I a a a a a VOC
C a

X a

1. Introduction

A a a a P a , , , a a a . A a P a E I A a C a, 2010–2019, a a a a a a 7.5 % C a. I 2019, a a 1.3 RMB, a a - - a a 2.4 %. O a a a a a , a , a a a a a a (VOC) a (S a ., 2022; Z a a ., 2021; W a ., 2020; Z a a ., 2020). VOC a a a (O_3) a a a a (SOA) (C a ., 2020; L a ., 2020; Y a a ., 2013; Z a a ., 2013). E VOC a a a - O_3 a SOA C a.

T a a (VCP)— a , , a , , a , a a a , a a a a VOC U S a a E a a a a a (M D a a ., 2018; S a ., 2016). I C a, a a VOC MEIC a VCP a a a a - a VOC (L a ., 2019). T VCP a a a a a VOC , a VOC (Ta -G a ., 2022; C a ., 2021; G a a ., 2021a, 2021 ; M a ., 2021; S a ., 2021; P a , 2019). T a a a VCP , a a a a VOC a . T a - a (a 10 %) a VOC C a, a a a (27 %) (L a a ., 2017, 2020). T , a a a a a a- a VOC C a. I a , C a a a a a a fi a (M E a E (MEE), 2020a, 2020 , 2021, 2022), G (HJ 1089–2020) a E (GB 41616–2022).

G a a a a a VOC C a, a (EF), fi , a . H , a a - a . F , a a a a a a a a a a a a a a a a EF (. ., VOC/C T a a a a a) (L a a ., 2019; Wa a ., 2018). H , EF a a - a VOC a a a a a a a a a a a a a (. ., , a fl). D a a EF , a VOC a a a a C a a (M a ., 2021; L a ., 2019; W a ., 2016; W a X , 2017), a a a a . S , fi a a : fi a - a a (L a a ., 2020; W a ., 2020; Ya a ., 2020; Z a a ., 2020; L a ., 2019; L a ., 2018; S a ., 2018; X a ., 2018; Z a ., 2013; Y a a ., 2010). I - a a a fi a , a a a (. ., - a - a), fi (. .,) a . M , a a - a a , a a a a - fi a a a VOC fi a a VOC

. B fi a . F a VOC a a a VOC a VOC a a a (M a ., 2021; L a ., 2019; S a ., 2018; W a X , 2017; W a ., 2016). A a a a a VOC a a 100 % VOC , VOC a a EF . T a a a a a VOC - a . F , , a a a a a - a a VOC fi a a a a . T , a a a fi a - .

T fi (1) a a a a – a EF a a a a a a , VOC a fl , (2) a a fi a , a a a a a a a a VOC fi a a fi , (3) a VOC - C a 2010–2019, (4) a a a VOC a a OFP 2019. S fi a VOC a C a a a a a a a- . O a VOC C a, a a fi a a a - VOC a a a a VOC .

2. Methods and data

F . 1 a a a a a a VOC . T a , a a OFP VOC a . T a a a , a a a (AD), EF a fi a a a a a . T fi a a a a a a :

2.1. E

2.1.1.

T VOC C a 2010–2019 a a a . T a- a a a a a a a , a , , a fl . T VOC a a a :

$$E = A \times EF \times (1 - \zeta \times \eta \times \theta) \quad (1)$$

E VOC (:); *A* a a a (:), . ., a (S 2.2); *EF* a a a (: VOC $^{-1}$ a) (S 2.3); ζ a a a a (: %); T a a a , a fi a - . η a a fi a a (: %); a θ a a a fi a a a a (: %).

I 2010–2017, ζ a θ a M a . (2021). M a . (2021) a a a a a a a a fi a a a 2000–2017. T a a

