

19 **Abstract:** China's household energy demands' life-cycle water uses from 2002 to
20 2015 are quantified with an Input-Output analysis disaggregating rural and urban
21 impacts. 9.73 and 1.60 km³ of water was withdrawn and consumed respectively in
22 the life cycle of Chinese household energy demands in 2015, which was dominated
23 by power and heat uses. An average urbanite's household energy uses, including coal,
24 gas, petroleum products, power and heat, require about four times of life-cycle water
25 uses than its rural counterpart. Among all upstream sectors, while agricultural
26 sectors accounted for the largest shares for all energy uses, oil and gas extraction
27 made significant contributions to petroleum products and gas consumption. A
28 Structural Decomposition Analysis is conducted to disentangle the impacts of four
29 driving factors, i.e. population, demand, economic structure and technology.
30 Population change reduced energy consumption's life-cycle water use for rural
31 households but increased that for urban households. Each economic sector's water
32 intensity decreases, which represent technology advancement, played the dominant
33 role curbing household energy consumption's life-cycle water uses. While power and
34 heat dominates the household energy use profile, urbanization is accompanied by
35 household consumption shifting from coal to gas and petroleum products. In order to
36 reduce household energy consumption's impacts and reliance on water resources, it
37 is imperative to reduce energy production's water use by adopting water-saving
38 technologies, such as air cooling, as well as to reduce upstream sectors' water
39 intensities, such as by promoting drip irrigation.

40 **Key words:** urbanization; household energy consumption; life-cycle water use;

41 structural decomposition analysis; input-output model

42

43 **1. Introduction**

44 China has experienced unprecedented economic growth since its “Reform and
45 Opening Up” Policy being initiated in 1978. Such growth has been accompanied by
46 two concurrent changes in terms of its citizens’ living conditions: household
47 consumption expansion and rapid urbanization.

48 China’s household consumption has been expanded considerably both as means and
49 results of the substantial economic growth. In 2016, household consumption
50 increase contributed to 64.6% of China’s GDP growth (National Bureau of Statistics,
51 2016). On one hand, the average household consumption per capita in China has
52 increased by 2.19-fold from 1992 to 2007 (Liu *et al.*, 2011). On the other hand,
53 household consumption composition has undergone significant changes. Food
54 consumption occupies a decreasing share while, on the contrary, numbers of private
55 cars, refrigerators, computers, air conditioners and other energy-consuming
56 appliances have grown considerably, which leads to soaring household energy
57 consumption, e.g. electricity, petroleum products (Liu *et al.*, 2011). China’s total
58 household electricity consumption has increased almost three fold from 288.5 TWh
59 in 2005 to 756.5 TWh in 2015. Correspondingly, annual electricity consumption per
60 capita has increased from 220.6 KWh to 550.3 KWh (National Bureau of Statistics,
61 2016).

62 Meanwhile, rapid urbanization has taken place in China (Hubacek *et al.*, 2009). In

63 2011, China's urban population reached 619 million and exceeded its rural
64 counterpart for the first time by occupying 51.27% of the total (National Bureau of
65 Statistics, 2016). The numbers have since grown to 793 million and 57.35%,
66 respectively, in 2016. Moreover, the central government issued its 'National New
67 Urbanization Plan (2014-2020)' in 2014 and expected that the share of urban
68 population in China could reach 60% by 2020 (Central Committee of the Communist
69 Party of China and State Council, 2014). As more intensive energy provision is
70 required by urban lifestyles, urbanization accelerates the expansion of household
71 energy consumption (Zhang and Lin, 2012). It can be seen from the national
72 Input-output tables (2000 price) in Table 1 that (1) urban household energy
73 consumption is significantly higher than their rural counterparts; (2) coal
74 consumption has decreased steadily for urban households; (3) other types of energy
75 consumption have all increased from 2002 to 2015 for all households, especially gas
76 and petroleum products consumption for urban households; (4) urban power and
77 heat consumption has decreased from 2007 to 2012, but then increased until 2015.

