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 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 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 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 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 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 VOC - a . F , , a a a a a - a a VOC fi a a a a . T , 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 a- . O a VOC C a, 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 (: %).

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

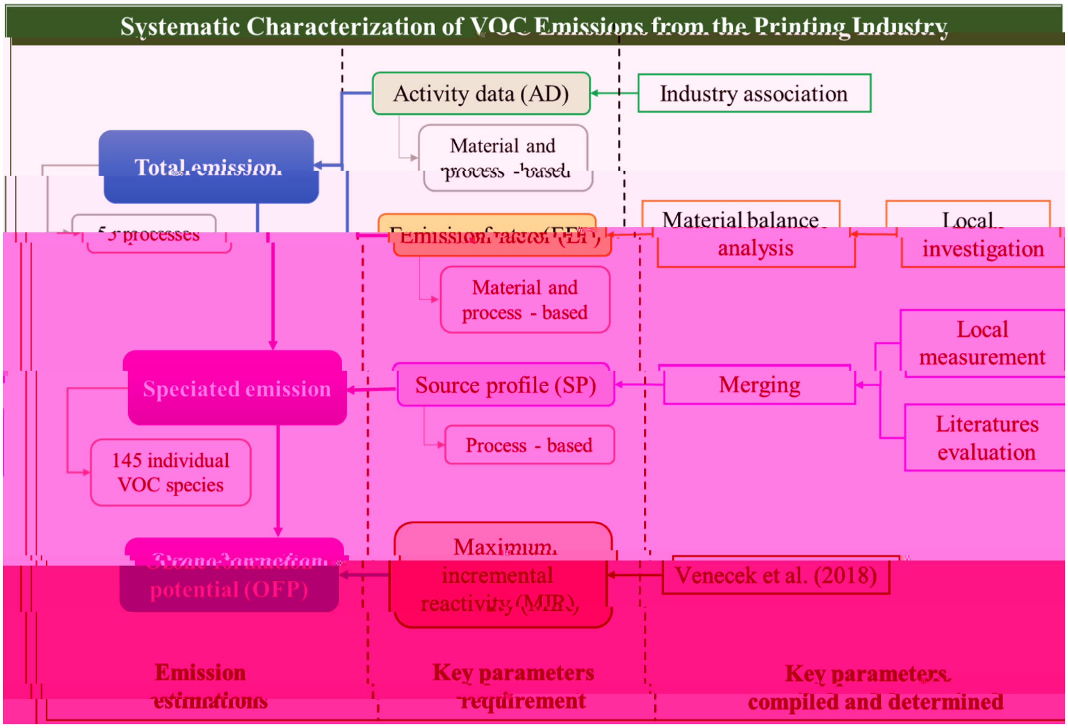

Fig. 1. T a a . a a a VOC

a a VOC a a a a 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 a . T a a a a a a a a 2017 (M a ., 2021), a a a 2018–2019 a 10 % 2015–2017 5 %. A fi a 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 %)

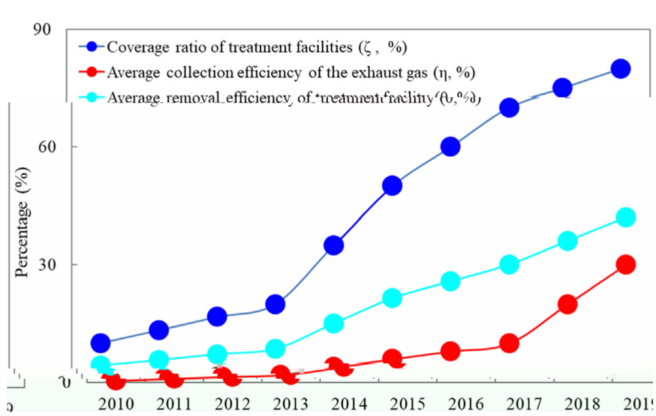

Fig. 2. A a a a a a a , fi a a a a fi a a 2010–2019.

