

# 1.A.3.a i (i) - International Civil Aviation: LTO

## Short description

In NFR category *1.A.3.a i (i) - International Civil Aviation: LTO* emissions during LTO stage (Landing/Take-off: 0-3,000 feet) are reported. In the following, information on sub-category specific AD, (implied) emission factors and emission estimates are provided.

| Category Code | Method          |                 |                 |      |     | AD    |     |     |     |      | EF       |    |     |                  |                   |
|---------------|-----------------|-----------------|-----------------|------|-----|-------|-----|-----|-----|------|----------|----|-----|------------------|-------------------|
| 1.A.3.a.i.(i) | T1, T2, T3      |                 |                 |      |     | NS, M |     |     |     |      | CS, D, M |    |     |                  |                   |
| Key Category  | SO <sub>2</sub> | NO <sub>x</sub> | NH <sub>3</sub> | NMVO | CO  | BC    | Pb  | Hg  | Cd  | Diox | PAH      | HC | TSP | PM <sub>10</sub> | PM <sub>2.5</sub> |
| 1.A.3.a.i.(i) | -/-             | -/-             | -/-             | -/-  | -/- | -/-   | -/- | -/- | -/- | -    | -/-      | -  | -/- | -/-              | -/-               |

**T** = key source by Trend **L** = key source by Level

| Methods                                                                                                  |                                      |
|----------------------------------------------------------------------------------------------------------|--------------------------------------|
| <b>D</b>                                                                                                 | Default                              |
| <b>RA</b>                                                                                                | Reference Approach                   |
| <b>T1</b>                                                                                                | Tier 1 / Simple Methodology *        |
| <b>T2</b>                                                                                                | Tier 2*                              |
| <b>T3</b>                                                                                                | Tier 3 / Detailed Methodology *      |
| <b>C</b>                                                                                                 | CORINAIR                             |
| <b>CS</b>                                                                                                | Country Specific                     |
| <b>M</b>                                                                                                 | Model                                |
| * as described in the EMEP/CORINAIR Emission Inventory Guidebook - 2007, in the group specific chapters. |                                      |
| AD - Data Source for Activity Data                                                                       |                                      |
| <b>NS</b>                                                                                                | National Statistics                  |
| <b>RS</b>                                                                                                | Regional Statistics                  |
| <b>IS</b>                                                                                                | International Statistics             |
| <b>PS</b>                                                                                                | Plant Specific data                  |
| <b>AS</b>                                                                                                | Associations, business organisations |
| <b>Q</b>                                                                                                 | specific questionnaires, surveys     |
| EF - Emission Factors                                                                                    |                                      |
| <b>D</b>                                                                                                 | Default (EMEP Guidebook)             |
| <b>C</b>                                                                                                 | Confidential                         |
| <b>CS</b>                                                                                                | Country Specific                     |
| <b>PS</b>                                                                                                | Plant Specific data                  |

## Methodology

### Activity Data

Specific jet kerosene consumption during LTO-stage is calculated within TREMOD AV as described in the [main chapter](#) on civil aviation.

Table 1: Percentual annual fuel consumption during LTO-stage of international flights

|                          | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|--------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| <b>Jet Kerosene</b>      | 8,17 | 7,80 | 8,19 | 8,00 | 7,97 | 7,95 | 7,91 | 7,86 | 7,90 | 7,81 | 7,92 | 7,98 | 7,98 | 8,09 | 8,11 | 8,13 | 8,18 | 8,15 |
| <b>Aviation Gasoline</b> | 5,24 | 11,8 | 11,1 | 19,1 | 20,5 | 23,2 | 20,4 | 20,2 | 19,8 | 17,3 | 19,1 | 22,2 | 26,3 | 20,8 | 42,2 | 43,7 | 51,4 | 61,6 |

