Supplementary Information

Path Analysis of Beijing's Dematerialization Development Based on System Dynamics

Tiejun Dai [1], Shuo Shan [1,*]

1 College of Economics & Management, Beijing University of Technology, Beijing 100124, China

* Correspondence: shanshuo_bjut@hotmail.com; Tel.: +86-188 1177 3570

List of files

A. Material flow accounting method of Beijing.

B. The results of material flow accounting (Unit: Million metric tons).

C. The discussion on Beijing's MFA data accounting results

D. System dynamics sub-model flow diagram.

E. All formulas and parameters of SD.

F. The best dematerialization scenarios for eight materials during 2017–2030.

A. Material flow accounting method of Beijing.

The material flow accounting method of Beijing in this study is based on the research of [1-3]. The material flow analysis framework of Beijing is shown in the section of Beijing's material metabolism accounting in Figure 1. Overall, the input part of the Beijing's material flow analysis framework includes imports and domestic extraction materials (DE), and the output includes exports and DPO (including four types of pollutants). The following describes the accounting method and data source of each part of the data.

A.1 Domestic extraction material accounting

The DE part mainly includes four major categories of metals, non-metals, fossil fuels and biomass. The types, method and data sources of the input part is displayed in Table A.1. And material conversion factors are shown in Table A.2.

Table A.1.1 Types, method and data sources of the input part.

Types	Method	Data sources
A.1.1.1 Cereals A.1.1.2 Fruits, roots, and tubers A.1.1.3 Oil-bearing crops A.1.1.4 Sugar crops A.1.1.5 Cotton A.1.1.6 Other crops n.e.c.	Domestic Extraction (DE) based on available statistical data (or with simple conversion)	National Bureau of Statistics of China (NBSC) [4]; Ministry of Agriculture and Rural Affairs of China [5]
A.1.2.1 Crops residues (used) A.1.2.2 Fodder crops and grazed biomass	Estimation based on the method recommended by Eurostat in its Economy-wide Material Flow Accounts (EW-MFA) Compilation Guide 2013; [6]	National Bureau of Statistics of China (NBSC) [4]; Ministry of Agriculture and Rural Affairs of China [5]
A.1.3 Wood	DE based on available statistical data (or with simple conversion)	The state forestry administration of China [7]
A.1.4 Wild fish catch		Ministry of Agriculture and Rural Affairs of China [5]
A.2.1 Iron		National Bureau of Statistics of China (NBSC) [4]
A.3.1 Non-metallic minerals	Non-oil and non-gas raw ore mining (a statistical indicator obtained directly in the yearbook) minus metal ore mining and coal mining	Editorial Office of China Mining Yearbook [8]; Beijing Municipal Commission of Planning and Natural Resources [9]

A.4.1 Coal	DE based on available statistical data (or with simple conversion)	National Bureau of Statistics of China (NBSC) [10]
A.4.2 Petroleum		National Bureau of Statistics of China (NBSC) [10]
A.4.3 Natural gas		National Bureau of Statistics of China (NBSC) [10]

Table A.1.2 Material conversion factors.

Item	Original Units	Conversion factor
Wood	m^3	1.92 m^3 = 1t
Grazed biomass	head	4.5 t per head and year (cow) 3.7 t per head and year (horse) 2.2 t per head and year (donkey) 0.5 t per head and year (sheep) 4.5 t per head and year (camel)
Iron ore	t	2493 kg/t (crude steel) 2227 kg/t (steel) 27.26 kg/t (cement)
Washing machines	unit	40 kg/unit
Refrigerators	unit	55 kg/unit
Color TVs	unit	30 kg/unit
Cameras	unit	2 kg/unit
Computers	unit	12 kg/unit
Microwave ovens	unit	13.5 kg/unit
Mobile phones	unit	0.2 kg/unit
Air conditioners	unit	50 kg/unit
Family vehicles	unit	1.5 t/unit
Motorcycles	unit	120 kg/unit
Demolition waste	10 000 m^2	1336 t/10 000 m^2
Locomotives	unit	0.028 t/unit
Railway wagon	unit	0.0015 t/unit
Industrial boiler	t	0.000749 t/unit
Bicycle	10 000 unit	0.0058 t/unit

A.2. Imports and exports accounting

Referring to the regional material flow accounting framework and measurement method that has been established in [2,3], the calculation formula of the material flow imports and exports in Beijing is：

$$S_t = I_t - O_t \tag{A-1}$$

where, S_t represent the quantity of material imports or exports in Beijing in year *t*, I_t represents the material consumption of Beijing in year *t*, O_t represents the material production in Beijing in year *t*. When a certain material consumption in year *t* is greater than the production, S_t is a positive number, and the material is considered to be imported; on the contrary, when S_t is a negative number, the material is considered to be exported. The materials imported and exported in the material flow accounting of Beijing mainly include raw materials, semi-finished products and finished products. In general, the production of raw materials and their products can be obtained directly from the corresponding yearbook, but consumption is generally estimated. Consumption can be calculated through the relevant input-output relationship. The estimation methods for the imports and exports of four materials involved in the material flow accounting of Beijing are as follows:

1) The import and export of metals mainly include three parts: raw ore, semi-finished products and finished products. Iron ore and its products account for the absolute proportion of metal consumption in Beijing. Therefore, the quantity of iron ore and its products imported and exported represents the quantity of metal materials imported and exported of Beijing. Iron ore consumption is converted according to crude steel output. Steel consumption calculates the amount of steel consumed in construction, railway locomotives, railway passenger cars, railway wagons, boilers, large and medium-sized tractors, automobiles, bicycles and power generation equipment. The import and export of finished metal products is described in the finished product.

2) The import and export of non-metals mainly include industrial non-metallic minerals and their products and building materials. Since cement and flat glass account for a large proportion of non-metallic materials consumption, and other material data are not easy to obtain, the quantity of cement and flat glass imported and exported is selected to represent the quantity of non-metal materials imported and exported of Beijing.

3) Fossil fuels, mainly including raw coal, crude oil, natural gas, etc., their imports and exports can be calculated in Beijing's energy balance sheet.

4) For biomass, the quality of semi-finished products and finished products is relatively small compared to raw materials. Therefore, only the import and export of biomass raw materials are calculated. Household consumption and industrial consumption of semi-finished products and finished products are converted into the quality of soybean, forage grass, cereals and other raw materials [2].

5) In terms of finished products, the imports and exports quantity of residents' main durable consumer goods are mainly counted, including household cars, motorcycles, washing machines, refrigerators, color televisions, air conditioners, cameras, mobile phones, fixed telephones, fans, computers, microwave ovens. Production data is available directly in the relevant yearbook and consumption data is obtained through estimates. Consumption data includes new consumption and updated consumption. The new consumption is estimated based on the total amount of durable goods owned by the residents. The consumption of a certain durable goods in a certain year is the difference between the number of durable goods owned by the residents in that year and the number of durable goods owned by the residents in the previous year. Updated consumption is estimated based on product life expectancy [11-13]. Finally, the quality of the finished product is obtained by conversion [2,11-13].

A.3. DPO accounting

DPO accounting mainly includes four major types of materials, namely, atmospheric pollutants, water pollutants, solid wastes, and dissipative materials. The accounting items are described in detail below.

1) The main statistical items of atmospheric pollutants include carbon dioxide, sulfur dioxide, soot, industrial dust, and nitrogen oxides. Carbon dioxide emissions are estimated according to the IPCC 2006 method. Other pollutants emissions are obtained from the corresponding statistical yearbooks in Table 4.

2) The main statistical items of water pollutants are divided into five categories: total nitrogen (N), phosphorus (P), Heavy metals, organic materials and other materials. Total nitrogen (N) does not include nitrogen fertilizers that have been counted in dissipative materials. As with nitrogen, total phosphorus (P) does not include agricultural emissions. Heavy metals mainly count lead, mercury, cadmium, chromium and arsenic. The amount of organic materials is converted from the amount of chemical oxygen demand (COD). Other material statistics include ammonia nitrogen emissions, petroleum, volatile phenols, and cyanide. The data is obtained directly from the corresponding yearbook in Table 4. Some missing data were estimated by exponential smoothing prediction model.

3) The main statistical items of solid wastes are divided into municipal wastes and industrial wastes.

Municipal garbage discharge is achieved by the difference between the amount of household garbage produced and the amount of household garbage cleared. The amount of domestic garbage produced is estimated according to per capita 0.6 kg/day [14]. The amount of domestic garbage removal is directly obtained from the corresponding yearbook in Table 4.

Industrial wastes mainly include industrial solid wastes and construction wastes. Industrial solid wastes discharge is directly obtained from the corresponding statistical yearbooks in Table 4. Construction wastes is estimated by construction wastes, demolition construction wastes and decoration wastes. Construction wastes is estimated at 5% of concrete consumption [15]. The building life is set as 38 years [16], that is, the building area of 1954–1978 is considered to be the building demolition area of 1992–2016, and the unit demolition area mass is 1335.5Kg [17]. The decoration wastes is estimated according to 10% of the first two [15].