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

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

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 :

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

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

2.2. A (AD)

T a a (+ -) a a a-
a a a a a aa
a a a a Na a I
S a a a T a C , P a E I
A 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 , 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 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 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 aa a a -
(L a a ., 2019). A a 14 a
20 , fi a 10
a a a a (Ta 1). T
a a C a, a
, a a a . F
a , a a a a a , a
a a . I a , - a - -
fi a
. T EF a a a a a a aa a a a
E . (5):

$$EF_j = \frac{\Sigma_j E_j}{\sum C_{,I\ A}} = \frac{\Sigma_j C_j \times \ _j}{\sum C_{,I\ A}} \quad (5)$$

EF$_j$ a a a a a*j*; *E*$_j$ VOC a a a a a*j*; *C*$_{,I\ A}$ a a a , a
a a a a a *C*$_j$ a a
a a a *j* ; a $_j$ VOC a a a*j*
, a a a VOC a a a a
a a (MSDS) . D a a a -
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 -
a97020.6(61.4(a)- 2.5( )5.6( )234.3((Ta)-267.54)-273.4(.7967 .8(a))

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 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 T a L a a . (2019). F , EF a - a a a 15 a a a - a a , a a VOC . D a a EF 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 , 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 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 - 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 a a a a . T EF - a - a fi a , a a EF a - 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 a a fi a (Ta 1): II (>3), III (<3) a IV ( ). T a a a 80 %, 150 % a 300 %, D a , EF a a a VOC a a B a a a 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 F . 4, a - a (S7), OVOC a a a a , a a

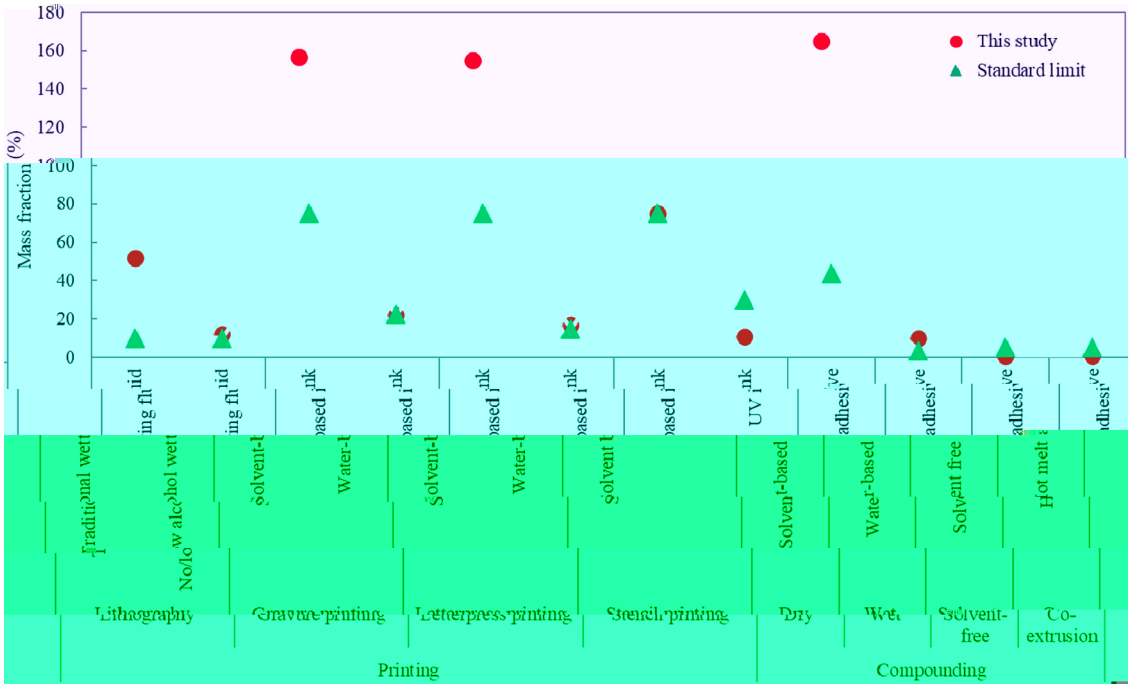

Fig. 3. C a a a a C a.