78

79 **Table 1** Rural and urban household energy consumptions in 2002, 2007, 2012 and
80 2015

Per capita consumption (RMB per person)	Rural Households				Urban Households			
	2002	2007	2012	2015	2002	2007	2012	2015
Coal	8.28	7.17	6.55	7.30	25.38	5.85	3.80	3.12
Petroleum Products	5.71	7.10	13.61	21.89	20.11	60.77	129.15	167.55
Power and Heat	24.28	49.93	57.60	74.96	167.90	214.10	177.69	189.11
Gas	0.00	3.92	5.30	8.06	30.23	27.24	87.94	127.50

81

82 While energy consumption is vital to the wellbeing and functioning of any household
83 in a modern society, it creates environmental externalities throughout its life-cycle
84 supply chain. The most researched and acknowledged environmental impacts from
85 household energy consumption include the emissions of air pollutants and
86 greenhouse gases (Hao *et al.*, 2002; Li *et al.*, 2015; Zhang *et al.*, 2017). It has been
87 concluded that while carbon/pollution intensities declined, population increases,
88 expansion of urbanization and increases in household consumption per capita all
89 contributed to the increase of carbon emissions.

90 However, the interconnectedness between household energy consumption and its
91 impacts on water resources have been largely overlooked by the existing literature.
92 In order to fulfill final household energy consumption, water is used throughout its
93 life-cycle (Meldrum *et al.*, 2013). Take electricity for example, water is used in the
94 upstream sectors, e.g. coal mining and dressing, as well as in power plants, primarily
95 for cooling purposes (Meldrum *et al.*, 2013). Water footprint has been proposed as
96 an indicator to quantify such impacts (Hoekstra and Chapagain, 2006; Hoekstra *et al.*,
97 2011). Water footprint includes three components: (1) green water that refers to
98 rainwater stored in soils and vegetation; 2) blue water that is freshwater resources,
99 including surface water and groundwater; 3) grey water that refers to freshwater
100 requirement to dilute pollutants to a permissible concentration by related water
101 quality standards. We are only concerned with surface water use in the blue water
102 category. Moreover, when water is used in the production processes of certain
103 products, it transforms into virtual water and can be transferred with corresponding

104 trading activities (Allen, 1993). Based on the Input-Output model first proposed by
105 Leontief (1970), Environmental Extended Input-Output (EEIO) models provide a
106 comprehensive framework as well as a useful tool to assess human activities' impacts
107 on natural resources, e.g. water (Lenzen and Foran, 2001; Lenzen, 2009; Wang et al.
108 2013). Furthermore, in order to study the impacts of economic, social and
109 technological variables on the various environmental issues, Structural
110 Decomposition Analyses (SDA) within the Input-Output framework has been widely
111 used (Su and Ang, 2012a; Wang et al., 2017; Carrascal-Incera et al. 2017).

112 Some scholars have quantified the life-cycle water uses for energy production and
113 consumption on various geographical scales (Zhang and Anadon, 2013; Okadera et al.
114 2015; Wang and Chen, 2016). However, few have shed light on how household
115 consumption, especially with the rapid urbanization and people's change of lifestyles,
116 has impacted this issue. This study aims to quantify the life-cycle water uses to meet
117 China's rural and urban household energy consumption, including coal, petroleum
118 products, gas and power and heat, from 2002 to 2015. These four energy types are
119 studied because they make up the majority of China's household commercial energy
120 consumption that is accounted in the national Input-Output tables (National
121 Academy of Development and Strategy, 2016). Data on non-commercial energy
122 consumption, such as woods, animal excretion, are not available. A structural
123 decomposition analysis (SDA) is conducted to estimate the respective impacts of four
124 driving factors, i.e. population, energy consumption per capita, water intensities and
125 the economic structure, for both rural and urban households. Findings in this study

126 are useful for China, as well as other developing countries that are undergoing rapid
127 urbanization with immense development needs to improve their citizen's rising living
128 standards but also with limited natural resources thus seeking a sustainable
129 development path.

130

131 **2. Method and data**

132 **2.1 Environmental Extended Input Output model**

133 Input-Output analysis is able to map out the flows of goods and services among the
134 producing and consuming sectors of a given region (Leontief, 1986). By including
135 natural resources as inputs, Environmental Extended Input-Output (EEIO) analysis
136 can be used to track the life-cycle use of natural resources, e.g. water, for the final
137 demands of economic sectors, e.g. energy sectors (Meng *et al.*, 2015; Mi *et al.*, 2016;
138 Mi *et al.*, 2017; Mi *et al.*, 2017). For example, to quantify the life-cycle water use for
139 household energy consumption, the basic equations can be expressed as below:

