# Supporting Information for:

## XXXX XXXX1, XXXX XXX2, XXXX XXXXXX3

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**Number of pages: , Number of tables: , Number of figures:**

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## 1 The current state of wastewater and sludge treatment in China

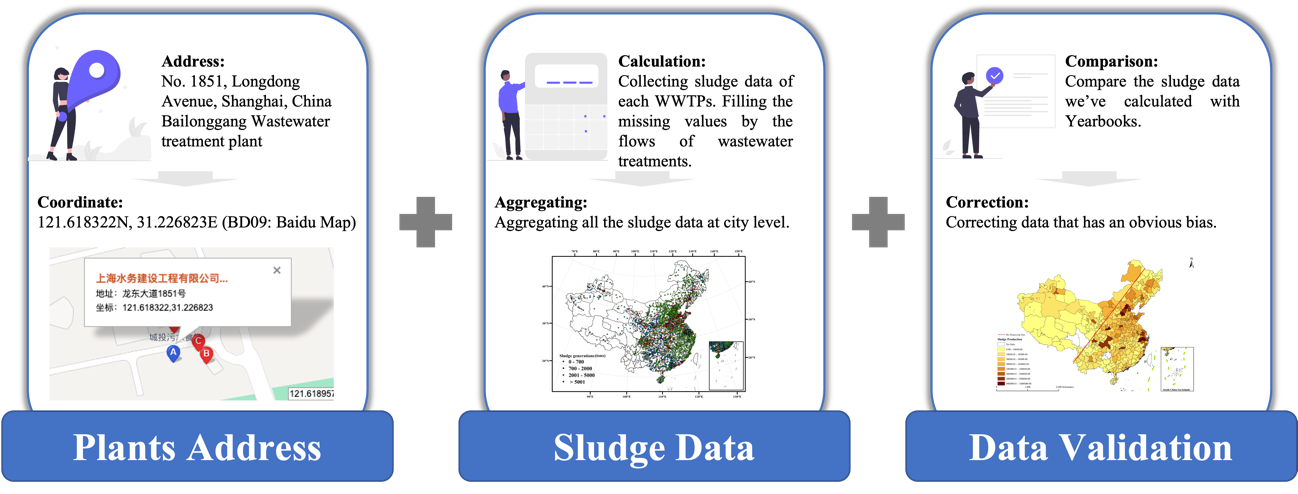
## 2 Methodology

### 2.1 Data Preparation

#### 2.1.1 Sludge data calculation

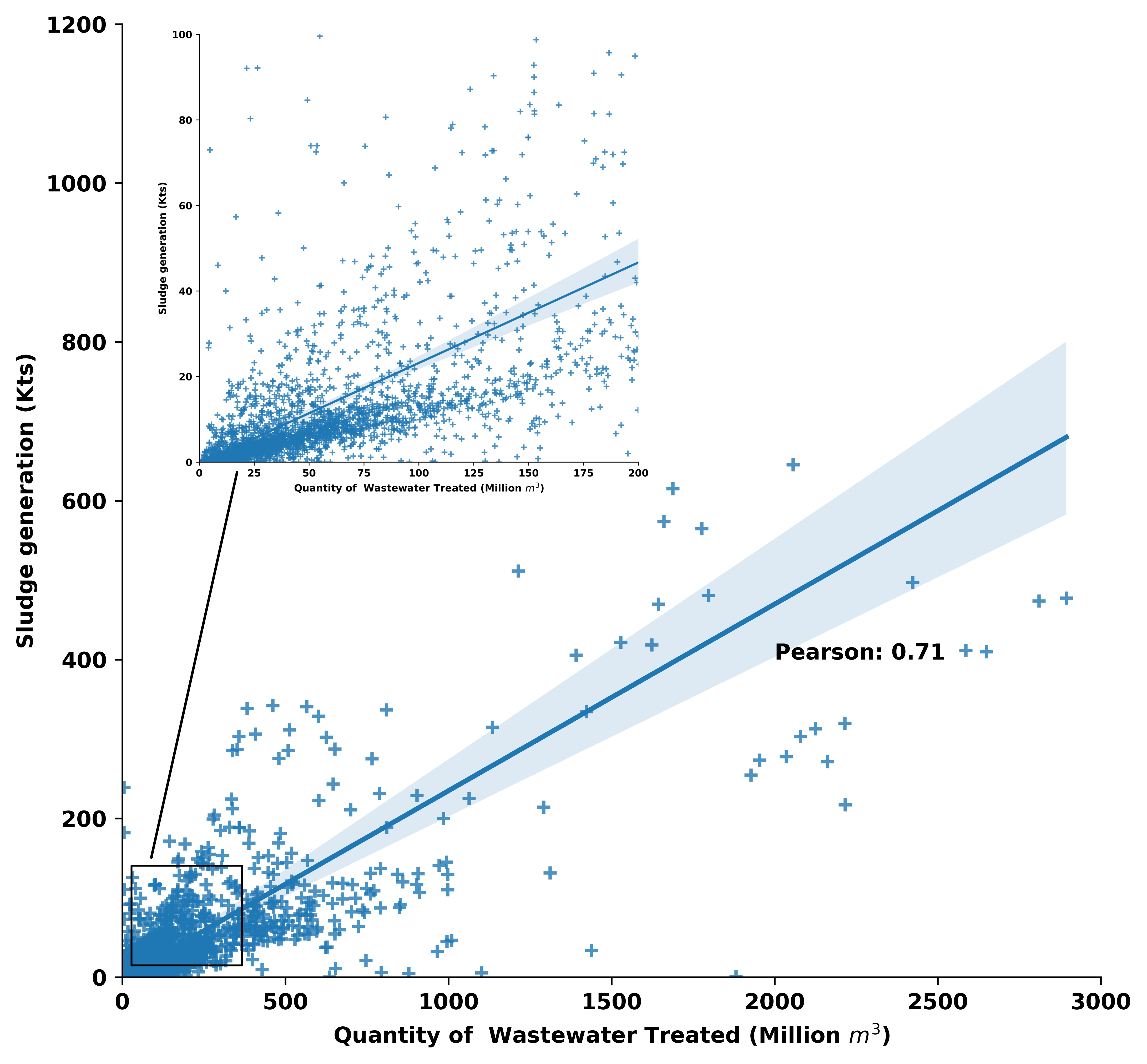
Sludge data in China are collected by the Ministry of Housing and Urban-Rural Development of the People’s Republic of China (MHURD). MHURD publishes *Urban Construction Yearbook* every year which has yearly sludge production in each city. However, some data from this *Yearbook* has an obvious bias. For example

To eliminate the bias and inconsistency, we collected the information from *Urban Drainage Yearbook* which contains the yearly treatment data of all the wastewater treatment plants (WWTPs) in China. We used the name of WWTP to find its location (coordinate) through Baidu map. Identifying the city where the WWTP locates and summing all the sludge data of each WWTP in that city. Finally, we used our calculation to substitute the biased data in the *Urban Construction Yearbook* (Figure S1).



**Figure S1.** The workflow of collecting sludge data

### Sludge Projection



**Figure 2.** Correlation between sludge generation and the quantity of wastewater treated

#### 2.2.1 Production sector classification

The IO table in Xiamen contains 139 sectors (Table S2), with a water supply and production aggregated with wastewater treatment.

### Scenario analysis

Two scenarios were considered to assess the effects of possible changes in industrial structure and diet patterns. The first one (Scenario 1) is based on the rate of industrial growth prescribed in the 13th Five-Year Plan for economic and social development in Xiamen city. In that plan, sectors such as electronic information and mechanical manufacturing are expected to play a vital role in economic growth, with the output of electronic information expected to increase from 0.3 trillion RMB in 2015 to 0.7 trillion RMB in 2020, or a 2.3-fold increase. To assess the impacts of planned industrial growth, we evaluated the effects on wastewater and sludge of the same 2.3-fold increase in the final demand for the products of 15 manufacturing sectors consisting of cars, ships, machinery, electronics, computer, and communication equipment. Denoting by , , and the direct wastewater discharge, wastewater footprint, and sludge footprint under Scenario 1, respectively, we have

(S11)

(S12)

(S13)

where refers to the expected rate of change in the output of sector *i*.