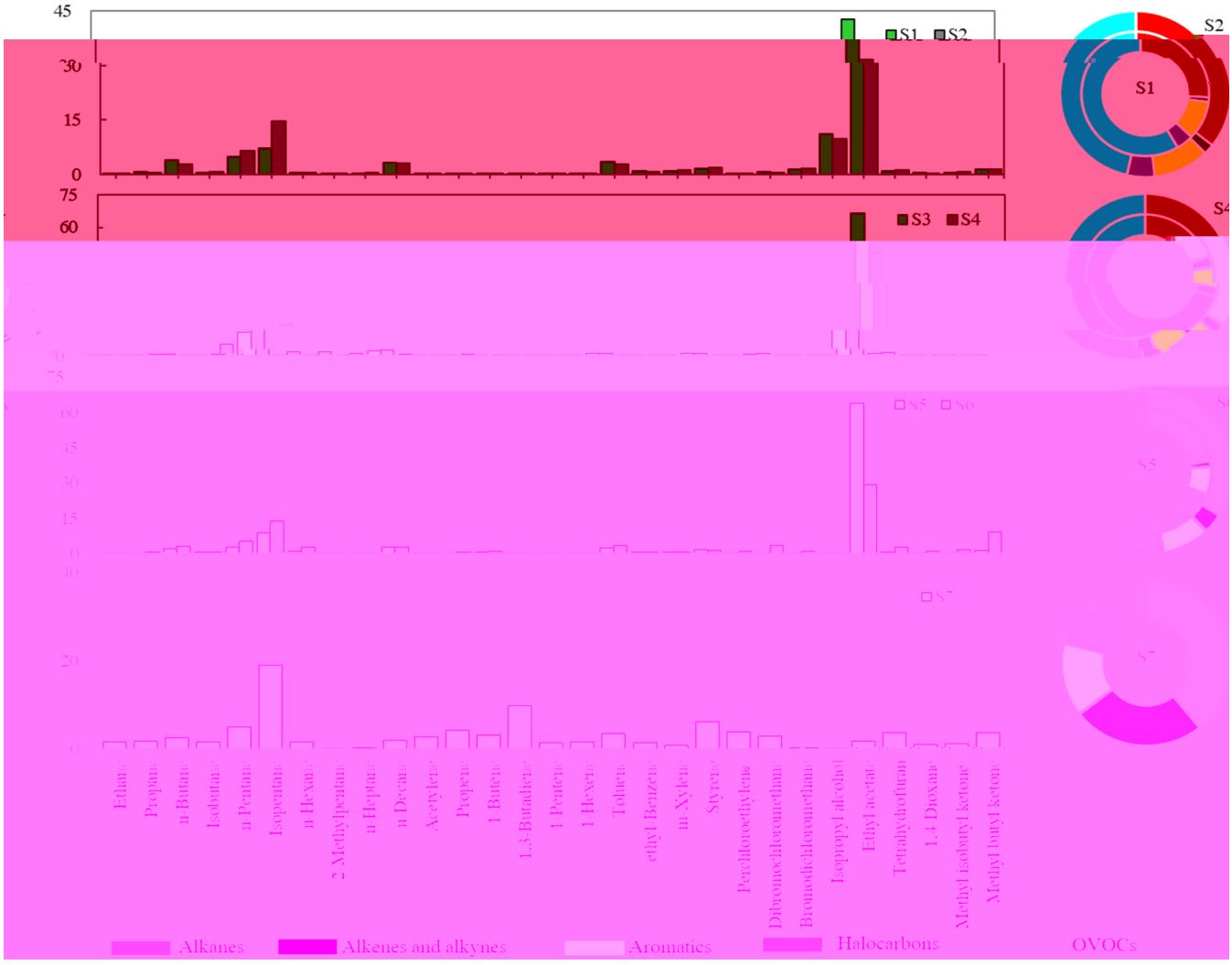

Fig. 4. T VOC a a a . S1 a S2 a a - a , S3 a S4 a a - a , S5 a S6 a a a - a , S7 a - a .

