Category	Title
General guidance	Time series consistency
Version	Guidebook 2019

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Contents

1 Overview

This guidance has been adapted from the *2006 IPCC guidelines for national greenhouse gas inventories* (IPCC, 2006), published by the Intergovernmental Panel on Climate Change, and the *2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories* to the IPCC guidelines (IPCC, 2019). The basic methods and principles are the same unless otherwise indicated. The time series is a central component of an air pollutant inventory because it provides information on historical emission trends and tracks the effects of strategies to reduce emissions at the national level. As is the case with estimates for individual years, emission trends should be neither over- nor underestimated as far as can be judged. All emission estimates in a time series should be estimated consistently, which means that, as far as possible, the time series should be calculated using the same or comparable methods and data sources in all years. Using different methods and data in a time series could introduce bias because the estimated emission trend will reflect not only real changes in emissions but also the pattern of methodological refinements. In the event that it is not possible to use exactly the same methods over the time series, the differences in the methods and activity data shall be transparently documented in the informative inventory report.

This chapter describes good practice in ensuring time series consistency. Section 1.2 provides guidance on common situations in which time series consistency could be difficult to achieve: when carrying out recalculations; while adding new categories; and when accounting for technological change. Section 1.2.3 describes techniques for combining or 'splicing' different methods or data sets to compensate for incomplete or missing data. Additional guidance on reporting and documentation, and quality assurance/quality control (QA/QC) of time series consistency is given in Sections 2 and 3.

1.1 Ensuring a consistent time series

1.1.1 Recalculations due to methodological changes and refinements

A methodological change in a category is a switch to a different tier from the one previously used. **Methodological changes** are often driven by the development of new and different data sets. An example of a methodological change is the improvement of the method to a higher tier instead of a tier 1 default method. For example, if site-specific emission data, e.g. from measurements, for an industrial category has become available, that can be used directly or for development of national emission factors, and there may even be data to establish different emission factors for different years in the time series.

A **methodological refinement** occurs when an inventory compiler uses the same tier to estimate emissions but applies it using a different data source or a different level of aggregation. Examples of a refinement would be, for example, if new data permit further disaggregation of a livestock enteric fermentation model, animal categories could then be more homogeneous or have a more accurate emission factor applied to them. In this case, the estimate is still being developed using a tier 2 method, but it is applied at a more detailed level of disaggregation. Another possibility is that data of a similar level of aggregation but of higher quality could be introduced, due to improved data collection methods. As an example, new data on the performance of already previously applied process/abatement techniques on an industrial process could become available.

Both methodological changes and refinements over time are an essential part of improving inventory quality. It is good practice to change or refine methods in the following situations:

- **The available data have changed or are available in more or less detail than earlier.** The availability of data is a critical determinant of the appropriate method, and thus changes in available data may lead to changes or refinements in methods. In cases in which countries gain experience and devote additional resources to preparing emission inventories, it is expected that data availability will improve. Sometimes collection of data may be reduced, which can result in a less rigorous methodological outcome.
- **The previously used method is not consistent with good practice for that category.** Inventory compilers should review the guidance for each category in the detailed sector chapters.
- **A category has become a key category.** A category might not be considered a key category in a previous inventory year, depending on the criteria used, but it could become a key category in a future year. Countries anticipating a significant increase in emissions in a category may want to consider this possibility for a category becoming a key category and estimate all years using a higher tier method.
- **The previously used method is insufficient to reflect mitigation activities in a transparent manner.** As techniques and technologies for reducing emissions are introduced, inventory compilers should use methods that can account for the resulting changes in emissions in a transparent manner. Where the previously used methods do not reflect the historical changes or are insufficiently transparent, it is good practice to change or refine them. See Section 1.1.3 of this chapter for further guidance.
- **The capacity for inventory preparation has increased or decreased.** Over time, the human or financial capacity (or both) necessary to prepare inventories may change. In the event of increased inventory capacity, it is good practice to change or refine methods so as to produce more accurate, complete and transparent estimates, particularly for key categories. If resources decrease, maintaining the quality of the inventory should be a key aim.
- **New inventory methods have become available.** Over time, new inventory methods may be developed that take advantage of new technologies or improved scientific understanding. For example, the continuous improvements in remote-sensing technology make it possible to estimate emissions of certain sources with increasing levels of certainty.
- **New emission factors are available in the EMEP/EEA Guidebook that could be different from those in previous versions of the Guidebook.** Every 3-4 years the joint *EMEP/EEA air pollutant emission inventory guidebook* (the Guidebook) is updated in an effort to introduce new methodologies and emission factors based on the latest available science. Under these circumstances, the inventory compiler has to carefully consider the emission factors presented in the most up-to-date version of the Guidebook and make a determination of the appropriateness of such emission factors to the category in question for the full time series. If the emission rate changes over time, the inventory compiler should consider the appropriateness of the emission factor in relation to changes in the emission rate for specific periods of the time series. It is possible for the inventory compiler to apply the old emission factors in part of the time series and the latest emission factors for other parts of the time series,

