CO2 AND PRIMARY ENERGY CONSUMPTION REDUCTIONS POTENTIAL WITH HEAT PUMP TECHNOLOGIES IN THE FOOD AND BEVERAGE SECTOR

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Abstract: Heat pumps have become increasingly important in the world as a technology to contribute to CO2 reductions. So far, heat pumps have been widely used in building air-conditioning and are expected to spread to industrial fields in the future. In business categories such as food and beverage manufacturing factories, since the operating temperature level is relatively low, the introduction of heat pumps into this field is considered to be easy. In this analysis, CO2 reductions potential in 11 countries by applying heat pumps in the food and beverage sector was estimated for the purpose of determining the CO2 reductions effect produced by introducing heat pumps. On the assumption that an electric drive compressor heat pump is used, heat demands below 100 ℃ out of steam from boiler are selected as a heat pump applicable area. As a result of this estimation, it has been concluded that the emissions of 47 million tons of CO2 per year can be reduced and this amounts to about 1.4% of CO2 emissions from fuel combustion in the industrial sector in countries surveyed.

Key Words: heat pumps, CO2 emissions and primary energy reductions, food and beverage sector

1 INTRODUCTION

Recently, heat pumps have made great technological progress such as improved efficiency, increase in capacity, output at higher temperatures, etc. The possibility of replacing boilers, which are a conventional heat source, with heat pumps has increased in the industrial field.
In business categories such as food and beverage manufacturing factories, the operating temperature level is relatively low. The introduction of heat pumps into this field is considered to be easy because the temperature required in process is below 100℃ in many cases.
In this survey, CO2 and primary energy consumption reduction potential in 11 countries by applying heat pumps in the food and beverage sector was estimated for the purpose of determining their effects obtained by introducing heat pumps.

A total of 11 countries, namely France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, the UK, the USA, and China, were surveyed to estimate CO2 and primary energy consumption reduction by introducing current-technology heat pumps into the food and beverage sector. On the assumption that an electric drive compressor heat pump is used, applications at heat demands below 100 ℃ out of steam from boiler are selected as a heat pump applicable range. Note that MVR (mechanical vapor recompression) in the beer brewing industry was included as well.
Business categories covered by the survey: Food and beverage fields (Analyzed by industrial category shown in Diagram 1 Analyzed by smaller category grouping for the countries other than China, and by middle classification for China)

We estimated CO2 and primary energy reductions potential with heat pump technologies in the food and beverage sector in 2010 and will report here including our calculation methods and result of the estimation with the latest data of each country.

2 ESTIMATION OF ENERGY CONSUMPTION STRUCTURE (ENERGY CONSUMPTION BY COUNTRY, BY INDUSTRIAL CATEGORY (SUB CLASSIFICATION), AND BY ENERGY TYPE)

To estimate CO2 reduction potential by applying heat pumps, it is necessary to understand the energy consumption structure (energy consumption by country, by industrial category (sub classification), and by energy type) in the food and beverage sector in each country. To estimate CO2 emissions before replacement, it is particularly necessary to determine energy consumption by energy type because the CO2 emission factor differs from type to type. In addition, it is desirable to understand the energy consumption structure by industrial category (sub classification) because the share of fuels for steam boiler relative to energy consumption that is to be replaced differs depending on each industrial category (sub classification).
Therefore, in this survey, we determined the energy consumption structure by country, industrial category (sub classification), and energy type, though the middle classification was used for China due to limited statistical data. In this survey, we mixed and matched many different statistical materials to estimate the energy consumption structure for China because documents on relevant data were not available.

2.1 Estimation Method

In this survey, we estimated the consumption of each country by industrial category (sub classification) and energy type in 2008 in the following manner.

