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RESEARCH ARTICLE

Sustaining high value agricultural products in cold storage systems in India: Mitigation of environmental impact through alternative energy-mix

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ABSTRACT

With the changing consumption pattern, people's demand for high-value agricultural products (HVAP), such as meat, fish, eggs, fruits, vegetables, milk, and milk products, has been increasing in India in recent decades. This has led to a growth in the production of HVAP and an increased requirement for cold storage, which currently has an installed capacity of 37.5 million tons. The cold storage sector, which primarily uses vapor absorption and vapor compression technologies, is a significant consumer of energy and a potential cause of environmental degradation in India. This sector consumes 6 percent of the annual electrical energy output and produces 2.35 percent of carbon dioxide emissions in the country. Based on the changing consumption patterns and production trends of HVAP, the current study makes projections for the production of HVAP, required cold storage capacity, resultant energy consumption, and carbon dioxide emissions for 2030, 2040, and 2050. The study further shows that the use of an alternative energy mix through a switch from non-renewable to renewable energy can significantly reduce the share of the cold storage sector in total emissions to a mere 0.41 percent by 2050, thereby improving India's energy and emissions future.

Keywords: Cold storage, CO2 emissions, energy mix, environmental degradation, high-value agricultural products (HVAP).

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INTRODUCTION

The need for storage, warehousing, and refrigeration has been growing significantly in India with the rising consumption of high-value agricultural products (HVAP) in recent times. There is a visible change in consumption patterns with the focus shifting from cereals and grains to other agricultural and dairy products such as meat, fish, and eggs (MFE), fruits and vegetables, milk and milk products (MMP) that have a high economic value per kilogram and/or calorie and/or per hectare of agricultural production (Gulati, 2006). Diversification of the Indian consumption basket has been triggered by several socio-economic factors, such as an increase in income, rapid urbanization, changing habits of urban families, changes in dietary patterns, greater awareness

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about nutritional requirements, etc. (Pandey et al, 2020; Chengappa et al., 2017; Srivastava and Chad, 2017; Mittal, 2006). With the increasing trend in the consumption of HVAP, cold storage (CS) warehouses are becoming increasingly important in the logistics chain for storing food after harvest and before transportation to markets and distribution, which involves several stages of refrigeration under the ‘cold chain.’

The cold storages are major consumers of energy. There are three stages of energy consumption in the process of food storage. To begin with, energy is required to cool the food item from its temperature at harvest to the desired storage temperature in pre-cooling chambers. In the second stage, energy is required to cool the produce stored to compensate for the rise in temperature due to heat influx through air leakages such as air ingress during opening of doors for loading or unloading. Finally, energy is required to cool the product to compensate for the rise in temperature due to the heat of respiration of the biological material of the stored product. The energy requirement of the cold store for a given storage temperature depends on the size of the cold store, insulation thickness, insulation material, air leaks, design, and components of the refrigeration system. The high consumption of electrical energy in the CS sector is a major cause of environmental degradation in the form of carbon dioxide (CO2) emissions because most electricity generated in India is coal-based.

Many of the refrigerants used in the cooling systems are known to have a major environmental impact. There is a direct impact due to leaked refrigerant causing depletion of the ozone layer, quantified as Ozone Depletion Potential (ODP), and due to the greenhouse effect, quantified as Global Warming Potential (GWP). This direct impact occurs due to the refrigerant leaking into the atmosphere during manufacturing, installation, service, or disposal at the end of life. In addition, there is an indirect impact on global warming occurring from the choice of refrigerant, which affects the energy efficiency of the refrigeration system.The fact that around 40 percent of all foods require refrigeration, and that the shelf life of HVAP needs to be prolonged through the use of the cold chain, motivates the study of the energy consumption patterns and the associated environmental burden of the CS system in India. A sustainable storage system must complement sustainable agriculture in order to achieve the global targets of sustainable development through improved energy efficiency and reduced environmental degradation while addressing the question of food security. The present study analyzes the CS and refrigeration system in India with the objectives to:

- Make projections for the required CS capacity based on the quantities of HVAP for 2030, 2040 and 2050.
- Estimate the energy consumption and CO2 emissions from the above projections for 2030, 2040 and 2050 as per the current trend.
- Predict energy consumption and estimate the CO2 emissions for the future according to an alternative energy mix for 2030, 2040 and 2050.
- Recommend policies for the choice of optimal energy mix for a sustainable CS system for India to be achieved by 2050.

