Easy LCCP analysis for Domestic Hot Water Heat Pumps

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Why performing an LCCP analysis?

Source: https://www.green-cooling-initiative.org/country-data/#!total-emissions/all-sectors/absolute

Incentives to reduce direct and indirect climate impact:

<u>Globally</u>:

The Paris Agreement

…aims to strengthen the global response to the threat of climate change by "holding the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels…

<u>Locally</u>:

- EU: F-gas Regulation

Article 11 exemption from equipment POM:

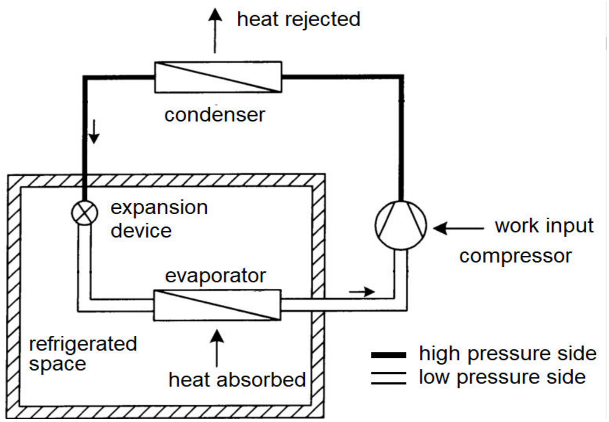
The prohibition … shall not apply to equipment for which … due to higher energy efficiency during its operation, its lifecycle CO_2 equivalent emissions would be lower than those of equivalent equipment which …does not contain hydrofluorocarbons.

- Future legislations and policies

Metrics for climate change impact assessment

- GWP (global warming potential)
- GTP (global temperature change potential)
- other (GCP, GDP, etc.)

- TEWI (total equivalent warming impact)
- LCCP (life cycle climate potential)
- Other (EIF, etc.)



Performing LCCP analysis isn’t difficult, is it?

International Institute of Refrigeration
www.iifiir.org

Life Cycle Climate Performance Working Group

Guideline for Life Cycle Climate Performance

January 2016

V. 1.2

Source: IIR, available online at goo.gl/fVi9pd

LCCP = Direct Emissions + Indirect Emissions

Direct Emissions = C * (L * ALR + EOL) * (GWP + Adp. GWP)

Indirect Emissions = L * AEC * EM + ∑(m * MM) + ∑(mr * RM) + C * (1+ L * ALR) * RFM + C * (1-EOL) * RFD

C = Refrigerant Charge (kg)
L=Average Lifetime of Equipment (yr)
ALR = Annual Leakage Rate (% of Refrigerant Charge)
EOL = End of Life Refrigerant Leakage(% of Refrigerant Charge)
GWP = Global Warming Potential (kg CO_{2e}/kg)
Adp. GWP = GWP of Atmospheric Degradation Product of the Refrigerant (kg CO_{2e}/kg)
AEC = Annual Energy Consumption (kWh)
EM = CO_2 Produced/kWh (kg CO_{2e}/kWh)
m = Mass of Unit (kg)
MM = CO_{2e} Produced/Material (kg CO_{2e}/kg)
mr = Mass of Recycled Material (kg)
RM = CO_{2e} Produced/Recycled Material (kg CO_{2e}/kg)
RFM = Refrigerant Manufacturing Emissions (kg CO_{2e}/kg)
RFD = Refrigerant Disposal Emissions (kg CO_{2e}/kg)

Source: IIR, available online at goo.gl/fVi9pd

Example of LCCP calculation:

$$\mathbf{LCCP = Direct\ Emissions + Indirect\ Emissions}$$

$$\mathbf{Direct\ Emissions = C * (L * ALR + EOL) * (GWP + Adp.\ GWP)}$$

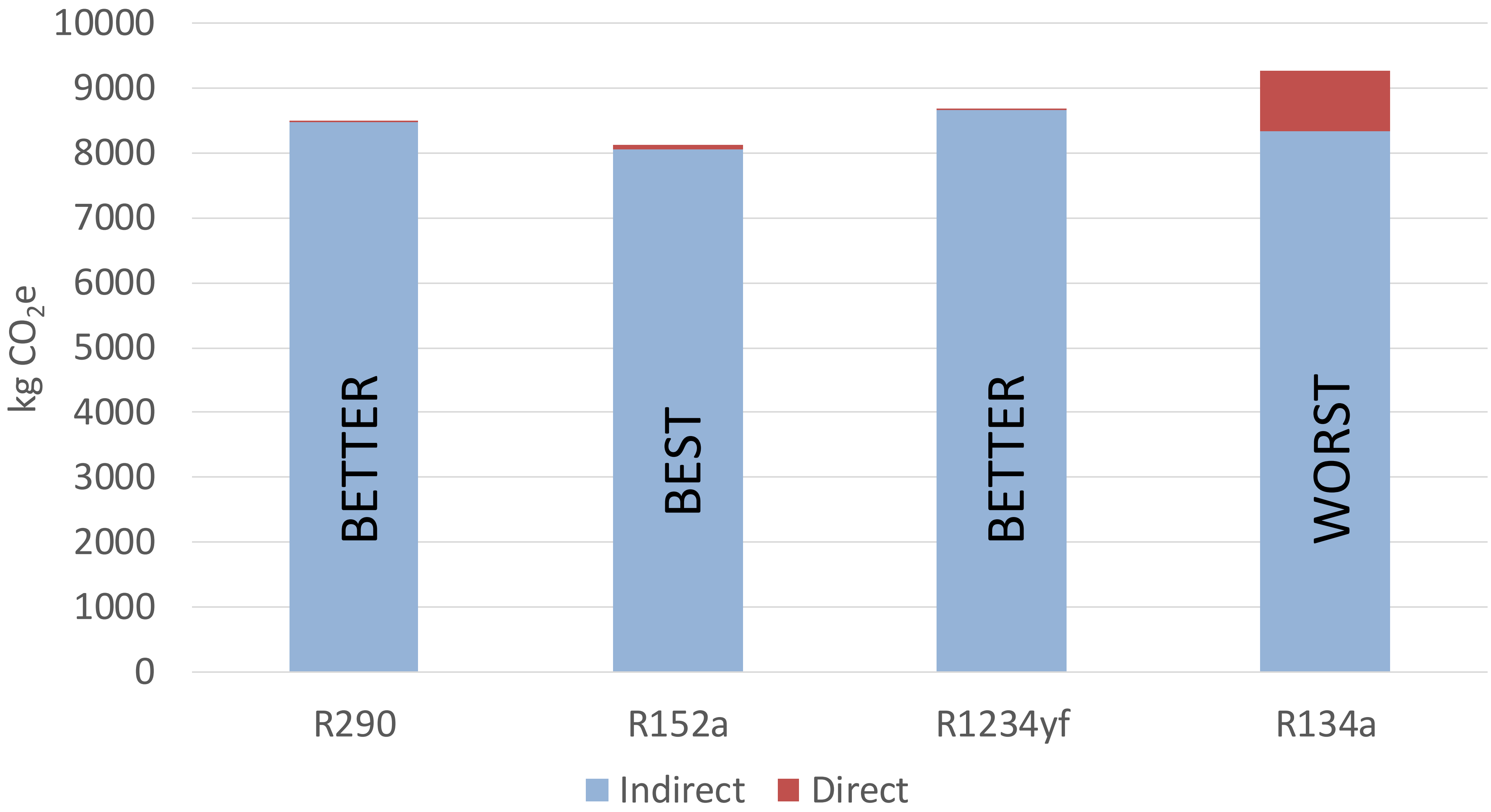
$$\mathbf{Indirect\ Emissions = L * AEC * EM + \sum(m * MM) + \sum(mr * RM) + C * (1+ L * ALR) * RFM + C * (1\text{-}EOL) * RFD}$$

- C is the refrigerant charge, 1 L
- L is the average lifetime of equipment, 15 yr
- ALR is the annual leakage rate, 2.5%
- EM, kg CO_2 produced/kWh, 0.03 $kgCO_2e\ kWh^{-1}$
- GWP is the Global Warming Potential, in kg $CO_{2e}\cdot kg^{-1}$

Refrigerant	R290	R1234yf	R152a	R134a
GWP 100 yr	3.3	0.4	137.4	1297.7
AEC, kWh yr^{-1}	18 323	17 360	18 698	17 999
RFM, $kgCO_2e/kg_{ref.}$	0.05	7.5	13.7	5.0

- Unit mass (100 kg); composition, material manufacturing and recycling emissions, – according to IIR LCCP guideline
- Adp. GWP and RFD – neglected

LCCP analysis results:



- Was it difficult?

- Not

(provided that all the input values are available and certain)

But is it always the case?

Average lifetime of equipment

Assumed 15 yr.