1) The energy consumption structure of each country in the most recent year can be compared at a glance in the “Energy Balances of OECD Countries 2010 Edition” (IEA) and “Energy Balances of Non-OECD Countries 2010 Edition” (IEA). First of all, we used these two reports to calculate “① Consumption by industrial category (middle classification) and energy type in the food and beverage fields in countries surveyed” (2008 data).
2) We used various statistical data to set energy consumption ratio by industrial category (sub classification) composing the food and beverage sector and to estimate “⑤ Energy consumption by industrial category (sub classification) and energy type.”
3) The method by which the energy consumption shares by industrial category (sub classification) were set differs from country to country. For the countries listed in the “Structural Statistics for Industry and Services Volume 2 Energy Consumption 2000 Edition” (IEA), i.e. France, Germany, Japan, Norway, Sweden, and the UK, we set “② Energy consumption shares by industrial category (sub classification) and energy type in countries surveyed” based on this document (data up to 1999).
4) Method 3) could not be employed for other countries. Among other countries, for the countries listed in the “Structural Statistics for Industry and Services database- ISIC Rev. 3 Vol 2006 release 01” (OECD), that is, Italy, the Netherlands, and Spain, we set the energy consumption ratio by industrial category (sub classification) and energy type based on “③ Shares of energy purchases by industrial category (sub classification) in countries surveyed” (2003 data).
5) Neither Methods 3) nor 4) could be employed for the remaining countries, the USA and China. We set “② Energy consumption shares by industrial category (sub classification) and energy type in countries surveyed” by examining the statistical data by country. Note that since such a subcategorized estimation for China was difficult owing to limited

statistical materials, we had to estimate the energy consumption by industrial category (middle classification) and energy type as a last resort.

(a) France, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom

Food and tobacco			
	15 Food products and beverages		
		151 Production, processing and preserving (PPP)	
			1511 PPP of meat and meat products
			1512 Processing and preserving of fish products
			1513 Processing, preserving of fruit & vegetables
			1514 Vegetable and animal oils and fats
		152 Dairy products	
		153 Grain mill prod., starches & prepared animal feeds	
			1531 Grain mill products
			1532 Starches and starch products
			1533 Prepared animal feeds
		154 Other food products	
			1541 Bakery products
			1542 Sugar
			1543 Cocoa, chocolate and sugar confectionery
			1544 Macaroni, noodles,couscous & similar farinaceous prod.
			1549 Other food products, nec
		155 Beverages	
			1551 Distilling, rectifying and blending of spirits
			1552 Wines
			1553 Malt liquors and malt
			1554 Soft drinks; production of mineral waters
	16 Tabacco Products		

2-digit: Middle classification; 3-digit: Small classification; 4-digit: Sub classification

: Definition of size of industry classification in this survey

Industry classification: ISIC (International Standard Industrial Classification of All Economic Activities) Rev.3

(b) Germany

Food and tobacco		
	311/2 FOOD	
		3111 Slaughtering, preparing and preserving meat
		3112 Dairy products
		3113 Canning, preserving of freuits and vegetables
		3114 Canning, preserving and processing of fish
		3115 Vegetable and animal oils and fats
		3116 Grain mill products
		3117 Bakery products
		3118 Sugar factories and refineries
		3119 Cocoa, chocolate and sugar confectionery
		3121 Other food products
		3122 Prepared animal feeds
	313 BEVERAGES	
		3131 Distilling, rectifying and blending of spirits
		3132 Wine industries
		3133 Malt liquors and malts
		3134 Soft drinks
	314 TOBACCO	

3-digit: Middle classification; 4-digit: Sub classification

: Definition of size of industry classification in this survey

Industry classification: ISIC (International Standard Industrial Classification of All Economic Activities) Rev.2

(c) United States

Food and tobacco				
	311 Food Manufacturing			
		3112 Grain and Oilseed Milling		
			311221 Wet Corn Milling	
			31131 Sugar Manufacturing	
		3114 Fruit and Vegetable Preserving and Specialty Food Manufacturing		
		3115 Dairy Product Manufacturing		
		3116 Animal Slaughtering and Processing		
	312 Beverage and Tobacco Product Manufacturing			
		3121 Beverage Manufacturing		

3-digit: Middle classification; 4-digit: Small classification; 5-digit, 6-digit: Sub classification

: Definition of size of industry classification in this survey

Industry classification: 2007 NAICS (North American Industry Classification System)

(d) China

Food and tobacco
Processing of Food from Agricultural Products
Manufacturing of Foods
Manufacturing of Beverage
Manufacturing of Tobacco