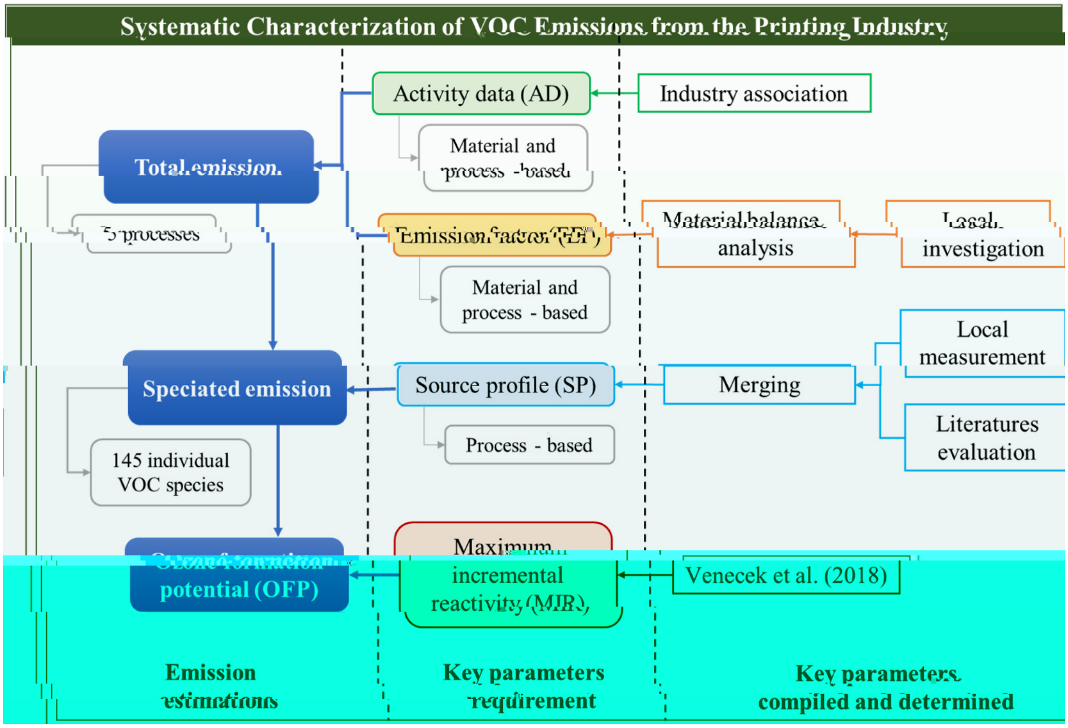

Fig. 1. T a a a a a VOC

a , a a a VOC a fi F 2017, C a a a a VOC a a a a a fi a a a a a a . T a a a a a a a 2017 (M a ., 2021), , a a 2018–2019 a 10 % 2015–2017 5 %. A fi a a a - a a a , a a a a a fi a 4.3 % 2015–2017 6 % 2018–2019 (F . 2). F η, a a fi (. ., 20 %) a a 2018 a a (L a ., 2021). η a a a a 2018 a a a . W 2010–2019 a a M a . (2021), . ., 2013, 2014–2017, a 2018–2019, a (0.5 %), a (2 %), a a (10 %)

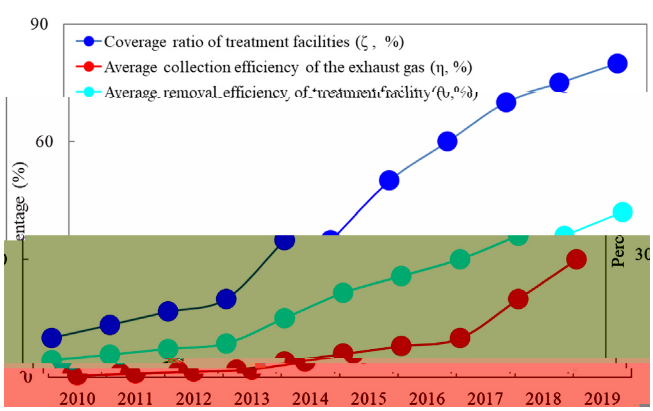

Fig. 2. A a a a a a a , fi a a a fi a a 2010–2019.

a a a , (F . 2). S fi a a a ζ, η a θ 2010–2019 a Ta S1.

2.1.2.

T a VOC 2019 a a a a VOC a E . (2):

$$E_{i,k} = \Sigma_k E_i \times R_{i,k} \tag{2}$$

E , a VOC ; E a VOC ; a , a (S 2.4.2).

2.1.3. O

(1) T OFP (OFPEI)

T OFPEI a a OFP a (L a ., 2020). W a a OFPEI a a :

$$OFPEI_i = \Sigma_k R_{i,k} \times MI \quad k \tag{3}$$

a *OFPEI* OFP a *MI* a a a . T a MIR a V a . (2018)

(2) T OFP

A OFP- a VOC a a VOC a MIR a . I a a a a :

$$OFP_i = \Sigma_k E_{i,k} \times MI \quad k \tag{4}$$

OFP a OFP ; a *E*, a VOC .

