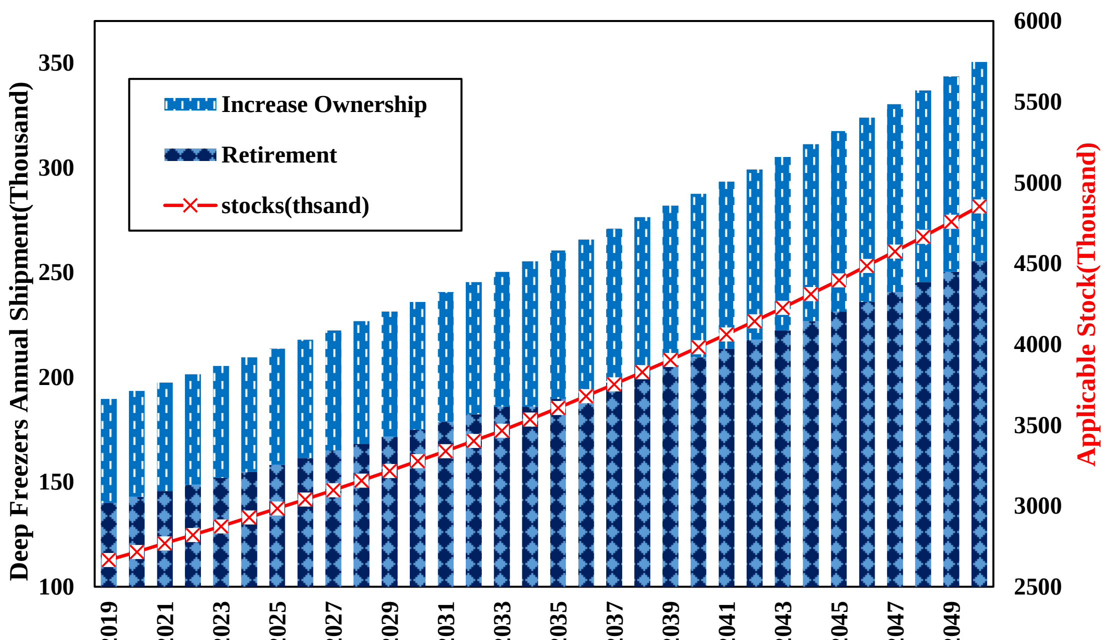

Figure 6-7 Pakistan's Deep Freezers Annual Shipments, Retirement and Applicable Stock

6.2.2 Potential Electricity Savings and CO_2 Emission Reductions

The improvement of efficiency is based on a period of 5 years with the improvement of 10% at each revision of standards considering the technical limitation of the technology[5]. The implementation year of CIS scenarios will be 2020. The consumption of these appliances (Demand) is illustrated in figure 6-8.. The consumption from these three appliances in 2030 will reach 74.7 TWh in BAU while in CIS and BAT the consumption will be 64.5 and 36.55 TWh, which 86% and 49% respectively.

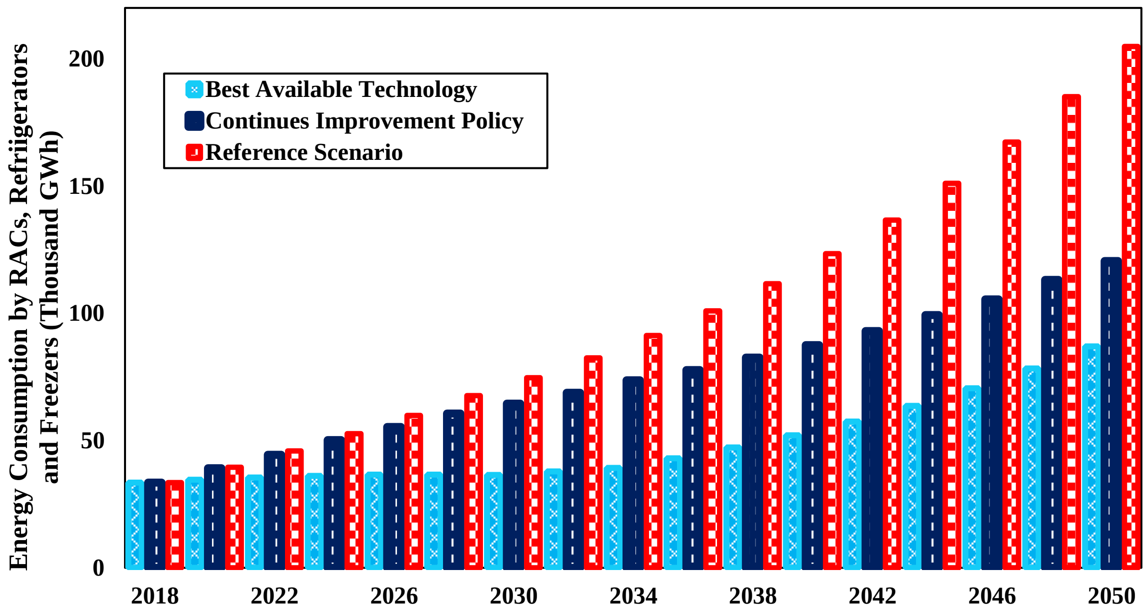

Figure 6-8 Total Energy Consumption under Three Scenarios of RACs, Refri and Deep Freezers.

The figure 6-9 shows the RACs energy consumption and 54% of the total consumption is due RACs because of intensive energy nature. In the CIS scenario the improvement of 10% after 5 years is considered to 2040 then onward 5% increase in efficiency is considered. In the BAT scenario, the world's best efficient RACs of European is considered in 2019[6] with an improvement of 5% in 2035.

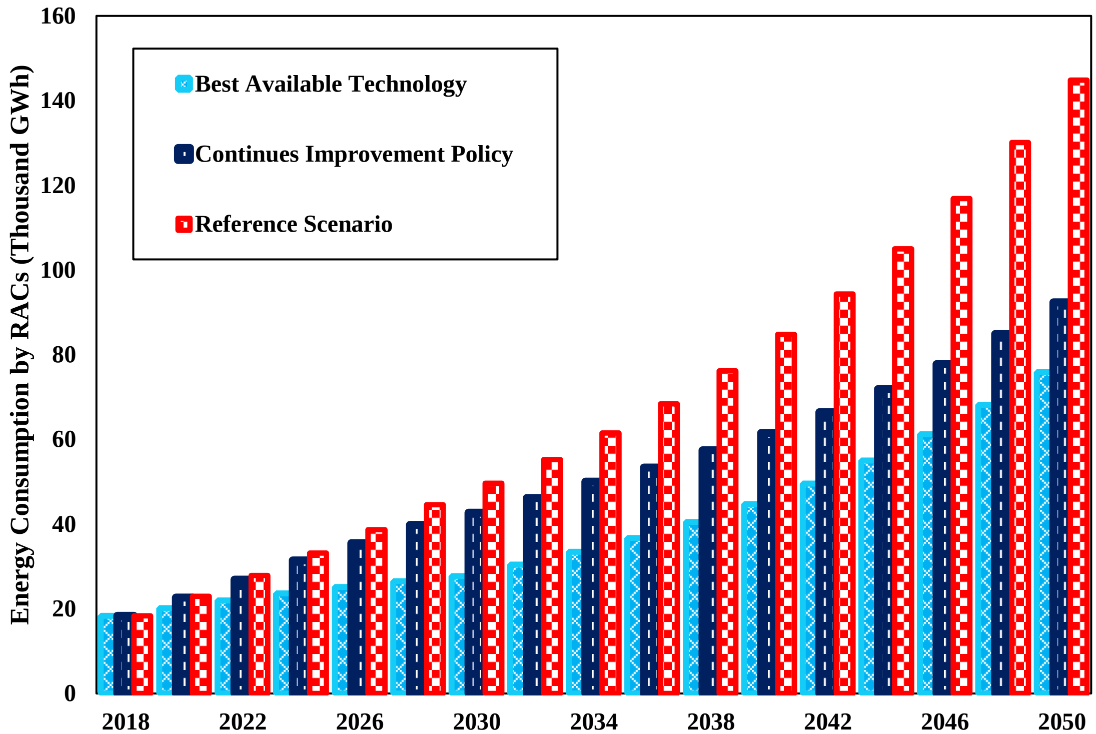

Figure 6-9 Pakistan's RACs Energy Consumptions in Ref, CIS and BAT Scenarios

The refrigerators consume 40% of the energy as from the assessment section, the refrigerators and deep freezers energy consumption in Ref and world BAT shows the tremendous difference which can be easily depicted in figure 6-10 and 6-11.