The second scenario (Scenario 2) refers to a possible shift in diet from the traditional Chinese one mostly based on staples toward a European (Spanish) one involving larger amounts of animal-sourced foods. The evaluation was carried out by altering the consumption of "Vegetable oil and forage” “Slaughtering and meat processing”, “Prepared fish and seafood”, “Vegetable, fruit and nut processing,” and “Liquid milk and dairy products” to the Spanish level (the last column of Table S3), and applying the same calculation as in Scenario 1.

### Sensitivity analysis

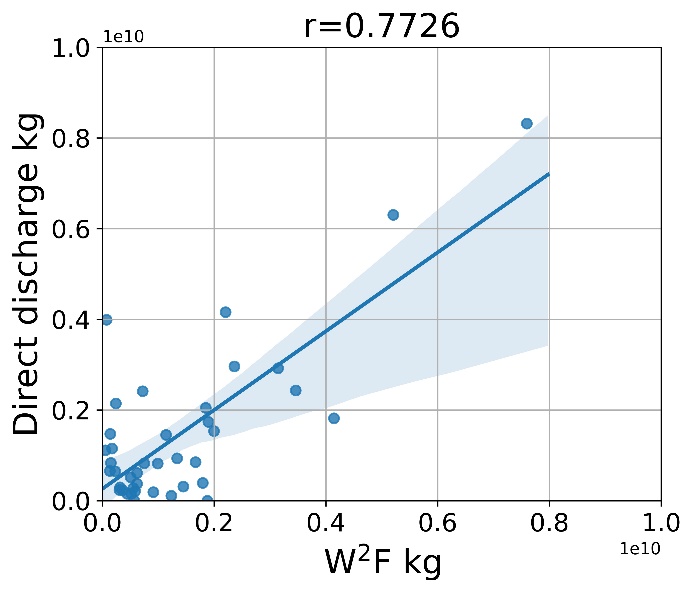
To examine the robustness of the results, we conducted a sensitivity analysis for key parameters based on the sensitivity elasticity of parameters (Heijungs and Lenzen, 2014; Lin et, al., 2020), which indicates the ratio by which a change in “key parameters” changes the results, W2F and SF in our case. The elasticity is given by

(S14)

where denotes W2F or SF and the parameter under study. Among others, and are considered as key parameters.

## 3 Results

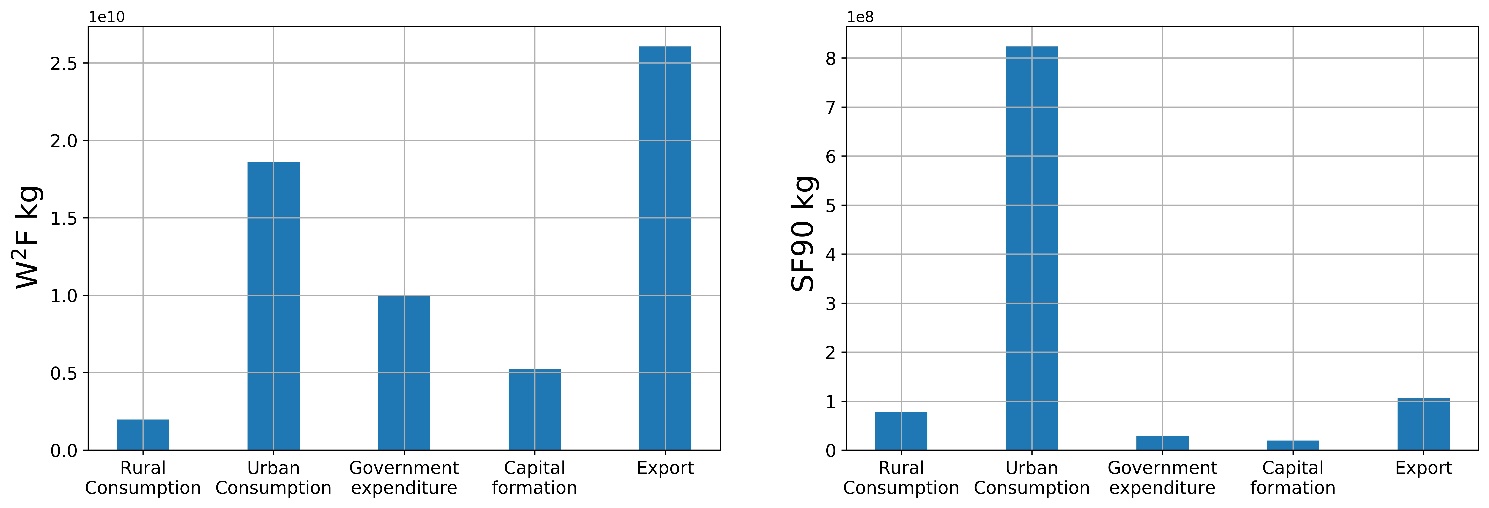
### 3.1 Direct discharge versus footprint



