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Original article

# The environmental cost of unwarranted variation in the use of magnetic resonance imaging and computed tomography scans

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ABSTRACT

*Background:* Pollution is a major threat to global health, and there is growing interest on strategies to reduce emissions caused by health care systems. Unwarranted clinical variation, i.e. variation in the utilization of health services unexplained by differences in patient illness or preferences, may be an avoidable source of CO2 when related to overuse. Our objective was to evaluate the CO2 emissions attributable to unwarranted variation in the use of MRI and CT scans among countries of the G20-area.

*Methods:* We selected seven countries of the G20-area with available data on the use of CT and MRI scans from the organization for Economic Co-operation and Development repository. Each nation's annual electric energy expenditure *per* 1000 inhabitants for such exams ($\text{T-En}_{\text{ex-1000}}$) was calculated and compared with the median and lowest value. Based on such differences we estimated the national energy and corresponding tons of CO2 that could be potentially avoided each year.

*Results:* With available data we found a significant variation in $\text{T-En}_{\text{ex-1000}}$ (median value 1782 kWh, range 1200–3079 kWh) and estimated a significant amount of potentially avoidable emissions each year (range 2046–175120 tons of CO2). In practical terms such emissions would need, in the case of Germany, 71900 and 104210 acres of forest to be cleared from the atmosphere, which is 1.2 and 1.7 times the size of the largest German forest (Bavarian National Forest).

*Conclusion:* Among countries with a similar rate of development, unwarranted clinical variation in the use of MRI and CT scan causes significant emissions of CO2.

## 1. Background

Pollution and related climate changes have a major impact on global health. In 2015 pollution accounted for an estimated 9 million premature deaths and 16% of all deaths globally [1,2]. Humanity is facing a climate crisis that has been defined as one of the major threats to global health of the 21st century [3].

While the mission of healthcare systems all over the world is to guarantee and promote health among citizens, emissions from the health care sector significantly and paradoxically contribute to climate change. If it were a country, healthcare systems would be the fifth largest emitter on the planet [4]. Greenhouse gas emissions from the health care sector vary between 1 and 10% of total national emissions depending on the country considered [4–8].

Recent publications have called for an emergency action to reduce the healthcare environmental footprint [9–11]. Such a change would surely need medium and long-term projects dedicated at developing low-emitting and resilient hospitals and health care supply chains.

Nevertheless, a more immediately actionable source of greenhouse emissions could reside in the reduction of inappropriate and avoidable tests, procedures, and treatments used in everyday clinical practice. A strategy to identify sources of medical overuse could be using what Wannenberg has defined as "*unwarranted variation in clinical practice*" i.e. a variation in the utilization of health services that cannot be explained by any variation in patient illness or patient preferences [12], specifically when such use is not related to a significant benefit for the

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patient.

Radiology has been shown to be a significant contributor of greenhouse emissions due to the significant energetic consumption, to production of radioactive waste [13], and to the need for MRI cooling systems with rare gasses, whose global resources are running short [14, 15]. Recent evidence suggests that the overuse of radiologic exams is a compelling and growing issue [16–20] and that unwarranted variation from radiologic exams may be indeed related to overuse [21–24]. Our hypothesis is that the identification of unwarranted clinical variation in the clinical use of radiological exams may represent a potential source of avoidable $CO_2$ emissions [13].

Thus, the main objective of the present study is to estimate the amount $CO_2$ emissions related to the unwarranted variation in MRI and CT scans use among countries of the G20 area.

## 2. Methods

### 2.1. Datasets, variables, and measures

We initially identified all countries with available data on MRI and CT scan use within the organization for Economic Co-operation and Development (OECD) repository.

The OECD is an international organization whose mission is to provide evidence-based international standards and solutions to a range of social, economic, and environmental challenges. Datasets are publicly available on a dedicated internet website (https://www.oecd.org/). To compare countries with a similar degree of development we decided to limit enrolment to countries of the G20 area.