140

$$141 \quad W_u = w^* (I - A)^{-1} Y_{e,u} \quad (1)$$

$$142 \quad W_r = w^* (I - A)^{-1} Y_{e,r} \quad (2)$$

143

144 Where W_u and W_r are the life-cycle water uses to meet urban and rural household
145 energy consumption $Y_{e,u}$ and $Y_{e,r}$, respectively; $(I - A)^{-1}$ is the Leontief inverse matrix,
146 also called total requirement matrix, that represents the required inputs from each
147 sector to fulfill each sectors' final demands, in which I is an identity matrix and A is

148 the matrix of inter-sector intermediate input coefficients; $w^* = [w_1^*, w_2^*, \dots, w_n^*]$ is a
 149 row vector of all sector's water intensities, which equals to direct water inputs in
 150 each sector dividing the sector's economic output. In summary, Eq. (1) and (2)
 151 calculate how much water inputs to each economic sector's production, w^* , flow
 152 through different economic sectors, $(I - A)^{-1}$, and are used to meet each sector's final
 153 demands, e.g. Y_e for the energy sector. We do not differentiate imported energy
 154 products and domestically produced energy products for household consumption
 155 and assume they have the same water intensities.

156

157 **2.2 Structural Decomposition Analysis**

158 According to the Impact = Population × Affluence × Technology (IPAT) model (Ehrlich
 159 and Holdren, 1971; Mi *et al.*, 2017), household energy consumption Y_e in Eq. (1)
 160 and (2) can be further decomposed to population P , including urban and rural, and
 161 household energy consumption per capita y_e (MWh/p) as in Eq. (3) and (4).

162

$$163 \quad W_u = w^* \cdot (I - A)^{-1} \cdot P_u \cdot y_{e,u} \quad (3)$$

$$164 \quad W_r = w^* \cdot (I - A)^{-1} \cdot P_r \cdot y_{e,r} \quad (4)$$

165

166 where water use efficiency of each economic sectors w^* denotes the *Technology*
 167 *effects*; total requirements matrix $(I - A)^{-1}$ represents the *Structure Effect*; P is the
 168 *Population Effect* and y_e is the *Demand Effect*.

169 In order to assess those four abovementioned drivers, there are two techniques of

170 decomposition, i.e. additive and multiplicative (Su and Ang, 2014, 2015, 2017). We
 171 adopt the additive mathematical form as its results are easier to interpret and thus
 172 more commonly used in the existing literature (Su and Ang, 2012b). Changes in the
 173 life-cycle water uses, ΔW , can be expressed as:

174

$$175 \quad \Delta W = w^{*t} + L^t + P^t + y_e^t \quad (5)$$

176

177 Where w^{*t} , L^t , P^t and y_e^t denote the impacts brought by changes of water
 178 intensities w^* , Leontief inverse matrix $(I - A)^{-1}$, population P and energy consumption
 179 per capita y_e , respectively.

180 Assuming during the time interval $[0, t]$, ΔW can be expressed as Eq. (6):

181

$$182 \quad \Delta W = W^t - W^0 = w^{*t} L^t P^t y_e^t - w^{*0} L^0 P^0 y_e^0 = (w^{*0} + \Delta w^*) (L^0 + \Delta L) (P^0 +$$

$$183 \quad \Delta P) (y_e^0 + \Delta y_e) - w^{*0} L^0 P^0 y_e^0 \quad (6)$$

184

185 Where superscripts all denote either the start, 0 , or the end point, t , of the time
 186 period $[0, t]$ and Δ represents the changes of corresponding variables during this
 187 time period. S/S method is adopted in this study (Sun, 1998). According to the
 188 'jointly created and equally attributed' principle in Sun (1996), we assume that each
 189 factor contributes equally to its joint effects with other factors. For example, Δw^* ,
 190 ΔL , ΔP and Δy_e all have equal contribution to the mixed term - $\Delta w^* \Delta L \Delta P \Delta y_e$.

