

1 **Life-cycle environmental implications of China's ban on post-consumer** 2 **plastics import**

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10

11 **Abstract**

12 China used to receive more than 50% of the global post-consumer plastics export, the largest share of
13 which was PET bottles. However, China recently banned the import of foreign wastes including waste
14 plastics. The original intention of this ban was to protect China's ecosystem quality and human health,
15 while its environmental implications have yet to be examined. This study analyzes the life-cycle
16 environmental impacts of this ban on post-consumer PET under a number of post-ban scenarios. Our
17 analysis shows that the ban may substantially exacerbate environmental impacts both in China and
18 globally, if China, in the absence of imported recyclates, increases its virgin PET fiber production using
19 carbon-intensive coal as the feedstock. Recycling waste PET bottles within the countries that generate
20 them to replace China's virgin PET fiber production, however, is shown to significantly reduce life-
21 cycle environmental impacts both in China and globally. Our study highlights the potential unintended
22 environmental consequences of the ban and the need to consider marginal technologies and their
23 consequences in policy decisions. Our results call for cost-effective recycling infrastructure among the
24 waste-producing countries and the mechanism to coordinate plastics recycling on a global scale.

25 **Keywords:** China; foreign waste ban; post-consumer plastics; environmental implications; life cycle
26 assessment (LCA); consequential modeling

27 **1. Introduction**

28 Since the 1980s, China has been importing solid wastes from overseas in order to ease the
29 problem of raw materials scarcity, while fueling China's manufacturing industry (Yoshida et al.,
30 2005). China soon became the number one destination for recyclable wastes (Kellenberg, 2012). It
31 received 7.3 Tg of post-consumer plastics from 43 different countries in 2016 alone (Brooks et al.,
32 2018), which accounted for more than 50% of the global post-consumer plastics export. According to
33 China Customs statistics, the largest share of waste plastics imported by China was polyethylene
34 terephthalate (PET), representing 2.5 Tg out of 7.3 Tg of all post-consumer plastics imported in 2016
35 (Chen et al., 2018). Major exporters were industrialized countries including European countries, the

36 US, and Japan (Brooks et al., 2018).

37 In July 2017, the Chinese government issued a new regulation—the Implementation Plan for
38 Prohibiting the Entry of Foreign Waste and Advancing the Reform of the Solid Waste Import
39 Administration System (GOCSC, 2017)—that laid out the plan to ban the imports of foreign wastes
40 from 2018. The ban lists two dozen types of solid wastes including post-consumer plastics from
41 municipal sources. China is expanding the coverage of the initial import ban, and post-consumer
42 plastics from industrial sources are banned from 2019.

43 The ban had an immediate effect on the global structure of post-consumer plastics flows (Pu et
44 al., 2019; Wang et al., 2019); it reduced China’s share in the import of plastics waste exported by G7
45 countries from 60% during the first half of 2017 to less than 10% during the same period a year later.
46 The volume of plastic waste exports from G7 countries fell by 20% on average from 2017 to 2018
47 (Hook and Reed, 2018). The reduction in post-consumer plastics export was, however, the result of
48 temporary measures; bales of trash piled up in the US, in the UK, in Australia, and other
49 industrialized countries (Parker, 2018). In the short run, these recyclables are being landfilled due to
50 the limited recycling and incineration capacities in the waste-producing countries (Hook and Reed,
51 2018; Qu et al., 2019). The ban already caused chaos among plastics recycling industries around the
52 globe.

53 Previous literature placed its focus mainly on the global changes in flows and structure of waste
54 plastics before and after the ban came into force. Brooks et al. (2018) indicates that China has
55 imported a cumulative 45% of plastic waste since 1992 and estimates that 111 million metric tons of
56 plastic waste will be displaced with the ban by 2030. Wang et al. (2020) constructed global plastic
57 waste trade networks and analyzed the spatiotemporal evolution of the networks between 1988 and
58 2017. Parker (2018) indicates that the ban has redirected the waste flows to South-East Asian
59 countries and the governments of the region are also imposing a slate of new regulations including
60 bans, inspections, and taxes and fees. Multiple studies have also suggested that the ban may deeply
61 affect global sustainability and calls for developing an appropriate policy framework to prevent
62 unintended consequences (Huang et al., 2020; Qu et al., 2019; Tan et al., 2018).