4) The main statistical items of dissipative materials are divided into four categories: organic fertilizer, mineral fertilizer, pesticides and agricultural plastic film. The estimation of organic fertilizer is based on EUROSTAT [18]. The amount of mineral fertilizer, pesticide and agricultural plastic film is obtained from the corresponding statistical yearbook in Table 4. Some missing data were estimated by exponential smoothing prediction model. Due to the lack of data, Dissipative losses are ignored here.

References

1. Dai, T.J.; Liu, R. Dematerialization in Beijing from the perspective of material metabolism. *Journal of Cleaner Production* **2018**, *201*, 792-801.
2. Dai, T.J.; Wang, W.J.; Liu, R. Spatio-temporal variation of resource and environmental pressure in China. *Resources Science* **2017**, *39*, 1942-1955. (in Chinese).
3. Dai, T.J.; Liu, R.; Wang, W.J. Material metabolism in Beijing by material flow analysis. *Acta Scientiae Circumstantiae* **2017**, *37*, 3220-3228. (in Chinese).
4. National Bureau of Statistics of China (NBSC). *China statistical yearbook*; China Statistics Press: Beijing, China, 1993-2017. (in Chinese).
5. Ministry of Agriculture and Rural Affairs of China. *China Agriculture Yearbook*; China Agriculture Press: Beijing, China, 1993-2017. (in Chinese).

6. Bi, Y.Y.; Wang, D.L.; Gao, C.Y., et al. *Straw Resource Evaluation and Utilization in China*; China Agricultural Science and Technology Press: Beijing, China, 2008. (in Chinese).
7. The State Forestry Administration of China. *China forestry statistical yearbook*; China Forestry Publishing House: Beijing, China, 1993-2017. (in Chinese).
8. Editorial Office of China Mining Yearbook. *China mining yearbook*; Seismological Press: Beijing, China, 1993-2017. (in Chinese).
9. Beijing Municipal Commission of Planning and Natural Resources. *Beijing land and resources statistical yearbook*; China Social Sciences Press: Beijing, China, 1993-2017. (in Chinese).
10. National Bureau of Statistics of China (NBSC). *China energy statistical yearbook*; China Statistics Press: Beijing, China, 1993-2017. (in Chinese).
11. Zhang, W.; Jiang, H.Q.; Wang, J.N. Amount of electronic waste generated in China: prediction and characteristics analysis. *Environmental Science & Technology* **2013**, *36*, 195-199. (in Chinese).
12. Liu, J.Y.; Qiao, Q.; Chang, L. Forecast on the amount of end- of- life vehicles in province and municipalities in China. *Recyclable Resources and Circular Economy* **2011**, *4*, 31-33. (in Chinese).
13. State Economic and Trade Commission; State Development Planning Commission; Ministry of Public Security. Interim provisions on the scrap standard of motorcycles. *Road Traffic Manage* **2002**, 46-46. (in Chinese).
14. He, D.W.; Jin, Y.; Chai,L.Y., et al. Influence Factors Investigate on Output and Component of Municipal Solid Waste in China Cities. *Environmental Sanitation Engineering* **2005**, *13*, 7-10. (in Chinese).
15. Wang, L.C.; Zhao, Y.C. *Construction waste treatment and resource*; Chemical Industry Press: Beijing, China, 2004. (in Chinese).
16. Liu, G.W.; Xu, K.X.; Zhang, M.L., et al. A Study on the Life-Span of Demolished Buildings:Based on the Investigation of Demolished Buildings in Chongqing. *Urban Development Studies* **2012**, *19*, 109-112. (in Chinese).
17. Chen, J.; He, J.J.; Shao, L.M., et al. Methods Discussion on Quantity Estimating of Demolition Waste. *Environmental Sanitation Engineering* **2007**, *15*, 1-4. (in Chinese).
18. EUROSTAT. Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide. Eurostat Luxembourg City, Luxembourg: 2013.

B. The results of material flow accounting (Unit: Million metric tons).

Table B. The results of material flow accounting (Unit: Million metric tons).

	Metals	**Non-metals**	**Fossil fuels**	**Biomass**	**Atmospheric pollutants**	**Water pollutants**	**Solid wastes**	**Dissipative materials**	**DMI**	**DPO**
1992	22.35	62.43	40.92	14.18	48.52	0.76	7.11	1.65	139.88	58.03
1993	24.57	69.08	40.94	15.16	51.07	0.70	8.45	1.48	149.74	61.70
1994	24.49	75.64	40.92	15.14	52.08	0.66	8.06	1.61	156.19	62.41
1995	19.80	78.66	40.07	15.91	53.59	0.63	7.19	1.47	154.45	62.89
1996	16.23	81.41	42.64	16.70	58.19	0.61	9.87	1.45	156.98	70.13
1997	16.83	80.53	41.60	17.65	55.52	0.56	7.91	1.45	156.61	65.45
1998	14.13	80.56	39.96	17.68	57.54	0.49	10.07	1.43	152.33	69.53
1999	11.64	90.26	41.13	18.76	57.33	0.45	7.39	1.45	161.79	66.61
2000	11.85	89.38	42.66	21.07	57.89	0.47	6.60	1.65	164.97	66.61
2001	13.70	92.61	43.12	17.97	60.02	0.47	6.29	1.79	167.40	68.57
2002	15.26	96.86	42.19	18.85	57.51	0.42	7.04	1.98	173.15	66.96
2003	17.76	99.28	45.26	18.43	60.09	0.37	7.69	1.97	180.73	70.12
2004	21.19	113.61	44.57	19.42	65.66	0.36	7.95	1.88	198.79	75.85
2005	33.65	115.21	65.63	20.68	66.11	0.32	6.84	1.66	235.17	74.93
2006	20.36	124.51	59.77	21.71	72.44	0.30	7.46	1.48	226.35	81.69
2007	21.22	109.14	56.36	22.67	77.00	0.29	6.44	1.43	209.40	85.16
2008	25.52	88.39	56.50	22.50	73.36	0.28	5.53	1.41	192.91	80.58
2009	34.84	111.27	58.12	23.20	75.40	0.27	6.89	1.41	227.44	83.97
2010	32.82	123.72	58.97	23.86	80.82	0.25	6.67	1.35	239.37	89.09
2011	44.75	85.35	55.74	24.02	72.70	0.25	6.54	1.34	209.86	80.83

2012	41.60	91.12	57.00	25.77	73.24	0.24	6.94	1.35	215.49	81.77
2013	48.69	92.64	53.50	24.06	68.70	0.23	7.78	1.31	218.89	78.03
2014	56.03	87.11	50.51	23.84	68.24	0.23	6.26	1.29	217.50	76.02
2015	52.96	78.89	46.65	23.81	67.61	0.22	7.29	1.16	202.31	76.28
2016	54.25	73.54	44.43	23.80	65.83	0.11	8.17	1.07	196.02	75.18

C. The discussion on Beijing's MFA data accounting results.

To ensure the credibility of the accounting method, the results of China's material flow data based on previous research which adopted in this paper [1], UNEP [2] and Wang, H.M., et al [3] have been compared (see Figure C.1).

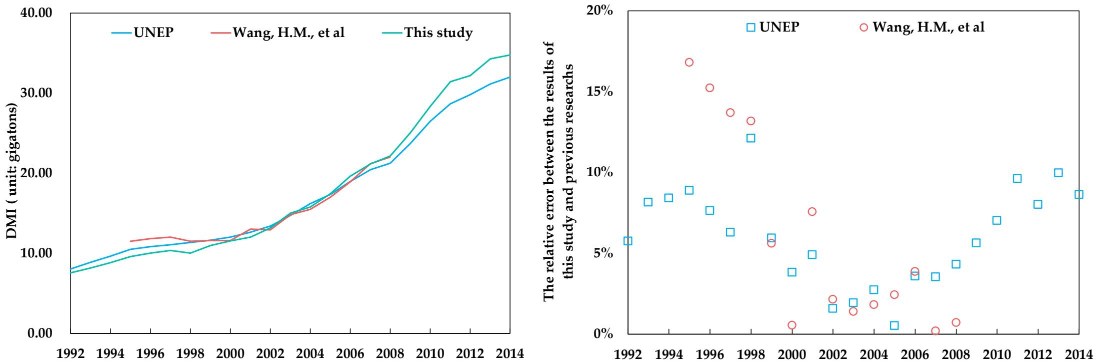

Figure C.1. Comparison of China's DMI accounting results of our results and previous studies (left) and their relative errors (right).

As can be seen from the Figure C.1, the difference of the accounting results of China's DMI between our results and other researches is relatively small (the relative error is in the range of 0.17% -16.79%). Therefore, the accounting results and methods have relative reliability. In order to illustrate the possibility and rationality of the difference between Beijing's DMI data and China's DMI data, the 10 provinces [1] were selected (see Figure C.2).

