

Supplementary Material B

Compilation method for the hybrid input-output table

SB.1. Rows of energy sectors

First, the energy balance table (ANRE 2021) was transposed, and then positive/negative signs were exchanged in part (i.e., secondary energy sectors and import/export/inventories of primary energy sectors) in alignment with the framework of the hybrid input-output (IO) table.

Second, energy carriers and sectors in the energy balance table were re-arranged to the 57 sectors of **Table 1** of the main text, plus an “in-house transportation” sector. However, the column (energy consumption) of this sector must be re-allocated to other columns and thereby eliminated, because the linked IO table of Japan does not contain this sector. This re-allocation was performed using the output coefficients (i.e., output to each destination divided by the total output) of the in-house transportation (row) sector that is found in the standard (not linked) national IO of Japan (MIC 2020).

During the above aggregation of sectors, the column sector “oil product” in the transposed energy balance table was segregated into each oil product (i.e., Columns 9–17 in the hybrid IO) in proportion to the energy outputs of each product, assuming all the segregated columns have identical input structures. The objective of this segregation is to make the resultant input coefficient matrix square so that mathematical modeling is simpler. Meanwhile, sectors incorporated in the domestic final demands (y^{11} and y^{21} in **Fig. 2** of the main text) were household consumptions, transportation attributable to households, changes in inventories and statistical errors.

Third, consumption figures of energy carriers, especially fossil fuels, by non-energy sectors in the energy balance table, included minor non-energy (material) consumptions such as use of oil products as feedstocks for chemical industries. To extract only energy flows, therefore, such material uses need to be separated from the total consumptions and transferred to the final-demand sector of the hybrid IO. For this purpose, the energy balance table offers a separate appendix that shows amounts of material uses as constituent parts of consumption figures. However, this appendix is not detailed enough to make precise separations, so I needed to conduct estimations¹. Then, the separated material uses as well as any remaining estimation errors (less than 3%) were all transferred to the domestic final-demand sector (“increase in stocks”), so the columns of intermediate demands contain only energy flows.

Fourth, I chose to modify non-fossil primary energy inputs to electricity sectors in the energy balance table, which correspond to the intersection of Rows 4–7 and Columns 19–20 of the hybrid IO, as follows. On the one hand, the energy balance table estimates the non-fossil energy inputs to electricity sectors by assuming a non-fossil power plant has the same energy conversion efficiency as a standard fossil-fuel power plant in the target year (hereafter called

¹ Appendix at the bottom of the energy balance table shows material uses in terms of each energy carrier by 12 aggregated (“big”) non-energy sectors, whereas the far-right column \$1402 indicates total material use (an aggregate of all energy carriers) by each (detailed) non-energy sector. (Note the rows/columns of this original table are placed opposite to the hybrid IO table.) Therefore, I classified each non-energy sector into one of the 12 “big” sectors, and allocated total material use of each non-energy sector (according to the column \$1402) to each energy carrier, assuming the allocation coefficients (estimated from the appendix) remain the same for all non-energy sectors belonging to the same “big” sector.

the Standard Conversion Efficiency) (Kainou 2012)². This is a common approach to make primary energy inputs at power plants comparable among various types (e.g., Hannon et al. 1983; Han and Lakshmanan 1995).

On the other hand, this study considered it appropriate to equate a non-fossil energy input with an electricity output, thereby differentiating energy conversion efficiencies between fossil-fuel and non-fossil-fuel power plants. Counting an energy loss on conversion from fossil fuels to electricity is justifiable because it constitutes an opportunity cost since the loss may have been used as heat if fuels were directly combusted, say, in a stove. By contrast, a similar loss for renewables – like a portion of solar wavelengths not converted to electricity by a PV panel – generally commands no such opportunity costs. Therefore, I counted only the portion of renewable energy captured by PV panels or wind/water turbines as the energy inputs for electricity generation. As for nuclear power, similar treatment may be justified because nuclear fuel *can potentially be processed multiple times*, and so the ultimate energy extractable from the ore is hard to estimate (Kainou 2012). Hence, I followed the method of Nansai et al. (2002), who assumed that all non-fossil energy input is equal to the electricity output. Accordingly, I multiplied the original figures in the corresponding block of the energy balance table (Rows 4–7/Columns 19–20) by the Standard Conversion Efficiency (e.g., 0.4146 for 2015) to obtain the hybrid IO table.

SB.2. Rows of non-energy sectors and compilation of the hybrid table

First, the original sectors in the linked IO tables (MIC 2020) were aggregated into 57 sectors in **Table 1**. In doing so, the two columns of “coal, crude oil and natural gas” and “oil products” were segregated into each energy carrier in the same way as Section SB.1 to create a square table.

Second, the resultant IO table contained all the sectors in **Fig. 2**, expressed in monetary units. Therefore, to compose the table in hybrid units, rows of the energy sectors (shaded sub-matrices) were substituted by the figures in energy units, which were prepared in Section SB.1. Finally, I repeated all the above procedures for the target years 2005, 2011 and 2015. This completed the compilation of the hybrid IO tables, provided in **Supplementary Material A** of this article.

Reference

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² For instance, in 2015, the Standard Conversion Efficiency was 41.46%, and hence, at every non-fossil power plant, the energy input was deemed to be 2.412 (1/0.4146) times as large as the electricity output.

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