White Paper on Heat Pumps' Contribution to Carbon Neutrality (2022)

Summary

1. Background

China is the world's largest CO_2 emitter, with 11.9 billion tons of carbon emissions in 2021. Coal remains China's primary energy source, accounting for 57% of China's energy consumption in 2020. As China has pledged to peak carbon emissions before 2030 and achieve carbon neutrality before 2060 (net-zero greenhouse gas emissions), this “dual carbon goal” becomes a huge opportunity and challenge for China's energy development. One significant measure to achieve carbon neutrality is to promote an energy transition. In the transition process, heat pumps are the best approach to efficiently use electricity for heating and to meet the needs of the electrification development at the end-user side.

The 2060 carbon neutrality goal requires the electric grid to be completely decarbonized. When the main electricity supply is no longer generated by fossil fuels, heat pumps' potential in energy saving and applicability will be rediscovered. In the past, it was widely believed that energy savings could only be achieved if the coefficient of performance (COP) of heat pumps was higher than 3. But in the future, when electricity will mainly come from wind, photovoltaics, hydropower, and nuclear power, heat pumps will be more energy-efficient than electric boilers and ready for deployment as long as the COP value is higher than 1. Even though 70% of the electricity currently still comes from coal and gas, the proportion of zero-carbon electricity keeps increasing year by year. The end-using electrification development and the zero-carbon electricity development must be carried out simultaneously and be mutually reinforcing. Breaking the boundaries of heat pump application will create many new fields for heat pumps and accelerate the comprehensive electrification process, which is significant for China's "dual carbon goal".

This white paper investigates the roles of heat pumps in achieving the “dual carbon goal” through five aspects: technology principles, application status, application prospect, carbon reduction potential, and economic benefit, and analyzes the emissions reductions of heat pumps based on practical investigation data.

2. Heat Pump Application Areas and Prospects

Heat pump technologies have wide applications in China under the backdrop of the “dual carbon goal.” In the building sector, heat pumps can be used for space heating, cooling, and hot water generation for new and existing buildings. In the industry sector, high-capacity and high-temperature heat pumps are effective solutions for industrial energy decarbonization. In the agriculture sector, heat pump technology will save 20–60% of energy consumption in agri-environmental regulation and product drying. In addition, heat pumps also have application in electric vehicle air conditioners, dishwashers, and washing

machines. In 2021 in China, water heating accounted for 39.8% of air source heat pump applications, space heating accounted for 49.7%, and drying 10.5%.

3. Energy Consumption and Emissions in Heat Pump Application Areas

In 2020, the total building area of China was about 66 billion m^2, with 29.2 billion m^2 of urban residential area, 22.7 billion m^2 of rural residential area, and 14 billion m^2 of public building area. It is estimated that the total population of China will be saturated after 2040 at 1.4 billion, and the total building area will reach to 75–80 billion m^2, with 20 billion m^2 of northern urban space heating area and 10 billion m^2 of northern rural space heating area.

In 2020, the energy consumption of the building sector (including construction and operation) in China accounted for 32% of total energy consumption and 32% of total carbon emissions. Carbon emissions from building operations alone were 2.2 billion tons, 19% of total emissions. It is likely that as China gradually enters a new stage of urbanization and people's living standards improve further, the proportion of building energy consumption and emissions will continue to grow.

Urban buildings in North China require 5 billion GJ for heating in 2021. About 40% of this heat was provided by coal and gas boilers of various sizes, 50% was provided by combined heat and power generation (CHP) power plants, and only 10% was provided by different electric heat pumps from various low-grade heat sources such as air, sewage, groundwater, and underground soil. According to the "2021 Annual Development Report of China's Urban Heating Supply", looking at the heating structure of northern China in 2020, CHP accounted for 62%, coal-fired boilers 17.9%, and gas-fired boilers 18.4%. In distributed heating, about 5% of residential buildings adopted gas boilers; however, more than 70% of residential buildings in northern rural and some urban-rural fringe areas were still using coal stoves for winter heating. Coal remains the primary heating source in China, and the share of renewable energy and electric heating is still very low. These heating facilities produce more than 300 million tons of CO_2 each year and should be the focus of direct CO_2 emission mitigation efforts in the building sector. Distributed air source heat pumps are one of the best solutions to reduce emissions in this field, worth being promoted in most of the northern urban areas except in extremely cold regions.

