PROJECTING FUTURE CO_2 EMISSIONS IN JAPAN BASED ON CEMENT CONSUMPTION INTENSITY AND PREFECTURAL POPULATION CHANGE

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1. Introduction

The environmental impacts of concrete construction are widely documented, and include natural resource consumption and greenhouse gas emissions. Improving resource efficiency and reducing greenhouse gas emissions are important steps in realizing a sustainable society, but they need to be quantitatively assessed so that progress and policies can be evaluated. For concrete construction, the cement consumption intensity (CCI), defined as the cement consumption per capita, is a useful indicator for evaluating construction resource efficiency, particularly between regions or over time. Furthermore, by applying inventory values, the environmental benefits of improved efficiency can also be calculated.

In this paper, the CCI is used to evaluate how resource efficiency related to concrete construction varies between the 47 prefectures in Japan. The potential for reducing greenhouse gas emissions in the future is then explored considering projected changes in prefectural populations, as well as scenarios considering targeted actions for improving resource efficiency.

2. Trends in the cement consumption intensity

Using data on cement consumption and population acquired, respectively, from the Japan Cement Association and Japan Ministry of Internal Affairs, Statistics Bureau, CCI data at the prefectural level from 1950 to 2013 were calculated (Figure 1). Three periods can be identified: a linear increase from 1950 to 1973, relative stabilization from 1973 to 1996, and a linear decrease from 1996 to the present. Although historical trends in the CCI were affected by population growth and cement consumption, from 2011 the national population began to contract, so recent trends in the CCI have depended primarily on cement consumption alone.

To better understand how the CCI varies between prefectures, the relationship between prefectural population and CCI was explored (Figure 2). Data for 2010 were utilized to avoid the effect of the 2011 Great East Japan Earthquake. It can be seen that the CCI tends to decrease and converge as population increases, and that there is larger variation in the CCI among prefectures with smaller populations than larger ones. A higher CCI value can be equated with lower resource efficiency, so prefectures with lower resource efficiency are primarily those with below-average populations.

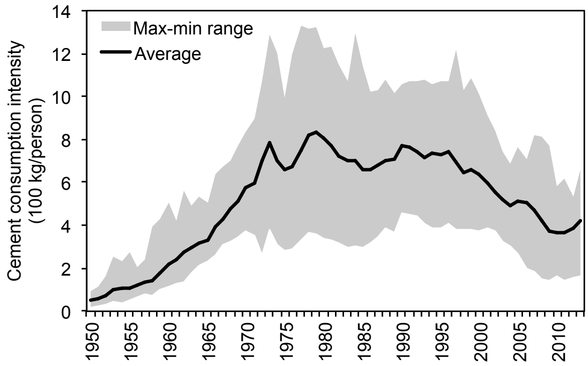

Figure 1 Annual average and range of CCI values

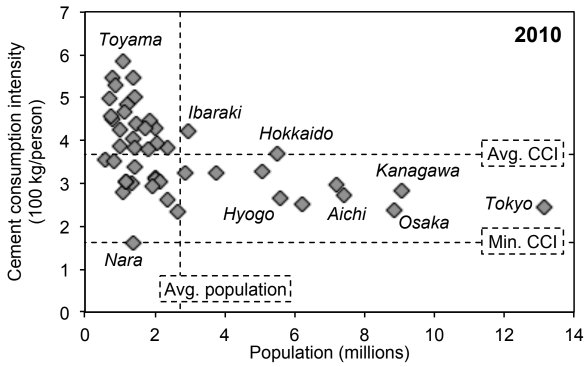

Figure 2 Relationship between CCI and population

3. Projection of future CO_2 emissions

3.1. Future changes in population and CCI

The National Institute of Population and Social Security Research has projected that Japan's population will decrease by 16.2% from 2010 (128.1 million) to 2040 (107.3 million), but the population loss will not be equal across all prefectures (Figure 3). If cement consumption were to remain constant, then the CCI would increase as population decreased. However, the recent trend (starting in 1996) shows the CCI decreasing linearly, with a small increase after the 2011 Great East Japan Earthquake. Conversely, the minimum CCI value has fluctuated only slightly in the last six years. This suggests that there may exist a "limit" or "ideal" CCI value towards which the prefectures are converging.

In order to project the future CCI, a linear regression equation was calculated based on the trend of the average

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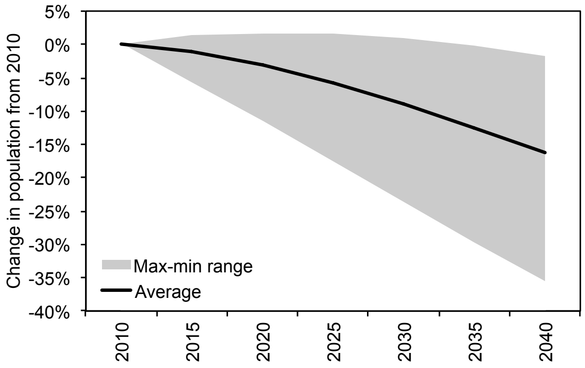

Figure 3 Projected change in prefectural populations

CCI from 1996 to 2010. The equation is shown below and has an R^2 value of 0.9689.

$$y = -0.2522(x - 1996) + 7.4868 \quad (1)$$

Where y: CCI (100 kg/person); x: calendar year. If it is assumed that each prefecture's CCI decreases at the same rate as the average, then the slope from this equation can be used to project each prefecture's future CCI.