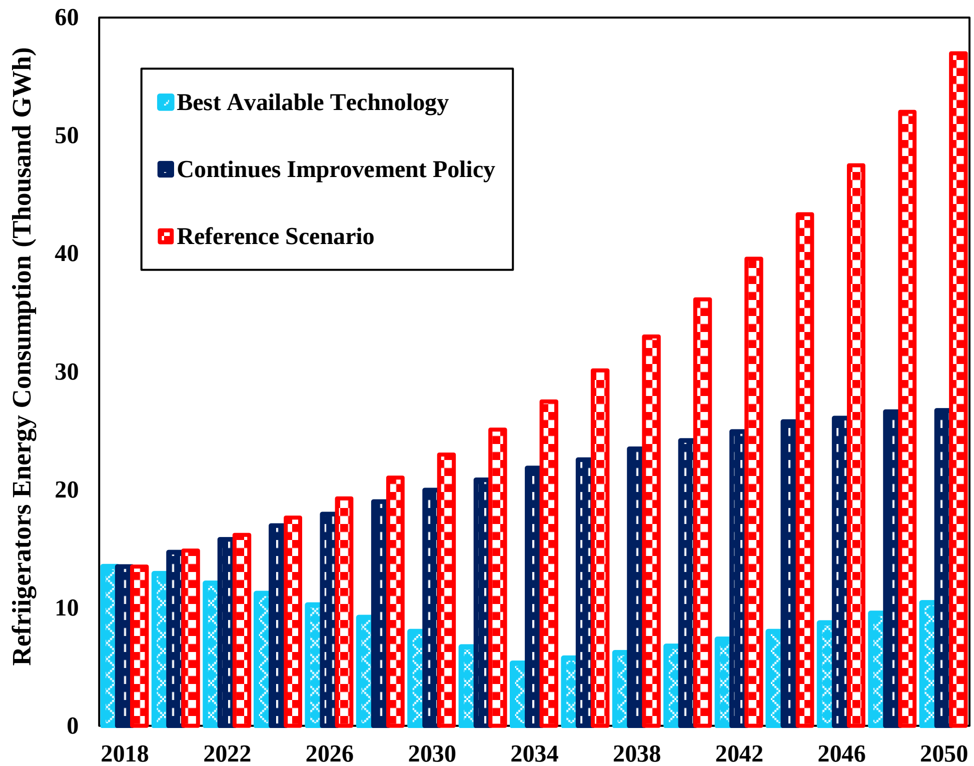

Figure 6-10 Pakistan's Refrigerators Energy Consumptions in Ref, CIS and BAT Scenarios.

The refrigerators and deep freezers have same nature of the operation, so the CIS scenario performance improvement of 10% is considered every 5 years period till to 2050 because they have large improvement potential as compared with world best available. For the case of BAT, the world's best of the European market is considered with the sale from 2019. For refrigerators and deep freezers, the energy consumption in BAT is decreasing till 2030 because of the retirement of inefficient devices which is replaced by an efficient one as shown Figure 6-10 and 6-11.

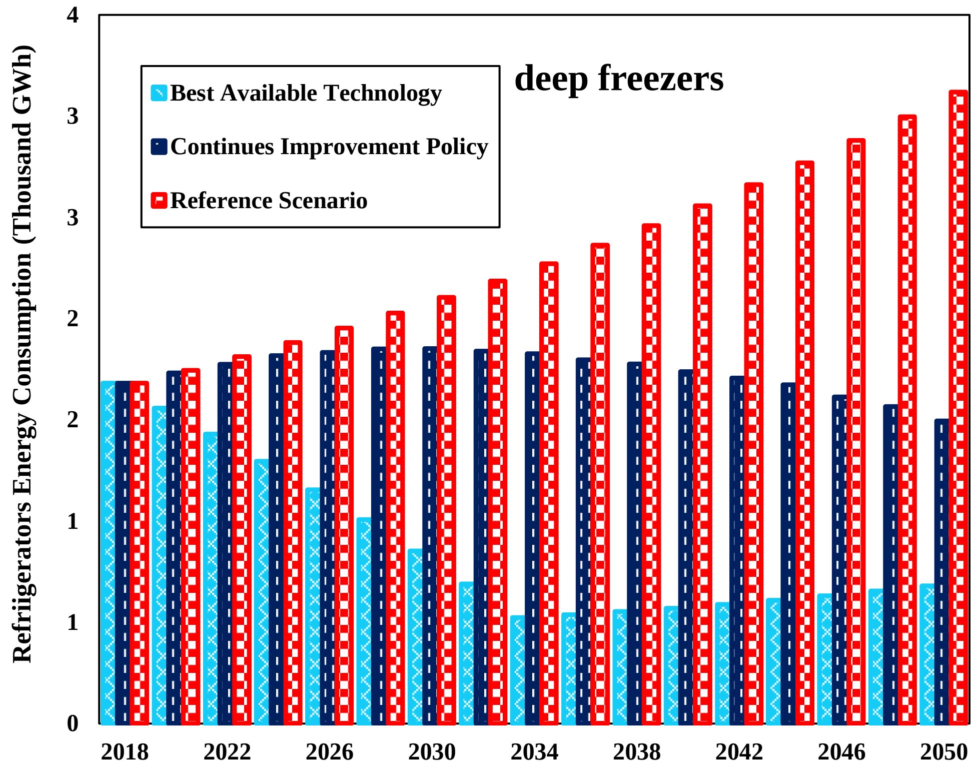

Figure 6-11 Pakistan's Deep Freezers Energy Consumptions in Ref, CIS and BAT Scenarios

6.2.2.1 Cumulative Saving

The accumulative electricity savings of CIS and BAT are equal to 204.08 TW h and 793.38 TW h, with shares of 12 % and 47% of the accumulative BAU scenario electricity consumption for 2020-2040. The electricity savings of CIS and BAT for this period are equal to 41 and 158 of a large coal-firing power plant of 1000 MW with 5000 hours annual operations. The CIS and BAT provide the saving potential limits of implementing efficiency policies in Pakistan and reference shows how large the unregulated market consumes the electricity as compared with a regulated market.