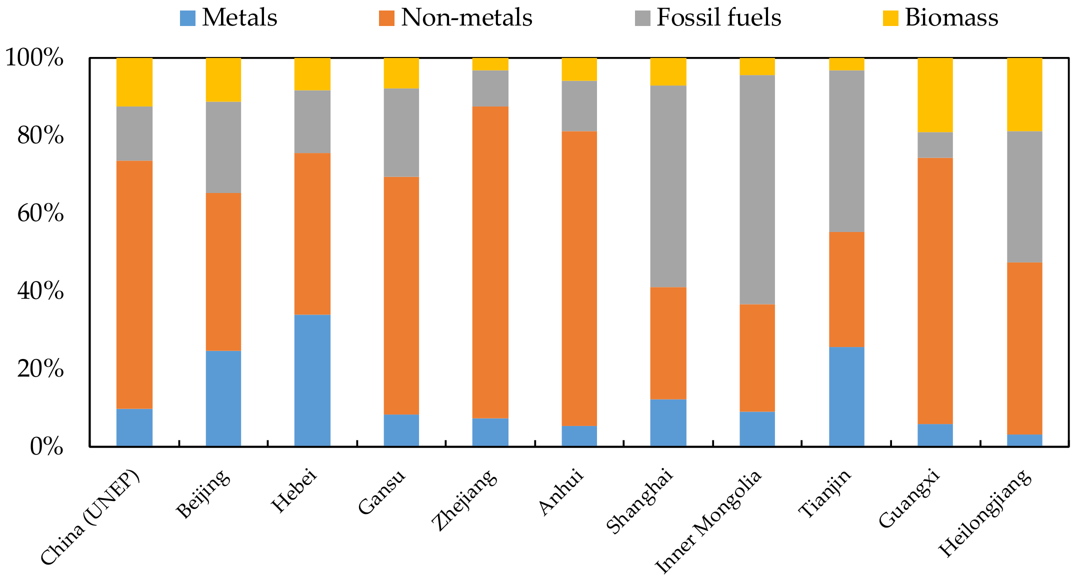

Figure C.2. Comparison of proportion of each material in DMI between China and 10 provinces.

It can be seen from the Figure C.2 that the ratio of material flows in each province is significantly different from that in China. National aggregate data offsets differences between provincial data. Beijing's DMI of metals accounts for a higher ratio of total DMI than in China and other provinces. The ratio of metals in DMI is composed of two parts: the ratio of domestic extraction material (DE) of metals in DMI and the ratio of metals import in DMI. In 2014, Beijing's DMI of metals accounted for 25.76% of the total DMI, of which DE of metals and metals imports accounted for 9.74% and 16.03% of the total DMI, respectively [1]. China's DMI of metals accounted for 9.81% of the total DMI, of which DE of metals and metals imports accounted for 6.37% and 3.44% respectively [2]. From this we can see that the ratio of Beijing's DMI of metals to total DMI is higher than that of China, which is mainly caused by Beijing's higher ratio of metals imports in total DMI. Since 2005, Beijing has implemented the relocation plan of the Capital Iron and Steel Plant, and completed the relocation plan in 2010. Crude steel output in Beijing decreased from 8.28 million tons in 2005 to 0.02 million tons in 2014 [1]. Beijing's metals consumption has become increasingly dependent on imports, which has led to a continuous rise in the ratio of Beijing 's metals imports in DMI. As a result, the ratio of Beijing's DMI of metals to total DMI was higher than in China.

Similarly, taking year 2014 as an example, DPO data of China and 10 provinces we calculated [1] were selected to illustrate the difference between Beijing's DPO data and China's DPO data (see Figure C.3).

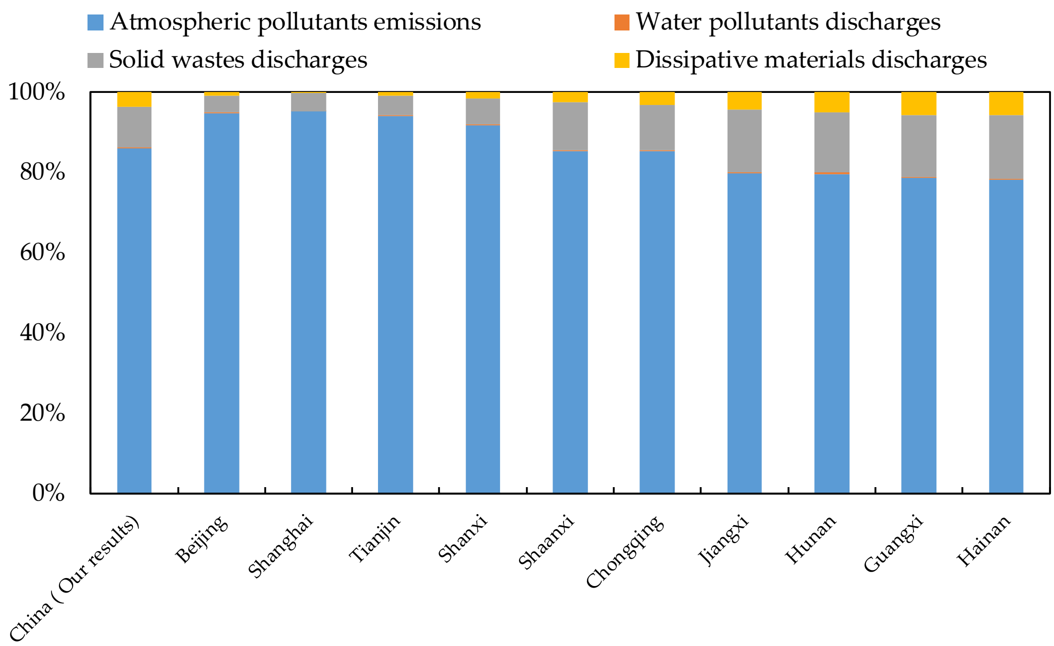

Figure C.3. Comparison of proportion of each material in DPO between China and 10 provinces.

As can be seen from the Figure C.3, there is a significant structure difference of DPO data between different provinces and China. Therefore, the difference between the DPO data structure of Beijing and the national DPO data structure is reasonable.

With the continuous clarification of the city's strategic positioning, significant achievements have been made in the control of the total amount of pollution emissions from the source and the treatment of the end discharges, which has greatly reduced the amount of various pollutants in Beijing. In terms of source control, a large number of high-pollution and high-consumption enterprises have been relocated from Beijing, which has greatly reduced Beijing's source emissions of pollutants. For example, Beijing has implemented the relocation plan of the Capital Iron and Steel Plant since 2005, and completed the relocation plan in 2010.

Crude steel output in Beijing decreased from 8.28 million tons in 2005 to 0.02 million tons in 2014 [4]. In terms of pollutant end treatment, a large amount of investment has been made in pollution control. In 2014, the investment in anti-pollution projects as percentage of GDP of Beijing was 1.94 times the national ratio [5]. Therefore, Beijing's final emissions of pollutants have been greatly reduced. For example, in 2014, the amount of industrial solid wastes generated in Beijing and China is 3256.2 million tons and 10.21 million tons, respectively. However, the industrial solid wastes utilization rate of Beijing was 87.7%, and the national ratio was only 62.1%, while Liaoning Province, which ranks third in terms of industrial solid wastes generated in the country, was only 37.1% [6]. Therefore, Beijing's industrial solid waste discharges is far below the national average discharges. Since Beijing leads the country in both source discharge and end treatment of pollutants, it is reasonable for Beijing's per capita pollutant discharge to be lower than the national average.

For these reasons, it is even more necessary for us to conduct more targeted material metabolism research at the city level, instead of using the national material metabolism level as the feature of each province.

References

1. Dai, T.J.; Wang, W.J. The characteristics and trends of socioeconomic metabolism in China. Journal of Industrial Ecology 2018, 22, 1228-1240.
2. UNEP. Available online: https://uneplive.unep.org/country/data/CN#charts (accessed on 25th December 2019).
3. Wang, H.M.; Yue, Q.; Lu, Z.W., et al. Resource use in growing China. Journal of Industrial Ecology 2012, 16, 481-492.
4. National Bureau of Statistics of China (NBSC). China statistical yearbook; China Statistics Press: Beijing, China, 1993-2017. (in Chinese).
5. National Bureau of Statistics of China (NBSC); Ministry of Ecology and Environment of China. China statistical yearbook on environment; China Statistics Press: Beijing, China, 2015. (in Chinese).
6. Ministry of Ecology and Environment of China. China environment yearbook; China Environment Yearbook Press: Beijing, China, 1993-2017. (in Chinese).