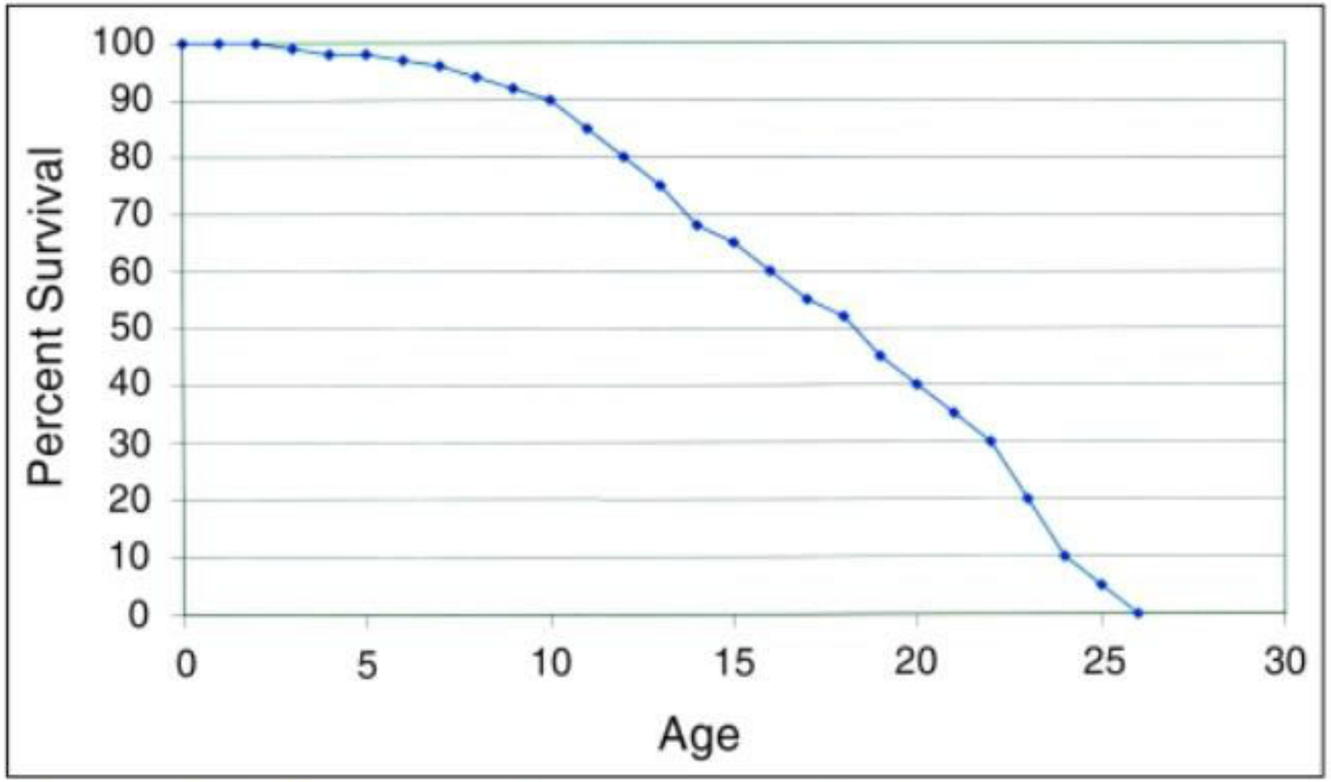


Figure 1: Classic equipment survival curve.