a 45.5–69.8 %. T a a VOC a a a a a . C a , OVOC a a , a a . A a a a a , OVOC a a a a a . F fi VOC , a a a , a a a a a . E 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 VOC a a - a . T a a a a a (Ta 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 (. ., a a 1,3- a a - a - a a). N a a , a a a a a - a a a , a a a a . F . 5 a VOC fi 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 a a . F - a (. ., S10), OVOC a a , a 78.7 % a VOC . A 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 OVOC a 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 a a

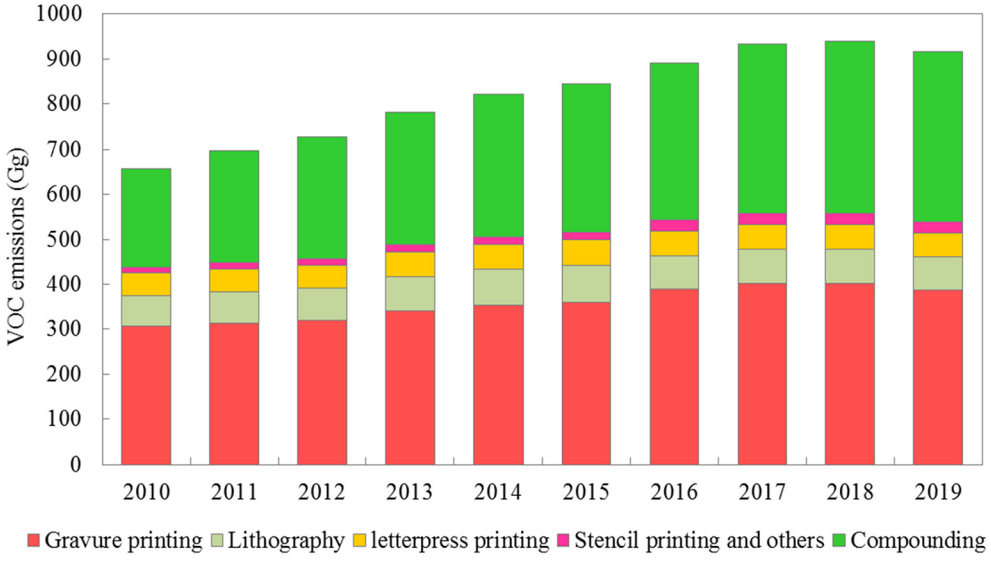

Fig. 6. A a VOC 2010 2019 C a.

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 a a a a - I a , a VOC a 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 a 80 %, VOC a - . R a , a 60 % a 30 % a a a - a a a , O 10 % - a . T , a a a VOC a P a VOC 2019 a a a a . A F . 7, G a , J a , a Z a a C a, a a >10 % a , a a 44 %. T a F . 7 a - VOC a (GDP). VOC a a a C a. I a, VOC a a a