63 The original intention of this ban was to protect China’s ecosystem quality and human health
64 (GOCSC, 2017), while the ban’s life-cycle environmental implications are not all that clear. China is
65 the largest producer of PET fiber in the world and the global demand for China’s synthetic fiber
66 remains strong. China already reached near maximum practicable collection rate for its domestically
67 generated post-consumer PET bottles (Zhang and Wen, 2014) and 86% of China’s imported post-
68 consumer PET bottles were downcycled to produce recycled PET fiber in 2017 (Chen et al., 2018).
69 In the absence of imported post-consumer PET recyclates due to the ban, the country needs to either
70 increase the use of virgin materials or reduce the domestic production of PET fiber (Yoshida et al.,
71 2005).

72 Moreover, China is increasingly reliant on coal for its PET fiber production. PET resin,
73 synthesized through the polymerization reaction of purified terephthalic acid (PTA) and ethylene
74 glycol (EG), is widely used to produce fiber, bottles, sheet, film, and engineering resin (Chen et al.,
75 2018). PET resin is traditionally derived from petroleum resources (Scheirs and Long, 2005). In
76 China, however, the use of abundant and inexpensive coal instead of petroleum for chemical
77 production has been encouraged by the government, and as a result, the production of EG is

78 increasingly relying on coal as the feedstock, which comes with its own environmental costs (Yang
79 et al., 2018). Production of PTA still uses petroleum feedstock in China. In this article, ‘Coal-based’
80 PET fiber production pathway refers to the production pathway that uses petroleum-based PTA and
81 coal-based EG as the feedstock, whereas the ‘Petroleum-based’ counterpart to that uses both
82 petroleum-based EG and PTA (see section 2 of the Supplementary Material).

83 To quantify the possible environmental impact of this ban, we designed a number of post-ban
84 what-if scenarios based on possible market conditions. Under the assumption that the amount of
85 global PET fiber production is kept equal in all scenarios, the change in environmental impact before
86 and after the ban coming into force is caused by using different feedstocks to produce PET fiber.
87 Therefore, we quantified and compared the environmental impacts of various PET fiber production
88 pathways by using the life cycle assessment (LCA) (ISO, 2006a, b) approach.

89 **2. Materials and Methods**

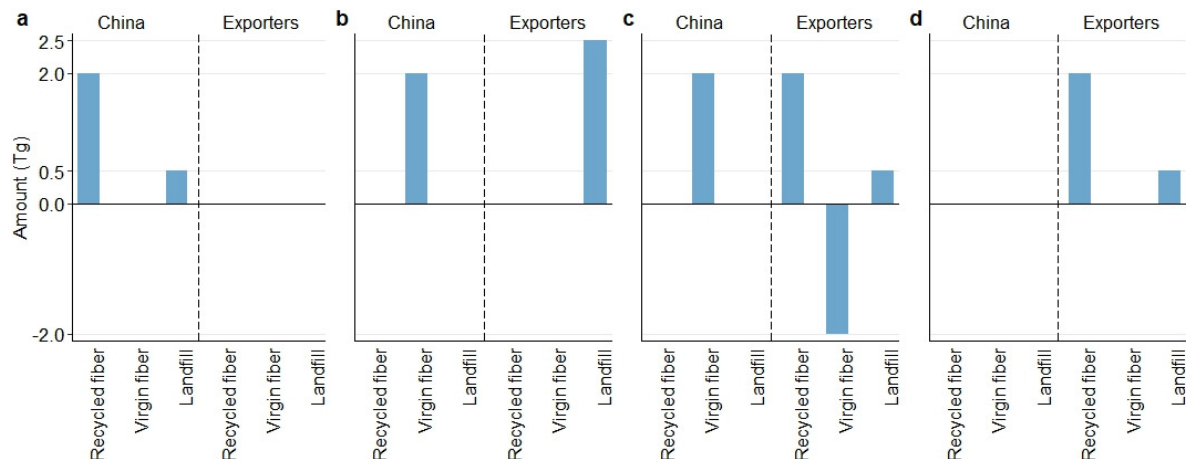
90 **2.1. Scenario design**

91 Currently, a significant portion of the post-consumer PET bottles used to be imported by China
92 prior to the ban, which amounts to 2.5 Tg yr⁻¹ (Chen et al., 2018), is being landfilled or stored within
93 the countries that generate them or sent to other countries. As a result, the ban creates a shortfall of
94 feedstock for PET fiber production in China, which is estimated to be about 2 Tg yr⁻¹ that were
95 produced using imported post-consumer PET bottles prior to the ban. The difference, about 0.5 Tg yr⁻¹
96 or 20% of the PET recyclate input, was the portion lost during the process, which was generally
97 landfilled (Nakatani et al., 2010).