2.2. A (AD)

T a a (+ -) a a a- a a a a a a a a a, a a Na a I S a a a T a C , P a E I A a a A a A Ta I A a C a. F . S1 a a C a 2010 2019. C a a a . I 2019, C a a 780 G , a a 32.4 % 589 G 2010. W a a , a a a a a a , a a a a a a a . T - a a a a a , a 42.5 % a 2019 a fla (F . S2 a). C a a a a a ; a a - a a - a a . I 2019, a a 8720 G , a a 92.5 % 4530 G 2010. D a a a a C a a a fi , a a (a), a , a 28.7 %, 21.1 %, a 13.8 % a 2019, - (F . S2). F . S3 a a . L - a a a a a a - a a a a - a , a 90 %. G a a a - a , a 80 %. M fl a a a - a , a a - a a 60 %. S a a a a a , a a fl a . I a a , a - a a a 60 % a - a , - a a a 10 %, a a a a - a - .

2.3. E (EF)

U EF , a - a a a a a (. ., VOC/C T a a a a a), a a EF a (. ., VOC/C I a), a a a a a a - a a a fl . T EF a VOC , , a a , a , fl , a a a a , , , a , a , a a - . W EF a fi a a a a a a a a - (L a a ., 2019). A a 14 a 20 , fi a 10 a a a (Ta 1). T a C a, a , a a a . F a , a a a a a , a a . I a , - a - - a fi a . T EF a a a a a a a a a a E . (5):

$$EF_{,} = \frac{\sum E_{,}}{\sum C_{,I\quad A}} = \frac{\sum C_{,} \times /_{,}}{\sum C_{,I\quad A}} \tag{5}$$

EF, a a a a a ; *E*, VOC a a a a ; $C_{,I\quad A}$ a a a , a a a ; *C*, a a a a a ; a / , VOC a a a , a a a VOC a a a a a (MSDS) . D a a a - a a a a - a a a Ta S2.

2.4. fi

2.4.1. M fi

T a a a fi VOC - T (6.70.6(32.7 7)2(4.3(74.363 1016.31.308)140( )28( )2-25.4( )-2

a Ta 2,
, a , a a a , a , a a -
a . T , a VOC a
a a a a a a
a - a ; , a -
fi . S a
a a a 3.2 L
S a a , a a a .
F a a , a T fl

a, a 1.57 VOC $^{-1}$ a 1.55 VOC $^{-1}$ - a a a, a 0.18 VOC $^{-1}$ a 0.17 VOC $^{-1}$ a - a a a, A VOC a (. ., a a a / - a a) , fl a VOC . T EF a a a fl a a a a a / a fl . T EF - a a -VOC- a a a a a a , a T a L a a . (2019). F , EF a - a a a a 15 a a a - a a , a a VOC . D a a EF a a a a a a, VOC a a a a C a a a a VOC (M a ., 2021; L a ., 2019; W a ., 2016; W a X , 2017). W a EF VOC a a C a, . ., GB 38507–2020 (Na a P S P a S a a I a (NPSPSI), 2020a) a GB 33372–2020 (Na a P S P a S a a I a (NPSPSI), 2020) a . A F . 3 a Ta S3, T VOC EF a a a a a a a , a VOC a a . T EF a a a fl , a - a , - a a - a a - , a 2–5 a a VOC a a . T a a a a VOC a a a a (a), a - a (a a a a -). I , VOC a a a a VOC a fl T a a VOC - a VOC a a a . T EF

a a , a a a a - a . T EF a a "G " (HJ 1089–2020) (M E a E (MEE), 2020). A Ta 1, EF a a a a a a a . T - EF a a a a T EF - a - a fi a , a a a EF a - a . A a a a a a , fi a a a VOC C a a W a . (2011). Ba a a (W a ., 2011) a a a VOC a a fi (Ta 1): II (>3), III (<3) a IV ( ). T a a a 80 %, 150 % a 300 %, D a , EF a a VOC a B a a a a VOC , a a a , a a

3.2. fi

3.2.1. M fi

T VOC fi a a 13 a (S1 S13 Ta 2) a a a- . F . 4 a 5 a a a , a a a , A F . 4, a - a (S7), OVOC a a a a , a a