We only included nations with reported data for both CT and MRI scans.

We then collected demographic data of the selected countries from the most recent year regarding population numerosity, mean age, and life expectancy at birth from various publicly available datasets (see Appendix). To compare healthcare systems of the different countries we used the Healthcare Access and Quality Index (HCQI) [25]. Such Index is measured on a scale from 0 (worst) to 100 (best) based on death rates from 32 causes of death that could be avoided by timely and effective medical care (also known as 'amenable mortality') [25].

Single CT scan and MRI exams' electric energy consumption were derived from a previously published article [26] that directly measured the energy consumption of three CT and four MRI scans on over 40,000 exams performed by the Radiology Department of a large University Hospital in Switzerland. The authors estimated for aggregate data a mean energy consumption of 20 kWh for each MRI and 1.2 kWh for each CT scan. Similar data have been reported by a previously published paper reporting an estimate of energy and materials consumed by single MRI exams [27]. Nevertheless, such article did not report any data on CT energy expenditure.

The use of MRI and CT scans *per* 1000 patients/year were derived from the OECD repository.

First, we estimated the energy expenditure *per* 1000 inhabitants/year for MRI and CT scans (MRI-$En_{ex\text{-}1000}$ and CT-$En_{ex\text{-}1000}$) as the product between energy consumption for each of the two exams and yearly use of these exams every 1000 inhabitants in the included countries. We then calculated the total energy expenditure every 1000 inhabitants/year (T-$En_{ex\text{-}1000}$) as the sum of MRI $En_{ex\text{-}1000}$ and CT $En_{ex\text{-}1000}$ and the median value of T-$En_{ex\text{-}1000}$. Finally, we estimated each country's total amount of Energy Expenditure (T-$En_{ex}$) as the product of T-$En_{ex\text{-}1000}$ and total population divided by 1000 (see Appendix for further details on used formula).

### 2.2. Outcomes

As outcome of interest, we considered the amount of yearly $CO_2$ emissions attributable to unwarranted variation of MRI and CT tests among enrolled countries. Since variation in MRI and CT scan use may depend on different complex variables such as healthcare accessibility, social and economic factors which are difficult to control for, no clear reference standard exists for the optimal rate of use of MRI and CT. We thus decided to address this issue setting two hypothetical reference standards at the median and lowest value of variation. We hypothesized two different scenarios:

- In the first one, we estimated the amount of potentially saved energy if variation was reduced towards the median value. For those countries that had a T-$En_{ex\text{-}1000}$ above the median value, we calculated the difference between estimated T-$En_{ex\text{-}1000}$ and the median T-$En_{ex\text{-}1000}$ value of the specific country.
- In the second scenario we estimated the amount of potentially saved energy if variation was reduced towards the less energy consuming country. For each country we calculated the difference between its T-$En_{ex\text{-}1000}$ and the lowest T-$En_{ex\text{-}1000}$ among the analysed countries, that was considered as the reference standard.

For each scenario we then assessed the amount of potentially avoidable national energy expenditure from MRI and CT scans (T-$En_{ex}$) for each country as the product between each country's avoidable T-$En_{ex\text{-}1000}$ and its total population divided by 1000.

Finally, we converted T-$En_{ex}$ in avoidable tons of emitted $CO_2$, considering the $CO_2$ emission factor ($CO2_{EF}$) of each country. This coefficient considers the kg of $CO_2$ produced with the use of 1 kWh of electric energy and varies from country to country, depending on how energy is produced, distributed, and consumed. There are several models to estimate $CO2_{EF}$, in fact we chose to consider the $CO2_{EF}$ related to consumption rather than production of electric energy. Where available we chose to use $CO2_{EF}$ calculated through the Life Cycle Assessment (LCA), i.e. an internationally standardised methodology that assesses the environmental impact considering the entire life cycle of a product or goods [28] (see Appendix).