The penetration rate of water heaters in China is growing rapidly from 80.3% in 2013 to 98.2% in 2019. There are three main domestic water heater types: gas, electric, and solar, accounting for more than 90% of the water heater market. Electric heat pump water heaters (mainly air source) represented a very small share, about 2%. The COP of electric heat pump water heaters can reach about 3, which is far more efficient than electric storage water heaters in terms of energy utilization. If air source heat pumps and solar water heaters were combined to form a hybrid water heating system, it would be even more energy efficient.

The current operating costs of gas, electric storage, and heat pump water heaters are shown in the table below. The annual operating cost of heat pump water heaters is the lowest. Although the price of heat pump water heaters is higher than gas and electric storage water heaters, it will gradually decline as the heat pump market expands.

Table 1: Energy performance and price of different type of water heaters

	Gas water heater	Electric storage water heater	Heat pump water heater
Annual water consumption (L)	18250（50L/d x 365d）		
Thermal efficiency	90%	95%	300%
Energy consumption	82.5 m^3	784 kWh	248 kWh
Energy cost (CNY)	248.4	376.5	119.2

In the industrial sector, annual carbon emissions from medium- and low-temperature industrial heating reached 2.528 billion tons annually.

4. Energy Saving and Carbon Reduction Potential Analysis of Heat Pumps

In new buildings, achieving carbon neutrality requires continuous promotion of the development of ultra-low energy consuming buildings and eliminating conventional fossil-fuel heating methods. Based on passive-building design, the combination of distributed renewable energy and advanced heat pump technologies can effectively reduce building energy consumption. In 2019, China officially implemented the "Technical standard for nearly zero energy buildings (GB/T51350-2019)", which proposes combining renewable energy and heat pump technology to significantly reduce building energy consumption. Combining heat pumps and heat storage equipment can also overcome the time gap between energy demand and supply to enable peak shaving.

This report sets 3 energy-saving and emission reduction scenarios, namely "business as usual (BAU)", "heat pump (HP) natural growth" and "heat pump (HP) high penetration". The key difference between the scenarios of different sectors is the market penetration rate of heat pumps.

4.1 Building Sector

In terms of the building space heating in Northern China, carbon emissions will reach 883 $MtCO_2$/year in 2060 under the BAU scenario. In the "HP high penetration" scenario (30% in urban areas and 70% in rural areas), emissions will be 229 $MtCO_2$/year and reductions

will reach 654 $MtCO_2$/year in 2060, which means 74% of carbon emissions will be reduced. Emissions reductions contributed by heat pump technology is 304 $MtCO_2$/year (accounting for 46%), 167 $MtCO_2$/year from demand-side practices, and 304 $MtCO_2$/year from the power supply side. The rapid deployment of heat pumps could bring significant carbon reductions in building space heating.

In terms of hot water supply in buildings, carbon emissions will reach 257 $MtCO_2$/year in the BAU scenario. Under the "HP high penetration" scenario, emissions will be 106 $MtCO_2$/year and emission reductions will reach 151 $MtCO_2$/year in 2060 (70% in urban areas and 30% in rural areas). Emissions reduced from heat pump total 105 $MtCO_2$/year.

4.2 Industrial Sector

In the industrial sector, the carbon emission will reach 1,844 $MtCO_2$/year in 2060 in the BAU scenario. Under the "HP high penetration" scenario (heat pump accounting for 60% in the medium- and low-temperature industrial heating), emissions will be 945 $MtCO_2$/year and the emissions reductions will reach 1,582 $MtCO_2$/year in 2060, of which 899 $MtCO_2$/year is contributed by heat pumps.