98 Our baseline scenario represents the conditions prior to the ban. We created three what-if
99 scenarios post the ban. Given that the waste plastic recycling industry is currently undergoing drastic
100 changes, these scenarios serve as an instrument to gauge the range of possible futures and are not meant
101 to be used as projections. Therefore, we intentionally explored extreme conditions, while the reality is
102 likely to reside in-between the scenarios that we evaluated. In all scenarios, the amount of PET fiber
103 production at the global level is kept equal to fulfill human needs. The baseline scenario, i.e., *business*
104 *as usual scenario prior to the ban*, (‘BAU-prior’, see Fig. 1a) follows the conditions prior to the ban
105 where 2.5 Tg of waste PET plastics are imported by and recycled in China to produce 2 Tg of recycled
106 PET fiber. Three post-ban scenarios assume that the shortfall of the 2 Tg of recycled PET fiber that
107 used to be produced in China is fulfilled by either China’s marginal virgin fiber production, or by
108 recycled PET fiber production within the countries that generate post-consumer PET bottles (hereafter
109 ‘Exporters’).

110 Among three post-ban scenarios, the current market response to the ban is the most closely aligned
111 with the case where Exporters landfill, stack up, or send to other nations the 2.5 Tg of post-consumer
112 PET bottles (Hook and Reed, 2018) and China makes up the 2 Tg shortfall in recycled PET fiber using
113 virgin feedstock, which, in China, is increasingly relying on coal (Yufang and Ming, 2011). This
114 scenario is referred to as *Business as usual scenario post the ban* (‘BAU-post’ scenario, see Fig. 1b)
115 in this paper. Under the *local recycling-substituting domestic fiber scenario* (‘LR-substituting
116 domestic’, see Fig. 1c), the shortfall of the 2 Tg of PET fiber is made up by China’s virgin PET fiber
117 production, as was is in the ‘BAU-post’ scenario, whereas the 2.5 Tg of post-consumer PET plastics
118 are locally recycled, rather than landfilled or piled up, within the waste-producing countries, replacing

119 2 Tg of domestic virgin fiber production, which is based mostly on petroleum feedstock. Lastly, the
 120 *local recycling-substituting Chinese fiber scenario* ('LR-substituting CN', see Fig. 1d) follows the
 121 same conditions as the 'LR-substituting domestic' scenario, except that the PET fiber produced through
 122 local recycling within Exporters replaces China's virgin PET production, not the domestic ones.
 123



124
 125 **Fig. 1. The fate of post-consumer PET bottles under the main what-if scenarios before and after**
 126 **the ban.** **a**, Business as usual scenario prior to the ban ('BAU-prior') where imported post-consumer
 127 PET bottles are used to produce recycled PET fiber in China. **b**, Business as usual scenario post the
 128 ban ('BAU-post') where the shortfall of the 2 Tg of PET fiber is fulfilled by virgin fiber in China
 129 marginally supplied by the coal-based pathway, and the 2.5 Tg of post-consumer PET bottles are
 130 landfilled or piled up in the countries producing them. **c**, Local recycling-substituting domestic fiber
 131 scenario ('LR-substituting domestic'), under which post-consumer PET bottles are recycled within the
 132 countries of generation to replace their domestic virgin fiber production. **d**, Local recycling-
 133 substituting Chinese fiber ('LR-substituting CN'), under which post-consumer PET bottles are
 134 recycled within the countries of generation to replace China's virgin fiber production.
 135

136 2.2. Life-cycle environmental impacts calculation

137 CO₂ and major air pollutant emissions of each PET fiber production pathway or under each
 138 scenario are quantified using LCA methodology, a tool to assess the potential environmental impacts
 139 and resources used throughout a product's life cycle (Foolmaun and Ramjeeawon, 2013; ISO, 2006b).
 140 The value of LCA to quantitatively assess products' life-cycle environmental impacts has been
 141 recognized and it is increasingly used to support decisions in policy and government arenas (Kirchain
 142 Jr et al., 2017).