We expressed the amount of yearly avoidable T-$En_{ex}$ for each nation in more intelligible parameters using the Greenhouse Gas Equivalencies Calculator provided by the United States Environmental Protection Agency [29]. We expressed the amount of national saved T-$En_{ex}$ in:

- Equivalent greenhouse gas emissions from miles driven by an average gasoline-powered passenger vehicle.
- Equivalent $CO_2$ gas emissions from homes' electricity use for one year.
- Equivalent carbon sequestered by tree seedlings grown for 10 years or acres of U.S. forests in one year.

For further info on data conversion see Appendix.

### 2.3. Uncertainty of estimates

To assess any potential uncertainty in estimates we performed all analyses considering variability of MRI and CT scan mean energy expenditure. We considered the lowest and highest value of electric energy consumption from CT and MRI scan respectively as the best- and worst-case scenario.

All calculations were also performed considering potential variability in $CO2_{EF}$ estimates, using the Intergovernmental Panel on Climate Change (IPCC) model, a widely used international standard that differs from LCA. The IPCC is the United Nations body for assessing evidence related to climate change and is a trusted institution for different international standards on this issue.

Finally, we calculated what would be the total reduction in national $CO_2$ emissions with a 10%, 20% and 50% reduction in T-$En_{ex\text{-}1000}$ in each country.

All secondary estimate calculations are reported in detail in the Appendix.

## 3. Results

We identified from the OECD database complete data on the use of MRI and CT scans for 7 countries of the G20 area: Australia, Canada, France, Germany, Italy, South Korea, and United States.

Demographics, HCA-Q index, rate of MRI and CT scans use per 1000 inhabitants, $CO2_{EF}$ of each country are reported in Table 1.

HCA-Q index varied from 89.9 in Australia to 81.3 in the US (median value 87.6).

The number of MRIs performed in each country varied from 51.2/1000 inhabitants in Australia to 145.1 in Germany (median value 73.9 exams per 1000 inhabitants corresponding to the number of exams performed in South Korea). France, Germany and the US had a value of MRI/1000 citizens higher than the median value.

The number of CT scans/1000 citizens was higher than that of MRI (median value 144.7 exams/1000 citizens, range 83.7–248.8 exams/1000 citizens). Italy was the nation with the lowest rate of CT scans (83.7/1000 citizens). South Korea and US had the highest rates and were, together with France, the only countries with values above the median (that of Germany).

Median $CO2_{EF}$ for included countries was 0.564 kgCO2/kWh of electric energy, but significantly varied among nations, with the lowest $CO2_{EF}$ in France (0.051 kgCO2/kWh), and the highest in Australia (0.870 kgCO2/kWh).

Table 2 reports the $En_{ex-1000}$ values attributable to MRI and CT scans.

For each country the considered total amount of MRI-$En_{ex-1000}$ was higher than CT-$En_{ex-1000}$. The value of $En_{ex-1000}$ related to MRI plus CT scans (T-$En_{ex-1000}$) varied from 1200 kWh in Australia to 3079 kWh in Germany, with a median value of 1782 kWh for aggregate data (South Korea). United States, Germany and France had a T-$En_{ex-1000}$ higher than the median value (South Korea, 1782 KWh). Australia and United States had respectively the lowest and highest national T-$En_{ex}$ (31 and 645 GWh).

Table 3 reports outcomes measures considering the two predefined scenarios.

T-$En_{ex-1000}$ of Australia and South Korea were used as reference standard, being the lowest and median values respectively. Based on each country's $CO2_{EF}$, we expressed values of total yearly "saved" energy in equivalent avoidable CO2 emissions.

If France, Germany, and US had the same levels of $En_{ex-1000}$ for CT and MRI exams as South Korea (median value), in one year they would have "saved" respectively 62, 108 and 54 GWh, that correspond to 5075, 60,729 and 38,563 tons of CO2 each year (Fig. 1). In the case of Germany such an amount of CO2 emissions would need an area of forest equivalent to 1.2 times the widest German national park (Bavarian Forest National Park) to be cleared from the atmosphere.