Source: Hiller 2000, ASHRAE Journal

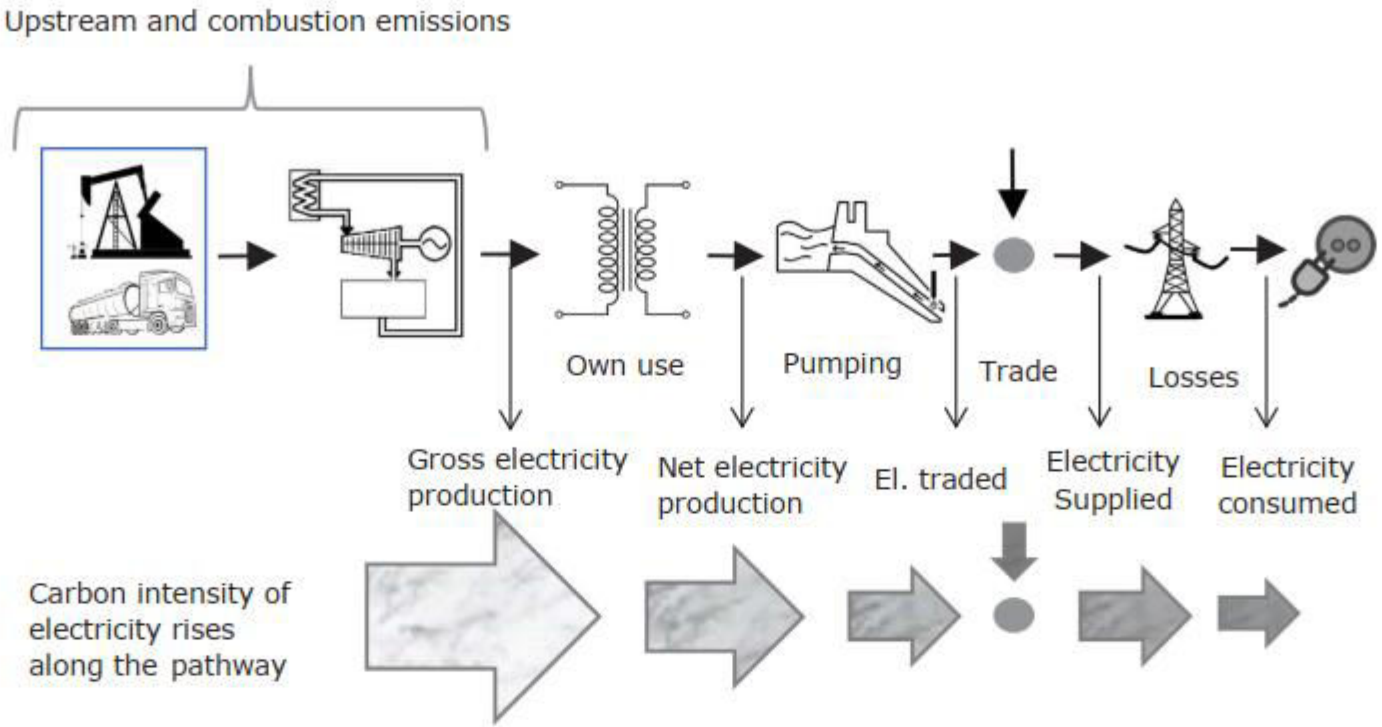
Average or median?

Carbon intensity of el. generation (EM) assumptions:

- EM assumed for a country average at production

- Regional average vs. country average?
- Regional average vs. global average?
- Country average vs. zone average?
- EM of generated energy or EM of used energy?
- EM of used energy today, or considering future energy mix?

Carbon intensity of el. generation assumptions:



Source:
Moro and Lonza, 2018. Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles.

DOI 10.1016/j.trd.2017.07.012

Carbon intensities of electricity for EU Member States.

Country	CI of gross electricity production (combustion only) [g/kWh]	CI of gross electricity production (with upstream) [g/kWh]	CI of net electricity production (with upstream emissions) [g/kWh]	CI of electricity traded (with upstream) [g/kWh]	CI of electricity supplied (with upstream) [g/kWh]	Variation of CI after trade [%]	CI of electricity consumed at HV (with upstream) [g/kWh]	CI of electricity consumed at MV (with upstream) [g/kWh]	CI of electricity consumed at LV (combustion only) [g/kWh]	CI of electricity consumed at LV (with upstream) [g/kWh]
Austria	133	151	156	170	315	85%	322	325	305	334
Belgium	188	224	233	239	257	8%	261	262	224	267

Table 3.1: GWP and Adaptive GWP

Refrigerant	GWP ($kg\ CO_{2e}/kg$)	Adaptive GWP ($kg\ CO_{2e}/kg$)
CO_2	1	0
HFC-32	677	Not available
HFO-1234yf	< 1	3.3 [6, 19,41]
HFC-134a	1,300	1.6 [6, 19,41]
HC-290	3	Not available
HFC-404A	3,943	Not available
HFC-410A	1,924	Not available

Table 4.4: Refrigerant Manufacturing Emissions

Refrigerant	Manufacturing Emissions ($kg\ CO_{2e}/kg$)
HFC-32 [6, 43]	7.2
HFO-1234yf [44]	13.7
HFC-134a [42,44]	5.0
HC-290 [44]	0.05
HFC-404A [6]	16.7
HFC-410A [41,45]	10.7

Typical problems in published LCCP studies:

- C, m: not modified between different refrigerants and/or configurations
- ALR: often independent on refrigerant and the effect of leakage on COP are not reflected
- L: old or arbitrary chosen values
- EOL: often not justified
- AEC: has significant impact on LCCP, but the uncertainty of theoretical analysis (or measured data) is not addressed
- EM: very different values can be assumed from study to study
- MM, RM, RFM: data source? What about the values after 15yr?