**Figure S1 Direct discharge versus W2F of the largest 40 sector**

### 3.2 Wastewater and sludge footprint by final demand categories

In terms of final demand categories, the largest share of W2F (42%) is attributed to export, followed by urban household consumption (33%). The largest share of SF (78%) is attributed to urban household consumption, followed by export (10%) (Figure S2).



**Figure S2 Wastewater and sludge footprint by final demand categories**

### 3.3 Sensitivity analysis

#### 3.3.1 The sensitivity of pre-consumption W2F and SF to input and waste generation coefficients

Table S7 shows input and wastewater generation coefficients elasticities of pre-consumption W2F and SF, and gives the ratio by which a change in relevant coefficients changes W2F or SF. For instance, the value 0.000003 at the upper-left cell shows that a one % change in the input coefficient of electricity of the composting process changes the wastewater footprint by 0.000003, that is, practically no impact. The results indicate that for most cases the elasticities are small, with the occurrence of large elasticities concentrated to sludge generation coefficients. The largest one, 2.77, refers to the effects on sludge80 footprint of the sludge90 generation coefficients of Dew80, Dew60, landfill, and incineration treatment processes. It implies that a one % change in the coefficient change would induce a 2.77% change in SF of sludge80. Since these coefficients were directly obtained from data on the real operation of WWTPs in the city, they are of high reliability, implying the robustness of our results of SF.

**Table S7 Sensitivity elasticity of** **pre-consumption W2F and SF to input and waste generation coefficients**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Footprint  Coefficients | | Wastewater | Sludge90 | Sludge80 | Sludge60 |
|  | Compost | 0.000003 | 0.000000 | 0.000002 | 0.000001 |
|  | A2O | 0.000037 | 0.000000 | 0.000029 | 0.000011 |
|  | OD | 0.000082 | 0.000000 | 0.000066 | 0.000024 |
| Electricity | BF | 0.000068 | 0.000000 | 0.000055 | 0.000020 |
|  | Dew80 | 0.000002 | 0.000000 | 0.000002 | 0.000001 |
|  | Dew60 | 0.000004 | 0.000000 | 0.000003 | 0.000001 |
|  | Landfill | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | Incineration | 0.000002 | 0.000000 | 0.000001 | 0.000001 |
|  | Compost | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | A2O | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | OD | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Wastewater | BF | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | Dew80 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | Dew60 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | Landfill | 0.000280 | 0.000000 | 0.000000 | 0.000000 |
|  | Incineration | 0.000280 | 0.000000 | 0.000227 | 0.000082 |
|  | Compost | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | A2O | 0.000000 | 0.192764 | 0.000000 | 0.000000 |
|  | OD | 0.000062 | 0.481927 | 0.534416 | 0.192783 |
| Sludge90 | BF | 0.000216 | 0.325310 | 1.870517 | 0.674760 |
|  | Dew80 | 0.000321 | 0.000000 | 2.772421 | 1.000108 |
|  | Dew60 | 0.000321 | 0.000000 | 2.772421 | 1.000108 |
|  | Landfill | 0.000321 | 0.000000 | 2.772421 | 1.000108 |
|  | Incineration | 0.000321 | 0.000000 | 2.772421 | 1.000108 |
|  | Compost | 0.000000 | 0.000000 | -1.772122 | 0.000000 |
|  | A2O | -0.000026 | 0.000000 | -1.772143 | -0.000007 |
|  | OD | -0.000026 | 0.000000 | -1.772143 | -0.000007 |
| Sludge80 | BF | -0.000026 | 0.000000 | -1.772143 | -0.000007 |
|  | Dew80 | -0.000026 | 0.000000 | 0.999976 | -0.000007 |
|  | Dew60 | 0.000015 | 0.000000 | 1.000013 | 0.000004 |
|  | Landfill | 0.000015 | 0.000000 | 1.000013 | 0.000004 |
|  | Incineration | 0.000015 | 0.000000 | 1.000013 | 0.000004 |
|  | Compost | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | A2O | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | OD | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| Sludge60 | BF | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | Dew80 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
|  | Dew60 | 0.000000 | 0.000000 | 0.000000 | 1.000000 |
|  | Landfill | 0.000267 | 0.000000 | 0.000217 | 1.000090 |
|  | Incineration | 0.000267 | 0.000000 | 0.000217 | 1.000090 |