143 The process-based matrix inversion method is employed as the computational approach (Suh and
 144 Huppes, 2005) and summarized as equation (1-4).

$$M = BA^{-1}Y \quad (1)$$

$$N = MC \quad (2)$$

$$M_i^* = (B + \delta B_i)(A + \delta A_i)^{-1}Y \quad (3)$$

$$N_i^* = M_i^*C \quad (4)$$

B Elementary flow matrix

A Intermediate flow matrix

Y Final demand matrix

M Life cycle inventory matrix

C Characterization vector

N Environmental impact matrix

δB_i Randomly sampled deviation matrix for the elementary flows

δA_i Randomly sampled deviation matrix for the intermediate flows

i Number of simulation, $i = 1, \dots, n$ ($n = 1000$)

M_i^* Life cycle inventory matrix under the i round of Monte Carlo Simulation

N_i^* Environmental impact matrix under the i round of Monte Carlo Simulation

145

146 To allocate environmental burdens among different useful lives of the material, we adopt the cut-
147 off rule (Shen et al., 2010), which has been widely applied for recycled or recovered products. Under
148 the cut-off approach, all virgin material production burdens are assigned to the first use of the material
149 and the burdens assigned to the recycled resin system begin with the recovery of post-consumer PET
150 bottles. Monte Carlo simulation is used to deal with uncertainty (Gregory et al., 2016; Suh and Qin,
151 2017) and we do 1,000 times of simulations (Qin and Suh, 2017). Section 3 of the Supplementary
152 Material provides more information about uncertainty analysis of this research.

153 (a) Life-cycle environmental impacts of each production pathway

154 We define the functional unit as “one kilogram of PET fiber” for the recycling pathway in China,
155 the coal-based pathway in China, the recycling pathway in Exporters, and the petroleum-based
156 pathway in Exporters and as “landfilling one kilogram of post-consumer PET bottles” for post-
157 consumer PET bottle treatment. Thus, the final demand matrix can be expressed as Y_0 . Each column
158 vector in Y_0 represents the final demand vector of one PET fiber production pathway.

159

$$Y_0 = \begin{matrix} & \text{CR} & \text{CV} & \text{ER} & \text{EV} & \text{L} \\ \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} & \text{Recycled PET fiber production in China} \\ & \text{Coal-based virgin PET fiber production in China} \\ & \text{Recycled PET fiber production in Exporters} \\ & \text{Petroleum-based virgin PET fiber production in Exporters} \\ & \text{Landfilling post-consumer PET bottles} \end{matrix} \quad (5)$$

Y_0 Final demand matrix, each column vector represents the final demand vector of one production pathway

160 * ‘CR’ represents the recycling pathway in China; ‘CV’ represents the coal-based virgin PET fiber production pathway in
161 China; ‘ER’ represents the recycling pathway in Exporters; ‘EV’ represents the petroleum-based virgin PET fiber
162 production pathway in Exporters; ‘L’ represents post-consumer PET bottle landfill.

163

164 The intermediate flow matrix and elementary flow matrix of coal-based EG production, virgin
 165 PET fiber production, and recycled PET fiber production are provided by three companies in China
 166 (foreground data is shown in the Supplementary Excel file). Bottle-to-fiber recycling mainly includes
 167 mechanical recycling and chemical recycling (Achilias and Karayannidis, 2004; Shen et al., 2010). In
 168 chemical recycling, PET polymer is broken down into monomers or oligomers, so the recycled
 169 polymer has very similar or even identical properties with virgin polymer (Shen et al., 2010). The
 170 company providing process data on recycled PET fiber production for us adopts chemical recycling
 171 technology. Data on other processes is collected from the ecoinvent V3.4 database (Wernet et al., 2016),
 172 which is currently the most widely used life cycle inventory database. Miscellaneous materials, which
 173 account for less than 1% by weight of the net process inputs, are typically cut off unless inventory data
 174 for their production are readily available (ERG, 2011).

175 Given that air quality and climate change are the main foci of the Chinese government’s
 176 environmental management, we selected the major air pollutants of concern: CO₂, PM_{2.5}, SO₂, and
 177 NO_x (Wang and Hao, 2012). As for the life cycle environmental impact categories, we used ReCiPe
 178 Endpoint 2016 (Huijbregts et al., 2017) that covers all three areas of protection, namely, human health
 179 damage, ecosystem quality, and resource scarcity.

180 **(b) Life-cycle environmental impacts under each scenario**

181 Based on the scenario design, the final demand matrix under the four scenarios is expressed as Y_s .
 182 Each column vector represents the final demand vector of one scenario.