Methods for dealing with uncertainties

- Scientific: Performing more research in order to increase the quality of the input values.
- Constructivist: Involving stakeholders so as to create consensus, standard and, or ’good practice’.
- Legal: Relying on legal authorities and their decrees.
- Statistical: Integrating statistical methods to evaluate uncertainties

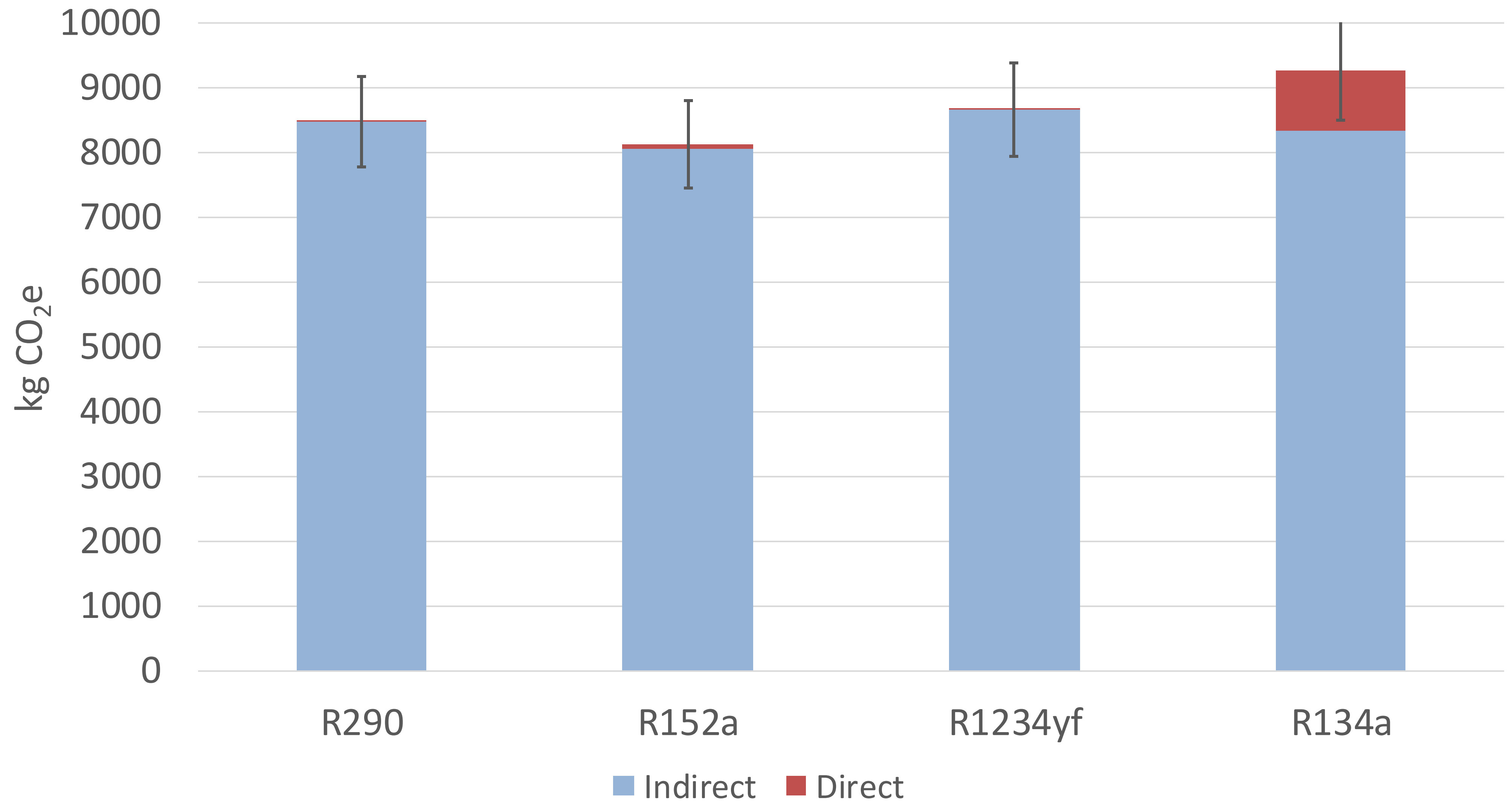
Some of the inputs, mean value and deviation from the mean:

- C is the refrigerant charge, 1±0.1 L
- L is the average lifetime of equipment, 15±1 yr
- ALR is the annual leakage rate, 2.5%±0.125%
- EM, kg CO_2 produced/kWh, 0.03±5% kgCO_2e kWh^{-1}
- GWP is the Global Warming Potential, in kg $CO_{2e}\cdot kg^{-1}$; Adp. GWP – neglected

Refrigerant	R290	R1234yf	R152a	R134a
GWP 100 yr	3.3±1.65	0.4±0.2	137.4±55	1297.7±433
AEC, kWh yr^{-1}	18 323±10%	17360±10%	18 698±10%	17 999±10%
RFM, kgCO_2e/$kg_{ref.}$	0.05±10%	7.5±10%	13.7±10%	5.0±10%