Trends in consumption and production of HVAP

The annual per capita consumption of HVAP has increased significantly at the turn of the millennium, in both rural and urban India (table 1). While the consumption of cereals and pulses has fallen, that of HVAP has increased by 112 percent in the case of vegetables, 69 percent for fruits, 71 percent for MFE, and 13 percent for MMP in rural areas, and 98 percent, 62 percent, 64 percent, and 6 percent respectively in urban areas. As per the data available in the latest National Sle Survey (NSS) reports, individual shares of most of the HVAP items in the total monthly per capita expenditure (MPCE) of the consumers have increased during the same period in both rural and urban areas. The greatest rise has been recorded in expenditure on fruits (221 and 60 percent for rural and urban areas), followed by MFE (30 and 32 percent respectively), MMP (27 percent and a decline of 9 percent respectively), and vegetables (a decline of 5 percent and an increase of 2 percent respectively). Considering both quantity and expenditure across rural and urban areas, the highest increase can be observed in the consumption of fruits, followed by MFE.

Table. 1: Changing Consumption Patterns of HVAP in India

Annual per capita consumption of HVAP (kg per capita)								
Food Item	**Rural**			**Urban**			**Change (2000-2012) (percent)**	
	1999-2000	**2004-05**	**2011-12**	**1999-2000**	**2004-05**	**2011-12**	**Rural**	**Urban**
MMP	45.48	46.8	51.6	61.2	61.2	64.8	13	6
Vegetables	39.6	36.0	84.0	41.9	37.6	82.8	112	98
Fruits	9.24	8.88	15.6	15.6	14.4	25.2	69	62
MFE	4.32	4.08	7.38	5.52	5.04	9.05	71	64
Share of HVAP in MPCE (Rs.) on food expenditure (percent)								
Food Item	**Rural**			**Urban**			**Change (2000-2012) (percent)**	
	1999-2000	**2004-5**	**2011-12**	**1999-2000**	**2004-05**	**2011-12**	**Rural**	**Urban**
MMP	14.7	15.3	18.7	18.1	18.6	16.4	27	-9
Vegetables	10.4	11.1	9.9	10.6	10.5	10.8	-5	2
Fruits	2.4	3.4	7.7	5	4.2	8	221	60
MFE	5.6	6.04	7.3	6.5	6.4	8.6	30	32

Source: Author’s calculations based on the NSS reports, 55th, 61st and 66th rounds

On the supply side, there has been a notable increase in the production of HVAP in India over the recent decades. India is the largest producer of several agricultural commodities and the second-largest consumption market globally. The production of HVAP in India has been rising in accordance with the growing consumption demand and changing dietary habits of the people. Production of HVAP has been commensurate with consumption with compounded annual growth rates (CAGR) of 3.3 percent for meat and 5.8 percent for eggs and around 4.5 percent for the rest (table 2).

Table. 2: Production Trends for HVAP in India

Year	Fruits	Vegetables	Milk	Meat	Fish	Egg
2000	43.1	N.A.	80.6	4.4	5.5	2
2001	43	88.6	84.4	4.5	5.8	2.1
2002	45	84.8	86.2	4.6	5.9	2.2
2003	46	88.3	88.1	4.8	6	2.3
2004	51	101.2	92.5	4.9	6	2.5
2005	55.3	111	97.1	5.1	6.5	2.6
2006	59.6	115	102.6	5.3	6.9	2.8
2007	65.6	128	107.9	5.6	6.9	2.9
2008	68.5	129	112.2	5.7	7.8	3
2009	71.5	133.7	116.4	5.9	7.9	3.2
2010	74.8	146.5	121.8	6	8.2	3.4
2011	76.4	156	127.9	6.4	7.9	3.5

Year	Fruits	Vegetables	Milk	Meat	Fish	Egg
2012	81.2	162.2	132.4	6.6	9	3.7
2013	89	162.8	137.7	6.7	9.1	3.8
2014	89.5	166.5	146.3	6.9	9.7	4.1
2015	90.1	169	155.5	7.1	10	4.3
2016	93	178	165.4	7.3	10.8	4.5
2017	96.4	184	176.3	7.6	11.6	4.8
2018	98	183.1	187.7	8	12.4	5.2
2019	99.1	191.7	198.4	8.1	13.1	5.8
2020	103.5	200.2	208.0	8.4	13.7	6.1
CAGR (percent) *	4.5	4.4	4.9	3.3	4.7	5.8