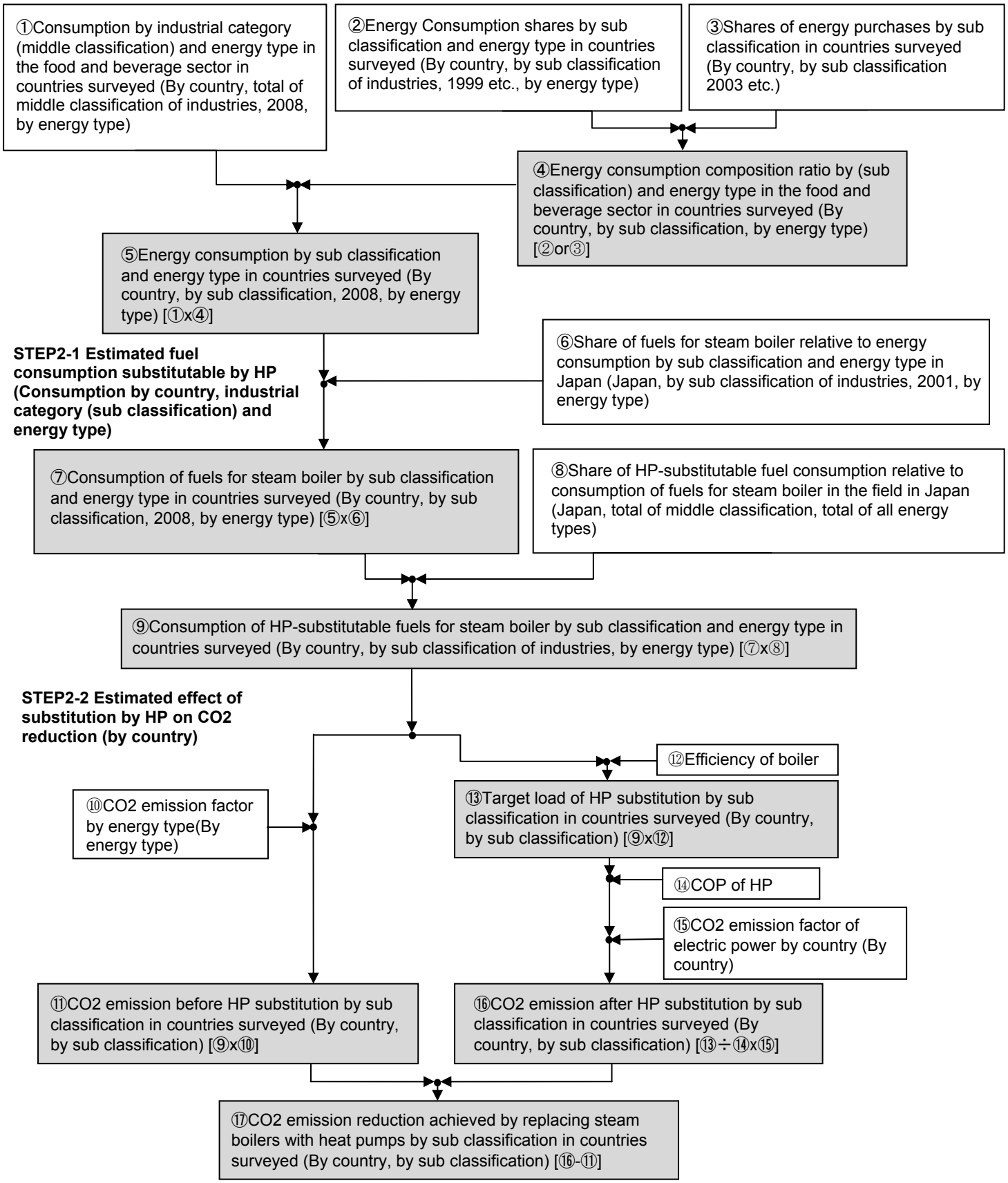
Middle classification

: Definition of size of industry classification in this survey

Classification described in “China Energy Statistical Yearbook” (China Statistics Press)

Figure 1: Structure of classification

STEP1 Estimated Energy Consumption Structure in the Food and Beverage Sector in Various Countries (Consumption by country, sub classification and energy type)



2.2 Estimation Results

Except for the USA and China, which have a different category classification from the other countries, among those covered by the survey, energy-intensive industries common to European countries and Japan are as shown below.
<energy-intensive six industries (sub classification) common to European countries and Japan>

- Manufacture of dairy products
- Production, processing and preserving of meat and meat products
- Manufacture of bakery products
- Processing and preserving of fruit and vegetables
- Manufacture of prepared animal feeds
- Manufacture of malt liquors and malt

The estimation results of the energy consumption structure (energy consumption by country, industrial category (sub classification), and energy type) in the food and beverage sector is shown in Figure 3 (example for France).