as changes in emission rates might be triggered by changes in process or technologies. When such changes occur, they should be properly documented.

- **There is a correction of errors.** It is possible that the implementation of the QA/QC procedures described in Chapter 6, will lead to the identification of errors or mistakes in the inventory. As noted in that chapter, it is good practice to correct errors in previously submitted estimates. In a strict sense, the correction of errors should not be considered a methodological change or refinement. This situation is noted here, however, because the general guidance on time series consistency should be taken into consideration when making necessary corrections.

1.1.2 Adding new categories

The addition to the inventory of a new category or subcategory requires the calculation of an entire time series, and estimates should be included in the inventory from the year emissions start to occur in the country. A country should make every effort to use the same method and data sets for each year. It may be difficult to collect data for previous years, however, in which case countries should use the guidance on splicing in Section 1.3.3 of this chapter to construct a consistent time series.

A country may add new categories or new gases to the inventory for a variety of reasons:

- **A new emission activity is occurring**. Emissions of some pollutants, particularly in the industrial processes and product use (IPPU) sector, are only generated as a result of specific technological processes.
- **There is rapid growth in a very small category**. A category that previously was too small to justify the resources needed for its inclusion in the national inventory could experience sudden growth and should be included in future inventories.
- **There are new nomenclature for reporting (NFR) categories**. The *EMEP emission reporting guidelines* contain some categories and subcategories that were not covered in the previous reporting guidelines. As a result, countries may include new estimates in future national inventories. Countries should include estimates for new categories and subcategories for the entire time series.
- **Country-specific categories are included in the inventory.** In cases in which the EMEP/EEA Guidebook does not provide guidance on allocation and methodological guidance for a specific category, a country may deem the category to be significant (according to its national definition) for its national emissions total.
- **There is additional inventory capacity.** A country may be able to use more resources or employ additional experts over time and thus include new categories and subcategories in the inventory.
- **An emission source is included or removed.** If a new emission-causing activity began or ceased after the 'base year' ([1]), or if a category previously regarded as insignificant (see Section 1.2.1 of this chapter regarding methodological choice as a reason for not estimating emissions from an existing source) has grown to the point where it should be included in the inventory,

([1]) Within the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) and National Emission Ceilings (NEC) Directive, the base year is a year upon which targets are based and often represents the start year of the inventory.

it is good practice to document the reason for not estimating emissions for the entire time series.

1.1.3 Tracking increases and decreases due to technological change and other factors

Emission inventories can track changes in emissions through changing activity levels or changing emission rates, or both. The way in which such changes are included in methodologies can have a significant impact on time series consistency.

Changes in activity levels

National statistics will typically account for significant changes in activity levels. For example, switching fuel from coal to natural gas in electricity generation will be reflected in the national fuel consumption statistics. Further disaggregation of activity data can provide more transparency and can indicate specifically where the change in activity is occurring. This approach is relevant when changes are taking place in one or more subcategories but not throughout the entire category. To maintain time series consistency, the same level of disaggregation into subcategories should, as far as possible, be used for the entire time series, even if the change began recently.