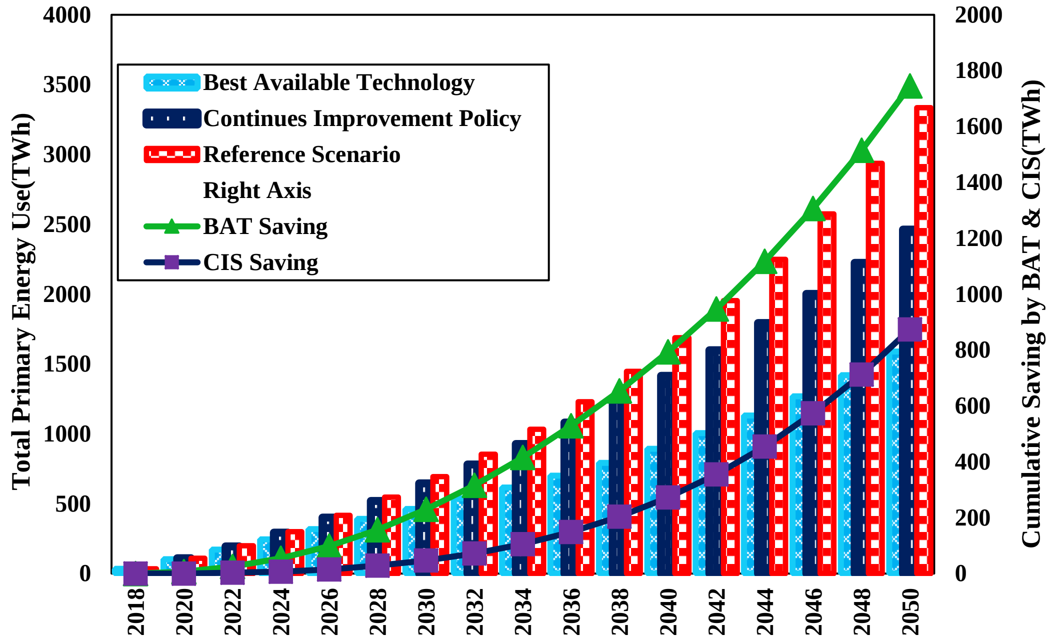

Figure 6-12 Cumulative Energy Use and Saving of Ref, CIS and BAT.

6.2.3 CO_2 Emissions

The figure 7-13 emissions show the emissions of the three scenarios, the grid emissions factor for Pakistan is 0.61537 kg per kWh. The CO_2 emission is a linear function of power consumption, so the trends of emissions are the same as of power. In the cumulative graph of emissions in figure 6-14 shows the reduction in CO_2 emission is 167.46 and 488.22 Mt for CIS and BAT scenario.

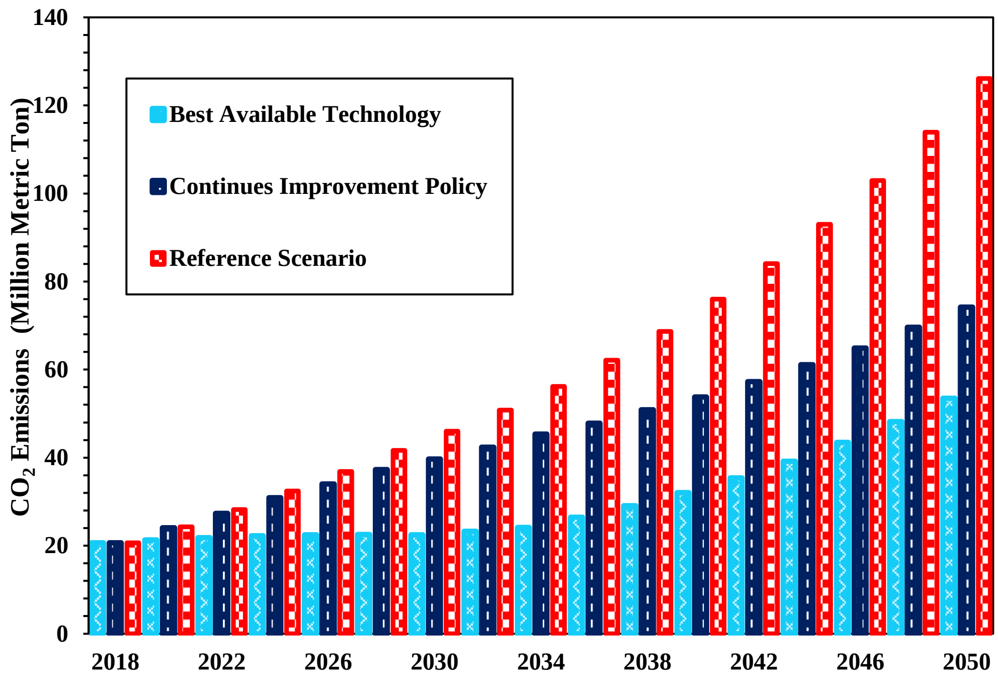

Figure 6-13 Indirect CO_2 Emissions in Ref, CIS and BAT Scenarios

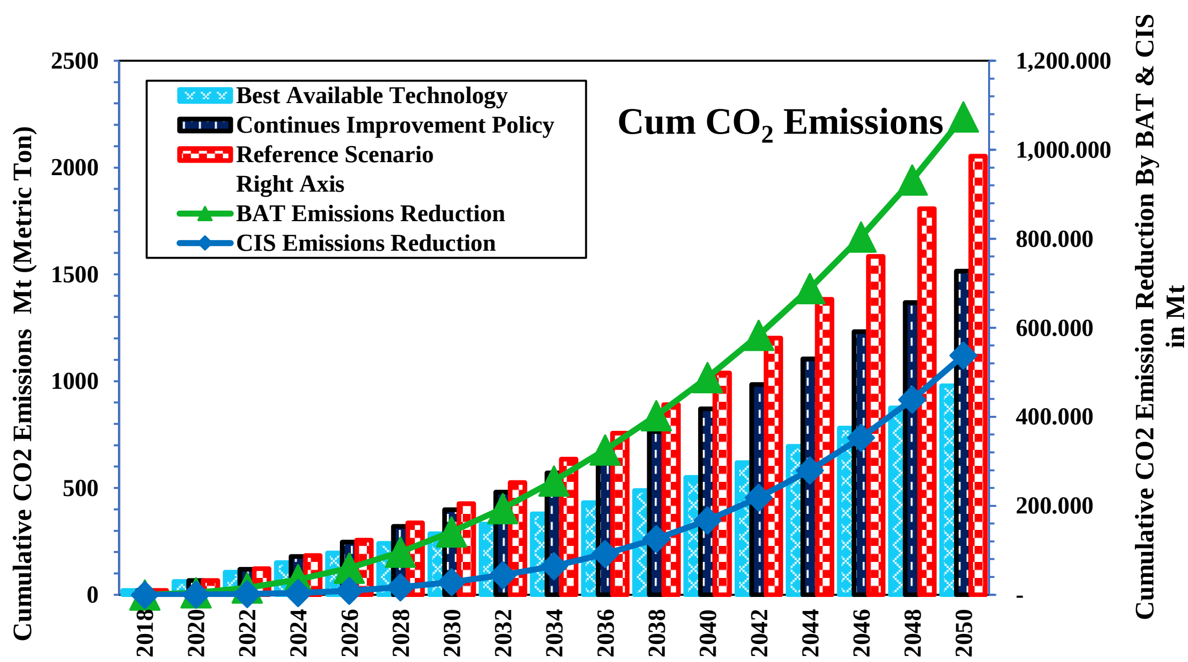

Figure 6-14 Cumulative CO_2 Emissions and Reduction in Three Scenarios.

Summary

The results of LEAP energy models are discussed. The graphs are presented to compare the performance. The stocks, shipment and retirement of each system is calculated with help of LEAP model. The LEAP energy models result show the energy consumptions, saving potential with the indirect CO_2 emissions.

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{Bibliography

Chapter 7
Conclusion

The present study assesses and evaluates the efficiency performance, potential electricity savings, CO_2 emission reductions of RACs, refrigerators and deep freezers.

7.1 Efficiency assessment

The efficiency is the main parameter that affects energy consumption and environmental impact. The Pakistan RACs, refrigerators and deep freezers market is highly influenced by Chinese due to large market shares by Chinese manufacturers and main parts suppliers. The average EERs the ACs coming into the stock is 3.40 which is more than the current MEPS limit propose by NEECA. Pakistan MEPS have no impact on RACs efficiency since it has a non-mandatory status. Customers' attraction for energy saving is the main driving force among the manufacturers to improve the efficiency of RACs. The inverter RACs share is increasing each year and 80 percent of the market on sale are inverters and the stock will be saturated of inverters ACs in the next decade due to the high influx of inverters.