Potentially avoidable CO2 emissions were significantly higher in the second scenario, using Australia as reference standard (Fig. 2). If Germany had the T-$En_{ex-1000}$ of Australia it would avoid each year the emission of 87,938 tons of CO2. To be cleared from the atmosphere such emissions would need an area of forest 1.7 times the Bavarian Forest National Park.

Equivalence of emitted CO2 into other intelligible parameters is reported in Figs. 1 and 2.

Results varied for less than 25% in the best-case scenario (lowest emission of CO2) when calculations were made using different values of MRI and CT scan energy expenditure or different models for $CO_{EF}$ (appendix Tables 1–5).

CO2 emissions were also significant with a simulation of a reduction of 10%, 20% and 50% of T-$En_{ex-1000}$ in each country.

All results of secondary analyses are reported in detail in the Appendix.

**Table 2**
Estimated $En_{ex-1000}$ and T-$En_{ex}$ from MRI and CT scan use.

| | MRI $En_{ex-1000}$ (kWh) | CT $En_{ex-1000}$ (kWh) | T-$En_{ex-1000}$ (kWh) | T-$En_{ex}$ (GWh) |
|---|---|---|---|---|
| Australia | 1024 | 176 | 1200 | 31 |
| Canada | 1240 | 177 | 1415 | 54 |
| France | 2462 | 243 | 2705 | 181 |
| Germany | 2902 | 177 | 3079 | 256 |
| Italy | 1272 | 102 | 1374 | 83 |
| South Korea | 1478 | 304 | 1782 | 91 |
| United States | 1648 | 298 | 1946 | 645 |
| Median | 1478 | 177 | 1782 | – |

Legend: MRI $En_{ex-1000}$: Energy Expenditure from MRI exams every 1000 citizens per year; CT $En_{ex-1000}$: Energy Expenditure from CT exams every 1000 citizens per year; T-$En_{ex-1000}$:Energy expenditure from MRI and CT scan every 1000 citizens per year; T- $En_{ex}$: National Energy expenditure from MRI and CT scan use per year calculated as T- $En_{ex-1000}$ * total population/1000.
For further details see Appendix.

## 4. Discussion

Our study confirms that reducing unwarranted variation of MRI and CT scan tests may significantly impact on the emission of CO2 in several countries of the G20 area.

Previous studies have evaluated the appropriateness of radiological exams in specific countries by combining codes from the International Classification of Diseases extracted from administrative data [30]. Our approach was based, instead, on the identification of clinical variation among countries with similar demographic characteristics, grade of industrial development and quality of healthcare systems. It is hard to explain why such variation may exist without assuming a certain grade of inappropriate use of radiologic exams. Previous data suggest that unwarranted clinical variation is a relevant issue both among different countries and among hospitals within the same countries or regions [12,31,32] Indeed, in many instances, higher utilization and increasing access to healthcare does not necessarily warrant better care nor outcomes for patients [33,34].

Our study quantifies for the first time what the environmental impact

**Table 1**
Demographics, incidence of CT and MRI use, and greenhouse emissions variables among included countries.

| | Population (n) | Age (median) | Life expectancy at birth (mean) | HCA-Q index | $MRI_{1000}$ | $CT_{1000}$ | $CO2_{EF}$ (kgCO2/kWh) |
|---|---|---|---|---|---|---|---|
| Australia | 25,687,041 | 37.4 | 83.4 | 89.8 | 51.2 | 144.6 | 0.87 |
| Canada | 38,005,238 | 40.5 | 82.4 | 87.6 | 62 | 144.2 | 0.25 |
| France | 67,012,883 | 41.2 | 82.7 | 87.9 | 123.1 | 199.2 | 0.082 |
| Germany | 83,019,013 | 45.9 | 81.3 | 86.4 | 145.1 | 144.7 | 0.564 |
| Italy | 60,359,546 | 45.9 | 83.5 | 89.7 | 63.6 | 83.7 | 0.378 |
| South Korea | 51,337,657 | 40.8 | 83 | 85.8 | 73.9 | 248.8 | 0.58 |
| United States | 331,449,281 | 37.6 | 78.9 | 81.3 | 82.4 | 243.9 | 0.709 |
| Mean | | | | 86.9 | 85.9 | 172.7 | 0.49 |