source: Knörr et al. (2019c) <sup>1)</sup> & Gores (2019) <sup>2)</sup>

Table 2: annual LTO fuel consumption for international flights, in terajoule

|                          | 1990   | 1995   | 2000   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   | 2019   |
|--------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| <b>Jet Kerosene</b>      | 13.252 | 16.012 | 21.465 | 24.860 | 26.063 | 26.992 | 27.184 | 26.249 | 26.115 | 24.796 | 27.036 | 27.726 | 26.778 | 27.115 | 29.304 | 32.205 | 33.340 | 32.948 |
| <b>Aviation Gasoline</b> | 25,7   | 21,6   | 21,5   | 21,7   | 22,5   | 23,2   | 21,1   | 19,2   | 19,0   | 14,3   | 14,3   | 13,9   | 14,2   | 15,3   | 11,8   | 12,5   | 12,8   | 10,5   |

source: Knörr et al. (2019c) <sup>3)</sup> & Gores (2019) <sup>4)</sup>



## Emission factors

All country specific emission factors used for emission reporting were basically ascertained within UBA project FKZ 360 16 029 (Knörr, W., Schacht, A., & Gores, S. (2010)) <sup>5)</sup> and have since then been compiled, revised and maintained in TREMOD AV <sup>6)</sup>.

For more information, please see [superordinate chapter](#) on civil aviation.

Table 2: Annual country-specific emission factors, in kg/TJ

|                          | 1990   | 1995   | 2000   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   | 2019   |
|--------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| <b>JET KEROSENE</b>      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>NH<sub>3</sub></b>    | 3,98   | 3,95   | 3,95   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   |
| <b>NMVOC</b>             | 59,7   | 36,11  | 25,68  | 22,88  | 22,86  | 22,46  | 22,02  | 21,16  | 21,23  | 20,77  | 20,46  | 20,30  | 19,88  | 20,48  | 20,25  | 20,77  | 21,43  | 20,69  |
| <b>NO<sub>x</sub></b>    | 297    | 306    | 303    | 324    | 325    | 330    | 331    | 338    | 342    | 345    | 346    | 349    | 353    | 352    | 357    | 358    | 355    | 357    |
| <b>SO<sub>x</sub></b>    | 19,7   | 19,5   | 19,5   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   | 19,6   |
| <b>BC<sup>1</sup></b>    | 1,78   | 1,63   | 1,45   | 1,37   | 1,33   | 1,28   | 1,25   | 1,23   | 1,21   | 1,20   | 1,18   | 1,17   | 1,15   | 1,14   | 1,13   | 1,12   | 1,12   | 1,10   |
| <b>PM<sup>2</sup></b>    | 3,71   | 3,40   | 3,02   | 2,86   | 2,76   | 2,66   | 2,60   | 2,56   | 2,52   | 2,49   | 2,46   | 2,44   | 2,40   | 2,38   | 2,35   | 2,33   | 2,33   | 2,30   |
| <b>CO</b>                | 249    | 227    | 236    | 219    | 217    | 211    | 209    | 203    | 203    | 199    | 199    | 197    | 194    | 196    | 192    | 192    | 195    | 192    |
| <b>AVIATION GASOLINE</b> |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>NH<sub>3</sub></b>    | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     | NE     |
| <b>NMVOC</b>             | 459    | 484    | 466    | 469    | 455    | 456    | 460    | 475    | 470    | 521    | 514    | 515    | 521    | 514    | 495    | 494    | 528    | 548    |
| <b>NO<sub>x</sub></b>    | 73,1   | 68,7   | 71,7   | 71,7   | 73,6   | 71,5   | 70,6   | 66,4   | 66,1   | 56,0   | 55,9   | 57,6   | 60,1   | 55,9   | 53,7   | 53,3   | 52,5   | 56,0   |
| <b>SO<sub>x</sub></b>    | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   | 0,46   |
| <b>BC<sup>1</sup></b>    | 9,05   | 9,59   | 9,33   | 9,59   | 9,21   | 9,48   | 9,44   | 10,2   | 10,3   | 11,0   | 11,0   | 10,9   | 10,4   | 11,3   | 11,3   | 11,0   | 11,9   | 11,2   |
| <b>PM<sup>2</sup></b>    | 60,3   | 64,0   | 62,2   | 64,0   | 61,4   | 63,2   | 63,0   | 67,8   | 68,6   | 73,5   | 73,4   | 72,7   | 69,2   | 75,5   | 75,6   | 73,4   | 79,1   | 74,5   |
| <b>TSP<sup>3</sup></b>   | 75,5   | 79,1   | 77,4   | 79,1   | 76,6   | 78,4   | 78,1   | 83,0   | 83,8   | 88,7   | 88,5   | 87,9   | 84,3   | 90,7   | 90,8   | 88,5   | 94,3   | 89,6   |
| <b>CO</b>                | 20.188 | 20.764 | 20.440 | 20.152 | 20.057 | 20.400 | 20.612 | 21.105 | 21.199 | 22.662 | 22.769 | 22.422 | 22.168 | 22.650 | 23.205 | 23.427 | 23.210 | 22.827 |