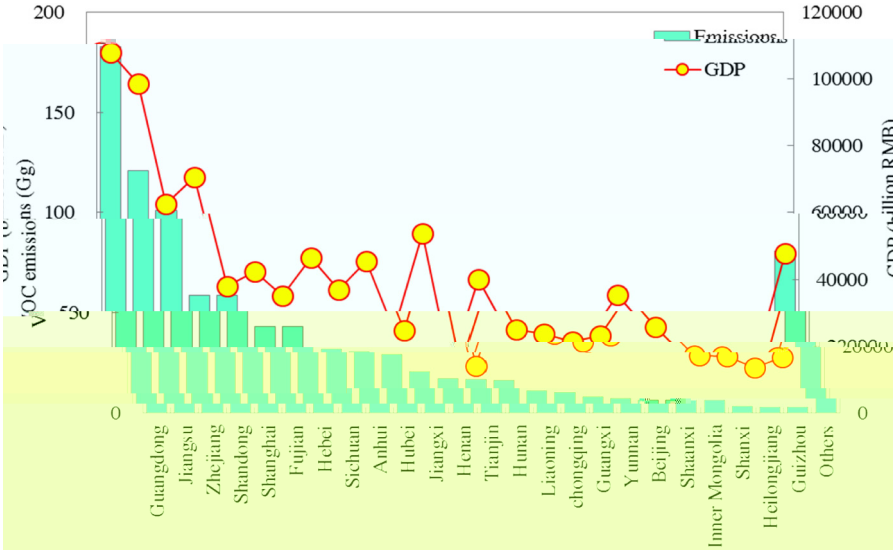

Fig. 7. P a VOC C a 2019.

a a a a 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 a VOC a a GDP.

3.4. OFP

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

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

4. Discussions

4.1. C w

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

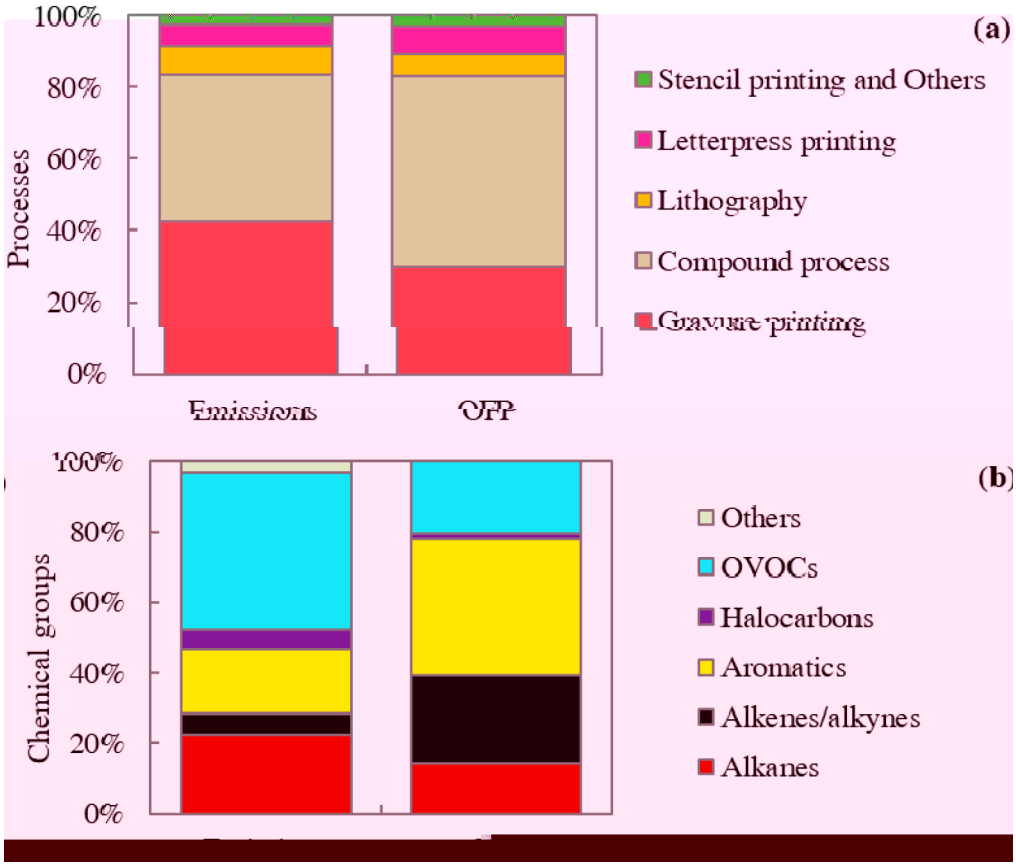

Fig. 8. S a a (a), a a a ( ) VOC a OFP C a 2019.