Changes in emission rates

Research may indicate that the average rate of emissions per unit of activity has changed over the time series. In some cases, the factors leading to a technological change may also make it possible to use a higher tier method. For example, a coke oven plant manager who introduces measures to reduce the frequency and intensity of fugitive coke oven leakage may also collect plant-specific parameters that can be used to estimate a new emission factor. This new factor might not be appropriate for estimating emissions for earlier years in the time series before the technological or practice change occurred. In these cases it is good practice to use the updated emission factor or other estimation parameters or data to reflect these changes for the relevant years only. As a general assumption, emission factors or other estimation parameters do not change over time unless otherwise indicated, so countries should clearly document the reason for using different factors or parameters in the time series. This is particularly important if sampling or surveying occurs periodically and emission factors or estimation parameters for years in between are interpolated rather than measured. Changes in process/management practices/technologies can be used as a guide to trigger the commissioning of periodic surveys.

Changes in data sources for different years of the time series

A change in data availability or a gap in data is different from periodically available data, because there is unlikely to be an opportunity to recalculate the estimate later using better data. In some cases, countries will improve their ability to collect data over time, so that higher tier methods can be applied for recent years but not for earlier years. This is particularly relevant to categories in which it is possible to implement direct sampling and measurement programmes because these new data may not be indicative of conditions in past years. Some countries may find that the availability of certain data sets decreases over time as a result of changing priorities within governments, economic restructuring, or limited resources. Some countries with economies in transition no longer collect certain data sets that were available in the base year, or, if available, these data sets may contain different definitions, classifications and levels of aggregation. For example, changes to national livestock surveys can lead to improvements in the details and certainty of the annual livestock numbers (or more specifically animal places) by recording the data within a more detailed livestock categorisation and by specifically including smaller farms or households that keep only a few farm animals. This implies that livestock emission estimates produced for different years of the time series will have different levels of resolution and completeness and will consequently use different methods. Differences in these attributes might introduce inconsistencies and highlight shortcomings in some data sets used in the time series.

Changes in abatement of emissions

In addition to improvements in processes and the use of raw material, emissions have also been decreased over the years due to the introduction of abatement techniques and improvements in their efficiencies. In some cases emissions might not be released to the atmosphere at all or are only a small fraction of the earlier emissions, as they are no longer occurring, are collected and treated or are used for other purposes. Therefore the methods to estimate emissions should be reviewed regularly to ensure that they correspond to the actual generation of emissions for both current and past years. In these cases it is good practice to document the reasons for the changes in the inventory report.

Below are some examples of how to take these changes into account in the time series:

- The most accurate method for the time series of energy production units and industrial processes is to use data reported by the plants, where available, and after proper QA/QC checks. These data are often based on continuous or periodic measurements and thus reflect rather accurately the real world emissions.
- If data reported by the plants are not available, for example regarding smaller boilers or industrial activities, but information on the national installation status of abatement techniques, their efficiencies, and the installation or improvement dates is, this information should be used in the calculation of emissions. In addition, emissions of certain pollutants depend on the existence of certain technologies or abatement techniques that might be applied only in part of the plants in a sector, and therefore the application rate is likely to change in the time series.
- When only one emission factor might be available, such as from a domestic measurement on a certain date or the Guidebook default value, and it is known that there have been changes in emissions over time, it is good practice to assess the exact time (in years) for which this emission factor corresponded to the activity. For the other years, changes in emissions can then be taken into account in the time series by establishing a ratio with another data set that correlates well with the development of emissions. Depending on the pollutant, examples of this type of data set are CO emissions (which are usually available and reliable as they are followed to monitor process performance) or total suspended particle emissions (which have been monitored for compliance purposes for decades).
- Regional or national studies carried out at different points in time and providing information on measurements, emission estimates or applied technologies can be assumed to be the best estimates for the particular time indicated in the study. For instance, instead of using default heavy metal emission factors, it is good practice to study how the metal content of tyres has decreased over time in a region. In addition, metal emissions from tyre wear are related to the use of studded tyres and the length of time they are used, for which annual sales and product description data or the share of vehicles using studded tyres, may be available

1.2 Resolving data gaps

1.2.1 Issues with data availability

For a complete and consistent time series, it is necessary to determine the availability of data for each year. Recalculating previous estimates using a higher tier method or by developing estimates for new categories will be difficult if data are missing for one or more years. Examples of data gaps are presented below.

Periodic data. Natural resource or environmental statistics, such as national forest inventories, waste statistics and agricultural statistics, may not cover the entire country on an annual basis. Instead, they may be carried out at intervals such as every 5th or 10th year, or region by region, meaning that national-level estimates can be directly obtained only once the inventory in every region has been completed. When data are available less frequently than annually, several issues arise. First, the estimates need to be updated each time new data become available, and the years between the available data need to be recalculated. The second issue is the problem of producing inventories for years after the last available data point and before new data are available. In this case, new estimates should be extrapolated from the available data, and then recalculated when new data become available.