Legend: HCA-Q index: Health care access and quality index; $MRI_{1000}$= numbers of MRI per 1000 inhabitants performed every year; $CT_{1000}$= numbers of CT per 1000 inhabitants performed every year. $CO2_{EF}$: coefficient of emission intensity (kgCO2/kWh).
For further details see Appendix.

**Table 3**
Differences in T-$En_{ex-1000}$ potentially saved T-$En_{ex}$ and CO2 production among countries.

| | ΔT-$En_{ex-1000}$ with median (kWh) | Δ$En_{ex}$ wtih median (GWh) | Avoidable CO2 emissions (tons) [diff with median] | Δ$En_{ex-1000}$ with lowest (kWh) | Δ$En_{ex}$ wtih lowest (GWh) | Avoidable CO2 emissions (tons) [diff with lowest] |
|---|---|---|---|---|---|---|
| Australia | −581 | – | – | – | – | – |
| Canada | −366 | – | – | 216 | 8 | 2045 |
| France | 924 | 62 | 5075 | 1505 | 100 | 8268 |
| Germany | 1297 | 108 | 60,729 | 1878 | 156 | 87,938 |
| Italy | −407 | – | – | 174 | 10 | 3963 |
| South Korea | – | – | – | 581 | 30 | 17,303 |
| United States | 164 | 54 | 38,563 | 745 | 247 | 175,120 |

Legend T-$En_{ex-1000}$:Energy expenditure from MRI and CT scan every 1000 citizens per year; T- $En_{ex}$: National Energy expenditure from MRI and CT scan use per year; Δ$En_{ex-1000}$: difference in T-$En_{ex-1000}$ (with median or lowest $En_{ex-1000}$ value); Δ$En_{ex}$: difference in T-$En_{ex}$ on national basis (with median or lowest $En_{ex-1000}$ value) calculated as ΔT-$En_{ex-1000}$ *total population/1000.
For further details and calculations see Appendix.