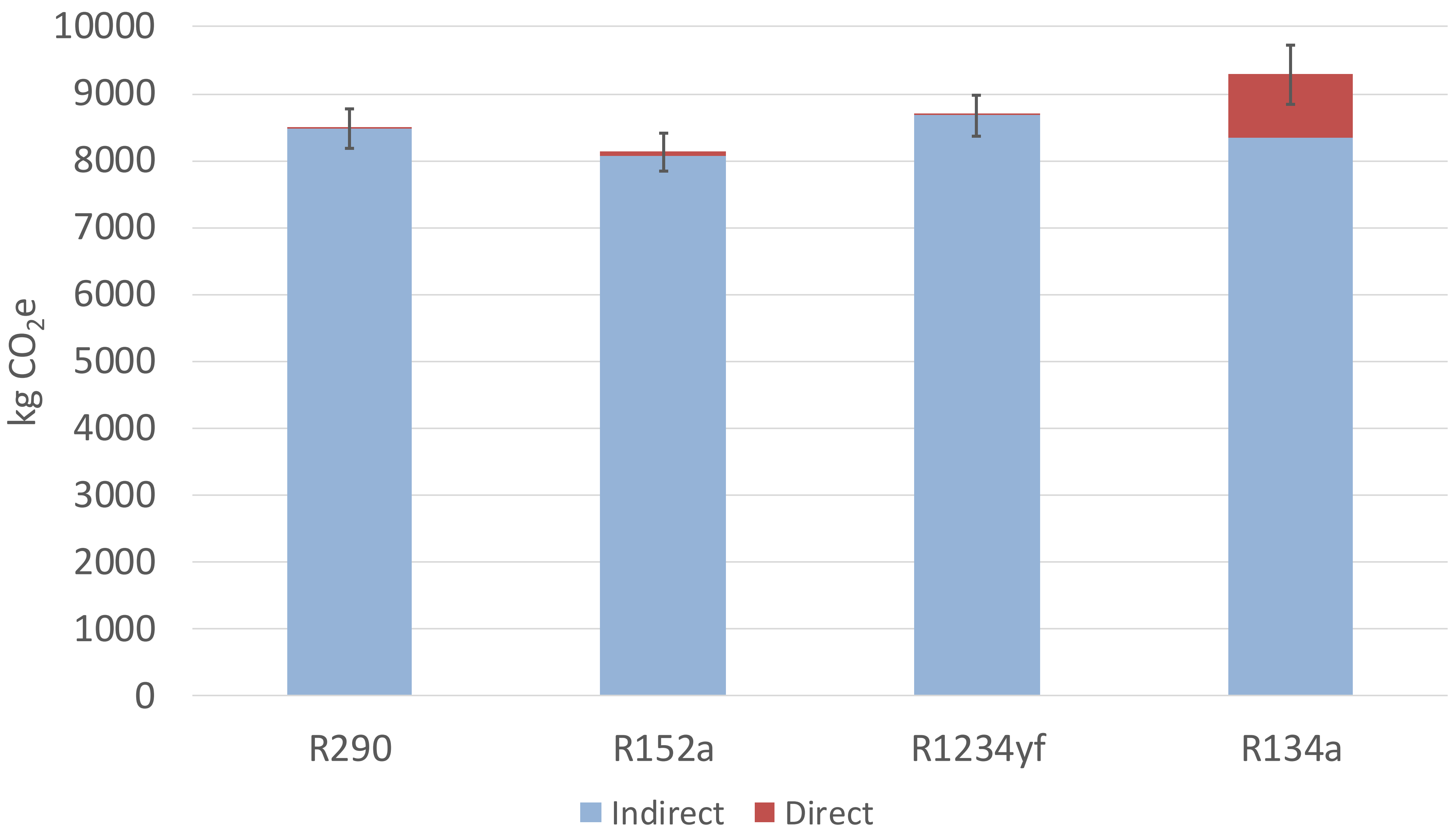
- Unit mass (100 kg±10%); composition, material manufacturing emissions and recycling emissions, – according to IIR guidelines