191 In this way, each term in Eq. (5) can be quantified through breaking down Eq. (6)

192 mathematically (Details see Appendix). An example equation to quantify w^{*t} is as

193 Eq. (7) below:

194

$$\begin{aligned} 195 \quad w^{*t} = & \Delta w^* L^0 P^0 y_e^0 + \frac{1}{2} \Delta w^* (\Delta L P^0 y_e^0 + L^0 \Delta P y_e^0 + L^0 P^0 \Delta y_e) + \frac{1}{3} \Delta w^* (\Delta L \Delta P y_e^0 + \\ 196 \quad & \Delta L P^0 \Delta y_e + L^0 \Delta P \Delta y_e) + \frac{1}{4} \Delta w^* \Delta L \Delta P \Delta y_e \end{aligned} \quad (7)$$

197

198 Similarly, L' , P' and y_e' can be quantified. It needs noting that the SDA method we

199 use in this study, S/S method, is a non-chaining method. It means if we are studying

200 changes throughout three time points a, b and c, there are two ways to conduct the

201 SDA for the whole period by: (1) analyzing the whole period [a, c] directly or (2)

202 accumulating the results from analyzing [a, b] and [b, c] respectively. The results

203 given by these two ways are not exactly the same. In order to understand the

204 periodical change of the four drivers' impacts, the latter is adopted (Su and Ang

205 2012b).

206

207 **2.3 Data and treatment**

208 Four time-series Input-Output tables of China's 32 sectors in 2002, 2007, 2012 and

209 2015 are obtained from the national statistic bureau of China (National Bureau of

210 Statistics, 2016) and all prices are deflated to 2000 prices according to Liu and Peng

211 (2010) (Detailed sector aggregation and deflation method are presented in

212 Supplementary Information). Although there are other international IO databases

213 available, for example, Exiobase (Tukker et al., 2013) and WIOD (Timmer et al., 2015),

214 they are more suitable for studying international activities. Moreover, using
215 international databases involves exchanging the currency and induces higher
216 uncertainties in the deflation processes. Therefore China's national statistic data are
217 used. Urban household consumption and rural household consumption are included
218 in the IO tables. Urban and rural households are classified based on multiple
219 social-economic factors, such as the region's economic structure, population density
220 and so forth. Water use data include both water withdrawal and water consumption.
221 Water initially withdrawn from the environment but not discharged back to any
222 water bodies is defined as water consumption (AQUASTAT, 1998). Water withdrawal
223 data are obtained from the Water Resource Bulletins in these four years (Ministry of
224 Water Resources, 2002, 2007, 2012 and 2015). In the Chinese Water Resources
225 Bulletins, water withdrawal in service sectors is reported together with domestic
226 water withdrawal. About 50% of the urban domestic water withdrawal was for water
227 use in service sectors. Detailed sectoral distribution of water withdrawals by different
228 industrial and service sectors is approximated by data from the China Economic
229 Census Yearbook 2008 (The State Council Leading Group Office of Second China
230 Economic Census, 2008). Water withdrawal data in each sector are then converted to
231 water consumption by multiplying the water consumption coefficient for that sector,
232 which is taken from Water Resource Bulletins. It needs noting that although
233 hydropower also induces large volumes of water consumption through reservoir
234 evaporation, we do not consider hydropower in this study due to vast
235 methodological disputes and uncertainties (Bakken et al. 2016).

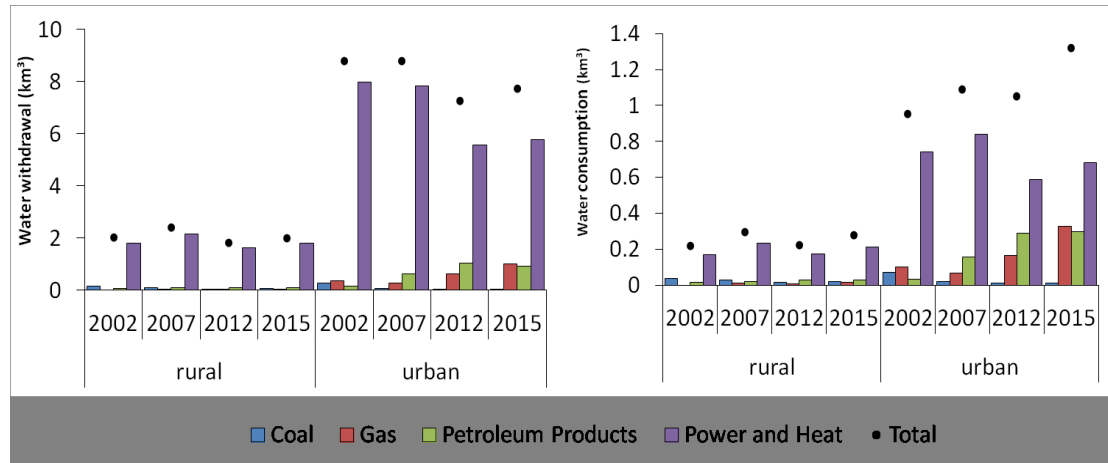
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237 **3. Results**