D. System dynamics sub-model flow diagram.

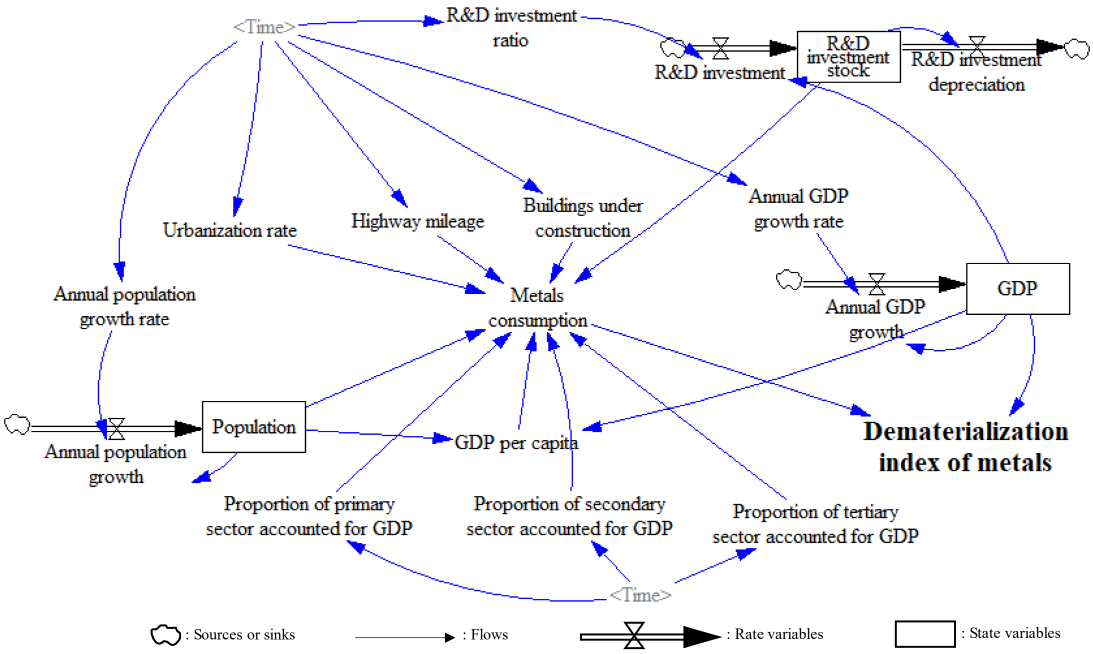

Figure D.1. Beijing's metals dematerialization development system dynamics model flow diagram.

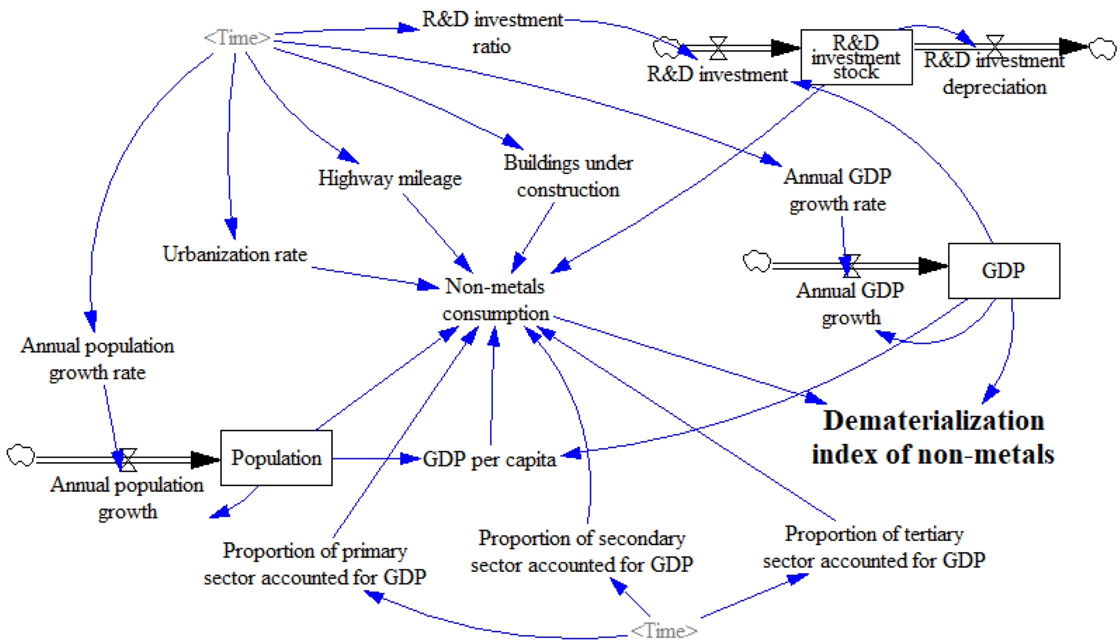

Figure D.2. Beijing's non-metals dematerialization development system dynamics model flow diagram.

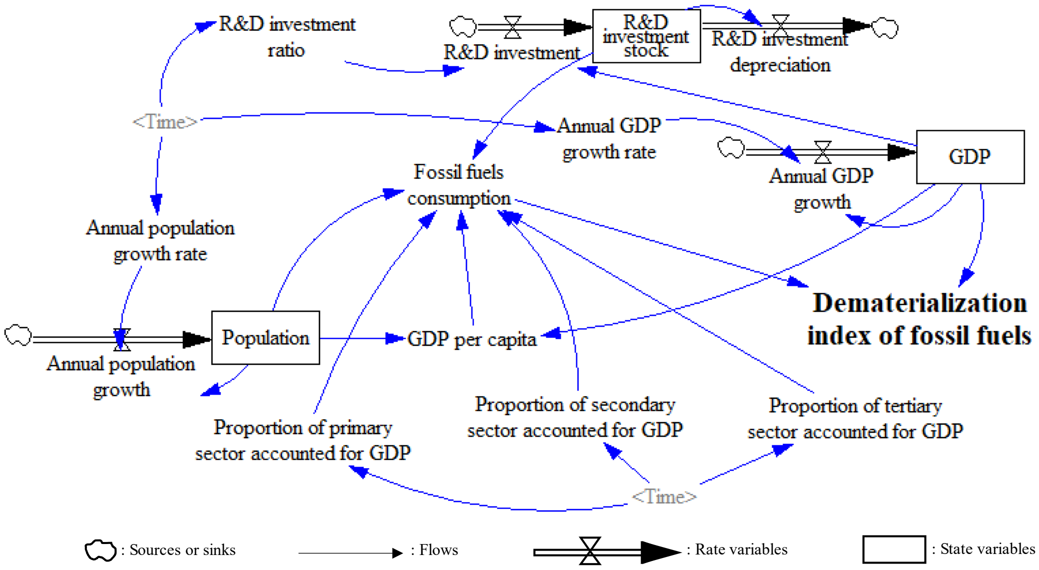

Figure D.3. Beijing's fossil fuels dematerialization development system dynamics model flow diagram.

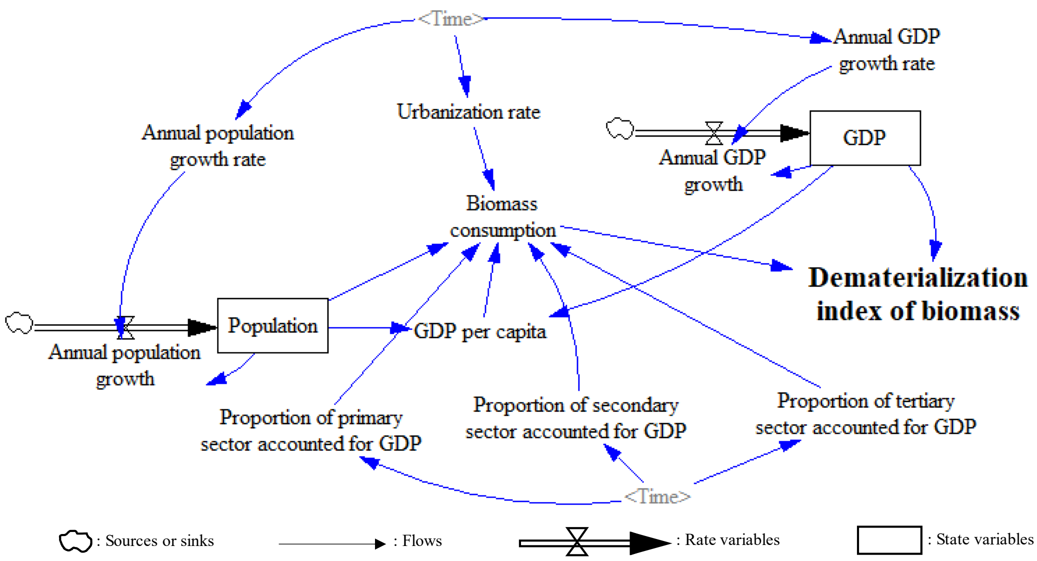

Figure D.4. Beijing's biomass dematerialization development system dynamics model flow diagram.