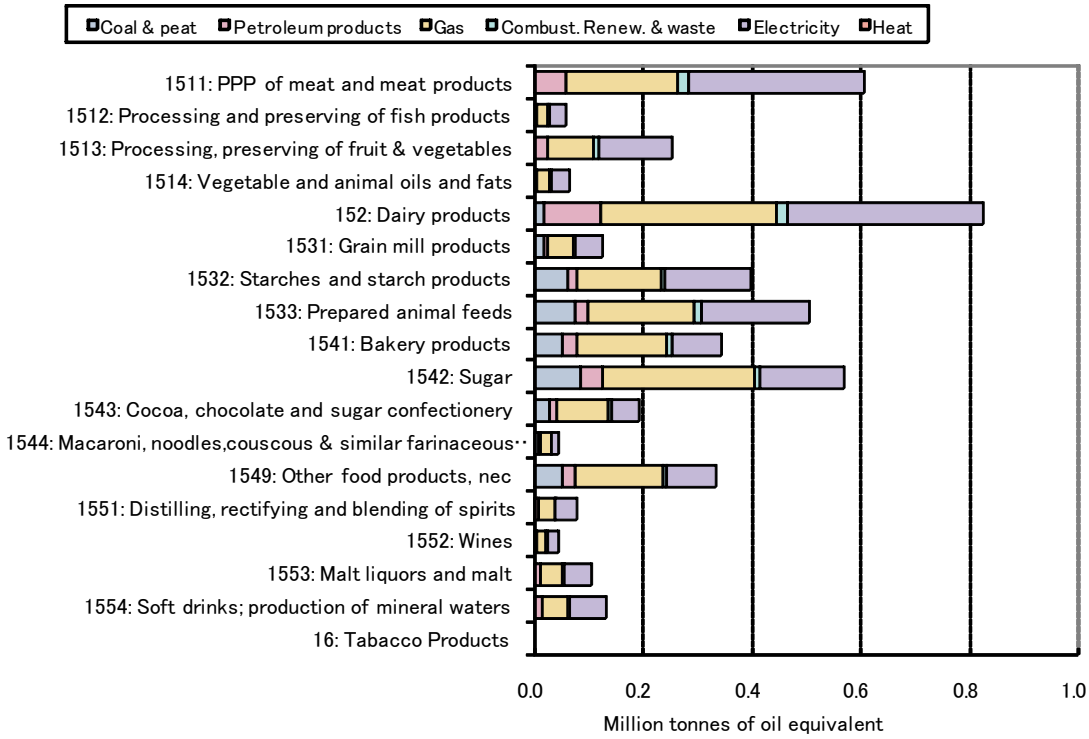


Figure 3: Estimated energy consumption structure by sub classification in food and beverage sector (example for France)

3 CO2 REDUCTION EFFECT BY APPLYING HEAT PUMPS

3.1 Estimation Method

3.1.1 Estimation of fuel consumption replaced by heat pumps

We estimated the CO2 reduction effect by applying current-technology heat pumps to the food and beverage sector according to the following procedure.

1）We obtained the "⑦ Consumption of fuels for steam boiler by industrial category (sub classification) and fuel type in countries surveyed" from the "⑤ Energy consumption by industrial category (sub classification) and energy type in countries surveyed" obtained previously and from the "⑥Share of fuels for steam boiler relative to energy consumption by industrial category (sub classification) and energy type in Japan."
2）We estimated "⑨ Consumption of HP-substitutable fuels for steam boilers by industrial category (sub classification) and energy type in countries surveyed" from the "⑦ Consumption of fuels for steam boiler by industrial category (sub classification) and energy type in countries surveyed" and based on the assumption that "⑧ Share of HP-substitutable fuel consumption relative to consumption of fuels for steam boilers in the food field in Japan" is 60%.
3）Next, we set the coefficient of performance (COP) of the heat pump, boiler efficiency, and CO2 emission factor in power generation of each country. We estimated CO2 emissions when the calorific value equivalent to the amount of CO2 emitted from the fuel consumption for steam boilers obtained in step 2) was replaced with that of electric drive compressor heat pumps. We obtained "⑰ CO2 emissions reduction achieved by replacing steam boilers with heat pumps by industrial category (sub classification) in countries surveyed" from the difference between them.

It is required to set "the composition ratio of consumption for steam boilers to energy consumption" and "the composition ratio of applications at an end use temperature below 100℃ consumption for steam boilers" to estimate fuel consumption for boilers at an end use temperature below 100 ℃ where heat pumps are applied. Ideally speaking, these composition ratios should be measured and collected through a fact-finding survey of many factories in each country. In this survey, however, we set the ratios by applying to each country existing survey results in Japan.