238 **3.1 Life-cycle water uses for household energy consumption in China from 2002 to** 239 **2015**

240 From 2002 to 2015, the life-cycle water withdrawal for household energy
241 consumption first increased from 10.79 km³ in 2002 to 11.18 km³ in 2007. It then
242 decreased to 9.08 km³ in 2012 and increased again to 9.73 km³ in 2015. The life-cycle
243 water consumption has experiences the same changes from 1.16 km³ in 2002 to 1.38,
244 1.27 and 1.60 km³ in 2007, 2012 and 2015 respectively. Overall, life-cycle water uses
245 for urban household energy consumption amounted to about 4 times of their rural
246 counterparts.

247 Zhang and Anadon (2013) estimated that 61.4 and 10.8 km³ was withdrawn and
248 consumed, respectively, for the life-cycle of energy production in China in 2007 using
249 a Multi-Regional Input-Output analysis. According to our results, only 11.18 and 1.38
250 km³ of which was used to meet final household consumption, which indicates that
251 the majority of energy production was used for intermediate inputs to other
252 economic sectors.



253

254 **Fig. 1** Life-cycle water uses for households energy consumption from 2002 to 2015

255

256 As shown in Fig. 1, life-cycle water uses for household power and heat consumption
 257 occupied a dominant but decreasing share, especially for water withdrawal. Life-cycle
 258 water withdrawal for household power and heat consumption amounted to 5.66 km³
 259 in 2015, occupying 74.6% of the total life-cycle water withdrawal for entire
 260 household energy consumption, down from 90.9%, 89.2% and 76.7% in 2002, 2007
 261 and 2012 respectively. Despite the declining share, overall, life-cycle water uses have
 262 increased for rural household electricity consumption while decreased for urban
 263 household electricity consumption.

264 Life-cycle water uses for both household gas consumption and petroleum products
 265 consumption have increased steadily since 2002. Especially for the life-cycle water
 266 consumption, gas consumption and petroleum products have each occupied 24.9%
 267 (0.33 km³) and 22.4% (0.30 km³) in 2015.

268 Life-cycle water uses for household coal consumption accounted for the smallest
 269 share and have fluctuated throughout the study period. In 2015, only 0.10 and 0.03

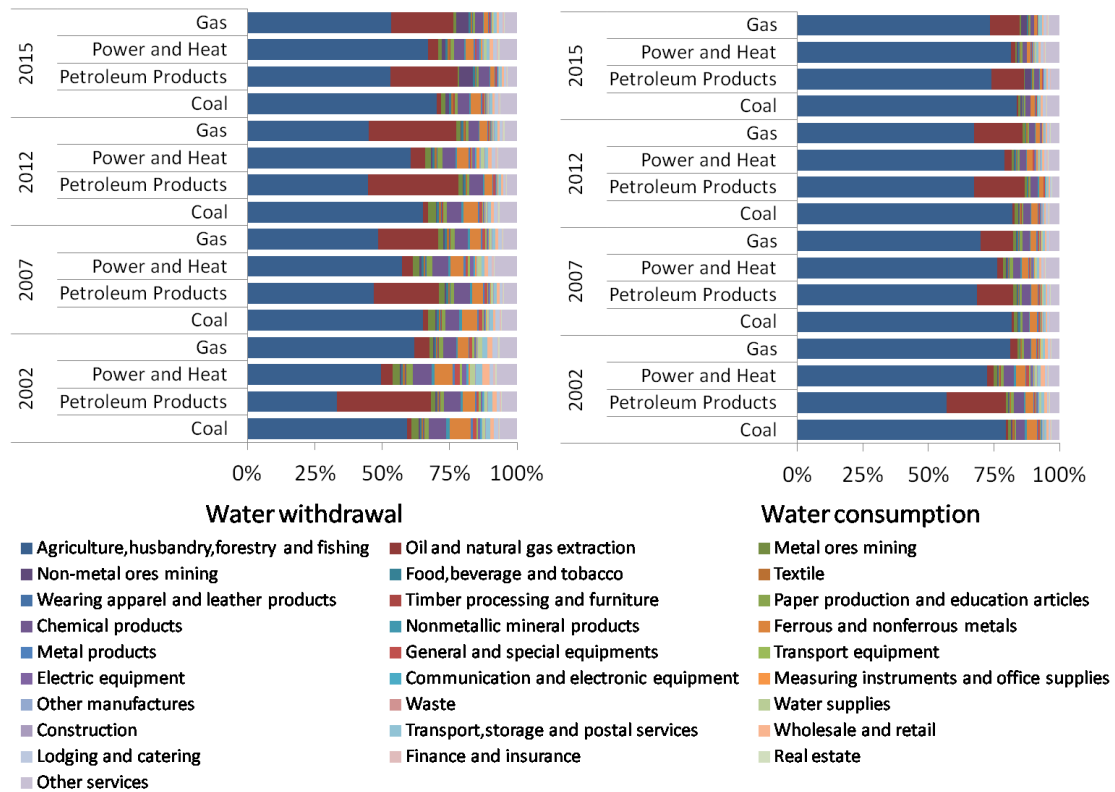
270 km³ was withdrawn and consumed respectively throughout the entire life-cycle
271 processes to meet household coal consumption in China.