Changes and gaps in data availability. A change in data availability or a gap in data is different from periodically available data because there is unlikely to be an opportunity to recalculate the estimate at a later date using better data. In some cases, countries will improve their ability to collect data over time, so that higher tier methods can be applied for recent years but not for earlier years. This is particularly relevant to categories in which it is possible to implement direct sampling and measurement programmes because these new data may not be indicative of conditions in past years. Some countries may find that the availability of certain data sets decreases over time as a result of changing priorities within governments, economic restructuring or limited resources. Some countries with economies in transition may no longer collect certain data sets that were available in the base year, or, if available, these data sets may contain different definitions, classifications and levels of aggregation.

Incorporation of data reported by facilities that are available for part of the time series*.* The availability of data and details of information may change over the period of the time series due to new legislation establishing regular data collection and emission monitoring systems at facility level. Examples are the requirements of data collected in the context of the European Emissions Trading System (EU-ETS), the European Pollutant Release and Transfer Register (E-PRTR), other facility monitoring programs in Australia and the United States of America. Therefore, inventory compilers may be able to implement higher tier methods for recent years but have difficulty in applying the same methods historically.

As far as feasible, the inventory compiler should make use of the most accurate emissions and other parameters collected within the relevant contexts. In addition, it is important that when using these data, either partially or totally, the consistency of time series in the preparation of the national inventory is assured to the extent practicable.

The sectoral coverage of the category to be estimated should be checked to ensure that it is complete and the data collected have undergone a validation process. The expert should then decide how to integrate these data into the national inventory (graduating from a Tier 1 to a Tier 2, or from a Tier 2 to a Tier 3), and from which point of the time series the use of such data starts.

The most recent information is usually more accurate or at least can be more transparently documented than older data, so judgement from sectoral experts, relevant associations and other experts in the field should be taken into account to decide if new data and information are also applicable for earlier years. For instance, discrepancies from old and new emission factors may be justified by the change in technologies and/or best practices, or they may be affected by incorrect assumptions and methods to ensure data consistency that need to be applied. When the same method is not used along the entire time series, relevant techniques should be selected to ensure the consistency of the time series (or that the appropriate documentation has been provided to justify the trend, e.g. change in technical conditions due to the introduction of mitigation technology).

This issue is relatively common in the industrial products and processes sectors. Although the relationship between emissions estimated from the Tier 3 and the Tier 2 methods should be relatively constant over time for a given plant this may vary if the industry has changed significantly over time. In some cases, if technologies and practices in the industry have not changed much, the expert should evaluate if emission factors derived from recent data may also be appropriate for historical years or if a splicing technique should be applied to ensure time series consistency.

For instance, if emissions and other data are collected from a certain point of the time series onwards in the context of a facility level reporting program, the expert should evaluate if an average emission factor or parameter derived from this collection may also be applied to earlier years of the time series (ensuring the consistency of the time series). There may be cases where the expert uses two different tiers (Tier 2 and Tier 3), and the expert should clearly document that the use of two different methods does result in the most appropriate EFs.

1.2.2 Non-calendar year data

When using non-calendar year data, it is good practice to use the same collection period consistently over the time series, as described in Chapter 3, on data collection. Countries should not use different collection periods within the same time series because this could lead to a bias in the trend.

1.2.3 Splicing techniques

Splicing in this context refers to the combining or joining of more than one method to form a complete time series. Several splicing techniques are available if it is not possible to use the same method or data source in all years. This section describes techniques that can be used to combine methods to minimise the potential inconsistencies in the time series. Each technique can be appropriate in certain situations, as determined by considerations such as data availability and the nature of the methodological modification. Selecting a technique requires an evaluation of the specific circumstances and a determination of the best option for the particular case. It is good practice to perform the splicing using more than one technique before making a final decision and to document why a particular method was chosen. The principal approaches for inventory recalculations are summarised in Table 1-2.