(1) Energy consumption structure of boilers in Japan

We set the "Share of fuels for steam boiler relative to energy consumption by industrial category (sub classification) and energy type" based on the "The structural survey of oil consumption in 2001" a Japanese statistical document compiled through Fiscal 2001.
The Heat Pump & Thermal Storage Technology Center of Japan collects information on heat pumps in Japan. For "Composition ratio of applications at a use temperature below 100℃ to consumption for steam boilers," the center estimates the composition ratio of applications (including air-conditioning) at a use temperature below 100℃ to consumption for steam boilers in the food field to be 60%.
When we prepared the past report, we had interviewed major domestic equipment manufacturers, sub-users, major domestic users, etc. that had knowledge about industrial processes to obtain the share of fuels for steam boilers replaceable with heat pumps relative to energy consumption. As a result, dairy products, meat products, bakery products, preservation of fruit and vegetables, and malt liquors, which are energy-intensive industries in the food and beverage sector, employ many low-temperature heating processes such as sterilization, cleansing, and fermentation and the share of applications (including air-conditioning) at a use temperature below 100℃ to steam consumption is approximately 60% or slightly more (Figure 4).

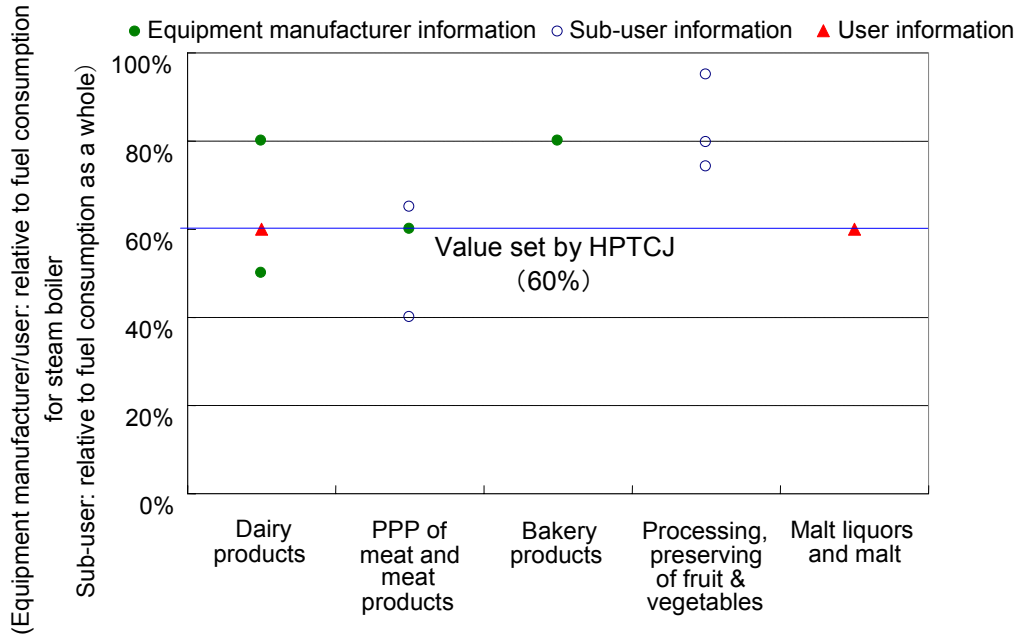


Figure 4: Energy Consumption Structure for Boiler in Japan

(2) Applying the composition ratio of Japan to each country

According to French domestic estimates, an absolute quantity of heat demand below 100℃ in the French domestic food and beverage sector is approximately 12 TWh/year, which is close to the estimation result (11 TWh/year) of heat demand obtained in this survey.
Based on the above, in this report we decided to apply the setting values for Japan to each country for the "composition ratio of consumption for steam boilers to energy consumption" and "composition ratio of applications at a use temperature below 100℃ to consumption for steam boilers."

3.1.2 Estimation of CO2 reduction effect by applying heat pumps

(1) Estimation of CO2 emissions in the present situation

We estimated "⑪ CO2 emissions before HP substitution by sub classification in countries surveyed" by multiplying "⑨ Consumption of HP-substitutable fuels for steam boiler (at a end use temperature below 100℃) by sub classification and energy type in countries surveyed" by "⑩ CO2 emission factor by energy type". We applied the same CO2 emission factor uniformly to every country and set coal & peat at 94.6 t-CO2/TJ (other bituminous coal), petroleum products at 73.3 t-CO2/TJ (other oil), and gas at 56.1 t-CO2/TJ (natural gas (dry)).