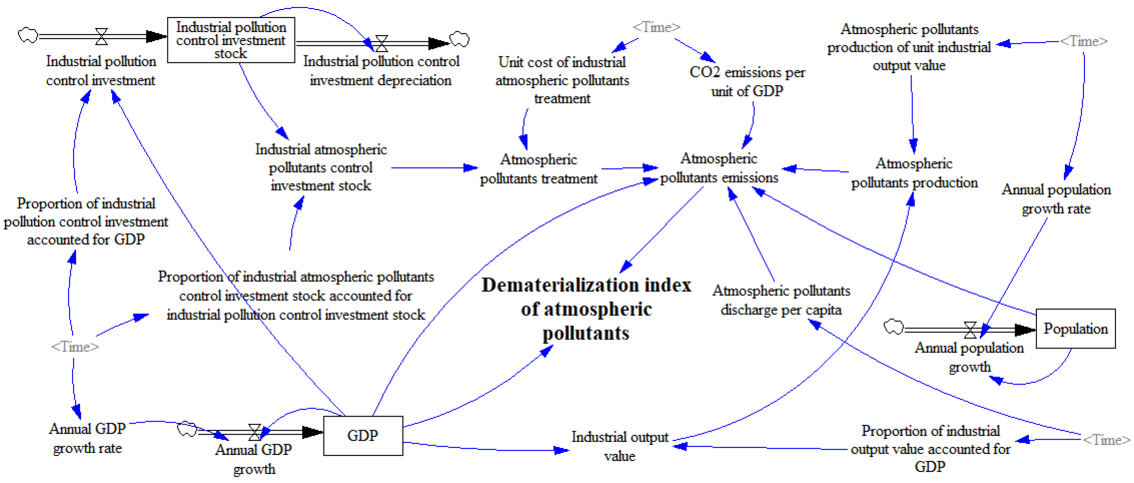

Figure D.5. Beijing's atmospheric pollutants dematerialization development system dynamics model flow diagram.

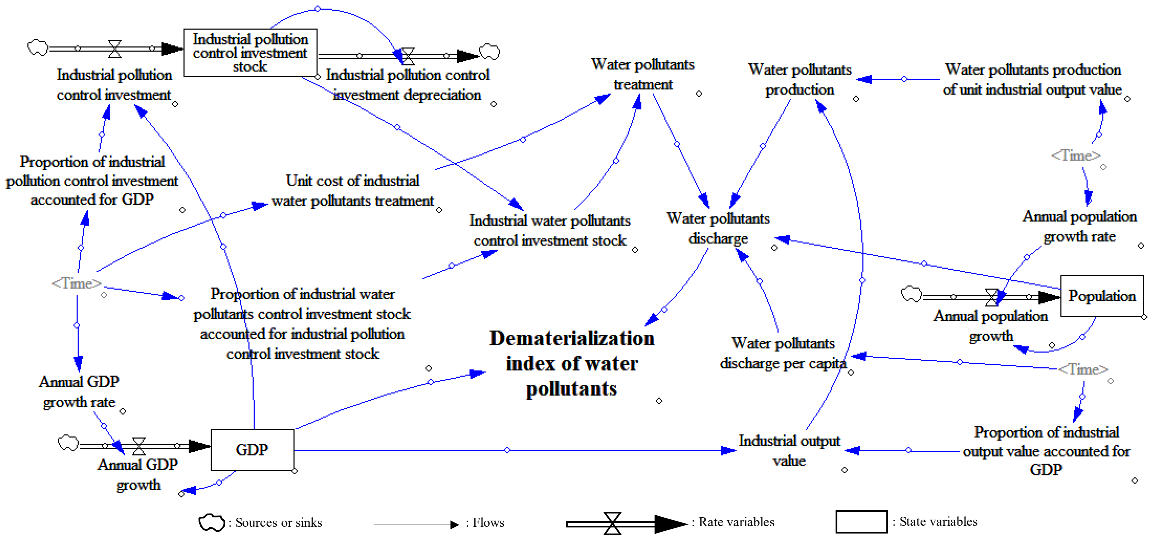

Figure D.6. Beijing's water pollutants dematerialization development system dynamics model flow diagram.

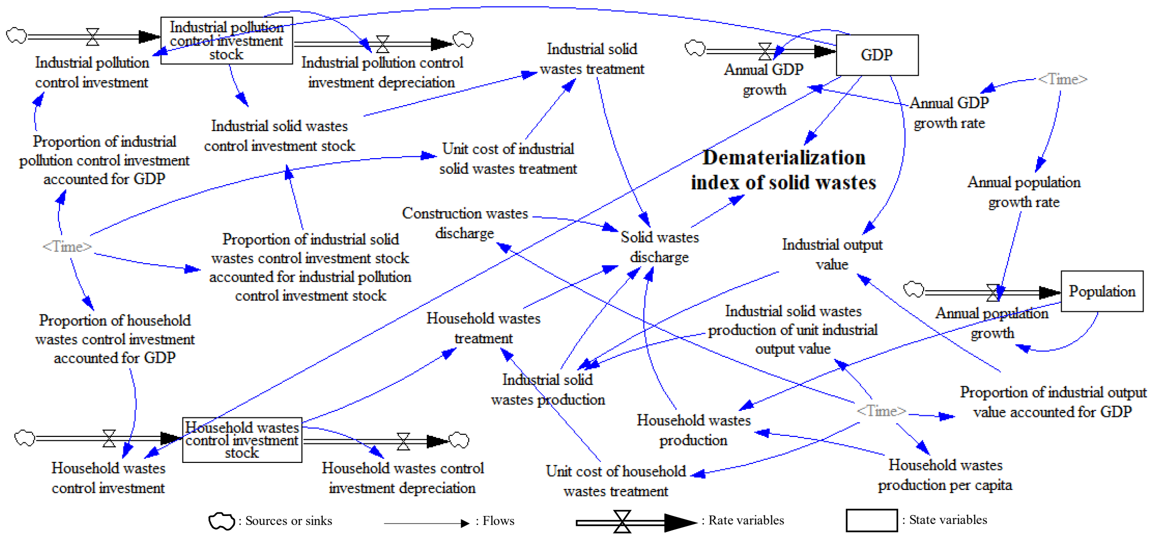

Figure D.7. Beijing's solid wastes dematerialization development system dynamics model flow diagram.

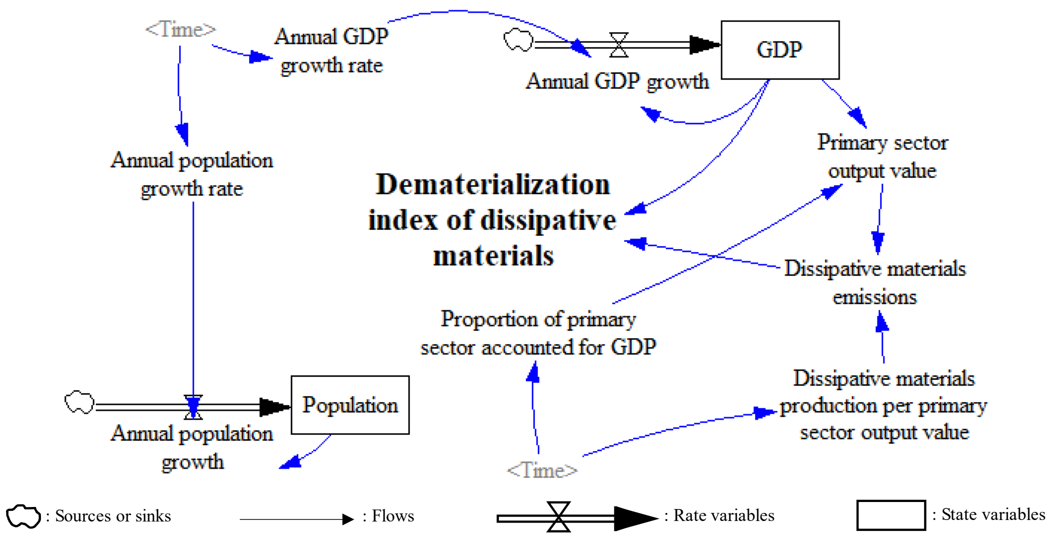

Figure D.8. Beijing's dissipative materials dematerialization development system dynamics model flow diagram.

E. All formulas and parameters of SD.

All the formulas and parameters of SD are as follows:

Dematerialization index of totality = IF THEN ELSE (GDP<=7.1e+06, 0, ((Total environmental pressure-DELAY1(Total environmental pressure, 1)) /DELAY1(Total environmental pressure, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Where, DELAY1 is the programming language of the Vensim software, which represents a first-order delay function with a delayed output function; 1 represents a delay time of 1 year.