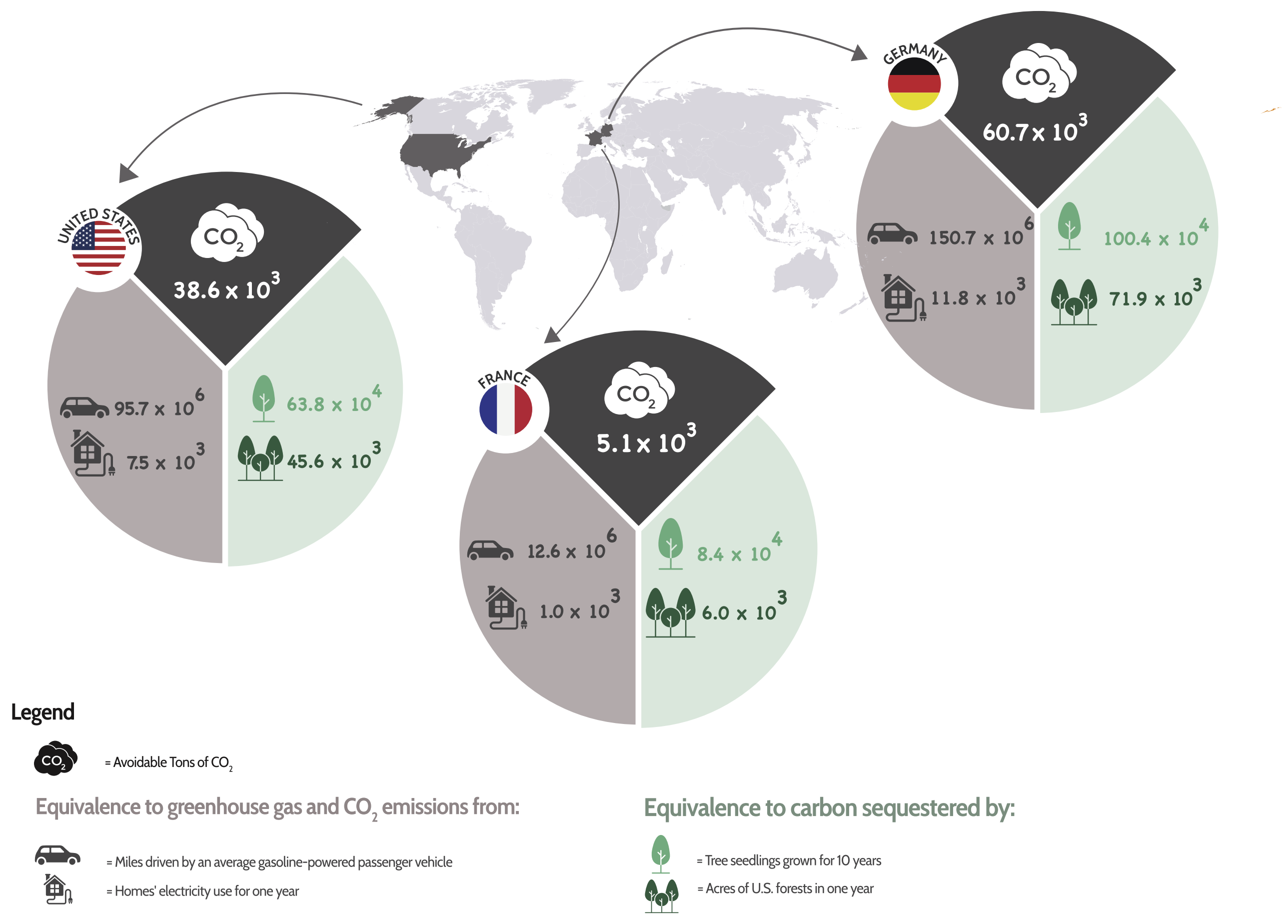


**Fig. 1.** Potentially avoidable CO2 emissions from reduction of countries' T-$En_{ex-1000}$ towards the median value.

of such unwarranted clinical variation may represent in terms of avoidable CO2 emissions.

We believe that our results are quite impressive, considering that we only analysed the use of two radiologic exams, and we believe that on a global scale the number of avoidable emissions from the healthcare sector related to inappropriate exams, test and procedures may be dramatic.

Our evaluations of the environmental footprint are in fact likely to be under-estimated.

In the first place our estimates for the different countries are based on the comparison with median and lowest values of energy expenditure *per* 1000 inhabitant (T-$En_{ex-1000}$). Nevertheless, it is likely that even the countries with the lowest T-$En_{ex-1000}$ use of exams may still perform a relevant number of inappropriate exams. As an example, US T-$En_{ex-1000}$ is quite close to the mean value even though previous studies have underlined a significant overuse of MRI exams in this country [18,19,30,35]. Also, many radiological scientific societies have called for a reduction of CT and MRI prescriptions [20].

Second, we limited our assessment of environmental footprint to electric energy use for CT and MRI, while energetic and environmental costs from waste products (including contrast media) and gas extraction needed for MRI cooling systems may be even higher. In a previously published article the total amount of energy consumption, both in and out of hospital for a single MRI exam was estimated in 105 kWh [27].