<sup>1)</sup> estimated via a f-BCs (avgas: 0.15, jet kerosene: 0.48) as provided in <sup>7)</sup>

<sup>2)</sup> EF(PM<sub>2.5</sub>) also applied for PM<sub>10</sub>, and TSP (assumption: > 99% of TSP from diesel oil combustion consists of PM<sub>2.5</sub>)

<sup>3)</sup> also including TSP from lead: EF(TSP) = 1.6 x EF(Pb) - see road transport



For the country-specific emission factors applied for particulate matter, no clear indication is available, whether or not condensables are included.

## Discussion of emission trends

NFR 1.A.3.a i (i) - International Civil Aviation - LTO is **no key category**.

## Recalculations

As mentioned in the superordinate chapter on 1.A.3.a, the LTO fuel consumptions applied in TREMOD AV have been adapted to Eurocontrol AEM model and the underlying fleet composition.

Hence, the percentual annual shares of kerosene consumed during L/TO for international flights have been re-estimated...

Table 3: Revised percentual share of kerosene consumed during L/TO for international flights, in %

|                        | 1990   | 1995   | 2000   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| <b>Submission 2021</b> | 8,17   | 7,80   | 8,19   | 8,00   | 7,97   | 7,95   | 7,91   | 7,86   | 7,90   | 7,81   | 7,92   | 7,98   | 7,98   | 8,09   | 8,11   | 8,13   | 8,18   |
| <b>Submission 2020</b> | 8,31   | 7,84   | 8,21   | 8,02   | 7,98   | 7,96   | 7,92   | 7,87   | 7,91   | 7,82   | 7,95   | 8,05   | 8,15   | 8,24   | 8,26   | 8,28   | 8,32   |
| <b>absolute change</b> | -0,15  | -0,03  | -0,02  | -0,01  | -0,01  | -0,01  | -0,01  | -0,01  | -0,01  | -0,01  | -0,03  | -0,07  | -0,17  | -0,15  | -0,15  | -0,15  | -0,15  |
| <b>relative change</b> | -1,75% | -0,42% | -0,27% | -0,14% | -0,13% | -0,15% | -0,16% | -0,18% | -0,17% | -0,17% | -0,34% | -0,85% | -2,05% | -1,79% | -1,80% | -1,82% | -1,78% |

... and the amounts of kerosene allocated to sub-category 1.A.3.a i (i) were revised accordingly:

Table 4: Revised kerosene usage in 1.A.3.a i (i), in terajoules

|                        | 1990   | 1995   | 2000   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| <b>Submission 2021</b> | 13.252 | 16.012 | 21.465 | 24.860 | 26.063 | 26.992 | 27.184 | 26.249 | 26.115 | 24.796 | 27.036 | 27.726 | 26.778 | 27.115 | 29.304 | 32.205 | 33.340 |
| <b>Submission 2020</b> | 13.676 | 15.973 | 21.785 | 25.168 | 26.381 | 27.295 | 27.439 | 26.538 | 26.256 | 24.701 | 27.164 | 28.075 | 27.274 | 27.546 | 29.875 | 32.999 | 34.160 |
| <b>absolute change</b> | -424   | 39     | -320   | -308   | -318   | -304   | -255   | -289   | -141   | 95     | -128   | -350   | -497   | -431   | -571   | -794   | -820   |
| <b>relative change</b> | -3,10% | 0,25%  | -1,47% | -1,22% | -1,21% | -1,11% | -0,93% | -1,09% | -0,54% | 0,39%  | -0,47% | -1,24% | -1,82% | -1,56% | -1,91% | -2,40% | -2,40% |

Furthermore, for the first time, the use of aviation gasoline (avgas) for international flights has been estimated. These amounts have been re-allocated from NFR 1.A.3.a ii (i), where 100% of avgas consumption has been allocated so far.