(2) Estimation of CO2 emissions after the application of heat pumps

First of all, we calculated power consumption by country and sub classification after the application of heat pumps by multiplying "⑫ Efficiency of boiler" (which was set at 85% uniformly for every country) by "⑨ Consumption of HP-substitutable fuels for steam boiler by sub classification and energy type in countries surveyed" and then dividing the obtained value by "⑭ COP of heat pump" (which was set at 4.0 uniformly for every country).
Next, we calculated "⑯ CO2 emission after HP substitution by sub classification" by multiplying the power consumption by "⑮ CO2 emission factor of electric power by country".

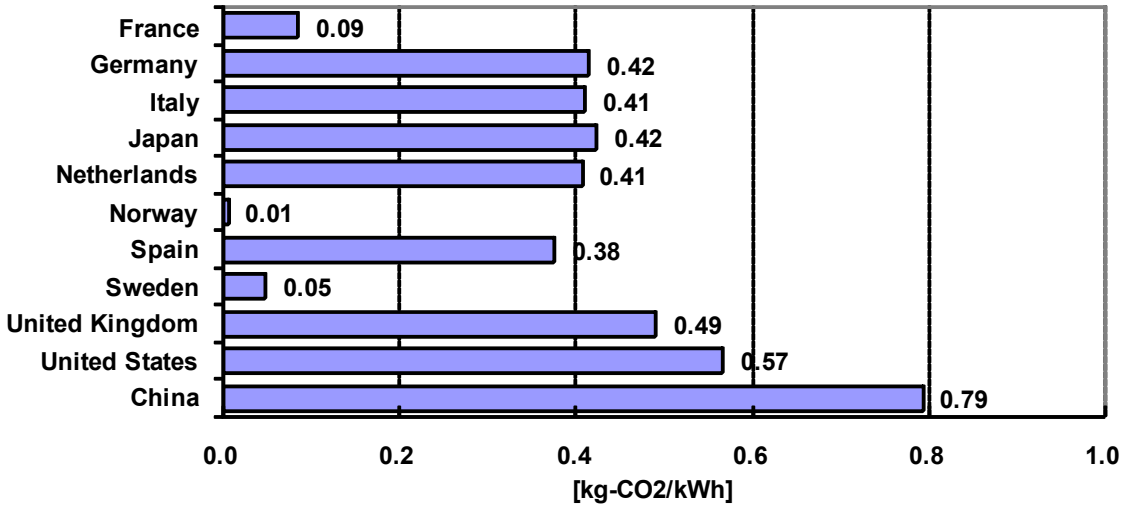


Figure 5: CO2 emissions per kWh from electricity and heat generation

(3) Estimation of CO2 reduction effect by applying heat pumps

We calculated "⑰ CO2 emissions reduction achieved by replacing steam boilers with heat pumps by sub classification in countries" by comparing CO2 emissions before and after the application of heat pumps. Note that we analyzed China with rougher category classification (middle classification) than the other countries owing to limited statistical materials.

3.1.3 Estimation results of CO2 emissions reduction

A total CO2 reduction effect of 47 Mt-CO2/year for all of the 11 countries can be expected by substituting heat pumps for steam boilers among applications at a use end temperature below 100℃ in the food and beverage sector. In particular, a significant CO2 reduction can be expected in China (21 Mt-CO2/year) and the USA (15 Mt-CO2).
It is instructive to look at the rate of CO2 reduction achieved by replacing applications at a end use temperature below 100℃ with heat pumps in the food and beverage sector relative to CO2 emissions in all industries. The combined CO2 reduction for the 11 countries accounts for 1.4% of CO2 emissions from fuel combustion in the industrial sector (3,475 Mt-CO2/year). Particularly in France, the rate of reduction reaches 4.1%. The data for China have a lower accuracy than that for other countries. A total CO2 reduction of 26 Mt-CO2/year in the 10 countries other than China can be expected. The impact of replacing applications at a use end temperature below 100℃ with heat pumps in the food and beverage sector on CO2 emissions reduction in all industries accounts for 2.0% of CO2 emissions from fuel combustion (1,307 Mt-CO2/year) in all industries in the 10 countries excluding China.