Total environmental pressure = 0.5*DMI+0.5*DPO

Dematerialization index of metals = IF THEN ELSE (GDP<=7.1e+06, 0, ((Metals consumption-DELAY1(Metals consumption, 1)) /DELAY1(Metals consumption, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Metals consumption = 4.73647e+17*Population^(1.824)*GDP per capita^1.414*Proportion of primary sector accounted for GDP^0.354*Proportion of secondary sector accounted for GDP^(-1.027)*Proportion of tertiary sector accounted for GDP^(-6.292)*Urbanization rate^7.018*("R&D investment stock"/10000)^0.17*Buildings under construction^(0.076)*Highway mileage^(-1.806)

Dematerialization index of non-metals = IF THEN ELSE (GDP<=7.1e+06, 0, ((Non-metals consumption-DELAY1(Non-metals consumption, 1)) /DELAY1(Non-metals consumption, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Non-metals consumption = 5.25e-12*Population^ (0.044) *GDP per capita^1.055*Proportion of primary sector accounted for GDP^ (0.006) *Proportion of secondary sector accounted for GDP^4.367*Proportion of tertiary sector accounted for GDP^ (4.308) *Urbanization rate^1.536*("R&D investment stock"/10000) ^ (0.019) *Buildings under construction^ (-0.362) *Highway mileage^ (0.514)

Dematerialization index of fossil fuels = IF THEN ELSE (GDP<=7.1e+06, 0, ((Fossil fuels consumption-DELAY1(Fossil fuels consumption, 1)) /DELAY1(Fossil fuels consumption, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Fossil fuels consumption = 1.579*Population^ (-0.181) *GDP per capita^ (-0.19) *Proportion of primary sector accounted for GDP^ (0.029) *Proportion of secondary sector accounted for GDP^ (1.347) *Proportion of tertiary sector accounted for GDP^ (1.674) *Urbanization rate^8.399*("R&D investment stock"/10000) ^ (-0.063)

Dematerialization index of biomass = IF THEN ELSE (GDP<=7.1e+06, 0, ((Biomass consumption-DELAY1(Biomass consumption, 1)) /DELAY1(Biomass consumption, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Biomass consumption = 0.72*Population^(0.484)*GDP per capita^(-0.164)*Proportion of primary sector accounted for GDP^(0.065)*Proportion of secondary sector accounted for GDP^(0.235)*Proportion of tertiary sector accounted for GDP^(0.957)*Urbanization rate^1.826

GDP = INTEG (Annual GDP growth, 7.1e+06)

INTEG is the programming language of Vensim software, which represents the state variable equation and has an accumulation function; 7.1e+06 is the initial value of the state variable GDP.

Annual GDP growth = GDP*Annual GDP growth rate

Annual GDP growth rate = WITH LOOKUP (Time, ([(1993,-1)-(2050,1)],(1993,0.123),(1994,0.137),(1995,0.12),(1996,0.09),(1997,0.101),(1998,0.095),(1999,0.109),(2000,0.118),(2001,0.117),(2002,0.115),(2003,0.11),(2004,0.141),(2005,0.118),(2006,0.12),(2007,0.145),(2008,0.091),(2009,0.102),(2010,0.103),(2011,0.081),(2012,0.077),(2013,0.077),(2014,0.073),(2015,0.069),(2016,0.068)))

Population = INTEG (Annual population growth, 1102)

Annual population growth = Population*Annual population growth rate
Annual population growth rate = WITH LOOKUP (Time, ([(1993,-1)-(2050,1)],(1993,0.009),(1994,0.012),(1995,0.112),(1996,0.006),(1997,-0.015),(1998,0.005),(1999,0.009),(2000,0.099),(2001,0.001),(2002,0.029),(2003,0.023),(2004,0.025),(2005,0.03),(2006,0.041),(2007,0.047),(2008,0.057),(2009,0.05),(2010,0.055),(2011,0.029),(2012,0.025),(2013,0.022),(2014,0.017),(2015,0.009),(2016,0.001)))
GDP per capita = (GDP/10000)/Population
R&D investment stock = INTEG (R&D investment-R&D investment depreciation, 79500)
R&D investment = GDP*R&D investment ratio
R&D investment depreciation = R&D investment stock*0.15
Proportion of primary sector accounted for GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,100)],(1992,6.9),(1993,6),(1994,5.8),(1995,4.8),(1996,4.2),(1997,3.7),(1998,3.2),(1999,2.9),(2000,2.5),(2001,2.1),(2002,1.9),(2003,1.6),(2004,1.4),(2005,1.2),(2006,1),(2007,1),(2008,1),(2009,0.9),(2010,0.9),(2011,0.8),(2012,0.8),(2013,0.8),(2014,0.7),(2015,0.6),(2016,0.5)))
Where, WITH LOOKUP is a user-defined function in the system dynamics program, usually represented by a chart. Generally used to reflect the special nonlinear relationship between two variables.
Proportion of secondary sector accounted for GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,100)],(1992,48.6),(1993,47.2),(1994,45.1),(1995,42.7),(1996,39.7),(1997,37.4),(1998,35.1),(1999,33.6),(2000,32.4),(2001,30.4),(2002,28.6),(2003,29.3),(2004,30.3),(2005,28.6),(2006,26.7),(2007,25.2),(2008,23.2),(2009,23),(2010,23.5),(2011,22.6),(2012,22.1),(2013,21.6),(2014,21.3),(2015,19.7),(2016,19.3)))
Proportion of tertiary sector accounted for GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,100)],(1992,44.5),(1993,46.8),(1994,49.1),(1995,52.5),(1996,56.2),(1997,58.9),(1998,61.7),(1999,63.5),(2000,65.1),(2001,67.4),(2002,69.5),(2003,69),(2004,68.3),(2005,70.1),(2006,72.3),(2007,73.9),(2008,75.8),(2009,76.1),(2010,75.7),(2011,76.6),(2012,77.1),(2013,77.6),(2014,78),(2015,79.7),(2016,80.2)))
Industrial output value = GDP*(Proportion of industrial output value accounted for GDP/100)
Proportion of industrial output value accounted for GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,100)],(1992,41.3),(1993,38.3),(1994,36.5),(1995,35),(1996,32.1),(1997,30.5),(1998,28.1),(1999,26.9),(2000,26.6),(2001,25.1),(2002,23.5),(2003,24.2),(2004,25.5),(2005,24.2),(2006,22.3),(2007,21),(2008,19.1),(2009,18.9),(2010,19.5),(2011,18.7),(2012,18.4),(2013,18),(2014,17.6),(2015,16.2),(2016,15.7)))
Primary sector output value = GDP*(Proportion of primary sector accounted for GDP/100)
Urbanization rate = WITH LOOKUP (Time, ([(1992,0)-(2050,1)],(1992,0.7432),(1993,0.7473),(1994,0.752),(1995,0.7563),(1996,0.7606),(1997,0.7648),(1998,0.7689),(1999,0.7729),(2000,0.7754),(2001,0.7806),(2002,0.7856),(2003,0.7905),(2004,0.7953),(2005,0.8362),(2006,0.8433),(2007,0.845),(2008,0.849),(2009,0.85),(2010,0.8596),(2011,0.862),(2012,0.862),(2013,0.863),(2014,0.8635),(2015,0.865),(2016,0.865)))
Buildings under construction = WITH LOOKUP (Time, ([(1992,0)-(2050,50000)],(1992,3126.8),(1993,3607.5),(1994,4460.9),(1995,5524.3),(1996,5633.2),(1997,5819.4),(1998,6496.1),(1999,6556.5),(2000,6995.9),(2001,8303.3),(2002,9697.7),(2003,11262.2),(2004,13121.9),(2005,14096.2),(2006,14069.2),(2007,14146.7),(2008,14145.3),(2009,14380.6),(2010,15572.1),(2011,18065.2),(2012,20045.4),(2013,21526),(2014,21677.7),(2015,20009.1),(2016,22721.4)))
Highway mileage = WITH LOOKUP (Time, ([(1992,0)-(2050,50000)],(1992,10827),(1993,11260),(1994,11532),(1995,11811),(1996,12084),(1997,12306),(1998,12498),(1999,12825),(2000,13600),(2001,13891),(2002,14359),(2003,14453),(2004,14630),(2005,14696),(2006,20503),(2007,20754),(2008,20340),(2009,20755),(2010,21114),(2011,21347),(2012,21492),(2013,21673),(2014,21849),(2015,21885),(2016,22026)))

Dematerialization index of atmospheric pollutants = IF THEN ELSE (GDP<=7.1e+06, 0, ((Atmospheric pollutants emissions-DELAY1(Atmospheric pollutants emissions, 1)) /DELAY1(Atmospheric pollutants emissions, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Atmospheric pollutants emissions = GDP*CO_2 emissions per unit of GDP+Atmospheric pollutants production-Atmospheric pollutants treatment+Population*Atmospheric pollutants discharge per capita

Dematerialization index of water pollutants = IF THEN ELSE (GDP<=7.1e+06, 0, ((Water pollutants discharge-DELAY1(Water pollutants discharge, 1)) /DELAY1(Water pollutants discharge, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Water pollutants discharge = IF THEN ELSE (Water pollutants production>=Water pollutants treatment, Water pollutants Production-Water pollutants treatment, 0) +Population*Water pollutants discharge per capita