3.2. Projection scenarios & calculation method

To estimate the potential for CO_2 emissions reduction due to changes in resource efficiency and population, five scenarios were constructed (Table 1).

The CO_2 emissions for each year were calculated per Equation (2). It should be noted that, for simplicity, only the inventory value for ordinary Portland cement (OPC) was applied in this calculation; in reality, the inventory values of other types of cement (such as blast furnace slag cement) are different than that of OPC.

$$E_{CO2,i} = I \times V_i \quad (2)$$

Where $E_{CO2,i}$: total CO_2 emissions in year i (kg-CO_2); I: inventory value for cement (766.6 kg-CO_2/ton); V_i: volume of cement consumption in year i (tons).

The volume of cement consumption in a given year was calculated following Equation (3).

$$V_i = \left(\sum_{j=1}^{n} CCI_{i,j} \times P_{i,j}\right) \div 1000 \quad (3)$$

Where $CCI_{i,j}$: CCI for prefecture j in year i (kg/person); $P_{i,j}$: population in prefecture j in year i (people); n: 47 (prefectures). The National Institute of Population and Social Security Research's projection data were used for the future prefectural populations.

The projected CCI for a given prefecture in a given year was calculated per Equation (4).

$$CCI'_{i,j} = -0.2522 \times (i - i_0) + CCI_{i_0,j} \quad (4)$$

Where $CCI'_{i,j}$: projected CCI for prefecture j in year i (kg/person); i_0: initial year (2010); $CCI_{i0,j}$: CCI value for prefecture j in the initial year (kg/person).

However, the actual CCI value used for calculating the volume of cement consumption will vary depending on the projection scenario, so the projected CCI has to be checked against the target CCI.

$$CCI_{i,j} = CCI'_{i,j} \ \ IF \ \ CCI'_{i,j} > CCI_{target} \quad (5)$$

$$CCI_{i,j} = CCI_{target} \ \ IF \ \ CCI'_{i,j} \le CCI_{target} \quad (6)$$

Where CCI_{target}: target CCI value depending on the projection scenario (kg/person).

3.3. Projection results

Figure 4 shows the calculation results for the projection scenarios. In the case that the CCI values are held constant (Scenario 1), population change alone will only lead to a 17.0% reduction in CO_2 emissions by 2040 (relative to the 2010 level). Conversely, the largest reduction in CO_2 emissions, 57.6%, is achieved when all prefectures decrease to the minimum CCI value (Scenario 2). Decreasing to the average CCI value for above-average prefectures (Scenario 3) only results in a 7.8% greater reduction than that due to population change alone. Finally, targeted CCI reduction based on prefectural population (Scenarios 4 and 5) can achieve a 37% to 38% overall reduction in CO_2 emissions, regardless of which population range is targeted. However, it takes longer for the CCI values of the prefectures with below-average populations to reach the minimum CCI value because they generally have higher CCI values in 2010.

4. Conclusion

Although CO_2 emissions due to cement consumption may decrease in the future due to population contraction alone, improving resource efficiency can lead to even greater reductions. The results shown here demonstrate a range of emissions reductions that may be achieved through targeted resource efficiency policies.

Table 1 Projection scenarios setting for target CCI

Scenario	Condition for target CCI
1	CCI remain constant at 2010 value
2	All pref. decrease to 2010 min. CCI value
3	Pref. with above average CCI decrease to 2010 average CCI value
4	Pref. with above average population in 2010 decrease to 2010 min. CCI value
5	Pref. with below average population in 2010 decrease to 2010 min. CCI value

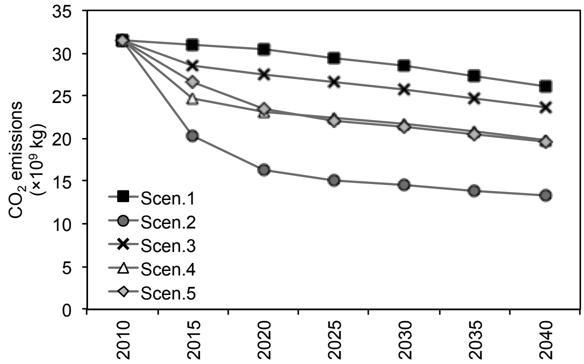

Figure 4 CO_2 emissions projection results