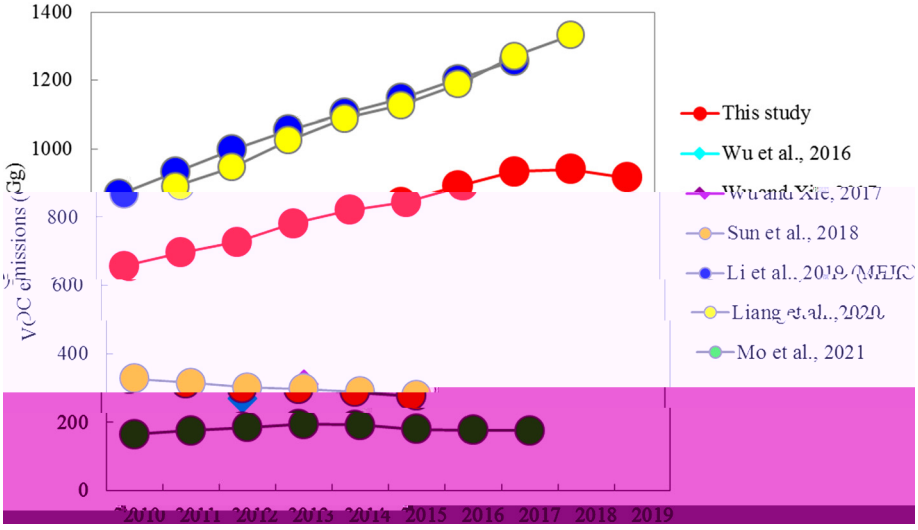

Fig. 9. C a VOC a .

a . (2018) a M a . (2021). T 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 EF a - a ., EF a a a . F a , EF a MEIC (L a ., 2019) a 540 VOC $^{-1}$, a EF 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 . M , 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 VOC C a, a >80 % a a OFP. T , fi a VOC a a . O . T a , UV - a a , a a a - a . S - a a a - , fi 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 - (NMHC). I a fi 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 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 - . 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 a (Z , 2017) a a .

5. Conclusions

A - VOC a 2010–2019 C a 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 a -VOC ; VOC a 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 .

Declaration of Competing Interest

T a a a fi 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 :// . /10.1016/ . .2022.161295.

References

C , S., Wa , H., L , K., Z , L., H , M., Z a , Y., 2020. T a B 2013 2019: a a a a - a A . E . 242, 117801.

C , M.M., G a , G.I., M D a , B.C., G a , J.B., S a , R.H., A a a , N., A , K.C., A , M.F., B , T.A., B , S.S., Ca , T.L., D , R.R., G , G., H J.F., I aa a -Va , G., K , A.R., L , M., M K , S.A., M a F., P , J., P a, V., R , X., W , A., W , Y., T a , M., Wa , C., 2021. V a a a a a a P . Na . A a . S . USA 118, 2026653118.

M D a , B.C., G , G a , J.B., Ja a , S.H., A a , A., Ca a, C.D., J , J.L., L -Ta , J., Ha , P.L., M K , S.A., C , Y.Y., K , S.W., G , D.R., I aa a - Va W , G., G , A , H., Ha R.A., F , G.J., R , J.M., R , T.B., T a , M., 2018. V a a a a a a a . S 359, 760.

M E a E (MEE), P.R. C a, 2020. N a "V a O a C G a Ta P a 2020". A a a aE . A . 2020 (33).. :// . . . / 2018/ / 03/202006/ 20200624_ 785827.

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

M E a E (MEE), P.R. C a, 2021. N a a a a . A a a aE . A . 2021 (65).. :// . . . / 2018/ / 03/202108/ 20210805_854161.

M E a E (MEE), P.R. C a, 2022. P a "E a a a a a ”a a a a a a a . N [2022] N . 24. A a a a :// . . . / 2018/ / 01/202211/ 20221117_1005189. .

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

G a , G.I., C , M.M., M D a , B.C., P , J., A , K.C., G a , J.B., T a , M., Wa , C., 2021a. I a a a a U.S. . E . S . T . 55, 188–199.