Table 5: Amounts of avgas consumed during the L/TO stage of international flights from Germany, in terajoules

|                        | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| <b>Submission 2021</b> | 25,7 | 21,6 | 21,5 | 21,7 | 22,5 | 23,2 | 21,1 | 19,2 | 19,0 | 14,3 | 14,3 | 13,9 | 14,2 | 15,3 | 11,8 | 12,5 | 12,8 |
| <b>Submission 2020</b> | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   | IE   |
| <b>absolute change</b> | 25,7 | 21,6 | 21,5 | 21,7 | 22,5 | 23,2 | 21,1 | 19,2 | 19,0 | 14,3 | 14,3 | 13,9 | 14,2 | 15,3 | 11,8 | 12,5 | 12,8 |

In parallel, the majority of **country-specific emission factors** has been revised within TREMOD AV based on information available from the Eurocontrol's AEM model, taking into account the development of fleet composition and engine technology.

Table 6: Revised country-specific emission factors applied for jet kerosene

|                        | 1990   | 1995   | 2000   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| NH,,3,,                |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>Submission 2020</b> | 3,98   | 3,95   | 3,95   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   | 3,97   |
| <b>Submission 2019</b> | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   | 4,00   |
| <b>absolute change</b> | -0,02  | -0,05  | -0,05  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  | -0,03  |
| <b>relative change</b> | -0,48% | -1,16% | -1,16% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% | -0,70% |
| NM VOC                 |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>Submission 2020</b> | 59,7   | 36,1   | 25,7   | 22,9   | 22,9   | 22,5   | 22,0   | 21,2   | 21,2   | 20,8   | 20,5   | 20,3   | 19,9   | 20,5   | 20,2   | 20,8   | 21,4   |
| <b>Submission 2019</b> | 56,6   | 37,1   | 25,0   | 22,6   | 22,8   | 22,5   | 22,1   | 21,3   | 21,9   | 21,8   | 21,8   | 21,7   | 21,2   | 21,9   | 21,7   | 22,3   | 23,0   |
| <b>absolute change</b> | 3,14   | -1,02  | 0,71   | 0,31   | 0,05   | -0,06  | -0,09  | -0,13  | -0,66  | -1,03  | -1,29  | -1,42  | -1,36  | -1,46  | -1,42  | -1,55  | -1,58  |