It means this amount of energy will be required to operate the new ACs and it is the increase in peak load because ACs are summers operating appliances. Pakistan also faces peak load in summers which means that cooling load plays a critical role in peak demand. Indirect emissions are 4.7 times greater than direct emissions this means that ACs are energy-intensive equipment. The emissions are also increasing at the same rate at which energy requirement increases increase because 82 percent of total emissions are indirect emissions.

From the performance analysis graph, we observe that the local ACs manufacturers in Pakistan (such as PEL) are struggling in the efficiency competition because they lack the research and innovation in the new technology. Thus, their market shares are shrinking against the Chinese brands which encapsulate the Pakistan ACs market by introducing new technologies.

7.2 Electricity Saving and CO_2 Reduction

The energy modeling section of the conclusion can be summarized in points below:

- The RACs ownership is very low in Pakistan, the potential is very huge
- According to the results, the accumulative electricity savings of CIS and BAT are equal to 204.08 TW h and 793.38 TW h, with shares of 12 % and 47% of the accumulative BAU scenario electricity consumption for 2020-2040
- The cumulative emissions show the reduction in CO_2 emission is 167.46 and 488.22 Mt for CIS and BAT scenario for 2020-2040

7.3 Policy Solution & Recommendations Using Quantified Data:

Improving efficiency and transition to low GWP shows incredible results which is a good approach to counter emissions and energy consumption simultaneously. Both targets can be aimed at one arrow which is S&L. Implementation of S&L in China increase the average efficiency of 16% in two years while in Malaysia the improvement was 8% with a reduction in indirect emissions. The European efficiency is much higher than our best one and they still revising their standard to include the part-time load performance in the future standard (EN 14825).

- Accredited labs and test centers for RACs and refrigerators should be established to measure accurate performance under different climate conditions
- Energy labels and Star system should be synchronized with MEPS so that customer easily estimate energy-saving potential
- Reconstitute the MEPS with mandatory enforce status and stringent limits because it lacks the main purpose to promote efficient product and restrict inefficient one
- Develop MEPS for inverter ACs separately because inverter technology is different from the fixed in term of operation and mechanism which shows a large difference in the Performance
- For the inverter, the part-time load performance should be included in MEPS to comprehensively show the performance chart

- Seasonal energy efficiency ratio (SEER) should be introduced in MEPS with EER and COP to show energy-saving options clearly for RACs.
- To counter the emissions, the refrigerant should be considered in the future MEPS, S&L program
- The government should provide support for local manufacturers in research and development to counter the pressure from bigger manufacturers and improve their efficiency for energy saving.
- Due to the high influence of Chinese manufacturers, Pakistan MEPS should be coordinating with Chinese so that the maximum output of the policies is achieved.

7.4 Future Work Recommendations

All refrigeration and air-conditioning systems (Cold storage plants, VRF, Central Systems and Commercial Refrigeration Systems) are to be model for this sector saving. Economic feasibility analysis along with environmental impact costs should be done for Pakistan's market to further signify the importance of efficiency improvement for cooling sector.

Assessment of Energy Efficiency and Contribution of Climate Change Impacts via Room Air Conditioners in Pakistan

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Abstract

Pakistan constitutes of the region where summers have high temperature with long duration. Consequently, the demand for cooling equipment is very high in most parts of the country. To meet such a high demand, increasing efficiency of cooling air conditioners is the best solution to reduce peak load, energy consumption and environmental impacts. Ministry of Water and Power established the Minimum Energy Performance Standard (MEPS) compliance. Due to lack of Market data there lies a barrier for the assessment of Air Conditioners (ACs) efficiencies and refrigerants used. The objective of this study is to assess the on-sale ACs energy efficiency ratio (EER), energy consumption, the quantity of refrigerants used and their global warming potential to climate change. The performance gap between the current MEPS EER 3.2 and the market on sale ACs with average EER 3.4 have also been analyzed. The inverter share is rapidly increasing but the efficiency is much low when compared with the best available contingent in world. The paper will also provide the direction for the next standards and labeling (S&L) implementation in Pakistan**.**

KEYWORDS—AIR CONDITIONERS, MEPS, EER, REFRIGERANT, EMISSIONS, CLIMATE CHANGE IMPACT,

1. INTRODUCTION

Pakistan is faced with huge demands in terms of Air conditioning units for residential and commercial cooling. As a result, it is very important to propose a solution that will address the core issues related the increase in the Room Air conditioners (RACs) equipment. The increase in demand of ACs will eventually increase energy consumption and consequently increase the environmental emissions. The improvement in energy efficiency of ACs will reduce the energy consumptions and indirect emissions. Before addressing the core issues the assessment of the current ACs market is very essential to show how these parameters are interlinked with each other. Pakistan is a developing country and the ACs demand in developing countries will reached 1.5 billion in 2030 due their hot and humid climate zone with increasing population (Goetzler, Guernsey, Young, Fuhrman, & Abdelaziz, 2016). The cooling requirement of Pakistan is increasing due to population growth and the urbanization in Pakistan ACs demand is increasing more rapidly than 5.95% per year(2011-2012) (No et al., 2014). As the economic prosperity increase the ACs utilization and volume also increase (Long, Zhong, & Zhang, 2007). Domestic cooling is the need in the heatwave hit cities of Pakistan in which the death tolls up to 2000 in 2015 mostly in Karachi. The cooling requirements for Pakistan is estimated 10TWh for 2018 (Gul & Qureshi, 2013). Pakistan have CDD 2810 with population of 197 million which 553.570 total cooling demand potential in billion person degree day which is 1.984 time that of USA(Goetzler et al., 2016). Energy use for space cooling is more rapidly increase than other end use in building sector, it contribute at average 16% peak load in summer and 70% in US ("Futur. Cool.," 2018). According to the Daily Times the AC production increase 24% July-Feb 2017-2018 and 37,554 units more produce than previous year. Pakistan estimated ACs annual production is 600,000-650,000 units for 2017(Hamza, n.d.). MEPS implementation in developing countries shows 16% improvement in average efficiency of ACs in China and reduction in carbon dioxide emission(Michel, Bush, Nipkow, Brunner, & Bo, 2019) .

Adaptation of ACs in developing is increasing with increase in income, decrease in the prices of ACs and due to their climate zone temperature because most of the developing countries lies in the hot and humid climate zone. This will put more strain on energy supply side and indirect emissions but the prices of electricity is uncertain which is a prime parameter along with energy efficiency to determine the energy consumption and future growth in ACs(Davis & Gertler, 2015). Pakistan have the energy saving potential from 1.2 to 2.9 GW(gigawatt) alone focusing on improvement of energy efficiency about 30% of the base line and by transition to low global warming refrigerants will also increase the efficiency about 5% avoiding 0.21-0.48GW (Shah, Wei, Letschert, & Phadke, 2015)(Analysis, Division, & Berkeley, 2019a).

Hydrofluorocarbons (HFCs) absorption in atmosphere is increasing from 10-15% each year(Velders et al., 2010). In Pakistan the government is also decreasing the CFCs import and HFCs taking place in this transition.(*Ozone*

Depleting Substances Alternative Survey Report, 2017). By adopting the best available technology(BAT) we can reduce the total emission of 373.0 GtCO2e(Analysis et al., 2019a).