G a , G.I., C , M.M., M D a , B.C., P , J., G a , J.B., A , K.C., R , M.A., Ca a , F., P , A.S.H., T a , M., Wa , C., 2021 . O a - fi a a a a a a a a U.S. . E . S . T . 55, 4332–4343.

L , A.C., H , J.R., Ca a , D.C., Ha , J.F., N , B.S., S a , G., D , J., Pa a , N., M , T., 2020. A a a a a a a a . P . Ta . S . A Ma . P . E . S . 378 (2183), 20190328.

L , G.H., W , W., S a , X., N , L., Wa , H.L., Ya , X., Z a , R., 2018. A - a fi a VOC a a a a VOC a a . J. E . S . 67 (05), 78–88.

L , M., Z a , Q., Z , B , T , D., L , Y., L , F , a., 2019. P a - - a a a a (NMVOC) C a 1990–2017: , a a a a . A . C . P . 19, 8897–8913.

L a , X.M., C , X.F., Z a , J.N., S , T.L., S , X.B., Fa , L.Y., Wa , L.M., Y , D.Q., 2017. R a a a a a a a - a a C a. A . E . 162.

L a , X.M., C , L.G., S , X.B., Z a , W., L , Q., S , J.R., C , P.L., Y , D.Q., 2019. Ra a a a a - a a a a (VOC) a . E . S . 40 (10), 4382–4394.

L a , X.M., S , X.B., X , J.T., Y , D.Q., 2020. I a VOC - a a OFP a C a. S . T a E . 745.

L , W.W., Fa , L., G , X.R., N , L., Wa , M.Y., 2019. E a a a a VOC B -T a -H . E . S . 40 (9), 3942–3948.

L , R.Y., Z , M.F., Z a , X.Y., L , S.W., T a , T.J., L , Y.S., H , M., L a , X.M., H a , H.M., Fa , L.Y., Y , D.Q., 2021. C a a a a (VOC) C a 2011 2019. E . S . 42 (11), 5169–5179.

M , Z.W., C , R., Y a , B., Ca , H.H., M D a , B.C., L , M., Z , J.Y., S a , M., 2021. A a - aa - a a (NMVOC) C a. A . C . P . 21, 13655–13666.

Na a P S Pa S a I a (NPSPSI), 2020. L a a (VOC) . A a a a :// . a . . / / a / D a ? =A0285713F6211875E05397BE0A0AFAC0.

Na a P S Pa S a I a (NPSPSI), 2020. L a a . A a a a :// . a . . / / a / D a ? =A0285713F6201875E05397BE0A0AFAC0.

P a , J.K., 2019. E a VOC a - a . A . E . 204, 118–124.

S a, Q.E., Z , M.N., H a , H.W., Wa , Y.Z., H a , Z.J., (.) 2 4 9 (, Z) 2 4 8, M] T 3 1 . 8 7 2 6 4 7

Y a , B., H , W.W., S a , M., Wa , M., C , W.T., L , S.H., a ., 2013. VOC , a SOA a a a a C a. A . C . P . 13, 8815–8832.
Z a , Y.S., L , C., Ya , Q.S., Ha , S.J., Z a , Q.Y., Ya , L.M., L , Y.G., Z a , R.Q., 2020. T a a - a a a fi a - a a Z , C a. A . P . R . 11 (5).
Z a , P.S., D , F., Ya , Y.D., H , D., Z a , X.J., Z a , W.Z., a ., 2013. C a a - a a a B , T a , a H , C a. A . E . 71, 389–398.
Z a , J.R., Ya , X.L., S , M., X , Y., Wa , S., Ca , D.X., L , J.H., 2021. E a a a a T a . E . P .C . 43 (05), 539–545.
Z , J.Y., Y , Y.F., M , Z.W., Z a , Z., Wa , X.M., Y , S.S., P , K., Ya , Y., F , X.Q., Ca , H.H., 2013. I a - a a a (VOC) fi a a a P a R D a, C a. S . T a E . 456–457.
Z , G.S., 2017. T a a a a a C a. P a . Pa a . 27 (2), 21–26.