183

$$Y_s = \begin{pmatrix} 2 & 0 & 0 & 0 \\ 0 & 2 & 2 & 0 \\ 0.5 & 0 & 0 & 0 \\ 0 & 0 & 2 & 2 \\ 0 & 0 & -2 & 0 \\ 0 & 2.5 & 0.5 & 0.5 \end{pmatrix} \begin{matrix} \text{Recycled fiber production in China} \\ \text{Coal-based virgin fiber production in China} \\ \text{Landfilling post-consumer bottles in China} \\ \text{Recycled fiber production in Exporters} \\ \text{Petroleum-based virgin fiber production in Exporters} \\ \text{Landfilling post-consumer PET bottles in Exporters} \end{matrix} \quad (6)$$

Y_s Final demand matrix, each column vector represents the final demand vector under one scenario

184 * ‘S1’ represents the ‘BAU-prior’ scenario; ‘S2’ represents the ‘BAU-post’ scenario; ‘S3’ represents the ‘LR-substituting
 185 domestic’ scenario; ‘S4’ represents the ‘LR-substituting CN’ scenario. Unit: Tg.

186

187 To quantify the environmental impact changes occurring in China under each scenario as
 188 compared to the case before the ban, we distinguish the impacts occurring in China and the rest of the
 189 world for the recycling pathway in China since the impacts of collection & sorting and sea
 190 transportation of post-consumer PET bottles occur in the rest of the world and impacts of transforming
 191 post-consumer PET bottles to recycled PET fiber occurs in China.

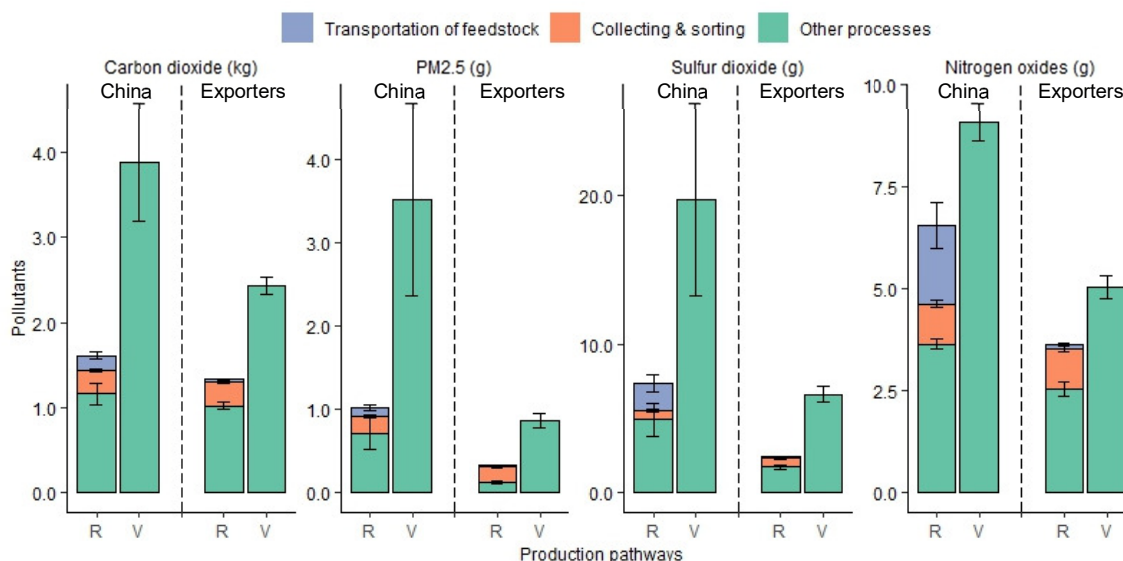
192 **3. Results**

193 **3.1. LCA results**

194 Given the inherent uncertainties in the parameters used in our study, we ran a Monte Carlo
 195 simulation, and the results are expressed as a distribution. Our LCA results (Fig. 2) show that

196 producing 1 kg of virgin PET fiber from petroleum feedstock in exporting countries emits on average
 197 2.4 kg of CO₂ throughout its life-cycle. Under the current technological configurations, producing 1
 198 kg of PET fiber in China using PET recyclates is estimated to generate 1.6 kg of CO₂ throughout its
 199 life-cycle. However, 1 kg of coal-based virgin PET fiber produced in China, is estimated to emit 3.9
 200 kg of CO₂ emission. For exporting countries, producing 1 kg of recycled PET fiber by recycling their
 201 own post-consumer PET bottles emits 1.3 kg of CO₂, which is 0.3 kg less than that from recycled
 202 PET fiber produced in China.