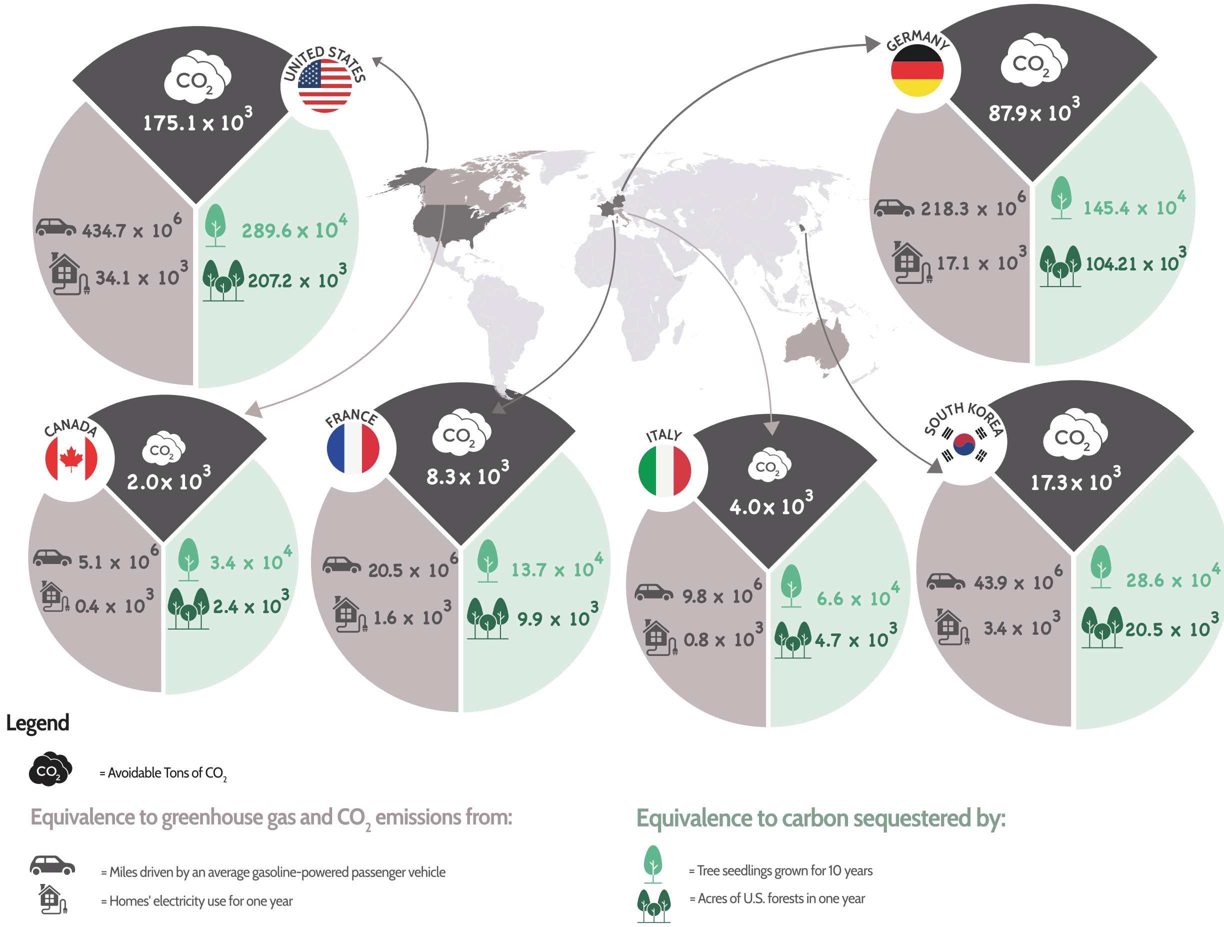


**Fig. 2.** Potentially avoidable CO2 emissions from reduction of countries' T-$En_{ex-1000}$ towards the lowest value.

With such values CO2 footprint would be 5 times our estimates.

Many initiatives, such as the Choosing Wisely and the Less is More campaigns [36,37], that have brought to the fore the potentially harmful role of the inadequate use of exams, medications, and procedures, have focused their recommendations on risks-benefits for patients and economic costs analyses. We believe that environmental costs should be assessed too and may further increase the value of such initiatives due to their potential benefit on global health. Such environmental costs may be quantified in terms of "avoidable CO2 emissions".