Source: https://ourworldindata.org/ FAO; All figures in million tons (Mt);

* Author's calculation

The status of CS infrastructure in India

Agricultural produce, including horticulture, dairy, poultry, and fish, is perishable in nature. Moreover, there is spoilage, wastage, and loss during post-harvest activities, at the farm gate, during transportation, and at storage facilities in India (Jha et al., 2015; Nanda et al., 2012). The overall fraction of wastage varies from 0.9 to 15.9 percent, averaging from 4.6 to 15.9 percent for fruits and vegetables, 5.2 percent for freshwater fish, 10.5 percent for marine fish and seafood, 2.7 percent for meat, 6.7 percent for poultry, and so on. The total value of annual losses in MFE, fruit, vegetables, and milk were estimated to be around ₹50,473 crores, and that of the loss in total agricultural produce, around ₹92,651 crores (MOFPI, 2014).

In view of the rapid growth in the production of HVAP and large amounts of wastage and product losses, it is imperative for India to develop a robust and extensive CS system. The CS infrastructure in India has been expanding rapidly in recent decades, especially since 1986. The number of cold storages in 1955 was a mere 83 units, with a total installed capacity of 43,000 t of produce. It increased moderately to 5,402 units with a total capacity of 2,607,000 t in 1986. There has been a steady increase in the capacity of CS units, from around 500 t per unit in 1955 to 1,700 t per unit in 1986, and to 4,600 t per unit thereafter (MOAFW, GOI, 2017). The current installed capacity has grown to 37.5 Mt with a CAGR of 2.73 percent (MOEFCC, 2021). The facilities are not uniformly distributed throughout the country, with more than two-thirds of the capacity being concentrated in the states of Uttar Pradesh (13.6 Mt), West Bengal (5.9 Mt), Gujarat (2.3 Mt), Punjab (2.0 Mt), and Andhra Pradesh (1.6 Mt). In terms of ownership, 92 percent of the total capacity is private.

The cold chain infrastructure consists of both static and mobile components, including pack houses, storages, ripening chambers, and reefer vehicles for transportation. At present, there are 207 pack houses, 8,186 CS (bulk and hub) units, and 12,700 reefer vehicles associated with the 37.5 Mt capacity mentioned above (MOAFW, 2020). Storage accounts for around 88 percent of the total capacity, while transportation accounts for the remaining 12 percent. However, this is far short of the requirement, with gaps of 99.7 percent in pack houses, 9 percent in capacity, and 82.5 percent in reefer vehicles (MOEFCC, 2021). The average capacity utilization is around 75 percent in India. Seventy-five percent of the capacity is used for single commodity storage for agri-based products (MOFPI, 2014) and may be stored for long durations of 6 to 8 months. Fruits, vegetables, and MMP are commodities stored for short periods of 7 to 10 days, while MFE may be frozen for years. Seventy-five percent of the total storage capacity is utilized for farm products like potatoes and chillies, 9 percent for processed food products, 8 percent for horticultural products, 7 percent for animal-origin products, and 1 percent for pharmaceuticals (NCCD, 2015).

Technology options in the Indian CS system

The technology choices for CS can be categorized according to the thermodynamic cycle used for refrigeration and the type of refrigerant used in the cycle (Arora, 2009). The two major technologies are based on the vapor compression cycle and the vapor absorption cycle, while the most common refrigerants are ammonia, hydrochlorofluorocarbons, and hydrofluorocarbons (HCFC and HFC). Vapor Compression Systems (VCS) are most widely used across the world, including the commercial CS systems in India. The main advantage of using VCS is the possibility of designing a system for any combination of storage temperature and ambient temperature. Sections maintained at different temperatures in such a CS unit are used for preserving different kinds of agricultural produce in multi-storage facilities. The ready availability of components and trained service technicians make it relatively easier to install and maintain these systems, since the industry has built up experience and expertise in these systems for more than a century. Depending on the design, VCS can be further sub-classified into single-stage systems and cascade systems. Both systems involve high electricity consumption and are liable to generate a significant amount of CO2 emissions. In the Vapor Absorption Systems, the vapor absorption refrigeration cycles (VAS) are capable of using heat directly as input, instead of electricity, using ammonia and water solution as a refrigerant with zero ODP. It is possible to use a heat source, such as waste heat or solar energy, to provide the energy needed for the cooling process, instead of electrical energy. Although the possibility of using low-grade waste heat or freely available solar energy makes VAS an attractive technology for reducing the environmental footprint of the CS industry, these systems have a very low coefficient of performance. Moreover, it may not be possible to reach the very low temperatures required to preserve certain products by using vapor absorption refrigeration. In addition, the cost of transitioning to such new technologies may not be acceptable to the private owners of CS units. Therefore, continuing with VCS along with an alternative energy mix for generating grid power may offer better economic options for mitigating the environmental impact of the Indian CS sector.