Policies play a crucial role in reduction of environmental emissions and improving efficiency. Japan and South Korea are taking the lead due to their energy efficient strategies like Japan Top Runner program started in 1997, which is mandated in 2004 which bring 7.2% improvement in efficiency per year. Similarly South Korea also launched the Energy Frontier Program in 2011 for key appliances which also include the ACs who's bring 12% improvement in efficiency per year (Lawrence, 2017).

The study assesses the current room ACs energy efficiency ratios (EER), refrigerant charge and capacity of Pakistan ACs market giants which cover two third of market. The EERs is compared with the current MEPS to show the implication of the current policies and future directions. The increase in energy consumption, peak load and total emissions related to new induction of ACs is annually evaluated. The results, challenges and policy recommendations are presented are after the assessment.

2. Overview of Pakistan MEPS and Energy Star

In December 2014 ministry of water resources power division propose ES&L for some electric appliances which include room air conditioners through NEECA (National Energy Efficiency and Conservation Authority) with help of UNOP
and GEF(November, 2014) . Sample is shown in figure 1. For ACs which have the capacity under 14000 watts are covered in the ES&L program who compliance is voluntary base (No et al., 2014). MEPS for window types and splits ACs with air cooling condenser, close motor compressor and operate in climate zone of T1 and T3 as shown in table 1.

TABLE 1. PAKISTAN MEPS 2014 SOURCE (NEECA et al., 2014)

Type	Cooling Capacity (CC) W (BTU)	Energy Efficiency (EER) W/W
Window	3517-4499 (558.86-714.91)	2.90
Split	≤ 4500 (715.07)	3.20
	4500 -≤ 7100 (715.07-1128.22)	3.10
	7100 -≤ 14000 (1128.22-2224.67)	3.00

The test should be conducted according PS: ISO: 5151 in certified laboratory but in Pakistan there in no such facility available for ACs. The three energy star labels are provided after qualifying the test criteria, but it still lacks the details of stars assigning and customers can't identify the efficient product among the labeled products.

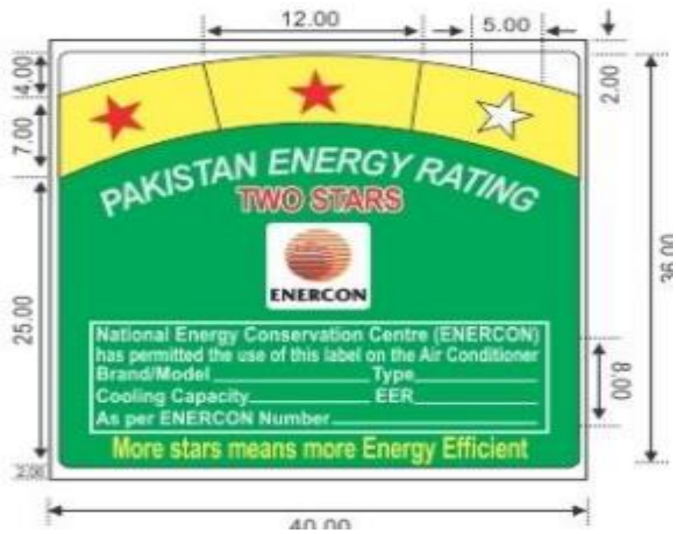

Fig. 1 Pakistan Energy Star Label (NEECA, November 2014)

3. Methodology

In this study the information of split-system ACs and window type systems has been collected from manufacturers and retail stores about different brands of Pakistan's ACs market. As Pakistan's 95% of ACs market is comprise of split ACs, so this assessment is done for split ACs which include both the inverter and fix frequency units. ACs units of higher capacity than 2 tons are standing units which have small share are included in refrigerants calculation. Information included the company name model number, system type, cooling capacity, refrigerants type, refrigerant charge, COP, EER, rated power. But in this study only EER, cooling capacity and refrigerants are analyzed of the market on sale. The EER used in this study is the ratio of cooling capacity in watt to rating power in watt, which is given on the manufacturers database in product specification("Pakistan ACs Companies," n.d.). The market share information of different manufacturers is based on the market survey and some reports(Hamza, n.d.). Haier, Gree, Orient, Dawlance and PEL are manufacturing and assembling in Pakistan. The information collected of 193 models available in Pakistan ACs market are presented in this study. Inverter and fixed frequency models are both included in this assessment. In 193 models included 55 Haier models, 25 orient models, 65 different Gree models, 16 PEL models and 28 are Dawlance models which is shown in Figure 5 as blue bar. The share of inverter models out of all modesl are given in percentage (orange bar) in figure 5. For example, the 64 different type of Gree models are present in which the 88% are inverters which means they marketed 56 different types of inverters model as compare with 8 fixed one. Dawlace models EER were not available on the website and on online retailer shop database so they are not included in EERs graphs. The information considered as per manufactures provided. The above mention EERs of different companies cover the 70 percent of Pakistan RACs Market. The remaining 30 percent represent some local (Dawlance, Sabro) and small foreign companies like Changhong Ruba, LG, Kenwood etc.

4. Pakistan ACs market characteristics

4.1. Pakistan Room Air conditioners Demand

According to the Japan refrigeration and air conditioning industry association(JRAIA) the annual average growth for five year (2012-2017) is 4.2% and for 2016-2017 the growth is 7.5% (Japan Refrigeration and Air Conditioning Industry Association (JRAIA), 2018). The number units required for each year are shown in figure 2.

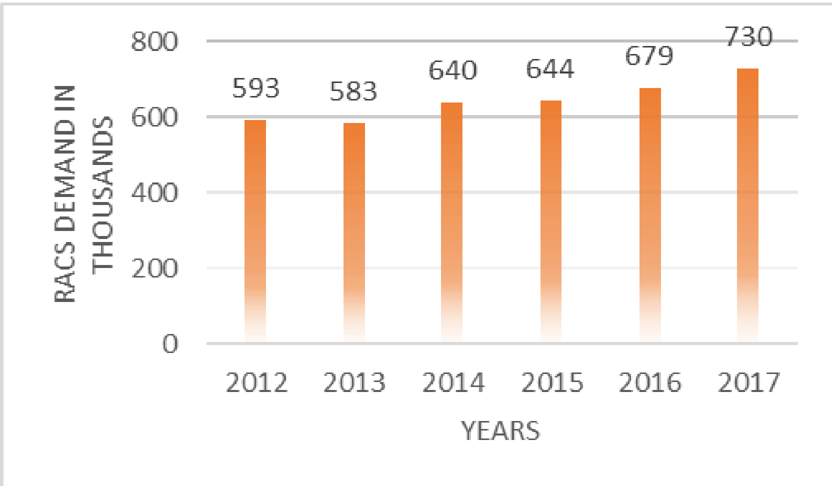

Fig.2. Pakistan Room ACs Demand (Japan Refrigeration & Air Conditioning Industry Association (JRAIA), 2018)

But according to the company's production and sales information the demand shows more rapid growth than the Japanese JRAIA estimation. CAGR for 2015-2018 is 26.79% from manufacturers point of view. The growth is affected in 2019 with Rupees devaluation because the manufacturers in Pakistan import most of the ACs parts from China, Malaysia and Thailand. The parts include the compressor, motors, capacitors, valves aluminum foils and galvanized iron sheets. As the imported parts become more expensive the manufacturers decrease the production as shown in figure 3 the demand for 2018 and 2019 is same because of the dollar reached to highest level of 160 Pakistani rupees. Haier, Gree, Orient, Dawlance and PEL are major market players which manufactures and assemble in Pakistan. Chinese brands like Haier, Gree and Chonghong comprise the major markets shares of more than half because some other Chinese brands like Midea have marketed their residential and commercial air conditioners with the help of Green leaves in Pakistan share in market (Leaves, Midea, Conditioners, & Group, 2019).