Propagated uncertainty of LCCP



Refrigerant	R290	R152a	R1234yf	R134a
LCCP, kg CO_2e	**8483.6**±704.3	**8133.6**±669.9	**8676.4**±720.8	**9285.4**±767.1
Direct, kg CO_2e	1.0 ± 0.5	72.9 ±30.4	0.3 ±0.1	938.1 ± 328.8
Indirect, kg CO_2e	8483.6 ±704.3	8060.7±669.2	8676.1±720.8	8347.3±693.1
- energy use	8245.4 ±687.1	7812.0 ±651.0	8414.1 ±701.2	8099.6 ±675.0
- material manufacture	232.6 ±16.5	232.6 ±16.5	232.6 ±16.5	232.6 ±16.5
- material recycling	5.6 ±0.6	5.6 ±0.6	5.6 ±0.6	5.6 ±0.6
- refrigerant manufacturing	0.0 ±0.0	10.4 ±1.1	23.8 ±2.4	9.5 ±1.0

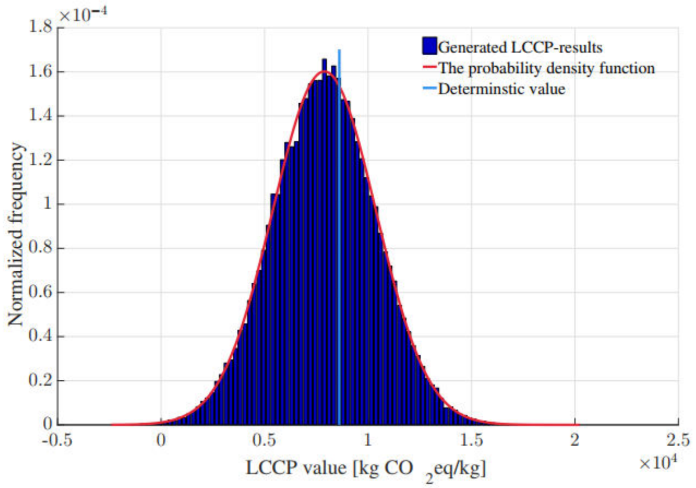
Indirect (energy use): L[yr] * AEC[kWh] * EM[$kgCO_2$/kWh]


10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
kg CO_2e
R290
R152a
R1234yf
R134a
Indirect
Direct

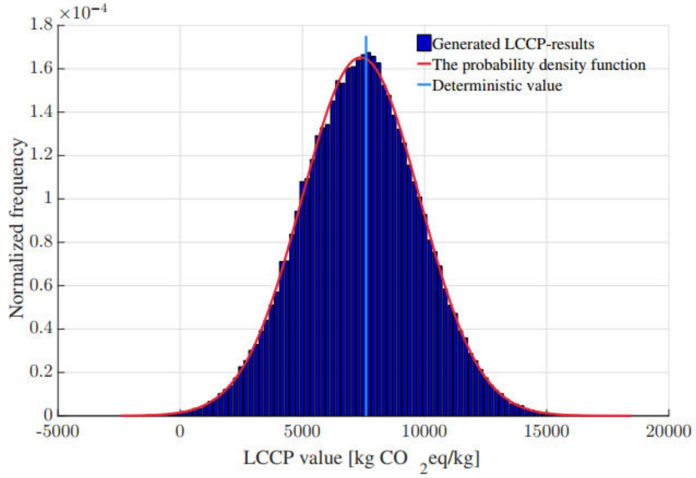
Approach for easier LCCP:

1. Identify initial set of the input values and their deviation from the mean
2. Perform LCCP and calculate uncertainty of LCCP (e.g. using Monte Carlo)
3. Reduce uncertainty of LCCP by improving input values. When not possible, consider performing several LCCP with different inputs (sensitivity analysis)
4. Reiterate until the result is achieved or no further improvement possible

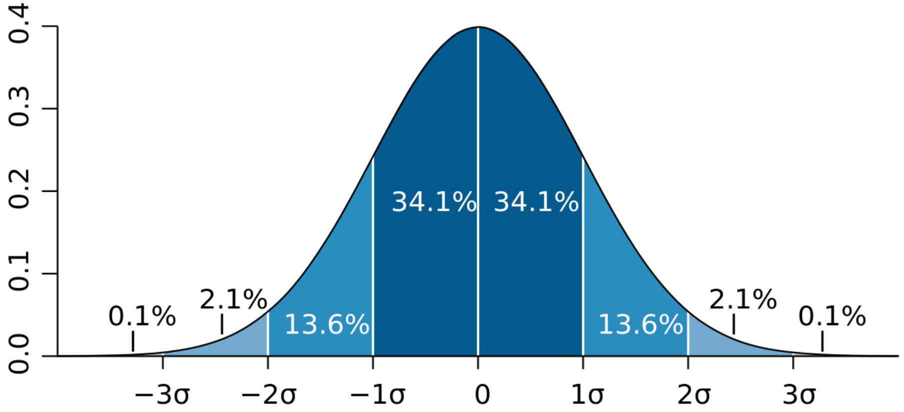
LCCP calculation using Monte-Carlo. Example