National Energy Scenario and Role of CS Sector

With the ever-increasing consumption demand due to continuous population growth and economic development, all sectors, including CS, have become major users of energy and consequently significant sources of environmental degradation. The current policy thrust for the energy sector in India is to chart a low-carbon growth path through changes in the energy mix, away from non-renewable energy sources (NRES) towards increasing the use of renewable energy sources (RES). The gross annual electrical energy generation has grown at a CAGR of 4.52 percent during 2011-2021. In line with the policy target, the CAGR of NRES-based electrical energy generation, which includes the use of coal, oil, gas, and nuclear, has been at 4.23 percent, while the CAGR of RES-based electrical energy generation, which includes hydro, solar, wind, and biomass, has recorded a higher CAGR of 5.63 percent (table 3). The share of NRES in total utility generation during 2020-21 is 78.31 percent. The dominance of NRES results in significant CO2 emissions, such as 2,880 Mt in 2020 and projected to be 4,480 Mt in 2030 (Narayan, 2021), 6,500 Mt in 2040, and 8,000 Mt in 2050 (Gambhir et al., 2014).

Table. 3: Annual Gross Electrical Energy Generation by Source (TWh)

Year	NRES-based	RES-based	Total utility generation
2011-12	741	181	922
2012-13	793	171	964
2013-14	827	194	1,021
2014-15	914	185	1,099
2015-16	981	183	1,164
2016-17	1,032	202	1,234
2017-18	1,078	225	1,303

Year	NRES-based	RES-based	Total utility generation
2018-19	1,110	262	1,372
2019-20	1,089	294	1,383
2020-21	1,075	298	1,373
CAGR* (percent)	4.23	5.63	4.52

Source:https://cea.nic.in/wp-content/uploads/pdm/2020/12/growth_2020.pdf ;

*Author's calculation

While addressing the food security challenge and the shift in consumption patterns towards HVAP, special attention needs to be paid to the sunrise sector around the cold chain, in view of its high energy intensity and environmental concerns. The CS sector consumes electrical energy at high intensity due to the nature of the machinery involved. Since the generation of electricity in India is primarily coal-based, the CS system in India heavily relies on the coal-based energy generation infrastructure to meet its requirements. The discussions at the 26th Conference of Parties (COP 26) in Glasgow have brought forth compelling requirements to minimize the indirect global warming impact due to coal-based energy generation. India has demonstrated its will to adhere to the Montreal Protocol for reducing ozone-depleting substances (ODS). A similar focus is indicated for GWP, and this sets the direction for decisions on future technology choices and/or energy mix for all sectors, including food storage in India. The changing shares of NRES and RES in total utility generation in the coming decades have the potential to bring positive effects on energy consumption and resultant CO2 emissions, thereby mitigating the adverse environmental outcomes of the CS sector.

MATERIALS AND METHODS

Projection of HVAP production and CS capacity

In this work, projections for the production of the six major categories of HVAP have been made based on the CAGR calculated previously in section 2.1, with 2020 as the base year. Medium and long-term projections of HVAP production have been made for the years 2030, 2040, and 2050, which have been used in the estimation of the required installed capacity in the CS sector for refrigeration and storage of the same. These have served as the bases for the calculation of energy consumption and GWP in the form of CO2 emissions and potential scenarios of alternative energy mix to mitigate the latter.

Estimation of energy consumption and CO2 emissions

The varying size and design of the CS applications preclude the use of a single set of engineering formulas to calculate energy consumption. However, an attempt has been made in this paper to estimate the energy consumption for the total existing capacity in India according to the dominant category of CS technology, namely, VCS based on HCFC and HFC, using some rules of calculation prevalent in the industry. These estimates have been used to calculate the CO2 emissions of the CS sector for the reference year 2020. Subsequently, projections of energy consumption and CO2 emissions have been made for 2030, 2040, and 2050, based on the projected figures of HVAP and the associated installed capacity.