1.2.4 Overlap

The overlap technique is often used when a new method is introduced but data are not available to apply the new method to the early years in the time series, for example when implementing a higher tier methodology. If the new method cannot be used for all years, it may be possible to develop a time series based on the relationship (or overlap) observed between the two methods during the years when both can be used. Essentially, the time series is constructed by assuming that there is a consistent relationship (usually a constant ratio) between the results of the previously used and the new method. The emission estimates for those years when the new method cannot be used directly are developed by proportionally adjusting the previously developed estimates, based on the relationship observed during the period of overlap. In this case, the emissions associated with the new method are estimated according to equation 1 ([2]).

$$y_0 = x_0 \bullet \left(\frac{1}{(n-m+1)} \bullet \sum_{i=m}^{n} \frac{y_i}{x_i} \right) \quad (1)$$

where:

y_0	=	the recalculated emission estimate computed using the overlap method;
x_0	=	the estimate developed using the previously used method;
y_i and x_i	=	the estimates prepared using the new and previously used methods during the period of overlap, as denoted by years *m* to *n*.

A relationship between the previously used and new methods can be evaluated by comparing the overlap between only one set of annual estimates, but it is preferable to compare multiple years. This is because comparing just one year may lead to bias and it is not possible to evaluate trends.

Figure 1-1 shows a hypothetical example of a consistent overlap between two methods for the years in which both can be applied. In Figure 1-2 there is no consistent overlap between methods, and it is not good practice to use the overlap technique in such a case.

Other relationships between the old and new estimates may also be observed through an assessment of the overlap. For example, a constant absolute difference may be observed. In this case, the emissions associated with the new method are estimated by adjusting the previous estimate by the constant amount equal to the average difference in the years of overlap.

([2]) Overlap equation 1 is preferred to the equation described in *Good practice guidance and uncertainty management for national greenhouse gas inventories* (IPCC, 2000):

$$y_0 = x_0 \bullet \left(\sum_{i=m}^{n} y_i \Big/ \sum_{i=m}^{n} x_i \right)$$

This is because the latter gives more weight to overlapping years with the highest emissions. However, in practical cases the results will often be very similar, and continued use of the previous equation is consistent with good practice where its use gives satisfactory results.

Figure 1-1 Consistent overlap

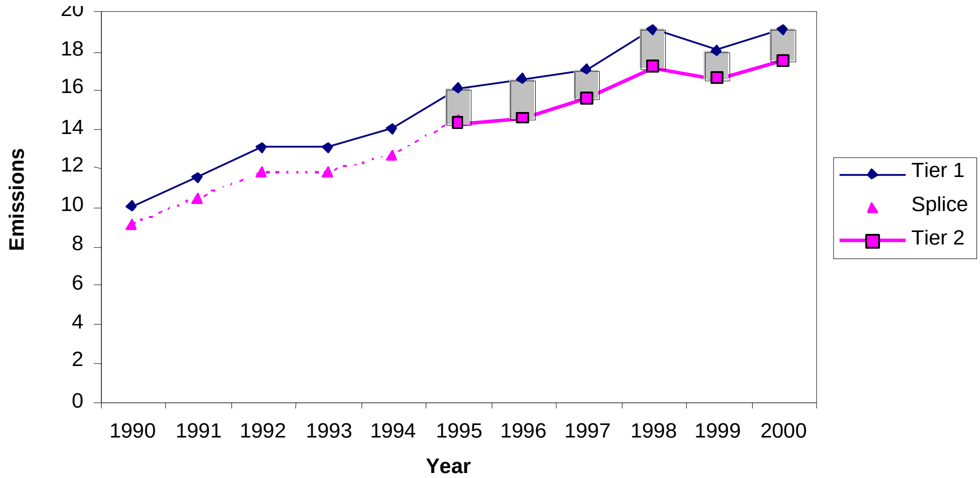
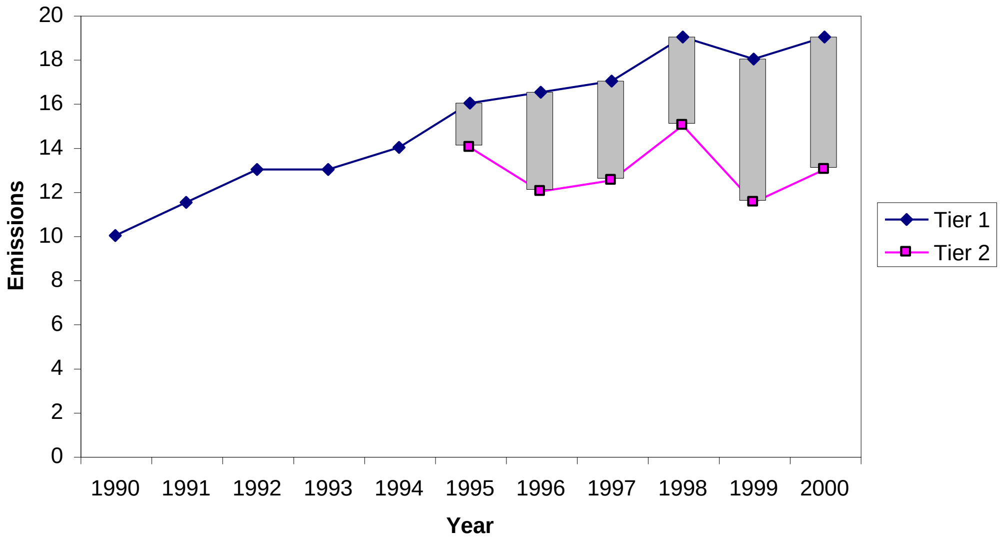