203 Furthermore, coal-based virgin PET fiber in China shows 38-246% higher PM_{2.5} SO₂ and NO_x
 204 emissions as compared to recycled PET fiber in China. Recycled PET fiber in exporting countries
 205 reduces major air pollutant emissions by 44-67% as compared to the recycled PET fiber in China,
 206 partly owing to the cleaner power supply in developed countries and partly because of the avoided
 207 carbon emission from shipping post-consumer PET bottles to China. Coal-based virgin PET fiber
 208 produced in China shows 80-300% higher life-cycle air pollutant emissions as compared to
 209 petroleum-based PET fiber.
 210



211

212 **Fig. 2. Life-cycle CO₂ and other major air pollutant emissions of PET fiber production**
 213 **pathways per kg of PET fiber.** Each bar represents pollutant emissions of one PET fiber production
 214 pathway. ‘R’ under China is recycling pathway; ‘V’ under China is coal-based virgin PET fiber
 215 production pathway; ‘R’ and ‘V’ under Exporters are recycling pathway and petroleum-based virgin
 216 PET fiber production pathway, respectively, within Exporters. The error bars are the standard
 217 deviation calculated over 1,000 times of runs using Monte Carlo simulation.

218 3.2. Scenario analysis results

219 Given the uncertainties in the underlying parameters, we have performed Monte Carlo simulation,
 220 and the results are presented in box plots (Fig. 3). Under the ‘BAU-post’ scenario, the average life-
 221 cycle CO₂ emissions increase by 5.4 Tg yr⁻¹ in China (Fig. 3a) due primarily to the increase in carbon-
 222 intensive, coal-based PET fiber production. At the global level, the ban reduces international shipment,

223 sorting activities, and associated emissions for post-consumer PET bottles. However, the reduction in
224 shipping and sorting activities does not negate the increase in life-cycle emissions from coal-based
225 PET fiber production, resulting in a net increase of life-cycle CO₂ emissions by 4.5 Tg yr⁻¹ on the
226 global scale (Fig. 3b). Likewise, life-cycle emissions of other major air pollutants including PM_{2.5},
227 SO₂, and NO_x increase both in China and globally under the ‘BAU-post’ scenario (Fig. 3).

228 If the 2.5 Tg yr⁻¹ of post-consumer PET bottles are recycled locally within the countries where
229 they are generated substituting domestically produced virgin PET fiber, global life-cycle CO₂
230 emissions are reduced from the ‘BAU-post’ case roughly by half to on average 2.3 Tg yr⁻¹ (Fig. 3b),
231 because producing 1 kg of recycled PET fiber within Exporters generates only about 1.3 kg of CO₂
232 emissions as compared to the 2.5 kg from petroleum-based virgin PET fiber within Exporters (Fig.
233 2). This scenario, i.e., ‘LR-substituting domestic’ scenario in this paper. Life-cycle emissions within
234 China do not change under this scenario as compared to ‘BAU-post’, as the substitution of virgin
235 PET fiber by recycled PET fiber is assumed to take place within Exporters. Under both scenarios,
236 i.e., ‘BAU-post’ and ‘LR substituting domestic’, life-cycle emissions of major air pollutants
237 including CO₂, PM_{2.5}, SO₂, and NO_x increase both in China (Fig. 3a) and globally (Fig. 3b) as
238 compared to the case prior to the ban.

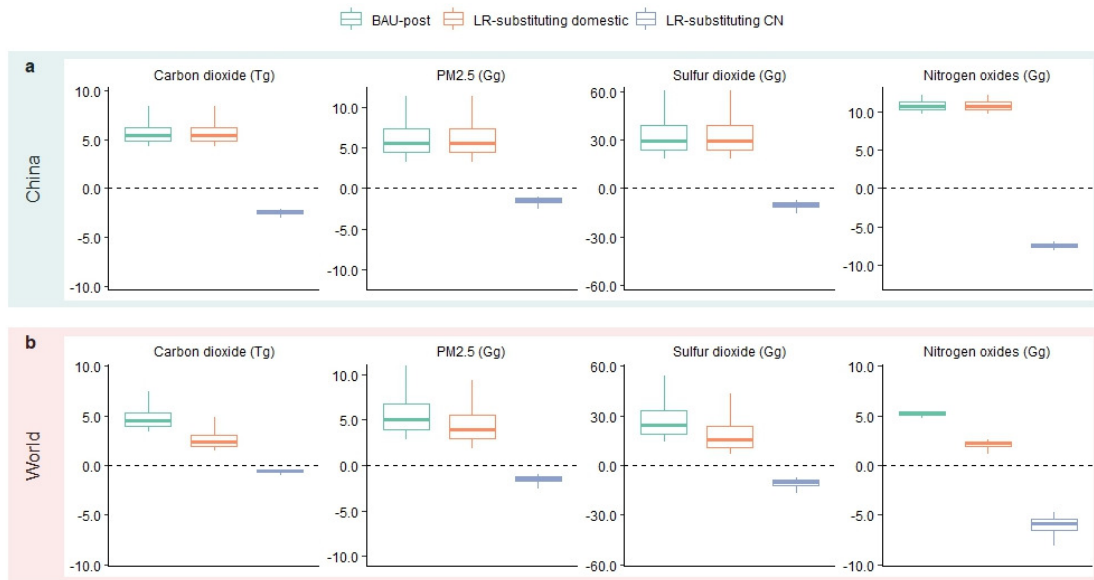
239 However, when post-consumer PET bottles are recycled within Exporters to produce PET fiber
240 *and* if the recycled PET fiber from Exporters replaces the virgin PET fiber produced in China, on
241 average 2.3 Tg yr⁻¹ and 0.6 Tg yr⁻¹ reductions in CO₂ emission are expected in China and in the world,
242 respectively, as compared to the case prior to the ban. This scenario, i.e., ‘LR-substituting CN’ scenario
243 in this paper, reduces not only CO₂ emissions but also other major air pollutants throughout the life-
244 cycle (Fig. 3). This is mainly due to the lower life-cycle emissions of recycled PET fiber within
245 Exporters as compared to virgin or recycled PET fibers produced in China. The difference in life-cycle
246 emissions is attributable in part to the cleaner power supply in Exporters and to the avoided pollutant
247 emissions from shipping and handling of post-consumer PET bottles to China (Fig. 2).