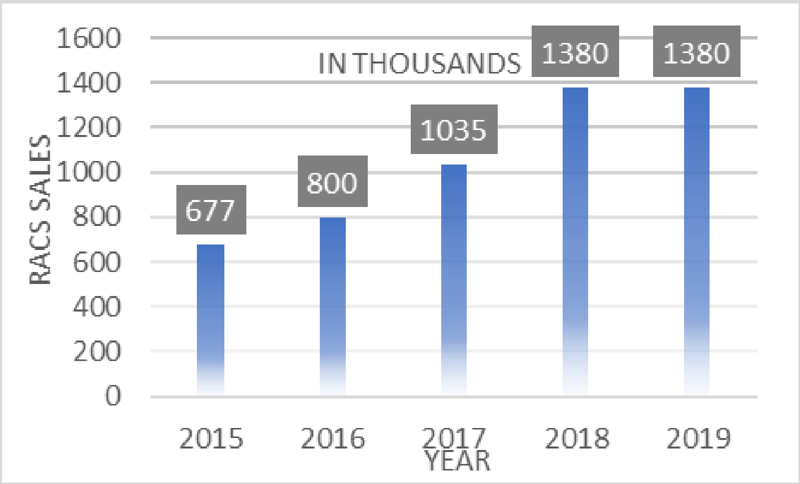

Fig. 3 Pakistan ACs Production [Author's Survey Base]

The imported ACs units have more of Chinese manufacturers as primary contingent (Naqvi, 2019)(Group, 2016). Pakistan market share is show in figure 4.

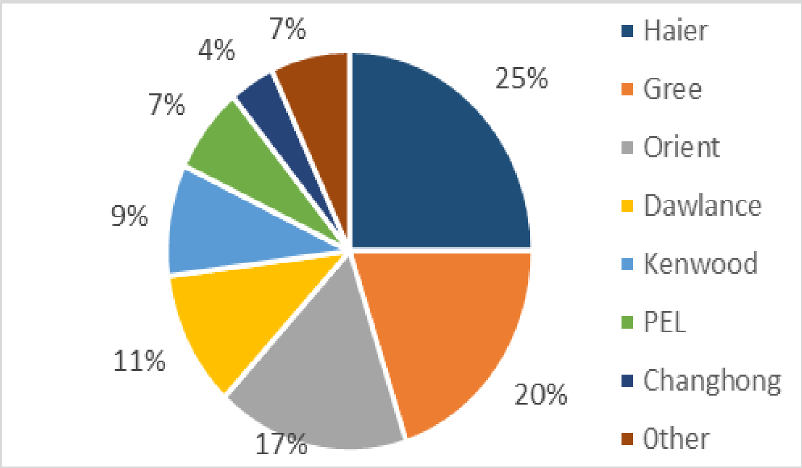

Fig 4. Pakistan's Market Share 2018(Hamza, n.d.).

4.2. Pakistan Product Characteristics

Pakistan inverter AC market is growing with increasing cooling demand. In 2016 Pakistan inverter ACs markets on sales share were increase from 30 to 70- 80% (www.techjuice.pk, 2016)(A. S. Khan, 2019). Now this share is more than 80% of the market because of increasing trend. The inverter type of models is 83% in Orient and 88% in Gree which means that they are penetrating more inverters ACs than fixed in the current market. The inverters types of models are 58% in Haier case with high share 23% market as shown in figure 5. The ACs manufacturers produce more types inverter ACs models than the fixed frequency because the high demand of inverters in new market. The AC product characteristics are shown in figure 5.

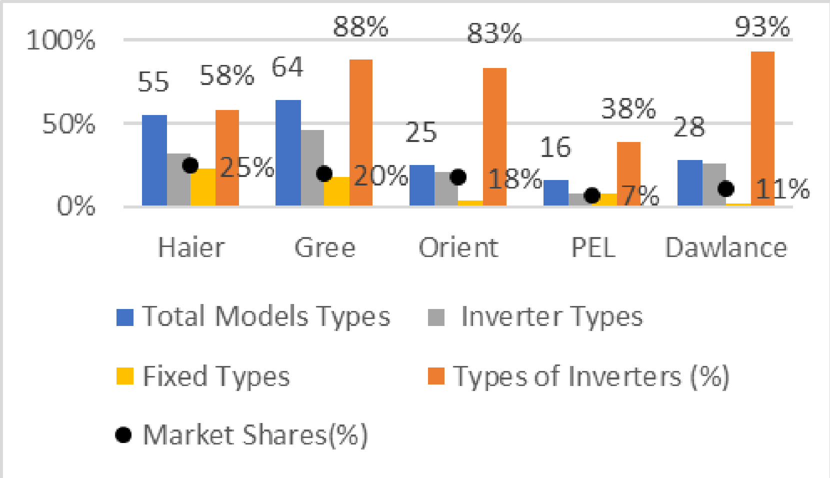

Fig. 5. Pakistan ACs Products Characteristics ("Pakistan ACs Companies," n.d.)*(Authors Survey base)*

5. PERFORMANCE CHARACTERISTICS OF PAKISTAN ACS

AC can be divided on the base of operation and technology like inverters and fixed speed drivers. The inverter is the one can adjust the frequency of the motor through DC inverter with load which consume less energy when load is decrease. The fixed frequency ACs which sample use thermostat to on/off the compressor when set temperature is achieved. The inverter reduces the peak load demand and the power consumption curve is smooth as compare to the fixed one which give the zigzag power curve.

In Pakistan Haier have their own lab according to our survey they perform the test according to the ISO 5151:2010 (A standard which provides guidelines regarding the testing of Non-Ducted Air condition). The EER of 194 different type RACs models are displayed of the current market in figure 6. The market on sale average EER black line of fixed and inverters ACs combine is 3.40 which is more than 3.20 the highest limit MEPS red line.

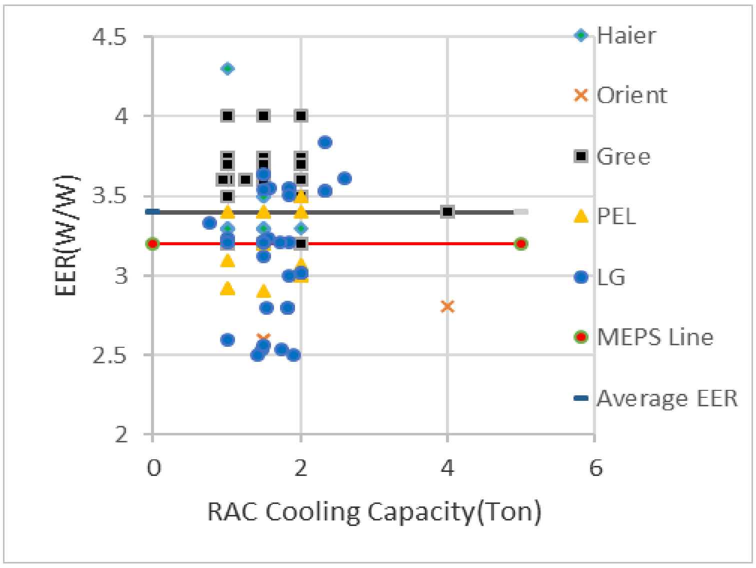

Fig.6.Pakistan MEPS Line vs Average EER(Hamza, n.d.)

If the MEPS is enforced, then 90% of the ACs will qualify the current MEPS limit 3.2. The current MEPS do not differentiate the limits for fixed and inverter ACs. Both ACs show a large difference in term of EER, rating power and operation. The Pakistan new ACs EER range from 2.5 to 4.3. The highest EER is4.3 and lowest EER is 2.5 which are further elaborated in figure 7 and 8 below.