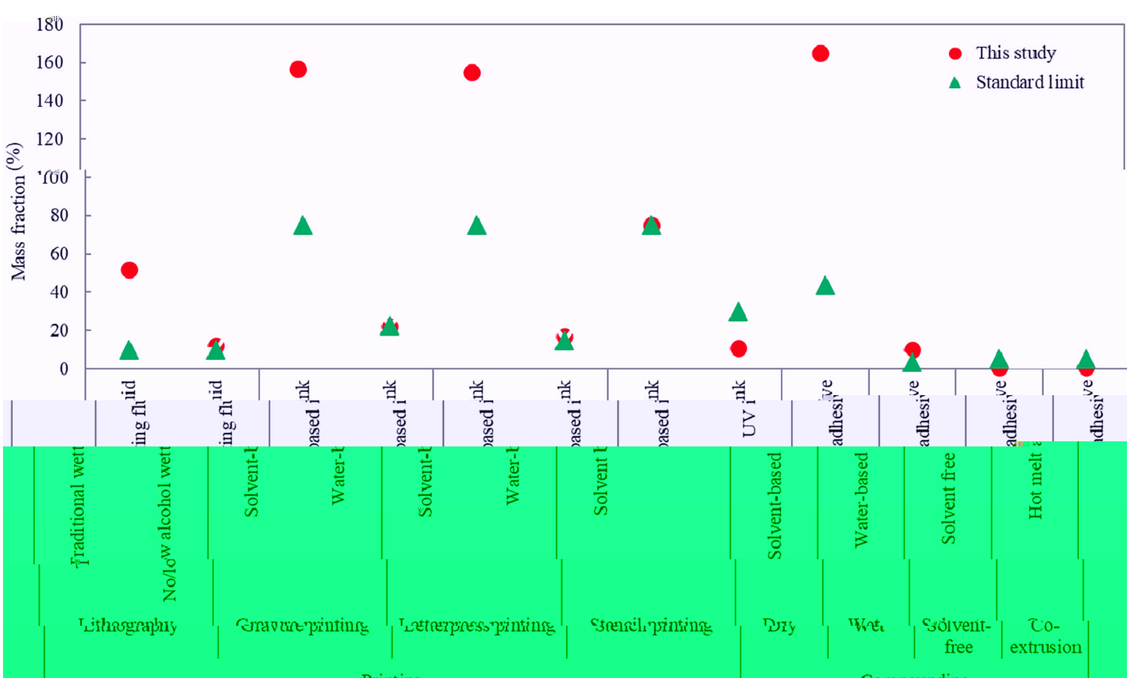

Fig. 3. C a a a a C a.