Dematerialization index of solid wastes = IF THEN ELSE (GDP<=7.1e+06, 0, ((Solid wastes discharge-DELAY1(Solid wastes discharge, 1)) /DELAY1(Solid wastes discharge, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Solid wastes discharge = IF THEN ELSE (Industrial solid wastes production>=industrial solid wastes treatment, Industrial solid wastes production-industrial solid wastes treatment, 0) +IF THEN ELSE (Household wastes production>=Household wastes treatment, Household wastes Production-Household wastes treatment, 0) +Construction wastes discharge

Dematerialization index of dissipative materials = IF THEN ELSE (GDP<=7.1e+06, 0, ((Dissipative materials emissions-DELAY1(Dissipative materials emissions, 1)) /DELAY1(Dissipative materials emissions, 1)) / ((GDP-DELAY1(GDP, 1)) /DELAY1(GDP, 1)))

Dissipative materials emissions = (Dissipative materials production per primary sector output value*Primary sector output value)/10000

Industrial pollution control investment stock = INTEG (Industrial pollution control investment-Industrial pollution control investment depreciation, 19996.8)

Industrial pollution control investment = GDP*Proportion of industrial pollution control investment accounted for GDP

Industrial pollution control investment depreciation = Industrial pollution control investment stock*0.05

Household wastes control investment stock = INTEG (Household wastes control investment-Household wastes control investment depreciation, 3265.01)

Household wastes control investment = GDP*Proportion of household wastes control investment accounted for GDP

Household wastes control investment depreciation = Household wastes control investment stock*0.05

Proportion of industrial pollution control investment accounted for GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,0.01)],(1992,0.00282),(1993,0.001401),(1994,0.001401),(1995,0.001025),(1996,0.001192),(1997,0.001136),(1998,0.001201),(1999,0.002265),(2000,0.001429),(2001,0.001327),(2002,0.001292),(2003,0.001426),(2004,0.000797),(2005,0.001623),(2006,0.001472),(2007,0.000721),(2008,0.00076),(2009,0.00027),(2010,0.000169),(2011,8.17e-05),(2012,0.000204),(2013,0.000266),(2014,0.000405),(2015,0.000412),(2016,0.000546)))

Proportion of household wastes control investment accounted for GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,0.1)],(1992,0.000460445),(1993,0.000460445),(1994,0.000460445),(1995,0.000460445),(1996,0.000460445),(1997,0.000460445),(1998,0.000460445),(1999,0.000460445),(2000,0.000460445),(2001,0.000460445),(2002,0.000460445),(2003,0.000460445),(2004,0.000460445),(2005,0.

000549129),(2006,0.00050868),(2007,0.00269501),(2008,2.45305e-05),(2009,0.00234398),(2010,0.000932376),(2011,0.0164419),(2012,0.000485362),(2013,0.000629316),(2014,0.001572),(2015,0.00226895),(2016,0.00238462)))

Proportion of industrial atmospheric pollutants control investment stock accounted for industrial pollution control investment stock = WITH LOOKUP (Time, ([(1992,0)-(2050,1)],(1992,0.7411),(1993,0.667128),(1994,0.628483),(1995,0.617136),(1996,0.618455),(1997,0.623586),(1998,0.622653),(1999,0.674981),(2000,0.68937),(2001,0.691501),(2002,0.723366),(2003,0.755223),(2004,0.749494),(2005,0.787224),(2006,0.807514),(2007,0.787686),(2008,0.798025),(2009,0.804326),(2010,0.807239),(2011,0.801455),(2012,0.803878),(2013,0.803083),(2014,0.816266),(2015,0.829759),(2016,0.846028)))

Proportion of industrial water pollutants control investment stock accounted for industrial pollution control investment stock = WITH LOOKUP (Time, ([(1992,0)-(2050,1)],(1992,0.2242),(1993,0.3053),(1994,0.3477),(1995,0.3209),(1996,0.3162),(1997,0.3163),(1998,0.3051),(1999,0.2622),(2000,0.259),(2001,0.263),(2002,0.2352),(2003,0.2081),(2004,0.2094),(2005,0.1777),(2006,0.1617),(2007,0.1825),(2008,0.1752),(2009,0.17),(2010,0.1678),(2011,0.1738),(2012,0.1709),(2013,0.1732),(2014,0.1616),(2015,0.1501),(2016,0.1357)))

Proportion of industrial solid wastes control investment stock accounted for industrial pollution control investment stock = WITH LOOKUP (Time, ([(1992,0)-(2030,1)],(1992,0.0347),(1993,0.0276),(1994,0.0238),(1995,0.062),(1996,0.0653),(1997,0.0601),(1998,0.0722),(1999,0.0629),(2000,0.0516),(2001,0.0455),(2002,0.0415),(2003,0.0367),(2004,0.0411),(2005,0.035),(2006,0.0308),(2007,0.0298),(2008,0.0268),(2009,0.0257),(2010,0.025),(2011,0.0247),(2012,0.0252),(2013,0.0237),(2014,0.0221),(2015,0.0202),(2016,0.0183)))

Industrial atmospheric pollutants control investment stock = Industrial pollution control investment stock*Proportion of industrial atmospheric pollutants control investment stock accounted for industrial pollution control investment stock

Industrial water pollutants control investment stock = Industrial pollution control investment stock*Proportion of industrial water pollutants control investment stock accounted for industrial pollution control investment stock

Industrial solid wastes control investment stock = Industrial pollution control investment stock*Proportion of industrial solid wastes control investment stock accounted for industrial pollution control investment stock

Atmospheric pollutants treatment = (Industrial atmospheric pollutants control investment stock/Unit cost of industrial atmospheric pollutants treatment)/10000

Unit cost of industrial atmospheric pollutants treatment = WITH LOOKUP (Time, ([(1992,0)-(2050,1)],(1992,0.0084),(1993,0.0124),(1994,0.0124),(1995,0.0109),(1996,0.0133),(1997,0.0148),(1998,0.018),(1999,0.0278),(2000,0.036),(2001,0.0381),(2002,0.0488),(2003,0.053),(2004,0.0441),(2005,0.0484),(2006,0.0497),(2007,0.0563),(2008,0.0747),(2009,0.087),(2010,0.0837),(2011,0.0612),(2012,0.0523),(2013,0.0524),(2014,0.0731),(2015,0.1696)))

Water pollutants treatment = (Industrial water pollutants control investment stock/Unit cost of industrial water pollutants treatment)/10000

Unit cost of industrial water pollutants treatment = WITH LOOKUP (Time, ([(1992,0)-(2050,10)],(1992,0.099),(1993,0.1209),(1994,0.1538),(1995,0.2114),(1996,0.3375),(1997,0.3857),(1998,0.391261),(1999,0.461),(2000,0.2549),(2001,0.7815),(2002,0.7219),(2003,1.0242),(2004,1.0487),(2005,1.1603),(2006,1.0123),(2007,1.2502),(2008,1.1587),(2009,1.0506),(2010,1.2186),(2011,0.6169),(2012,0.7806),(2013,0.8129),(2014,0.8334),(2015,0.8195)))

Industrial solid wastes treatment = Industrial solid wastes control investment stock/Unit cost of industrial solid wastes treatment

Unit cost of industrial solid wastes treatment = WITH LOOKUP (Time, ([(1992,0)-(2050,20)],(1992,0.9443),(1993,1.0261),(1994,1.0831),(1995,3.0186),(1996,3.5598),(1997,3.8202),(1998,5.4229),(1999,6.2197),(2000,6.0686),(2001,6.0255),(2002,6.6771),(2003,5.9276),(2004,6.

565),(2005,6.8243),(2006,6.2575),(2007,6.8989),(2008,6.8807),(2009,6.1488),(2010,5.7246),(2011,3.0225),(2012,6.1941),(2013,6.2229),(2014,6.1807),(2015,8.4539),(2016,9.3507)))

Atmospheric pollutants production = (Atmospheric pollutants production of unit industrial output value*Industrial output value)/10000

Atmospheric pollutants production of unit industrial output value = WITH LOOKUP (Time, ([(1992,0)-(2050,10)],(1992,0.7358),(1993,0.656),(1994,0.656),(1995,0.7396),(1996,0.7657),(1997,0.8009),(1998,0.7905),(1999,0.7222),(2000,0.6042),(2001,0.6062),(2002,0.5372),(2003,0.5122),(2004,0.5348),(2005,0.5657),(2006,0.6266),(2007,0.5241),(2008,0.4261),(2009,0.3368),(2010,0.3016),(2011,0.378),(2012,0.4137),(2013,0.394),(2014,0.2863),(2015,0.1344)))

Water pollutants production = (Water pollutants production of unit industrial output value*Industrial output value)/10000