272

273 **3.2 Sectoral distribution of household energy consumption's upstream water uses**

274 Fig. 2 demonstrates the upstream sectoral contributions of energy final demands'
275 life-cycle water uses in 2012. Agricultural, Husbandry, Forestry and Fishing (AHFF)
276 sector and Oil and Natural Gas Extraction (ONGE) sector contributed the biggest
277 shares among all upstream sectors. The main inputs from AHFF to final energy
278 consumption are timbers to produce mine props while Oil and Natural Gas Extraction
279 inputs Crude Oil and Natural Gas to be processed by the Petroleum Refinery and
280 Nuclear Fuel sector and Gas Supply sector, respectively, to provide Petroleum
281 products and Natural Gas for household consumption.

282



283

284 **Fig. 2** Sectoral distribution of household energy consumption's upstream life-cycle
 285 water uses

286

287 AHFF is the biggest contributor to the upstream water uses by the consumption of all
 288 four types of energy sources. Particularly for coal consumption, AHFF made up 70.0%
 289 of its upstream water withdrawal and 83.5% of its upstream water consumption in
 290 2015. Compared to coal and power consumption, ONGE occupied bigger percentages
 291 in terms of final petroleum products and gas consumption's upstream water uses. In
 292 2015, ONGE contributed to 24.2% and 22.6% to petroleum products and gas
 293 consumption's upstream water withdrawal, respectively, and 12.1% and 11.2%
 294 regarding water consumption. Recycling wastewater is an effective way to reduce
 295 water use in oil and gas extraction processes. Developing industry guidelines and