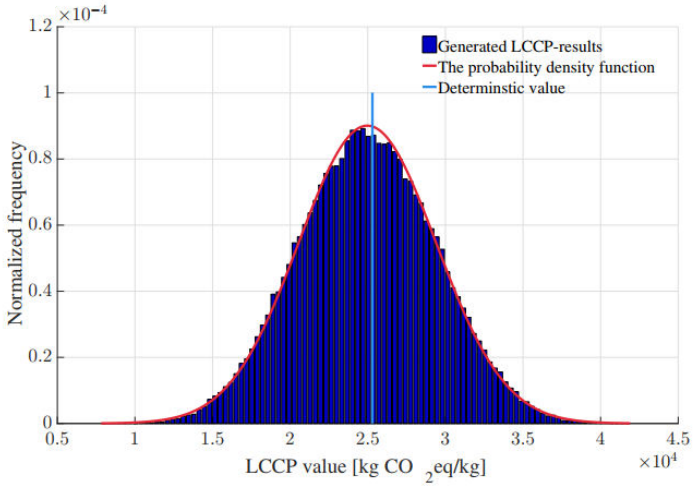


(a) R-1234yf

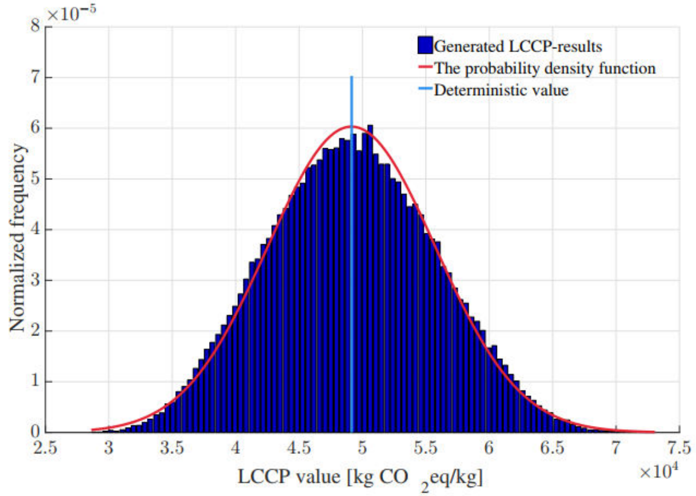


(b) IsoButane





(c) R-513A

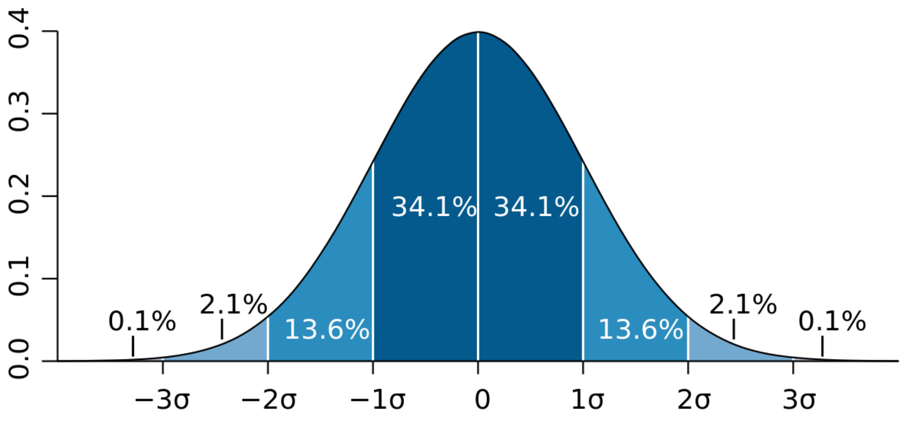


(d) R-134a

Sourse: Boström and Ljungberg, 2018. Dealing with uncertainty in global warming impact assessments of refrigeration systems

IPCC AR5 Summary for Policymakers.

The following terms have been used to indicate the assessed likelihood of an outcome or a result:



virtually certain - 99–100% probability
very likely - 90–100%,
likely - 66–100%,
about as likely as not - 33–66%,
unlikely - 0–33%,
very unlikely - 0–10%,
exceptionally unlikely - 0–1%

Conclusions:

- There is a need for environmental metric that combines direct and indirect emissions and can be reliably incorporated in future legislations
- LCCP can be used as such metric if the uncertainties and variation of input values is addressed
- Iterative approach of refining LCCP input data can facilitate the comparative LCCP analysis
- In some cases, when the data quality can not be obtained, the LCCP analysis can not lead to definitive conclusions

Questions?

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