Note: The first and second columns show the names of input and waste generation coefficient. The first row show the names of wastewater and sludge footprints.

#### 3.3.2 The sensitivity of post-consumption W2F and SF to key parameters

Table S8 shows the sensitivity elasticities of post-consumption W2F and SF to key parameters, and . The first block shows the effects of a change in the discharge rate of toilet water associated with the excretion of food item *i*, that is, , on post-consumption WWF. For instance, the value 0.12 of the upper-left cell indicates that a one percent change in the amount of discharge of toilet water associated with the excretion of grain mill products results in a 0.12% change in the amount of post-consumption W2F. The results indicate that the elasticities are rather small, with none exceeding 0.6. The largest value is observed for "Vegetable, fruits, and nut processing” on post SF, because of its largest share (53%) in the total mass food consumption.

The second block of Table S7 shows the impacts of a change in the ratio of raw sludge to total COD, , of the three WWTPs on the amount of post-consumption W2F. The results indicate that the amount of post-consumption W2F is relatively sensitive to the parameter of OD treatment, which can be explained by that its treatment capacity is larger than the other two treatment processes. The parameter is obtained from annual WWTPs operation data in the city and hence is of high credibility, implying the robustness of our post-consumption SF results.

**Table S8 Sensitivity elasticity of post-consumption W2F and SF with respect to key parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| Footprint  Parameters | | Wastewater | Sludge90 |
|  | Grain mill products | 0.12 |  |
|  | Vegetable oil and forage | 0.03 |  |
|  | Slaughtering and meat processing | 0.15 |  |
|  | Prepared fish and seafood | 0.06 |  |
|  | Vegetable, fruit and nut processing | 0.54 |  |
|  | Liquid milk and dairy products | 0.05 |  |
|  | Other food manufacturing | 0.02 |  |
|  | Wines, spirits and liquors | 0.02 |  |
|  | Non-alcoholic beverage | 0.01 |  |
|  | A2O |  | 0.19 |
|  | OD |  | 0.48 |
|  | BF |  | 0.33 |

Note: The first and second columns show the parameters. The first row show the names of wastewater technology and sludge footprints.

### 3.4 Transboundary impacts

In the literature on carbon footprint based on multi-regional input-output (MRIO) analysis it is common to look at the impacts embodied in trade. While the current IO data is a single region one, it is possible to estimate the amounts of wastewater and sludge embodied in trade, assuming that the technology of the exporting countries is the same as that of Xiamen, that is, in (S10). The results in Table S9 indicate that Xiamen is a net exporter of wastewater and sludge, although the extent of “trade surplus” for the latter is much smaller. It is not the case that the city is keeping its own water resources clean at the expense of other regions of China.

**Table S9 Wastewater and sludge embodied in trade**

|  |  |  |
| --- | --- | --- |
|  | Embodied in export | Embodied in import |
| Wastewater (107 kg) | 6778 | 5813 |
| Sludge90 (103 kg) | 291741 | 274283 |

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CCNPS (Compilation Committee for National Pollution Survey). Household Discharge Coefficient and Use Instructions. China Environmental Science Press. 2011.(in Chinese)

GSC (General Office of the State Council). Pilot Work Plan for the Construction of Wasteless Cities. 2018. In Chinese.

Heijungs R and Lenzen M. Error propagation methods for LCA - a comparison. International Journal of Life Cycle Assessment. 2014, 19(7): 1445-1461.