From such a perspective our data may represent a starting point for future studies on strategies for the reduction of healthcare systems' environmental footprint.

As first suggestion, researchers could try to evaluate the potential impact on greenhouses emissions of other tests and procedures commonly overused in clinical practice to both quantify the magnitude of the problem and, eventually, to raise awareness among healthcare workers and stakeholders.

Secondly, on the way towards more sustainable hospitals researchers could implement in clinical practice interventions aimed at reducing greenhouse emissions through the application of recommendations on the appropriate use of tests and procedures such as those developed by the Choosing Wisely and Less is More Campaigns.

We recognize that our study may have several limitations.

Our analyses were based on publicly available data from the OCSE organization. Several biases may be present in the collection and communication of data by the different included countries. Our objective was, though, to provide just a glimpse on how commonly used radiological exams may have a significant impact on the environment and indirectly on citizens' health.

The number of CT and MRI scans/1000 citizens may obviously depend on the population characteristics and healthcare accessibility, that may significantly vary among countries. We were not able to assess all such variables. Nevertheless, we limited our analysis to countries with similar rates of economic development and with comparable epidemiology and etiology of population diseases. While health care systems and reimbursement policies may differ among countries, we did not find any significant difference in demographics, nor health care quality that may justify the variation in performed exams. Moreover, among the included countries four out of seven (Canada, Italy, France, South Korea) have a full public healthcare system, two (Germany and Australia) a mixed public and private healthcare and only one (USA) has mainly a private non universalistic healthcare system.

Due to the different factors that may influence the variation in the rate of MRI and CT scans, we could not define *a priori* a desirable number. Our estimates were thus made on two different scenario settings, i.e. the reference standard at the median and lowest value of T-$En_{ex-1000}$.

$En_{ex-1000}$ is mainly determined by MRI, since such exam consumes almost 20 times the energy of a CT scan. In some instances, it is possible that MRI exams may be substituted by CT scans. Nevertheless, we doubt that such strategy may be a widely adopted solution due to the risk related to radiation exposure and to the fact that also many CT scan exams are likely to be inappropriate.

Finally, electric expenditure is influenced by the type of MRI used (1.5 vs 3 Tesla) and by the body section scanned. Nevertheless, our estimates were based on mean values from the direct measurement of over 40,000 exams in a major city hospital in Switzerland [26]. We also evaluated the effect on study results considering standard deviations of energy consumption estimates and $CO2_{EF}$ (Appendix Table 1 to 5). In the best-case scenario CO2 emission estimates would be 25% lower, which is still a significant amount.

Tons of CO2 produced were converted into a more comprehensible parameter, i.e. miles driven by an average vehicle, that may vary depending on the type of car, type of gasoline used, and rate of electric vehicles of each country. However, we were not interested in a precise conversion but rather in providing a more readable estimate of the magnitude of the problem. Moreover, regardless of the exact equivalence of CO2 emissions in terms of everyday activities, what's worrisome is the extension of forest or the number of new planted trees that would be needed to compensate for those CO2 emissions.

## 5. Conclusions

The unwarranted clinical variation in the use of MRI and CT scans among 7 major economies of the G20 area significantly contributes to CO2 emissions.

Environmental impact of inappropriate tests, procedures and treatments should be extensively assessed and recommendations from the Choosing Wisely Campaigns may integrate environmental costs as relevant issues to healthcare workers, stakeholders, patients, and citizens.

## Authors and contribution

LF, GCos and NM conceived and designed the paper.

LF and PDF performed literature search.

LF, PDF, GCa, NM and GCos contributed to data extraction and analysis.

All authors contributed to data interpretation.

All authors contribute to the writing of the manuscript.

All authors had full access to all the data in the study and accept responsibility to submit for publication.

## Declaration of Competing Interest

The authors do not have any conflict of interest.

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## Supplementary materials

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