The latest complete data on capacity and energy consumption, available for 2017-18 (MOEFCC, 2021), has been used as the benchmark for calculating energy consumption and CO2 emission rates. The installed capacity of 34.6 Mt across 7,543 CS units in the year 2017 indicates that the average refrigeration and storage capacity per unit is 4596 tons. The corresponding energy consumption figure of 71 Terra Watt Hour (TWh) per annum (p.a.) by the CS sector implies an average energy consumption of 9.4 Giga Watt Hour (GWh) per CS unit.

The energy consumption per ton of HVAP in CS, as per existing practice, has been calculated from the total energy consumption and capacity figures for 2017 by the following formula:

Energy consumption per ton of HVAP

= (total energy consumption) / (installed capacity) (1)

= 71 TWh p.a. / 34.6 Mt

= 2,052 kWh (kilo Watt Hour) p.a. / t

Given the current CS capacity of 37.5 Mt and a total HVAP output of 515 Mt approximately, it is found that around 7 percent of the output goes to the cold storage. Since a 9 percent gap has been identified for the same in the present scenario (MOEFCC, 2021), it has been assumed that the deficit will be met and around 8 percent of the total output will go to the CS in the future. Projected energy consumption and CO2 emissions have been calculated accordingly by the following formula:

Total energy consumption (kWh p.a.) with full capacity

= (Total HVAP in tons) (0.08) (energy consumption per ton of HVAP) (2)

= (Total HVAP in tons) (0.08) (2,052 kWh/t)

The GWP in the form of CO2 emissions has been calculated based on an average rate of conversion, namely, 0.97 kg/kWh (CEA, 2018). Considering that 75 percent of the country's total installed capacity is based on fossil fuel (GOI, MOP, 2021), a factor of 0.75 has been used in calculating CO2 emissions as follows:

Estimated CO2 emissions (kg p.a.)

= Total energy consumption (kWh p.a.) 0.75 0.97 kg/kWh. (3)

This has been used to calculate projections of energy consumption and CO2 emissions for the coming decades in the first decadal years 2030, 2040, and 2050 with the reference year 2020 as the base.

Estimation of impact of transformed energy-mix

There is a potential to decrease energy consumption by 30 percent through optimization of cooling load, use of low GWP and non-ODS refrigerants, minimization of refrigerant leakages, optimization of operational efficiency, and switching to clean technologies (MOEFCC, 2021). Besides these, a change in the input energy mix for electrical energy used by the CS sector may cause a significant reduction in CO2 emissions. The current study is focused on the transformation from NRES to RES-based electrical energy consumption that can significantly lower the GWP of the CS system over the coming decades.

The trends in electrical energy generation from NRES and RES in India have been calculated by the respective CAGRs for the years 2030, 2040, and 2050 over the reference year 2020. Subsequently, the shares (S) of non-renewable to total electrical energy generation (=NRES-based + RES-based) over the said period have been calculated for the respective projection years as follows:

S = (NRES-based generation) / (total utility generation) (4)

The share is supposed to decline with rising RES as per the declared national energy transformation goals. NRES-based generation has been fixed at the 2020 value and held constant thereafter, assuming that it will be phased down and eventually phased out. The additional energy demand will be met gradually by more and more RES-based energy that will be increasing continuously in line with the global agenda for the green energy transition. Assuming the national share to be applicable to the CS sector, the energy consumption from NRES in the CS sector after the change in the energy mix has been calculated by the formula given in equation (2), modified by the respective shares for the projection years 2030, 2040, and 2050 over the reference year 2020 as:

Total NRES-based energy consumption (kWh p.a.) with full capacity= (S) (Total HVAP in MT) (0.08) * (2,052 kWh/t) (2a)

This gives the series of projected values of energy consumption over the coming decades under the low-carbon growth path. The corresponding CO2 emissions have been calculated as per the formula given in equation (3), modified by the respective shares for the projection years 2030, 2040, and 2050 over the reference year 2020 as:

Estimated CO2 emissions from NRES-based energy consumption= (S) * Total energy consumption (kWh p.a.) 0.75 0.97 kg/kWh. (3a)

The CO2 emissions in these changed scenarios where RES is continuously replacing NRES in the energy mix are expected to decline significantly in the coming decades.