|                        |       |        |       |       |       |        |        |        |        |        |        |        |        |        |        |        |        |
|------------------------|-------|--------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| <b>relative change</b> | 5,54% | -2,74% | 2,84% | 1,39% | 0,22% | -0,25% | -0,41% | -0,63% | -3,02% | -4,72% | -5,94% | -6,55% | -6,42% | -6,67% | -6,57% | -6,93% | -6,86% |
| NO <sub>x</sub>        |       |        |       |       |       |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>Submission 2020</b> | 297   | 306    | 303   | 324   | 325   | 330    | 331    | 338    | 342    | 345    | 346    | 349    | 353    | 352    | 357    | 358    | 355    |
| <b>Submission 2019</b> | 283   | 299    | 285   | 307   | 310   | 314    | 316    | 324    | 330    | 333    | 334    | 337    | 343    | 340    | 345    | 347    | 345    |
| <b>absolute change</b> | 13,45 | 7,01   | 17,86 | 16,20 | 15,07 | 15,54  | 14,96  | 14,73  | 12,65  | 11,89  | 11,46  | 11,67  | 9,20   | 11,91  | 11,48  | 10,91  | 10,60  |
| <b>relative change</b> | 4,75% | 2,34%  | 6,26% | 5,27% | 4,86% | 4,94%  | 4,73%  | 4,55%  | 3,84%  | 3,57%  | 3,43%  | 3,46%  | 2,68%  | 3,50%  | 3,33%  | 3,15%  | 3,08%  |
| BC                     |       |        |       |       |       |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>Submission 2020</b> | 1,78  | 1,63   | 1,45  | 1,37  | 1,33  | 1,28   | 1,25   | 1,23   | 1,21   | 1,20   | 1,18   | 1,17   | 1,15   | 1,14   | 1,13   | 1,12   | 1,12   |
| <b>Submission 2019</b> | 1,20  | 1,19   | 1,19  | 1,20  | 1,20  | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   | 1,20   |
| <b>absolute change</b> | 0,58  | 0,44   | 0,26  | 0,17  | 0,13  | 0,08   | 0,05   | 0,03   | 0,01   | 0,00   | -0,02  | -0,03  | -0,05  | -0,06  | -0,07  | -0,08  | -0,08  |
| <b>relative change</b> | 48,2% | 36,8%  | 21,6% | 14,6% | 10,7% | 6,72%  | 4,06%  | 2,69%  | 1,16%  | -0,04% | -1,56% | -2,21% | -3,99% | -4,79% | -5,85% | -6,74% | -6,76% |
| PM                     |       |        |       |       |       |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>Submission 2020</b> | 3,71  | 3,40   | 3,02  | 2,86  | 2,76  | 2,66   | 2,60   | 2,56   | 2,52   | 2,49   | 2,46   | 2,44   | 2,40   | 2,38   | 2,35   | 2,33   | 2,33   |
| <b>Submission 2019</b> | 2,50  | 2,48   | 2,48  | 2,50  | 2,50  | 2,50   | 2,50   | 2,50   | 2,50   | 2,50   | 2,50   | 2,50   | 2,50   | 2,50   | 2,49   | 2,49   | 2,49   |
| <b>absolute change</b> | 1,21  | 0,91   | 0,54  | 0,36  | 0,27  | 0,17   | 0,10   | 0,07   | 0,03   | 0,00   | -0,04  | -0,06  | -0,10  | -0,12  | -0,15  | -0,17  | -0,17  |
| <b>relative change</b> | 48,2% | 36,8%  | 21,6% | 14,6% | 10,7% | 6,72%  | 4,06%  | 2,69%  | 1,16%  | -0,04% | -1,56% | -2,21% | -3,99% | -4,79% | -5,85% | -6,74% | -6,76% |
| CO                     |       |        |       |       |       |        |        |        |        |        |        |        |        |        |        |        |        |
| <b>Submission 2020</b> | 249   | 227    | 236   | 219   | 217   | 211    | 209    | 203    | 203    | 199    | 199    | 197    | 194    | 196    | 192    | 192    | 195    |
| <b>Submission 2019</b> | 225   | 214    | 209   | 192   | 192   | 188    | 186    | 181    | 186    | 185    | 188    | 187    | 182    | 186    | 182    | 183    | 185    |
| <b>absolute change</b> | 23,3  | 13,1   | 27,7  | 27,0  | 24,4  | 23,3   | 22,4   | 21,4   | 16,5   | 13,3   | 11,4   | 10,5   | 11,8   | 9,91   | 9,36   | 8,63   | 9,46   |
| <b>relative change</b> | 10%   | 6,13%  | 13,3% | 14,0% | 12,7% | 12,4%  | 12,0%  | 11,8%  | 8,87%  | 7,17%  | 6,05%  | 5,59%  | 6,49%  | 5,32%  | 5,14%  | 4,72%  | 5,10%  |



For more information on recalculated emission estimates for Base Year and 2018, please see the pollutant specific recalculation tables following chapter [8.1 - Recalculations](#).

## Uncertainties

For uncertainties information, please see [main chapter](#) on civil aviation.

## Planned improvements

For information on planned improvements, please see [main chapter](#) on civil aviation.

## FAQs

**bibliography** : 1 : Knörr, W., Schacht, A., & Gores, S. (2010): Entwicklung eines eigenständigen Modells zur Berechnung des Flugverkehrs (TREMOT-AV) : Endbericht. Endbericht zum F+E-Vorhaben 360 16 029, URL:

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<sup>6)</sup> (bibcite 2)

<sup>7)</sup> (bibcite 4)