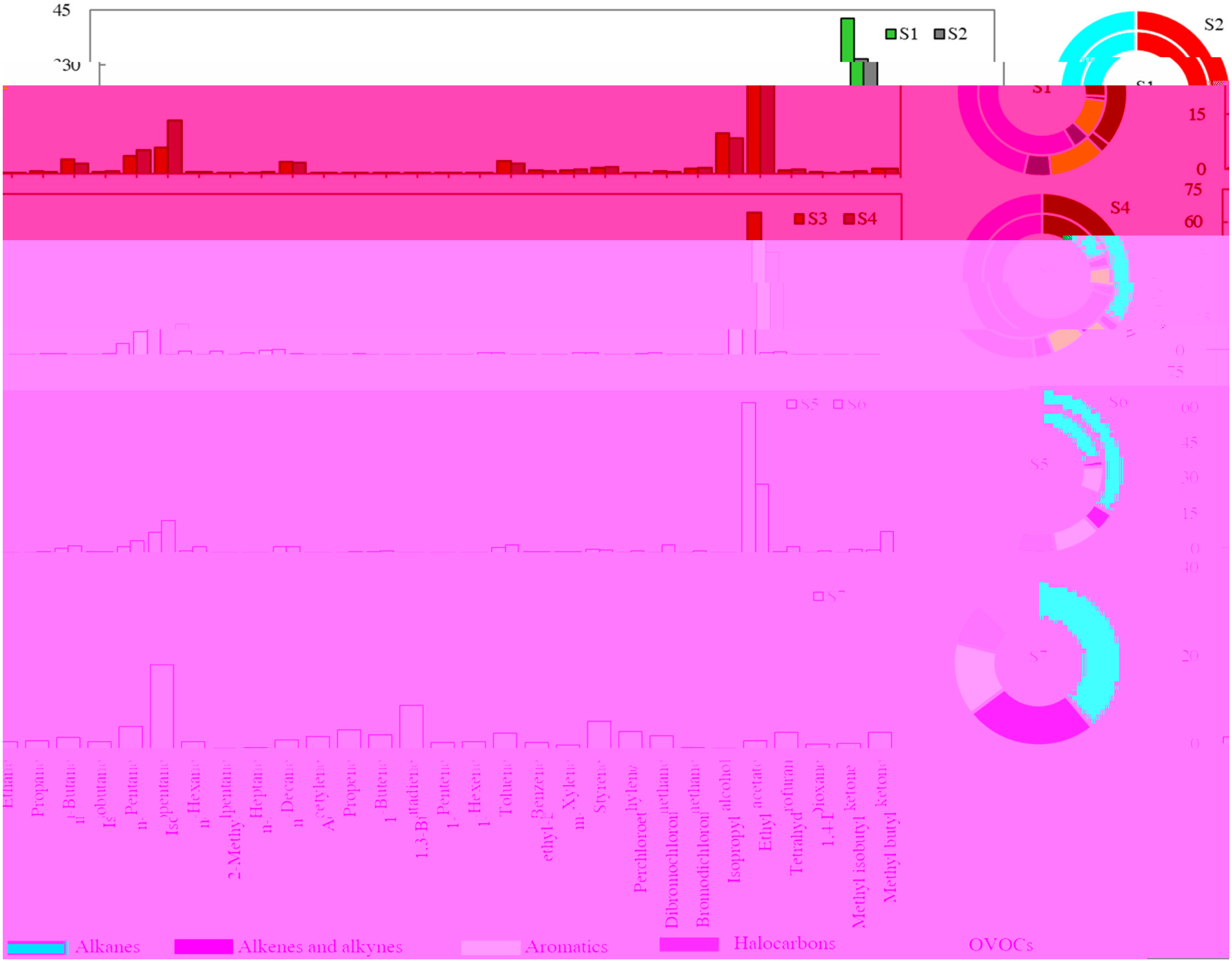

Fig. 4. T VOC a a a a . S1 a S2 a a a - a a , S3 a S4 a a a - a , S5 a S6 a a a a - a a , S7 a - a .

a a 45.5–69.8 %. T a a VOC a a a a . C a , OVOC a a , a a a . A a a a a , OVOC a a a a a a . F fi VOC , a a a , a a a a . E a a , a a a a a - a a a - , a VOC a . I a 43–66 % a 32–48 % a a VOC a a , E a a , a a , a a a VOC a a - a a . T a a a a a (Table 2) a , a a VOC . T a - a a , a a (39.1 %), a a a (25.4 %), a a (14.4 %), OVOC (12.4 %), a a a - (8.6 %). I a , 1,3- a , a 35.3 % a VOC .

T a a a (. ., a a 1,3- a a a - a - a a). N a a , a a a a a - a a a a , a a a a . Fig. 5 a VOC fi a a a - a a a a . F a - a a - a (. ., S8), a a a , a 75.0 % a VOC . A , a , - a , - a , a 2,2,4- a a a , a 16.2 %, 8.4 %, 5.2 % a 5.1 % a , T fi (. ., S9) a UV + a a a a a a a a . F - a (. ., S10), OVOC a a , a 78.7 % a VOC . A a , a a OVOC , a 78.1 % a VOC . I fi (. ., S11) a a a UV + a a a a a , OVOC a , a a a a . T OVOC a a a a a a ,

a 55.3 % a 54.6 % a VOC , F a - a
(. ., S12), a a , a a a , a
OVOC a , a 36.8 %, 34.2 %, a 28.9 %
a , T a a a a - a
, a a a a a a . A -
a a OVOC a a a a ,
a a a . A a a
VOC (. ., S13), a 93.0 % a
VOC . T a a a - a a a a
92.0 % a VOC .