Water pollutants production of unit industrial output value = WITH LOOKUP (Time, ([(1992,0)-(2050,0.1)],(1992,0.0515),(1993,0.0559),(1994,0.0397),(1995,0.035),(1996,0.0188),(1997,0.0272),(1998,0.0257),(1999,0.0217),(2000,0.0326),(2001,0.0161),(2002,0.0147),(2003,0.0092),(2004,0.0078),(2005,0.00697),(2006,0.0074),(2007,0.0063),(2008,0.0066),(2009,0.0064),(2010,0.0048),(2011,0.0088),(2012,0.0065),(2013,0.006),(2014,0.0055),(2015,0.0054)))

Industrial solid wastes production = (Industrial output value*Industrial solid wastes production of unit industrial output value)/10000

Industrial solid wastes production of unit industrial output value = WITH LOOKUP (Time, ([(1992,0)-(2050,10)],(1992,2.8444),(1993,2.846),(1994,2.9389),(1995,3.0091),(1996,3.1453),(1997,3.0417),(1998,3.2952),(1999,2.9215),(2000,2.5923),(2001,2.4524),(2002,2.1775),(2003,2.1456),(2004,1.9607),(2005,1.7557),(2006,1.8633),(2007,1.6246),(2008,1.486),(2009,1.4633),(2010,1.3132),(2011,2.2475),(2012,1.0401),(2013,0.9335),(2014,0.87),(2015,0.6149),(2016,0.5265)))

CO_2 emissions per unit of GDP = WITH LOOKUP (Time, ([(1992,0)-(2050,1)],(1992,0.00066),(1993,0.00062),(1994,0.00056),(1995,0.00051),(1996,0.00051),(1997,0.00045),(1998,0.00042),(1999,0.00038),(2000,0.00035),(2001,0.00032),(2002,0.00028),(2003,0.00026),(2004,0.00025),(2005,0.00023),(2006,0.00022),(2007,0.00021),(2008,0.00018),(2009,0.00017),(2010,0.00016),(2011,0.00014),(2012,0.00013),(2013,0.00011),(2014,0.0001),(2015,9e-05),(2016,9e-05)))

Atmospheric pollutants discharge per capita = WITH LOOKUP (Time, ([(1992,0)-(2050,0.1)],(203,0.0039),(1993,0),(1994,0),(1995,0),(1996,0),(1997,0),(1998,0.0120212),(1999,0.00749841),(2000,0.00911722),(2001,0.00867679),(2002,0.00836261),(2003,0.00762363),(2004,0.00716678),(2005,0.00812744),(2006,0.0160525),(2007,0.0164081),(2008,0.012253),(2009,0.0113441),(2010,0.0101427),(2011,0.00846954),(2012,0.0078637),(2013,0.00744681),(2014,0.00743494),(2015,0.00790419)))

Water pollutants discharge per capita = WITH LOOKUP (Time, ([(1992,0)-(2050,0.1)],(1992,0.0589),(1993,0.0548),(1994,0.0513),(1995,0.0447),(1996,0.0426),(1997,0.041),(1998,0.0353),(1999,0.0322),(2000,0.0313),(2001,0.0323),(2002,0.0283),(2003,0.0246),(2004,0.0233),(2005,0.02),(2006,0.0183),(2007,0.017),(2008,0.0154),(2009,0.0144),(2010,0.0127),(2011,0.0121),(2012,0.0117),(2013,0.0109),(2014,0.0105),(2015,0.0097) ,(2016,0.0049)))

Construction wastes discharge = WITH LOOKUP (Time, ([(1992,0)-(2050,2000)],(1992,646),(1993,821),(1994,791),(1995,705),(1996,957),(1997,767),(1998,860),(1999,706),(2000,577),(2001,611),(2002,688),(2003,789),(2004,781),(2005,593),(2006,700),(2007,626),(2008,537),(2009,677),(2010,666),(2011,654),(2012,694),(2013,779),(2014,626),(2015,730),(2016,817)))

Household wastes treatment = Household wastes control investment stock/Unit cost of household wastes treatment

Unit cost of household wastes treatment = WITH LOOKUP (Time, ([(1992,0)-(2050,2000)],(1992,11.6572),(1993,23.3316),(1994,34.9015),(1995,46.857),(1996,66.0006),(1997,82.1099),(1998,99.2714),(1999,116.569),(2000,163.522),(2001,153.342),(2002,166.815),(2003,135.205),(2004,143.337),(2005,182.269),(2006,177.102),(2007,318.252),(2008,278.229),(2009,425.004),(2010,491.502),(2011,1854.12),(2012,1766.84),(2013,1678.24),(2014,1602.22),(2015,1617.89),(2016,1600.02)))

Household wastes production = Population*Household wastes production per capita

Household wastes production per capita = WITH LOOKUP (Time, ([(1992,0)-(2050,0.7)],(1992,0.38),(1993,0.38),(1994,0.38),(1995,0.38),(1996,0.38),(1997,0.38),(1998,0.38),(1999,0.14),(2000,0.38),(2001,0.38),(2002,0.38),(2003,0.29),(2004,0.38),(2005,0.38),(2006,0.38),(2007,0.38),(2008,0.38),(2009,0.38),(2010,0.38),(2011,0.38),(2012,0.38),(2013,0.38),(2014,0.38),(2015,0.38),(2016,0.32)))

Dissipative materials production per primary sector output value = WITH LOOKUP (Time, ([(1992,0)-(2050,10)],(1992,3.376),(1993,3.098),(1994,3.057),(1995,3.029),(1996,3.134),(1997,3.227),(1998,3.359),(1999,3.388),(2000,3.996),(2001,4.606),(2002,5.064),(2003,5.386),(2004,5.157),(2005,4.753),(2006,4.546),(2007,3.834),(2008,3.463),(2009,3.48),(2010,3.02),(2011,3.127),(2012,2.922),(2013,2.639),(2014,2.756),(2015,2.706),(2016,2.811)))

F. The best dematerialization scenarios for eight materials during 2017–2030.

Table F. The best dematerialization scenarios for eight materials during 2017–2030.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Metals	IR (1.40)	IR (1.48)	IR (1.55)	BAU/EG (1.58)	BAU/EG (1.60)	BAU/EG (1.65)	BAU/EG (1.66)	BAU/EG (1.68)	BAU/EG (1.70)	BAU/EG (1.72)	BAU/EG (1.76)	BAU/EG (1.78)	BAU/EG (1.80)	BAU/EG (1.83)
Non-metals	IR (-0.77)	IR (-0.86)	IR (-0.95)	IR (-1.05)	IR (-1.16)	IR (-1.57)	IR (-1.71)	IR (-1.87)	IR (-2.04)	IR (-2.23)	IR (-2.74)	IR (-2.98)	IR (-3.26)	IR (-3.57)
Fossil fuels	IR (-0.76)	IR (-0.80)	IR (-0.85)	IR (-0.89)	IR (-0.93)	IR (-1.08)	IR (-1.13)	IR (-1.19)	IR (-1.24)	IR (-1.31)	IR (-1.49)	IR (-1.57)	IR (-1.66)	IR (-1.77)
Biomass	IR (-0.15)	IR (-0.16)	IR (-0.17)	IR (-0.17)	IR (-0.18)	IR (-0.19)	IR (-0.20)	IR (-0.21)	IR (-0.22)	IR (-0.24)	IR (-0.26)	IR (-0.27)	IR (-0.29)	IR (-0.31)
Atmospheric pollutants	ESD (0.28)	ESD (0.20)	ESD (0.16)	ESD (0.12)	ESD (0.07)	EG (-0.13)	EG (-0.23)	EG (-0.34)	EG (-0.48)	EG (-0.65)	EG (-1.05)	EG (-1.36)	EG (-1.79)	EG (-2.39)
Water pollutants	ESD (-0.15)	EG (-0.32)	EG (-0.53)	EG (-0.59)	ESD (-0.29)	ESD (-0.47)	BAU/IR (-0.22)	BAU/IR/EG (0.02)	BAU/IR/EG (0.02)	BAU/IR/EG (0.02)	BAU/IR/EG (0.02)	BAU/IR/EG (0.02)	BAU/IR/EG (0.02)	BAU/IR/EG (0.02)
Solid wastes	ESD (-0.70)	BAU/IR/EG (0.48)	BAU/IR/EG (0.51)	BAU/IR/EG (0.49)	BAU/IR/EG (0.48)	BAU/IR/EG (0.52)	BAU/IR/EG (0.51)	BAU/IR/EG (0.49)	BAU/IR/EG (0.48)	BAU/IR/EG (0.47)	BAU/IR/EG (0.49)	BAU/IR/EG (0.48)	BAU/IR/EG (0.47)	BAU/IR/EG (0.46)
Dissipative materials	ESD (0.61)	ESD (0.58)	ESD (0.57)	ESD (0.56)	ESD (0.55)	ESD (0.48)	ESD (0.46)	ESD (0.45)	ESD (0.43)	ESD (0.41)	ESD (0.34)	ESD (0.32)	ESD (0.29)	ESD (0.27)

Note: The numbers in brackets are the optimal dematerialization index values for the year.