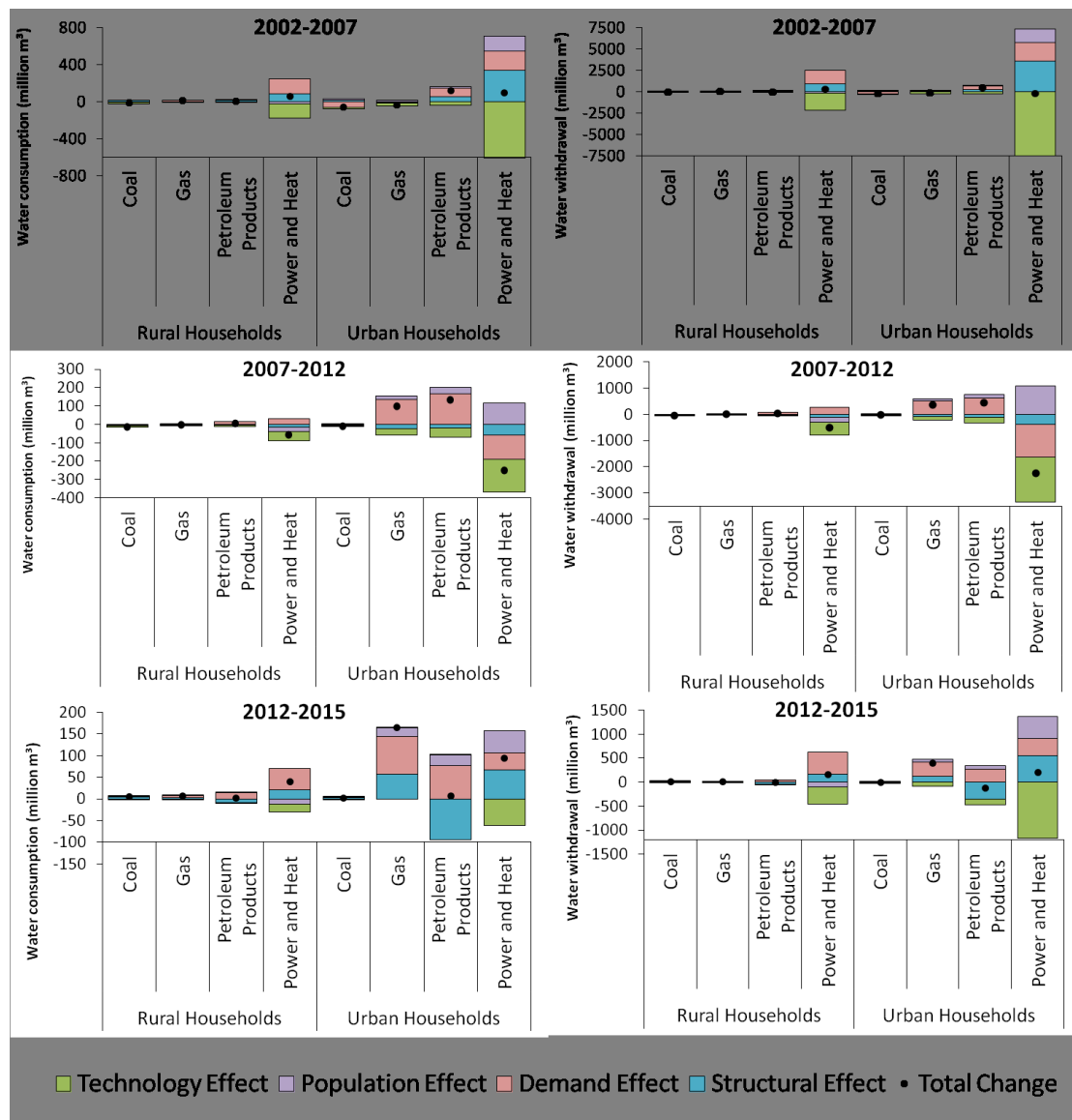
296 regulations that can be thoroughly implemented is also crucial.

297

298 **3.3 Driving factors of household energy consumption's life-cycle water use changes**

299 The impacts of four driving factors are analyzed for the changes of life-cycle water
300 uses of each energy type's final consumption. It can be seen from Fig. 3 that from
301 2002 to 2015, population change has had consistent negative effects on the life-cycle
302 water uses (0.57 km³ of water withdrawal and 0.07 km³ of water consumption) of
303 rural households' consumption of all energy sources while positive effects on those
304 of urban households (3.70 km³ of water withdrawal and 0.47 km³ of water
305 consumption), which is in line with the continuing declining rural population and
306 increasing urban population.

307



308

309 **Fig. 3** Drivers of household energy consumption's life-cycle water use changes

310

311 From 2002 to 2015, per capita coal consumption for urban households has kept
 312 decreasing and leads to 0.27 and 0.07 km³ of water withdrawal and consumption
 313 reductions. Such effects were especially acute from 2002 to 2007, occupying just
 314 below 90% of the total reductions. On the contrary, per capita demands for
 315 petroleum products have gone up consistently throughout the study period and
 316 resulted in 0.13 and 0.03 km³ of water withdrawal and consumption increases,

317 respectively, for rural households and 1.28 and 0.26 km³ for urban households. These
318 increases reflected the soaring vehicle ownerships in China and people's growing
319 demands for higher mobility.

320 Despite the increase from 2002 to 2007, urban households' per capita power and
321 heat demand has decreased from 2007 to 2012, resulting in 1.25 and 0.13 km³ of
322 water withdrawal and consumption declines, respectively. Such demand decreases
323 could be resulted from the aftermath of global financial crisis and economic
324 stalemate, which has also been found affecting China's carbon emission change (Mi
325 et al. 2017).

326 Economic structure change has contributed to 5.04 and 0.52 km³ of water
327 withdrawal and consumption increases, respectively, from 2002 to 2007. The effects
328 reversed from 2007 offsetting 0.74 and 0.13 km³ of water withdrawal and
329 consumption increases, respectively. However, from 2012 onwards, economic
330 structure change has had positive effects since. The structure change of the
331 economy's intermediate production inputs has shifted from a major driving factor for
332 household energy consumption's water uses to an offsetting one from 2007 and
333 changed back to a driving factor from 2012. Reducing the inputs from upstream
334 water-intensive sectors to the energy sector can help utilizing the offsetting potential
335 of the structural effect to reduce final energy demands impacts and dependencies on
336 water resources.