Finally, the percentage shares of CO2 emissions from the CS sector in the national CO2 emissions have been calculated for all the projection years with an expected decline as a result of the change in the energy mix. This has been used further to derive possible policies of greater transformations to low-carbon scenarios in the energy mix by faster switch to RES in order to reduce the share of the CS sector in the national CO2 emissions to an optimal level.

RESULTS AND DISCUSSION

The CAGR of production of HVAP has been found to vary between 3.3 percent and 5.8 percent for the six chosen categories. While egg production has the highest growth potential, meat has the lowest, with fruits, vegetables, fish, and MMP being moderate at over 4 percent. The projected figures for 2030, 2040, and 2050 reflect the dominance of milk, fruits, and vegetables respectively (table 4).

Table. 4: Projection of HVAP Production

Year	Fruits	Vegetables	Milk	Meat	Fish	Egg
CAGR (percent)	4.5	4.4	4.9	3.3	4.7	5.8
Reference year 2020	103.5	200.2	208.0	8.4	13.7	6.1
Projection for 2030	160.4	307.4	334.2	11.5	21.6	10.7
Projection for 2040	248.6	472.1	536.9	15.9	34.2	18.8
Projection for 2050	385.2	724.9	862.6	21.9	53.9	32.9

Source: Author’s calculation based on data available at https://ourworldindata.org/ FAO;

All figures in million tons (Mt)

Assuming that around 8 percent of the total quantities of produce will be sent to cold storages, the CS capacity requirement will grow to 67.7 Mt in 2030, 106.1 Mt in 2040, and 166.5 Mt by 2050. Correspondingly, the energy consumption of the CS sector is expected to rise to staggering levels of 139 TWh, 218 TWh, and 342 TWh, resulting in CO2 emissions amounting to 101 Mt, 158 Mt, and 249 Mt in the years 2030, 2040, and 2050 respectively. These will account for 2.25 percent, 2.44 percent, and 3.11 percent shares of CO2 emissions from the CS sector in the total emissions during 2030, 2040, and 2050 respectively (table 5).

Table. 5: Projected Energy Consumption and CO2 Emissions of the CS sector and Share in National Average

Year	Total output (Mt)	Required installed capacity (Mt)	Electrical energy consumption (TWh)	CO_2 emission (Mt)	Share of CS sector in national CO_2 emissions (percent)
2020	539.9	43.2	89	64	2.22
2030	845.8	67.7	139	101	2.25
2040	1,326.5	106.1	218	158	2.44
2050	2,081.4	166.5	342	249	3.11

Source: Author's calculation

The next part of the study refers to the case where NRES-based generation is assumed not to grow beyond the 2020 value of 10.75 TWh and the remaining part of the energy demand is met by RES-based energy eventually. This implies that the CAGR of 4.52 percent of total utility generation over 2011-21 will be maintained by a 9.13 percent CAGR in RES-based generation only, and no growth will be recorded in NRES-based generation. The projected energy generation in 2030, 2040, and 2050 will have continuously increasing shares from RES (table 6, lower panel) compared to the otherwise observable rates of growth as per the CAGR of 2011-21 (table 6, upper panel).

Table. 6: Projections for Electrical Energy Generation in India (TWh)

Year	NRES-based	RES-based	Total utility generation
Current CAGR (percent) in NRES and RES	4.23	5.63	4.52
2020	1,075 (78.31)	297 (21.67)	1,373
2030	1,627 (76.16)	514 (24.09)	2,136
2040	2,462 (74.07)	889 (26.77)	3,324
2050	3,725 (72.03)	1,539 (29.76)	5,172
CAGR (percent) with growth in RES only	0.00	9.13	4.52
2020	1,075 (78.31)	297 (21.67)	1,373
2030	1,075 (50.33)	1,061 (49.67)	2,136
2040	1,075 (32.35)	2,248 (67.65)	3,324
2050	1,075 (20.79)	4,096 (79.21)	5,172

Source: Author's calculation; Note: figures in parentheses are percentage shares in total.