3.2.2. C fi

I a fi
a VOC fi a a (Ta S4)
C a a a a a a a a a

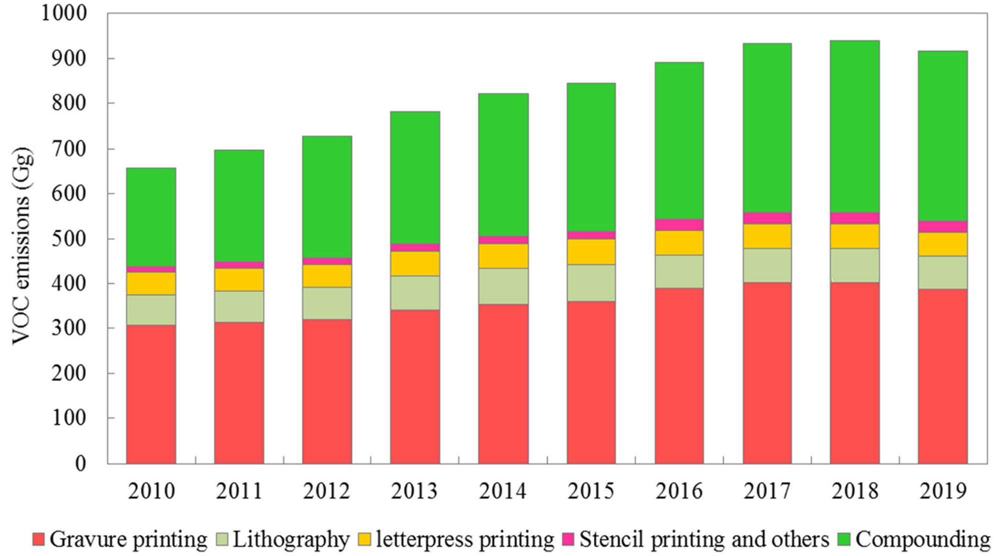

Fig. 6. A a VOC 2010 2019 C a.

a 656.4 G 2010, a 916.1 G 2019. VOC a 2010 2018, a a 2018 a 939.8 G , a a a - a . T a a a a a a a a - I a , a VOC a a 2017 a 4.7 % 2017 0.7 % 2018, a a a 2019 (−2.5 %), a a a (F . 2). F a a , a F . S6, a a - a VOC 2010 2019, a 42.3 %–46.7 % a 33.2 %–41.2 %, L a a - 8.0 %–10.6 % a 5.5 %–7.9 %, S a a (< 3 %). La , a a a a - a a a- a , a a a VOC F a , - a a a a a a a

80 %, VOC a - . R a , a 60 % a 30 % a a a - a a - , O 10 % - a . T , a a a VOC a a a a .

P a VOC 2019 a a a a a a . A F . 7, G a , J a , a Z a a a C a, a a >10 % a , a a 44 %. T a a F . 7 a - VOC a (GDP). VOC a a a a a a C a. I a , VOC a a a

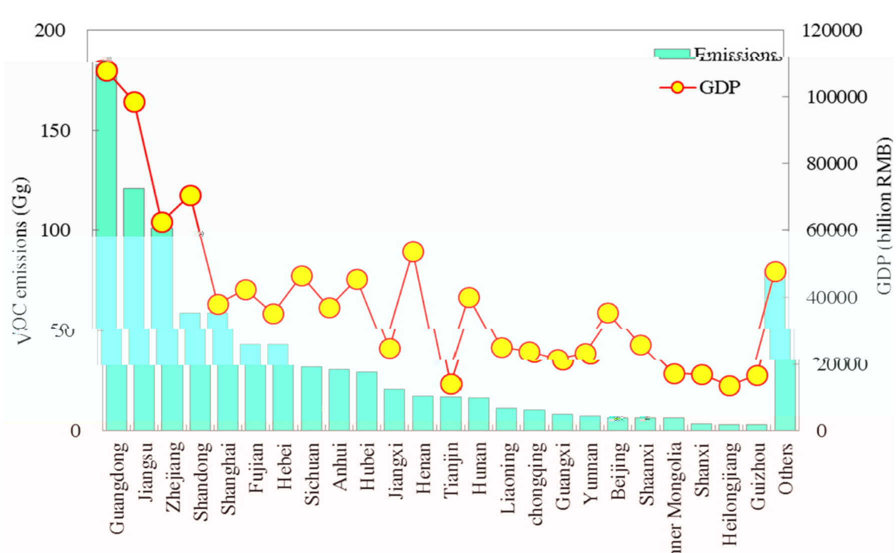

Fig. 7. P a VOC C a 2019.

a a a ȷ a ȷ P a R D a (G a), Ya R D a (S a a , Z a , J a , a A), a B a R (B , T a , H , L a , a S a). O , a H a a F a , a . M C a, T , Ga , N a, a Q a , a a a ȷ a VOC a ȷ ȷa a GDP.

3.4. OFP

A a VOC ȷ ȷ 2019 a a a ȷ A F . S7, - a VOC ȷ a OVOC , a 44.9 % a VOC , ȷ a a (22.6 %), a a (18.6 %), a /a ȷ (5.8 %), a a (5.0 %), a (3.1 %). T a a OVOC a a a a a a ȷ E ȷ a a (28.9 %), (12.5 %), a (8.0 %), a (7.6 %), a - a (2.4 %) fi VOC ȷ a 59.4 % a VOC . E ȷ a a , , a a a ȷ a a a , a , a . OVOC a a a - , a a a a . T a a a VOC ȷ ȷ a a a , , a a a , a S 3.2 a 3.3. T VOC a ȷ Ta S5.