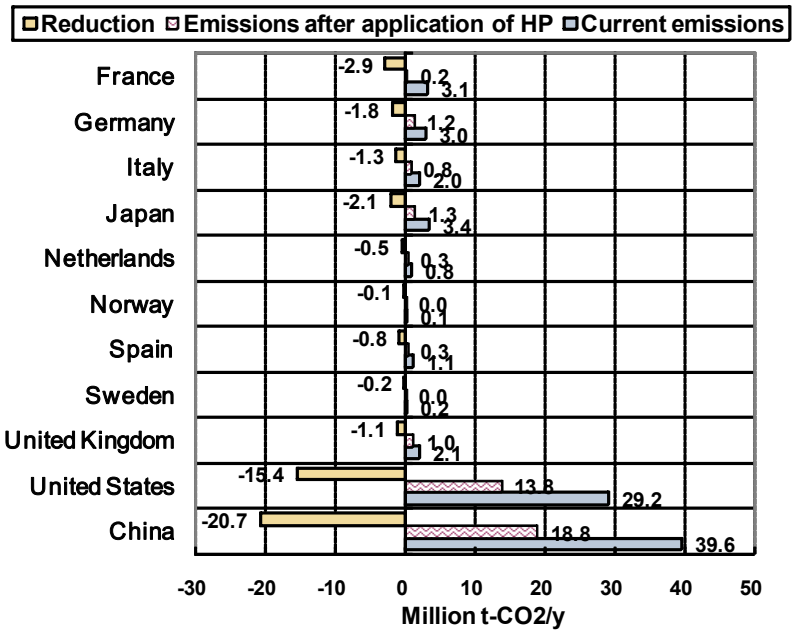


Figure 6: CO2 reduction by substitution of boiler by heat pump in uses at use end temperature of below 100°C in the food and beverage sector

4 PRIMARY ENERGY CONSUMPTION REDUCTION BY APPLYING HEAT PUMPS

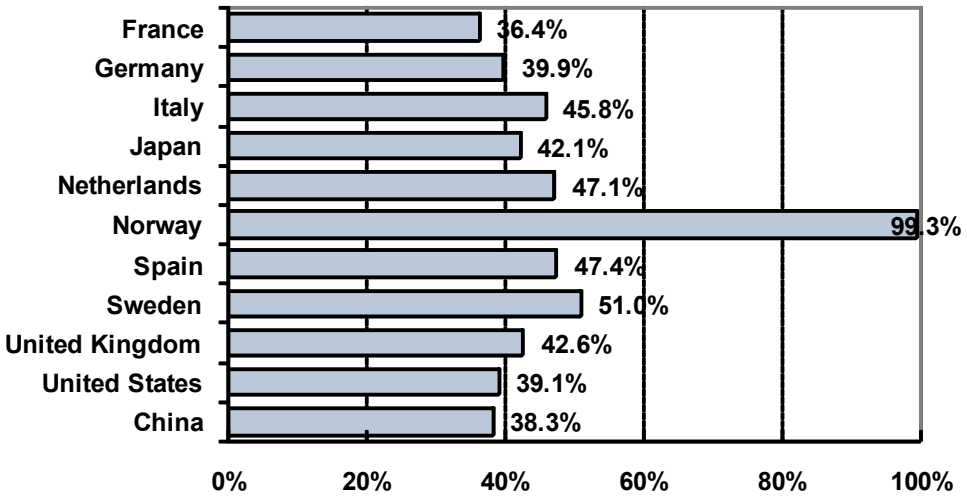
4.1 Estimation Method

4.1.1 Estimation of primary energy consumption in the present situation

We set "⑨ Consumption of HP-substitutable fuels for steam boiler (at a end use temperature below 100℃) by industrial category (sub classification) and energy type in countries surveyed" as the primary energy consumption in the present situation. Energy types estimated are coal, petroleum products and gas, and losses in energy conversion section are excluded.

4.1.2 Estimation of primary energy consumption after the application of heat pumps

At first, we calculated power consumption by country and category after the application of heat pumps by multiplying "⑫ Efficiency of boiler" (which was set at 85% uniformly for every country) by "⑨ Consumption of HP-substitutable fuels for steam boiler by industrial category (sub classification) and energy type in countries surveyed" and then dividing the obtained value by "⑭ COP of heat pump" (which was set at 4.0 uniformly for every country).
Next, we calculated "Primary energy consumption after HP substitution by industrial category (sub classification) in countries surveyed" by dividing the power consumption by "Power generation efficiency in countries surveyed".