The impact of changing energy mix, namely, the substitution of NRES-based energy by RES-based energy, has been studied under two scenarios (Table 7). The first scenario, A, is based on the assumption that only RES-based energy will grow after 2020, and the share of NRES-based energy in total utility generation will gradually decline from 78.31 percent in 2020 to 50.33 percent in 2030, 32.35 percent in 2040, and 20.79 percent in 2050, respectively, as per the above projections. The corresponding shares of RES-based generation will rise from 21.67 percent in 2020 to 49.67 percent in 2030, 67.65 percent in 2040, and 79.21 percent in 2050.

The second scenario B depicts the case where the shares of RES-based generation can grow even faster, namely 60 percent in 2030, 80 percent in 2040, and 90 percent by 2050, with the shares of NRES-based generation declining to 40 percent in 2030, 20 percent in 2040, and 10 percent in 2050. This portrays the scenario where NRES-based generation will decline from the 2020 value and will be continuously replaced by RES-based energy to meet the total projected demand in the CS sector. The minimum possible share of NRES-based energy has been kept at 10 percent until the end of the projection period because thermal power cannot be entirely replaced for reasons related to equipment design and operation, technical conditions in the

Indian CS sector, where the infrastructure may not be suitable for a complete switch-over to renewable sources, and other issues such as power grid stability.

Table. 7: Impact of Alternative Energy-mix on NRES use and CO2 Emissions in CS Sector

Scenario A: NRES-based generation fixed at 2020 value with growing share of RES-based generation

Year	Share of NRES in total utility generation (percent)	Share of RES in total utility generation (percent)	Electrical energy consumption from NRES-based generation (TWh)	CO_2 emissions (Mt)	Share of CS sector in national CO_2 emission (percent)
2020	78.31	21.67	69.70	67.61	2.35
2030	50.33	49.67	69.88	67.79	1.51
2040	32.35	67.65	70.44	68.33	1.05
2050	20.79	79.21	71.04	68.90	0.86

Scenario B: Highest possible share of RES-based generation with falling share of NRES-based generation

Year	Share of NRES in total utility generation (percent)	Share of RES in total utility generation (percent)	Electrical energy consumption from NRES-based generation (TWh)	CO_2 emission (Mt)	Share of CS sector in national CO_2 emission (percent)
2020	78.31	21.67	69.70	67.61	2.35
2030	40.00	60.00	55.54	53.87	1.20
2040	20.00	80.00	43.55	42.25	0.65
2050	10.00	90.00	34.17	33.14	0.41

Source: Author's calculation

The results show that continuous substitution of NRES by RES in energy generation can potentially lead to an improved environmental impact in terms of lower CO2 emissions from the CS sector. While in scenario A, the CO2 emissions remain around 68 Mt on average, they go down significantly in scenario B with 53.87 Mt in 2030, 42.25 Mt in 2040, and 33.14 Mt in 2050.

The contribution of the CS sector to national emissions will improve from 2.35 percent in 2020 to 1.51 percent in 2030, 1.05 percent in 2040, and finally 0.86 percent in 2050 in scenario A. The reduction may be more pronounced, from 2.35 percent in 2020 to 1.20 percent in 2030, 0.65 percent in 2040, and finally 0.41 percent by 2050, if the switch to RES-based energy is faster under scenario B. The possibility of such a major reduction through a fast transformation to greener energy pathways can enable the Indian CS sector to mitigate adverse environmental impacts significantly.

In view of the aggressive increase in the use of RES in the CS sector in the coming decades, as suggested above, refrigeration technologies capable of using heat sources directly in the form of solar energy, such as the VAS described in section 2.3.2, appear to be especially attractive. The author hopes to explore the capabilities of this technology and its potential in minimizing environmental impact in future work.

CONCLUSION

The Indian CS sector has not yet received much priority and policy focus despite its crucial role in minimizing loss in the value chain of perishables. It consumes around 6 percent of the total electrical energy generation and is responsible for around 2.35 percent of the total CO2 emissions of the country. The focus of environmental sustainability in the CS system needs to center mainly on GWP, as most of the ODP issues have already been addressed. The present study shows that the adverse environmental impact may be mitigated significantly by changing the energy mix, as per the national trends of green energy transformation. The clear policy recommendation of the study is faster transformation from NRES-based to RES-based energy generation, which can reduce the share of the Indian CS sector in the national CO2 emissions significantly. The Indian CS sector has le potential to contribute to the national goal of green transition by 2050 by charting a sustainable path in line with the globally declared environment-friendly targets.

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