248 Overall, ‘LR-substituting CN’ scenario presents the most favorable environmental outcomes
249 among the three major post-ban what-if scenarios examined. It is, however, questionable whether
250 locally recycled PET can successfully outcompete China-produced virgin PET fiber under the current
251 market conditions, given the high cost of recycling among industrialized countries.

252 In addition to these results, we have obtained additional results based on additional end-point
253 indicators of Life Cycle Impact Assessment (Pennington et al., 2004) and scenarios, which are
254 presented in section 4, Robustness Check, of the Supplementary Material.

255 China’s import ban greatly affected the global landscape of plastics recycling. Our research
256 focuses on the environmental implications of the ban taking waste PET recycling as an example. More
257 research is needed to understand the social and economic implications of this ban including but not
258 limited to occupational health and safety and child labor. Moreover, the implications of banning other
259 plastics (such as PP, PE, and PVC) merit further research.

260



261

262 **Fig. 3. Changes in China's and global annual CO₂ and other major air pollutant emissions**
 263 **under each scenario as compared to the case before the ban. a, changes in China. b, changes at**
 264 **the global level (including China). 'BAU-post' represents the Business as usual scenario post the ban**
 265 **where the shortfall of recycled PET fiber is fulfilled by virgin fiber production in China marginally**
 266 **supplied by the coal-based pathway, and post-consumer PET bottles are landfilled in the countries**
 267 **producing them; 'LR-substituting domestic' represents the scenario where post-consumer PET**
 268 **bottles are recycled within the countries of generation to replace their domestic virgin fiber**
 269 **production; 'LR-substituting CN' represents the scenario where post-consumer PET bottles are**
 270 **recycled within the countries of generation to replace China's virgin fiber production. Positive values**
 271 **and negative values indicate increases and decreases in emissions, respectively, as compared to the**
 272 **'BAU-prior' scenario. Boxplots show medians (horizontal lines), 25th and 75th percentiles (upper**
 273 **and lower box limits), and extreme observations (bars) based on 1,000 runs of Monte Carlo**
 274 **Simulation.**

275 4. Conclusions and policy implications

276 The original intention for the government of China to prohibit the imports of solid wastes was to
 277 protect its ecosystem quality and human health (GOCSC, 2017). But our study on PET, which
 278 constitutes the largest portion of the imported waste plastics prior to the ban, indicates that the ban
 279 may exacerbate environmental impacts both in China and globally. Even if the entire amount of post-
 280 consumer PET bottles that were exported to China are locally recycled within the countries where they
 281 are produced, life-cycle emissions of major air pollutants and impacts are likely to increase as
 282 compared to the case prior to the ban. Only under the unlikely scenario where virgin PET fiber
 283 produced in China is replaced by recycled PET fiber produced locally within industrialized countries,
 284 life-cycle emissions of major air pollutants and environmental impacts are reduced.