337 Overall, technology advancement played the essential role consistently reducing
338 household energy consumption's life-cycle water uses, offsetting 14.46 and 1.29 km³

339 of water withdrawal and consumption, respectively, in total from 2002 to 2015. This
340 indicates that water efficiency improvement in other sectors has generated
341 co-benefits of reducing household energy consumption's reliance on water. Further
342 actions to continue improving water efficiency in the upstream sectors are thus
343 imperative. Taking the agriculture industry for example, in order to improve the
344 water efficiency for irrigation, drip irrigation and alternative crops should be
345 promoted (Levidow et al. 2014).

346

347 **4. Discussions**

348 **4.1 Promote sustainable urbanization and consumer behaviors**

349 China has lifted over 800 million people out of poverty and the improvement of
350 people's living standards has been accompanied by growing energy consumption.
351 However, such growth has imposed increasing pressures on the natural environment,
352 such as water resources. Environmentally responsible and sustainable consumption
353 behaviours should be encouraged, especially among the increasing number of
354 urbanites, who consume significant larger amount of energy than their rural
355 counterparts.

356 Various policy instruments can be utilized. Market mechanisms such as subsidies for
357 energy-efficient household appliances, e.g. air conditioner, fridge, can be effective.

358 Environmental education to raise environmental awareness as well as environmental
359 information disclosure programs, such as energy labelling, should be adopted. Public
360 transportation should be further enhanced to reduce private car ownership as well

361 as the corresponding oil consumption.

362

363 **4.2 Reduce energy production's direct water uses**

364 A large amount of water is used in energy productions. Zhang and Anadon (2013)
365 have pointed out that electricity production dominates such water uses. As many of
366 China's thermoelectric power plants are located in water-stressed areas that are
367 close to coal reserves, it is important to encourage more efficient use of water in
368 those power plants. Improving their energy conversion efficiency and changing
369 cooling technologies are both feasible options. For example, since 2004, new power
370 plants are required to employ air cooling systems with water withdrawal intensities
371 less than $0.18 \text{ m}^3 \text{ s}^{-1} \text{ GW}$ in water-stressed regions (National Development and
372 Reform Commission 2004).

373 Furthermore, although grey water use is not considered in this study, energy
374 production and consumption also induce serious water pollution issues, especially
375 during coal mining processes. Enforcing wastewater treatment at coal mines is
376 necessary.

377

378 **4.3 Concerted effort is required to reduce energy consumption's indirect water uses**

379 Energy consumption's life-cycle water uses also depend on its upstream sectors,
380 therefore concerted efforts to save water are required throughout the entire
381 economy. For example, while household gas consumption has been steadily
382 increasing and China's Sichuan province is endowed with rich shale gas resources.

383 Water uses in the extraction processes, such as hydraulic fracturing, should be
384 further studied in the regional context before any exploitation plan is made. Gas
385 liquefaction is another industry that needs to be developed with caution. Water
386 scarcities have forced China to ban several Gas-to-Liquid factories in water-stress
387 regions (Qin et al. 2015).

388

389 **4.4 Limitations and future research directions**

390 Although household energy consumption magnitudes and patterns differ by region,
391 for example, northern households use more energy for heating during winters,
392 spatial disaggregation remains a limitation of this study. This study is the first study
393 disaggregating rural and urban households and looking at urbanization's impact on
394 China's water-for-energy uses. Future study with higher spatial resolution using
395 China's Multi-Regional Input-Output tables can be conducted.

396 Furthermore, while the additive form of SDA is used in this study to assess the
397 drivers of absolute water uses for household energy consumption, studies using the
398 multiplicative form to quantify the water intensity changes and corresponding drivers
399 will also be valuable (Su and Ang, 2015; Carrascal Incera et al. 2017).

400 Last but not least, while this study uses urban and rural household consumption data
401 from the national Input-Output tables, future studies are encouraged to quantify the
402 impacts of changes in household demographical characteristics, e.g. ages, income,
403 and consumer behaviours, e.g. car ownership, house type, on resources use based
404 on national household budget surveys.

405

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410

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