Most the DC inverter ACs are well above the MEPS limit. The best EER in Pakistan current market is 4.3 with inverter compressor of Haier is shown in figure 7. The best available ACs in European market is with EER 5.63

which is much higher than our best one and some Chinese models are more efficient than European models (Michel et al., 2019). There is no proper MEPS and S&L for inverters ACs, so we compare it we world best available technology to show the improvement opportunities in current ACs market. The inverter shows energy saving from 30-40% in operation(Fatihah Salleh, Mohd Isa, Eqwan Roslan, & Ab Rashid Tuan Abdullah, 2019) but improvement in EER can bring much more energy saving irrespective of their type.

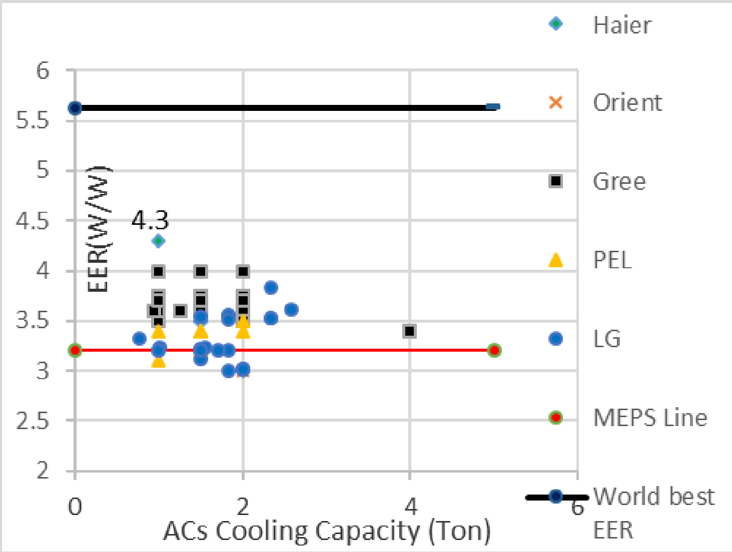

Fig. 7. Pakistan Inverters EER vs World best EER (Michel et al., 2019)

The fixed frequency ACs in Pakistan current market EER is low because most of the models lie below MEPS limit as shown in figure 8. But it's on sales market share is less than 20% which is further decreasing as customers adopt inverters ACs. By implementing the current MEPS, it will filter the inefficient ACs which are still on sales market.

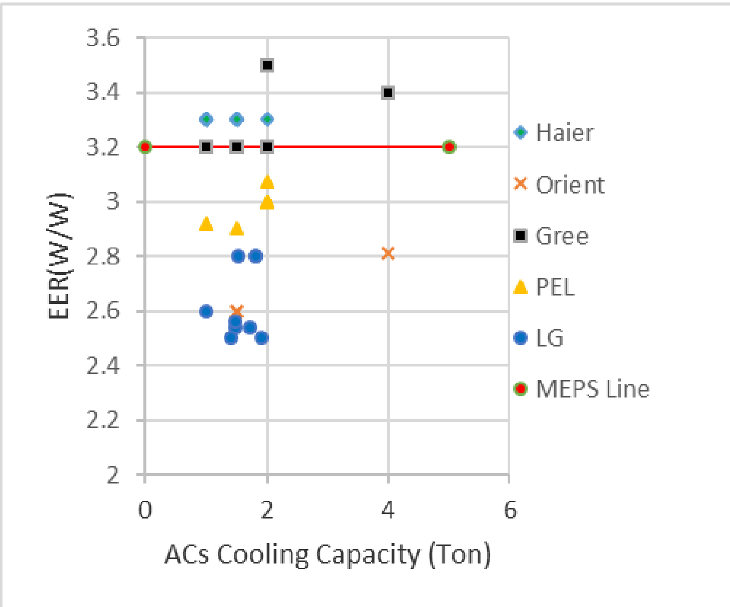

Fig. 8. Fixed Frequency ACs EER in Pakistan(Hamza, n.d.)

6. Annual Increase in Environmental Impact due to RACs in Pakistan

6.1. Direct Emissions from Room ACs

Direct emissions associate with refrigerant loss and leakage from the ACs equipment. There is no proper recovery of refrigerant at end life of ACs in Pakistan but here we consider leakage only. In Pakistan leakage is high, there is lack of awareness in technicians and customers which cause mishandling during refilling and installation. The annual leakage for split ACs is 10% of charge(Document & Protocol, 2017) (Shah et al., 2015) .In Pakistan manufacturers and assemblers using R410a which have no ozone depletion but high GWP of 2088. Some imported models are using R407C. A Small number of manufacturers are still using R-22 which will be phase out in 2020 according to Kyoto Protocol.

Refrigerant can be estimated from annual Demand units. To show the growth in the refrigerants demand for RACs. We will take 2016 as the base year instead of 2018. In 2016 estimated total production is 800000 units as shown in figure 3. We consider the manufacturers production information is more authentic and reliable as compared to estimate by the JRAIA 2018 in figure 2 (Japan Refrigeration and Air Conditioning Industry Association (JRAIA), 2018). Before estimation we assume on industrial experience that half of the unit's produce are 1.5-ton, 30% are 1-ton, 15% 2-ton remaining 5% are 4-ton units also depicted in table 2. The refrigerant charge per unit in the table 2 is the average of R410a of the Haier, Gree and Orient in each capacity units.

TABLE 2.[Author's own Elaboration] REFRIGERANT ESTIMATION FOR 2016

Capacity type	**Production %**	**Number of Units**	**Charge per unit**	**Tons Refrigerant R410a**
1.5 Ton	50	400000	1.4 kg	560
1 Ton	30	240000	0.8 kg	192
2 Ton	15	120000	2.0 kg	240
4 Ton	5	40000	4.0 kg	160
Total	100	802857	4.6 kg	1152

For 2016 the estimated volume for the R410a is 1152 metric ton. The leakage emission can be calculated as

$$E_m = V_a \times L_r \times GWP \qquad (1)$$

Where E_m is emission leakage, V_a is annual refrigerant volume and L_r is leakage rate. Using the above formula direct emission for each year can be calculated

Direct emission for 2016 is calculated as 240.53760 $KtCO_2e$. (Kilo tons of carbon dioxide equivalent). Similarly, the refrigerant quantity can be calculated for 2017 and 2018 is 1490.4 and 1987.2 metric ton. The direct emissions associated with this refrigerant can be calculated by using equation 1(above). The refrigerants direct emissions for each year is shown in the graph figure 9(below).

6.2. Indirect Emission and Annual Inccrease in Energy due to Roon ACs in Pakistan

The indirect emissions are associate with use of electricity by an equipment. Power plant generate electricity and produce emissions. As the electrical appliances use the electrical power it also indirectly releases the emission which is produce because of the generation of consumed electricity shown in figure 9. Cooling AC is an energy intensive appliance and its indirect emissions are more than direct one. Annual power consumption for inverter and fixed ACs are calculated by using equation 2 and 3(Fatihah Salleh et al., 2019).