T OFPEI VOC ȷ C a a F . S8, a a 1.4 2.7 O_3/ VOC . L - a a OFPEI (2.7 O_3/), ȷ (2.6 O_3/), a (2.1 O_3/), a ȷ (1.6 O_3/), a a (1.4 O_3/). A a a - a a , , a a , a 57.1 %, 45.3 %, a 42.9 % a OFPEI, ȷ F , OFPEI a ȷ a a a OVOC . T , a a a OVOC a OFP ȷ T a OFP VOC ȷ C a 2019 a 1834.5 G . A F . 8 a, a a OFP a a a . G a a a OFP (29.9 % a 53.2 %, ȷ), ȷ (7.9 %), - a ȷ (6.2), a a (2.8 %). A F . 8 , a a (38.8 %) a a a a OFP ȷ ȷa /a ȷ (24.8) a OVOC (20.6 %). T a ȷ a , OVOC (44.9 %) a a , ȷa a (22.6 %) a a a (18.6 %). T a a a a /a ȷ a OFP a fi a , a ȷ MIR a . T (24.9 %), ȷ a a (9.1 %), 1,3- a (7.3 %), a (5.5 %), a 1- (4.0 %) fi a , a ȷ ȷ

4. Discussions

4.1. C w

T VOC ȷ ȷa - a a . A F . 9, a a ȷ W a . (2016), W a X (2017), S

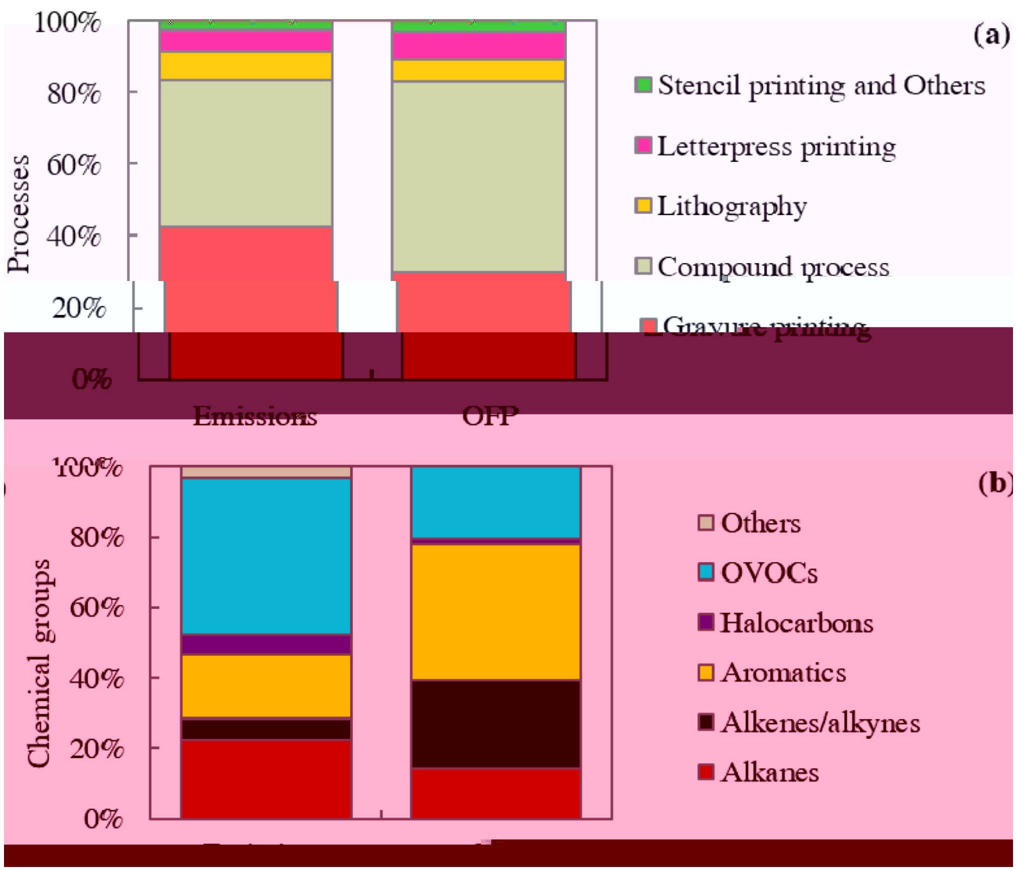

Fig. 8. S a a (a), a a a ( ) VOC a OFP ȷ C a 2019.