Note1) We calculated it by dividing electricity generated at the power plants described in the document by input energy (including non-fossil fuels such as nuclear energy).
Note2) In the document, input energy for non-fossil fuels is set as follows.
＊Nuclear energy; Input energy = Electricity generated / 33% ＊Geothermal energy; Input energy = Electricity generated / 10% ＊Hydro, solar, wind, tide/wave; Input energy = Electricity generated

Figure 7: Power generation efficiency for countries surveyed

4.1.3 Estimation results of primary energy consumption reduction

A total primary energy reduction effect of 12 million toe/year for all of the 11 countries covered by the survey can be expected by substituting heat pumps for steam boilers among applications at a use end temperature below 100℃ in the food and beverage sector. In particular, a significant primary energy reduction can be expected in the USA (4.8 million toe/year) and China (4.6 million toe/year).
The data for China have a lower accuracy than that for other countries. A total primary energy reduction of 7.7 million toe/year in the 10 countries other than China can be expected.

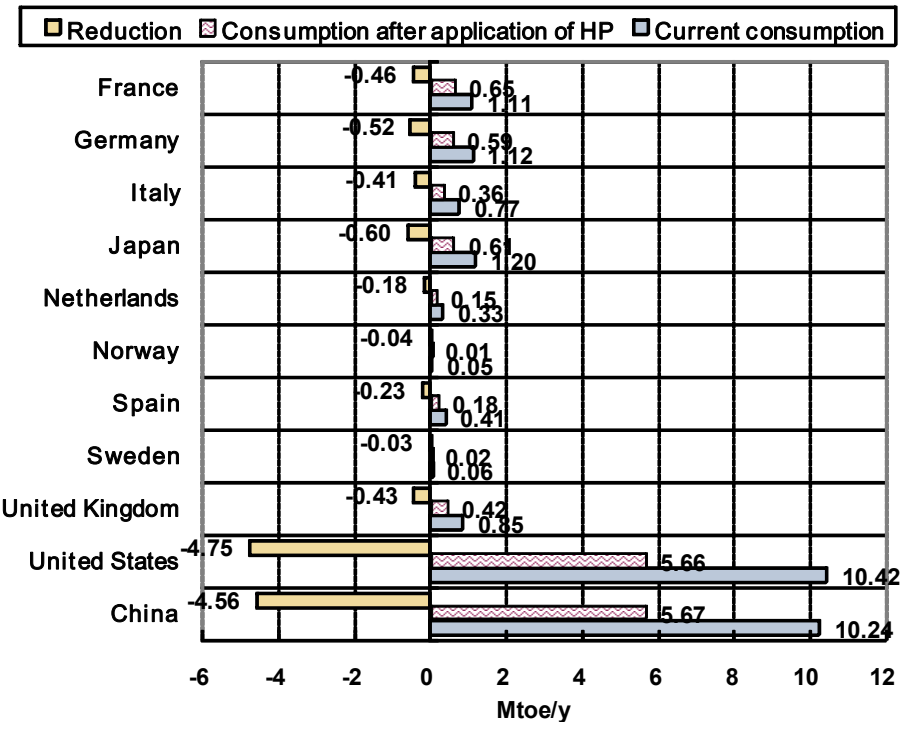


Figure 8: Primary energy reduction by substitution of boiler by heat pump in uses at use end temperature of below 100°C in the food and beverage sector

5 CONCLUSION

A total CO2 reduction effect of 47 Mt-CO2/year estimated through this survey corresponds to 1.4% of total emissions from fuel combustion in industrial sector, 3,475 Mt-CO2/year, in eleven countries surveyed. And it is also expected 26 Mt-CO2/year reduction which corresponds to 2.0%, 1,307 Mt-CO2/year, in ten countries other than China.
Through this survey, it is verified that we can expect significant CO2 emissions and primary energy consumption reductions by introducing heat pumps at a end use temperature below 100℃ including air conditioning in food and beverage sector.
Meanwhile, since there are a lot of manufacturing processes in which relatively low temperature are required such as washing, drying and air-conditioning including clean room in the sectors other than food and beverage, heat pump technologies should be considered as the technologies to be applied to whole sectors in industry. It is also applicable to agricultural sector for horticulture and storage processes, etc. that are fundamental to the food sector.
Heat pumps have been making steady progress with improving efficiency, larger capacity, operational at lower ambient temperature. Recently, heat pumps which generate steam at 165℃ started its sales as well.
Heat pump is extremely excellent and promising technologies which is expected adopted widely in industrial sectors and to contribute further CO2 reductions.

6 ACKNOWLEDGEMENTS

The authors would like to appreciate here for the great support from MAYEKAWA MFG. CO., LTD. and Hitachi Plant Technologies, Ltd. throughout this survey.

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