Figure 1-2 Inconsistent overlap



Before applying the overlapping technique, the expert should be aware of the relationship between the old and the new method applied to estimate emissions and should be able to understand the differences, so that they are sure that the new method actually improves the accuracy of emission estimates.

Box 1-1 provides a practical example in which the inventory compiler should evaluate the application of the overlap approach to estimate nitrogen oxide (NO_x) emissions for the years 2001-2003.

BOX 1-1 Case study of overlap method — NO_x emissions from iron and steel combustion

Consider the example below, which evaluates the application of the overlap approach to estimate greenhouse gas (GHG) emissions for the years 2001-2003.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Tier 1 quantified	4,000	4,000	4,100	4,200	4,800	4,900	5,000	4,800	4,900	5,000
Tier 2 quantified				4,035	4,598	4,410	4,500	4,320	4,513	4,790

Step 1. For each year, calculate the ratio between tier 2 and tier 1 (e.g. in 2010: 4 790/5 000 = 0.96):

Step 2. Calculate average and standard deviation of the differences:

- average = 0.93 (correction factor to be multiplied by the estimate developed, based on the previously used method, as per equation 1);
- standard deviation = 0.027 (low variability, and therefore the overlap approach seems appropriate).

Step 3. Apply average to calculate missing data:

- year 2001: 4 000 × 0.93 = 3 720;
- year 2002: 4 000 × 0.93 = 3 720;
- year 2003: 4 100 × 0.93 = 3 813.

1.2.5 Surrogate data

The surrogate method relates emissions to underlying activity or other indicative data. Changes in these data are used to simulate the trend in emissions. The estimate should be related to the statistical data source that best explains the time variations of the category. For example, mobile source emissions may be related to trends in distances travelled by vehicles, emissions from domestic waste water may be related to population and industrial emissions may be related to production levels in the relevant industry. See Chapter 3, on data collection.

In its simplest form, the estimate will be related to a single type of data as shown in equation 2:

$$y_0 = y_t \bullet (s_0 / s_t) \qquad (2)$$

where:

y	=	the emission estimate in years 0 and t;
s	=	the surrogate statistical parameter in years 0 and t.

Surrogate data should be selected based on country-specific circumstances and information. Although the relationship between emissions and surrogate data can be developed on the basis of data for a single year, the use of multiple years might provide a better estimate.

In some cases, relating emissions to more than one statistical parameter may develop more accurate relationships. Regression analysis may be useful in selecting the appropriate surrogate data parameters. Using surrogate methods to estimate otherwise unavailable data can improve the accuracy of estimates developed by the interpolation and trend extrapolation approaches discussed below.

In selecting and using surrogate data, it is good practice for countries to perform the following steps:

1. Confirm and document the physical relationship between the available data and the surrogate activity data for instances (e.g. years) in which both data sets are available.
2. Confirm and document a statistically significant correlation between the available data and the surrogate data.
3. Using regression analysis, develop a country-specific factor relating the available data to the surrogate data and estimate the missing values.

Table 1-1 presents examples of surrogate data that could be applied when using the surrogate data method.