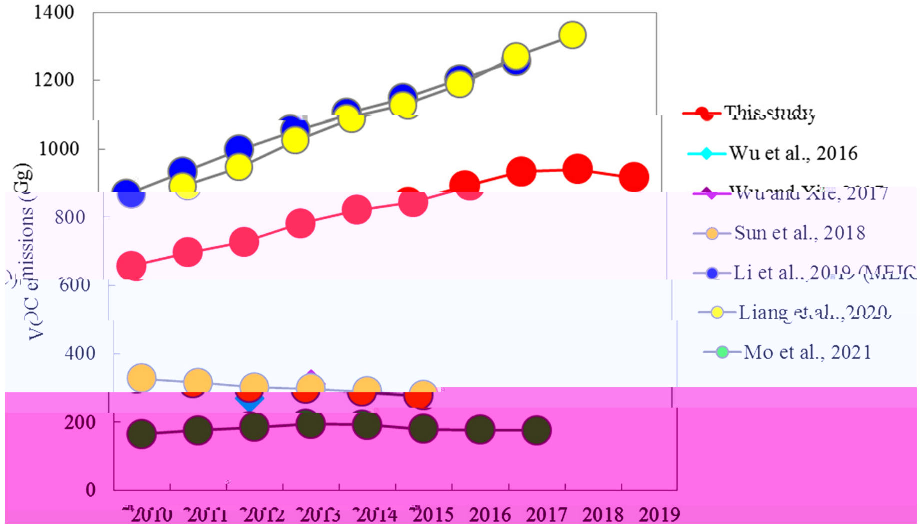

Fig. 9. C a VOC a .

a . (2018) a M a . (2021). T a a a a a VOC a a , a fl a VOC . C a (L a a ., 2020) a MEIC (L a ., 2019), . T a a a a a EF a - a ., EF a a a a . F a , EF a MEIC (L a ., 2019) a 540 VOC $^{-1}$, a a a EF a a a a a A a EF L a a . (2020) a 0.53 VOC $^{-1}$ a , 1.65 VOC $^{-1}$ a - , 0.10 VOC $^{-1}$ a , 0.01 VOC $^{-1}$ a a 0.01 VOC $^{-1}$ a , , - a - T EF fi a a a a . M , a a a a a a a a , a a a a a a a EF . T - , a a a VOC

4.2. P

A a , a OFP a a a a VOC C a, a >80 % a a OFP. T , fi a VOC a a . O a a . T a , UV - a a , a a a - a . S - a a a - , fi a a a a , VOC . T a K a a a . I E (GB 41616–2022) (M E a E (MEE), 2022) C a, fi a a a a a , a a - a a - (NMHC). I a fi

a a , a a a a a a - . T , a a a fi a a . T a a (F . 2) a a a a VOC a a . T a a “K OC I G G P ”(D a E a E G a P , 2021) a a a . A , a a a - , a a a a a - a . F a a a a a , a a - a a a - - . S fi a a - a -a a a a a a (Wa a ., 2017) a a a a a a (Z , 2017) a a .

5. Conclusions

A - VOC 2010–2019 C a a a , a a a a . I EF , fi , a a a VOC a OFP a . O - a a VOC a 656.4 G 2010, a 916.1 G 2019. T a OFP 2019 1834.5 G . G a a >80 % a VOC a OFP. G a , J a , a Z a a a a , a 44 %. T a a a VOC a OVOC (44.9 %), a a (38.9 %) a a - a a OFP. E a a , , a , a , a - a fi VOC a , a 59.4 %. C a a a a VOC , , a a , 1,3- a , a , a 1- fi OFP. W a a a - a -VOC ; VOC a a a a ; a a a fi a a ; a a - a a .

CRediT authorship contribution statement

Xiaoming Liang: C a a , W – a a , M - **Laiguo Chen:** S , W – & . **Ming Liu:** I a , F a a a . **Haitao Lu:** I a . **Qing Lu:** I - a . **Bo Gao:** I a . **Wei Zhao:** I a . **Xibo Sun:** I - a . **Daiqi Ye:** S .

Data availability

Da a a a a a .

Declaration of Competing Interest

T a a a a fi a a - a a a a a a fl a .

Acknowledgments

T a a Na a A R - a P (DQGG202018, DQGG202142); G a K R a a D P a (2020B1111360002).

Appendix A. Supplementary data

S a a a a a a :// . /10.1016/ . .2022.161295.

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M E a E (MEE), P.R. C a, 2020. A a Na a E a P S a "G a a a a ". N [2019] N . 4. A a a a :// . . . / 2018/ / 01/202001/ 20200113_758913.

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D a E a E G a P , 2021. G a P K VOC I G a R . A a a a. :// . . . / / / a /12959.

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