4.3 Agricultural Sector

In the sector of greenhouse farming, carbon emissions will reach 125.4 $MtCO_2$/year in 2060 in the BAU scenario. Under the "HP high penetration" scenario (90% of penetration rate for greenhouse heat pumps), emissions will be 38 $MtCO_2$/year and emission reductions will reach 87 $MtCO_2$/year in 2060. The emissions reductions from heat pumps are 125 $MtCO_2$/year.

In the sector of livestock farming, carbon emissions in the BAU scenario will reach 36 $MtCO_2$/year in 2060. Under the "HP best penetration" scenario (90% heat pump penetration rate in livestock breeding), emission will be 5 $MtCO_2$/year and emission reductions will reach 31 $MtCO_2$/year in 2060. The emissions reductions from heat pumps are 20 $MtCO_2$/year.

5. Contribution of Heat Pump Applications to Carbon Neutrality

Based on the analysis above, the emission reduction potential from each sector is shown in the table below. Under the HP high penetration scenario, space heating, domestic hot water supply, industrial medium- and low-temperature heating, greenhouse farming, and livestock farming in China will bring a total emission reduction potential of 2,506 $MtCO_2$/year in 2060. China's energy-related carbon emissions totaled about 10.4 billion tons in 2021. Based on this calculation, the emissions reduction amount brought by heat pump applications by 2060 is about 24.1% of China's current carbon emissions from

energy. Heat pumps can make great contributions to carbon peaking and carbon neutrality in the sectors above.

Table 2: Summary of emission reduction potential by sectors by 2060 (100 $MtCO_2$/year)

Sector	**HP High Penetration**	HP High Penetration		HP Natural Growth		Current Situation
	Emission reduction from HP*	Emission reduction	Emission	Emission reduction	Emission	Emission
Space heating	**3.04**	6.54	2.29	4.19	4.64	8.83
Hot water supply	**1.05**	1.51	1.06	0.76	1.81	2.57
Industrial heating	**8.99**	15.83	9.45	9.74	15.54	25.28
Greenhouse Farming	**1.25**	0.87	0.38	-0.16	1.41	1.25
Livestock Farming	**0.2**	0.31	0.05	0.15	0.21	0.36
Total	**14.53**	25.06	13.23	14.68	23.61	38.29

** The HP penetration rate is different for different sectors, which has been listed in the text above.*

Under the HP high penetration scenario, with the combined effects of heat pump application, green power generation, and demand-side management, the carbon emissions from building space heating and water heating, industrial medium- and low-temperature heating, and agricultural environment regulation will be reduced from the baseline emission of 3.829 billion tons to 1.323 billion tons in 2060, with a reduction rate of 65.4%. The emissions reduction contributed by heat pumps will be 1.453 billion tons, accounting for 58% of the total emissions reduction potential, and emissions reductions from green power generation and demand-side management will be 344 million tons and 567 million tons respectively. At the same time, heat pumps can also flexibly consume electricity, which will benefit grid load management. Emissions reductions from heat pumps will also create huge value in the carbon market.

6. China Heat Pump Market and Energy Saving and Emission Reductions Benefits

China is a major country in heat pump production and adoption. According to statistics from China Energy Conservation Association, China has produced more than 60% of the global heat pump products. By 2021, about 15 million air source heat pumps were sold in China and ground source heat pump application area reached about 570 million m^2. The

accumulated heat supply of installed heat pump systems reached 5.3 billion GJ and achieved carbon emissions reductions of 273 million tons by 2021. Heat supply and emissions reductions from heat pumps were 1.3 billion GJ and 81 million tons respectively in 2021. According to current pricing, air source heat pumps have satisfactory cost-effective heating performance in cold areas, and costs will be even lower for buildings with better insulation. The carbon reduction cost of replacing coal heating with air source heat pumps in rural areas of Beijing is only 145 CNY/tCO_2, which is an excellent example of the economic benefits of carbon reduction.