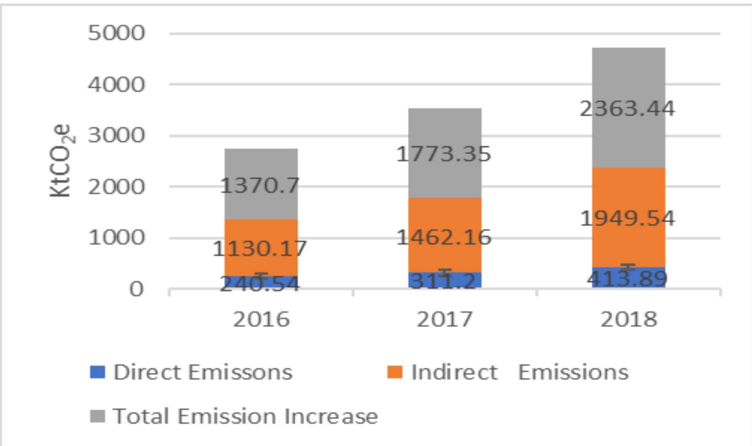

Fig. 9. Annual Increase in Room ACs Emissions

1) Fixed frequency ACs Annual Power Consumption (APC)

$$APC(Fixed)=No\ of\ days \times \frac{hours}{day} \times R_{AC} \times N \quad (2)$$

2) Inverter ACs Annual Power Consumption

$$APC_{in}=No\ of\ days \times \frac{hours}{day} \times \{(0.4 \times R_{AC}) + (0.6 \times HR)\} \times N \quad (3)$$

Where R_{ac} is rate power of AC, N is number of units sold. APC_{in} is APC inverter and HR are half rated power. Assume 8 hours operation of ACs for seven months because most populated cities in Pakistan the summer season is long up to seven months. 1843.11462 GWh energy is consumed by this new entry. The grid emission for Pakistan is 0.615374995 kg CO_2 /KWh (W. M. Khan & Siddiqui, 2017). Then the indirect emissions associate with this energy is 1130.1664 KtCO2e per year increase occur due to RACs as shown in table 3.

TABLE 3. FOR ACS IN 2016 [Base Year 2016 in Fig.3]

Capacity (Tons)	**Type AC**	**Share**	**Total No. of Units**	**Avg. Power rated**	**Energy (MWh)**
1.5	Inverter	80%	320000	1650	620928.00
1.5	Fixed	20%	80000	1650	221760.0
1	Inverter	80%	192000	1160	261918.72
1	Fixed	20%	48000	1160	93542.40
2	Inverter	80%	96000	2500	282240.0
2	Fixed	20%	24000	2500	100800.0
4	Inverter	80%	32000	5000	188160.00
4	Fixed	20%	8000	5000	67200.00
Total			8000000		1836549.12

The emission increasing rate is 29-33% per year. The indirect emissions are 82.5% of the total which means it consume a lot of energy which is coming from thermal power plant because of Pakistan thermal electrical power share is 75.7%(Availability, Primary, Supplies, & Consumption, 2018). The direct emission can be control through controlling the leakage of the refrigerants, follow proper procedure during installation and maintenance.

Transition of high GWP refrigerants R410a (2088) to low GWP refrigerants like R-32(677) and R-290(3) can mitigate the direct emissions from ACs but the low GWP refrigerants have safety issues because of their flammability which restrict their charge to 150 gram (Analysis, Division, & Berkeley, 2019b). The study found that the low GWP refrigerants shows better performance with high ambient temperatures than R410a(Abdelaziz, 2016).

ACs using R-32 and R-290 are manufactured in China and India(Analysis, Division, & Berkeley, 2017).Emissions can be control through aggregate approach by increasing efficiency and transitioning to low GWP refrigerants.

6.3. Annual Increase in energy and peak load demand

Pakistan experience the shortfall of electricity in summer season because of increase in cooling demand. The annual sale of ACs also take place in summer season so the new ACs sold are almost contribute in peak load demand. The power use for these units can be calculated by using the equation 2 and 3. The annual energy consumption increase due to ACs have been shown in figure 10 for 2016.

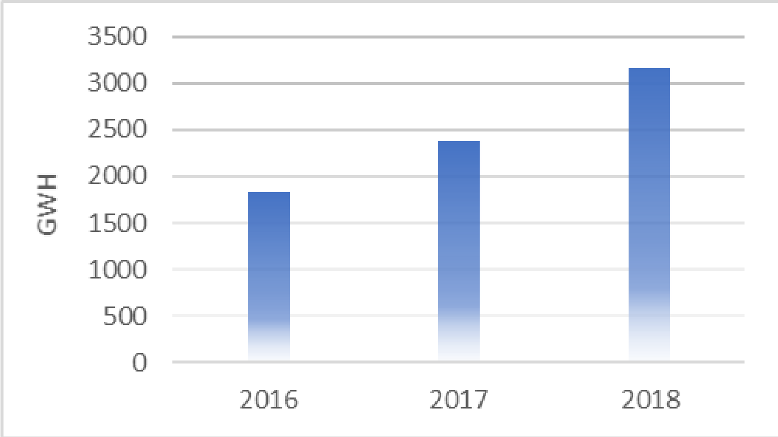

Fig. 10. Annual Energy Consumption Increase (GWh) due to Acs

[Calculation for 2017 and 2018 are Similar as in Table3]

The increase in the power consumption occur 29% for 2016-217 and 33% increase during the 2017 to 2018 is highest due to RACs coming into ACs stock. The previous study estimate 1500-3000 MW peak load can be avoided by improving efficiency 30% and transitioning to low GWP refrigerants in Pakistan by 2030(Shah et al., 2015).

7. Discussion and Conclusion

The efficiency of the ACs is the main parameter which effect the energy consumption and environmental impact. The Pakistan ACs market is highly influence by Chinese due to large market shares by Chinese manufacturers and main parts suppliers. The average EERs the ACs coming into the stock is 3.40 which is more than the current MEPS limit propose by NEECA. Most of the inverter ACs are well above the MEPS limit but more than 50 percent of the fixed frequency ACs EER are below the MEPS limit. Pakistan MEPS have no impact on ACs efficiency since it has a non-mandatory status. Customers attraction for energy saving is the main driving force among the manufacturers to improve efficiency of ACs. The inverter ACs share are increasing each year and 80 percent of the market on sale are inverters and the stock will be saturated of inverters ACs in next decade due to high influx of inverters.

The annual energy consumption increases in 2018 due new ACs entry to stock is 3168.064GWh which show 33 percent increase as compare with previous. It means this amount of energy will be required to operate the new ACs and it is also the increase in peak load because ACs are summers operating appliance. Pakistan also face peak load in summers which means that cooling load play a critical role in peak demand…

Indirect emissions are 4.7 time greater than direct emissions this means that ACs are energy intensive equipment. The emissions are also increase at the same rate at which energy requirement is increase because 82 percent of total emissions are indirect emissions.

From the performance analysis graph, we observe that the local ACs manufacturers in Pakistan (such as PEL) are struggling in the efficiency competition because they lack the research and innovation in the new technology. Thus, their market shares are shrinking against the Chinese brands which encapsulate the Pakistan ACs market by introducing new technologies.

Policy solution & recommendations using quantified data:

Improving efficiency and transition to low GWP shows incredible results which is a good approach to counter emissions and energy consumption simultaneously. Both targets can be aimed by one arrow which is S&L. Implementation of S&L in China increase the average efficiency 16% in two years while in Malaysia the improvement was 8% with reduction in indirect emissions. The European efficiency is much higher than our best one and they still revising their standard to include the part time load performance in the future standard (EN 14825).

- Accredited labs and test centers for ACs should be established to measure the accurate performance under different climate conditions

- Energy labels and Star system should be synchronized with MEPS so that customer easily estimate energy saving potential
- Reconstitute the MEPS with mandatory enforce status and stringent limits because it lacks the main purpose to promote efficient product and restrict inefficient one
- Develop MEPS for inverter ACs separately because inverter technology is different from the fixed in term
- of operation and mechanism which shows a large difference in the Performance
- For inverter the part time load performance should be included in MEPS to comprehensively show the performance chart
- Seasonal energy efficiency ratio (SEER) should be introduce in MEPS with EER and COP to show energy saving option clearly.
- To counter the emissions, the refrigerant should be considered in the future MEPS, S&L program
- Government should provide support for local manufacturers in research and development to counter the pressure from bigger manufacturers and improve their efficiency for energy saving.

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