285 As such, we believe that the ban is unlikely to achieve its intended objectives. This likely misfire

286 of the ban is rooted in the lack of marginal thinking in policy design (Kätelhön et al., 2016; Kätelhön
287 et al., 2015); the ban creates a shortage in recycle feedstock for PET fiber production in China, which
288 is likely to be fulfilled by the marginal technology for virgin PET production that uses coal-based
289 pathway. It is important to acknowledge that, however, the ban may alleviate other pressing issues such
290 as occupational health and safety and child labor, which were not quantified in this study.

291 For China, we recommend a comprehensive re-evaluation of the policy considering marginal
292 technologies that will be utilized as a consequence of the ban. Building modern recycling facilities
293 while selectively allowing the import of high-quality recyclable PET, rather than an outright ban might
294 be a possible alternative (Tan et al., 2018).

295 Our study indicates that the adverse environmental impacts of the ban are associated mainly with
296 the use of coal-based PET production. Coal-based chemical industry is rapidly expanding in China; in
297 addition to the coal-based EG production, coal-to-aromatics technology may soon be able to develop
298 coal-to-PTA technology on a commercial scale, enabling an entirely coal-based PET fiber production
299 pathway (both PTA and EG based on coal; see section 2 of the Supplementary Material for details).
300 Producing both PTA and EG out of coal would show an even stronger economic advantage (Li et al.,
301 2017)—and environmental disadvantage—over petroleum-based PET fiber production pathway.
302 Addressing the severe air pollutions associated with coal-based chemical production in China would,
303 therefore, be urgently needed before its mass-deployment.

304 For waste-producing countries, there is an urgent need to rapidly increase the capacity to recycle
305 end-of-life PET bottles cost-effectively (Walker, 2018). Currently, cost-competitive PET bottle
306 recycling within industrialized countries is a challenge. In the meantime, policymakers may consider
307 incentivizing the development of domestic infrastructure for PET recycling through e.g., taxing virgin
308 materials and taxing landfill of recyclable materials. Even if the amount of post-consumer PET bottles
309 that were used to flow to China before the ban is completely recycled within the countries that generate
310 them, the ban's adverse impacts on the environment, especially those within China, are likely to persist.
311 That is because locally recycled PET bottles within industrialized countries are more likely to replace
312 only locally produced virgin PET fiber, not the virgin PET fiber produced in China derived from coal.
313 Our results, therefore, suggest that closing the loop, or increasing material circularity of PET within
314 each country, alone may not negate the adverse impacts of the ban on the environment unless the global
315 economy institutes a mechanism under which heavily polluting processes are eliminated in the supply
316 chain regardless of where they are located; as long as the process with higher pollution intensity enjoys
317 price advantage over more environmentally benign process, global market will favor the pollution-
318 intensive process wherever it is. Our analysis did not consider the case where waste plastics flowing
319 into the least developed countries, in which case the environmental consequence of the ban may well
320 be far worse than any of the scenarios tested in our study. To prevent problem-shifting from one country
321 to another, a mechanism to coordinate plastics recycling on a global scale is in urgent need (Qu et al.,
322 2019). Creating the framework conditions under which the market favors environmentally benign
323 technologies over pollution-intensive ones demands a durable and global mechanism to
324 internationalize environmental externalities. A global level playing field in environmental tax and
325 carbon pricing schemes, for example, would be a key to create such framework conditions (Nordhaus,
326 2011). Neither political appetite nor the international governance structure that can enforce a global
327 mechanism to internalize externalities exists today, leading to a large disparity in e.g., carbon prices

328 across the world (World Bank, 2018). In the meantime, other opportunities including more aggressive
329 application of pollution abatement technologies and tightening emissions standards targeting heavy
330 polluters should continue to be pursued.

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337 material are those of the authors and do not necessarily reflect the views of US EPA. This work has
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339 **Interests:** The authors declare that they have no competing interests.
340

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447

448 **Supplementary Material**

449 fig. S1. Material flow analysis of non-fiber PET among ten world regions and over its life cycle in
450 2016.

451 fig. S2. PET fiber production pathways using different raw materials.

452 fig. S3. Life-cycle endpoint impacts of PET fiber production pathways per kg of PET fiber.

453 fig. S4. Changes in China's and global annual endpoint impacts under each scenario as compared to
454 the case before the ban.

455 fig. S5. The fate of post-consumer PET bottles under the possible what-if scenarios in robustness check.

456 fig. S6. Changes in China's and global annual major air pollutant emissions and endpoint impacts
457 under the possible what-if scenarios in robustness check.

458 data file S1. Sources, geographical appropriateness, and uncertainty information of life cycle inventory
459 data (Excel file).