Table 1-1 Examples of surrogate data by sector

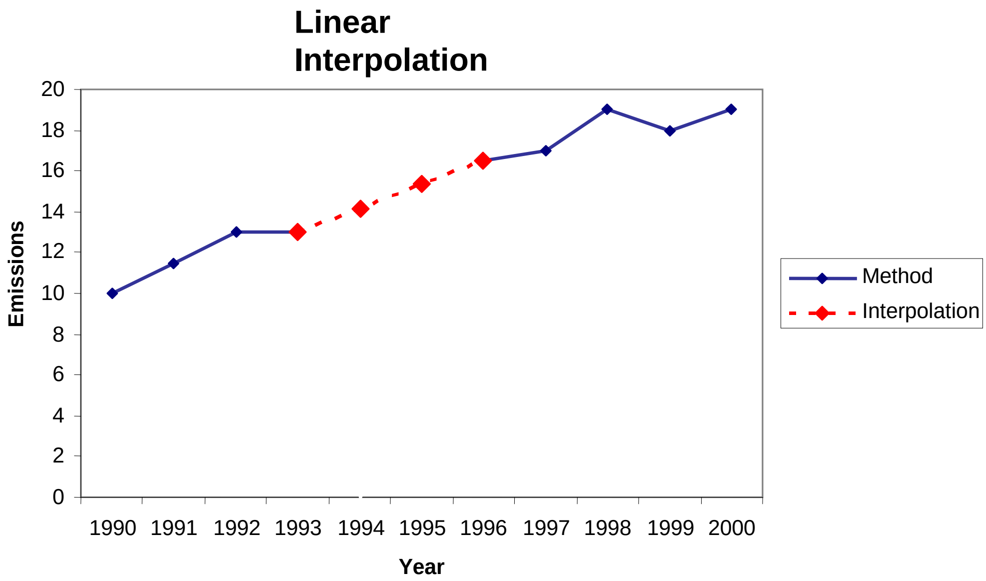
Energy	IPPU	Agriculture	Waste
• Gross domestic product • Population statistics • Vehicle fleet • Fuel sales data (taking into account import/export) • Annual income	• Commodity production statistics • Gross domestic product (of each specific category, where available) • Plant-specific parameters	• Crop sales data (taking into account import/export) • Crop productivity and harvested area • Milk production data • Animals slaughtered • Gross domestic product of each specific category	• Gross domestic product • Population statistics • Annual income • Protein intake data • Ratio of domestic/ industrial waste water

1.2.6 Interpolation

In some cases it may be possible to apply a method intermittently throughout the time series. For example, necessary detailed statistics may be collected only every few years, or it may be impractical to conduct detailed surveys on an annual basis. In these cases, estimates for the intermediate years in the time series can be developed by interpolating between the detailed estimates. If information on the general trends or underlying parameters is available, then the surrogate method is preferable.

Figure 1-3 shows an example of linear interpolation. In this example, data for 1994 and 1995 are not available. Emissions were estimated by assuming a constant annual growth in emissions from 1993 to 1996. This technique is appropriate in this example because the overall trend appears stable, and it is unlikely that actual emissions for 1994 and 1995 are substantially different from the values predicted through interpolation. For categories that have volatile emission trends (i.e. they fluctuate significantly from year to year), interpolation would not constitute good practice and surrogate data will be a better option. It is good practice to compare interpolated estimates with surrogate data as a QA/QC check.

Figure 1-3 Linear interpolation



1.3 Linear extrapolation

When detailed estimates have not been prepared for the base year or the most recent year in the inventory, it may be necessary to extrapolate from the closest detailed estimates. Linear extrapolation is conceptually similar to interpolation, but less is known about the actual trend. Linear extrapolation can be conducted either forwards (to estimate more recent emissions) or backwards (to estimate a base year). Linear extrapolation simply assumes that the observed linear trend in emissions during the period when detailed estimates are available remains constant over the period of extrapolation. Caution should also be used where linear extrapolation suggests that activity data fall to zero, as this is often not an accurate representation of reality. Where the observed trend is not linear, other forms of extrapolation may be used (see non-linear trend analysis in Table 1.2 below).

Extrapolation should also not be used over long periods of time without detailed checks at intervals to confirm the continued validity of the trend. In the case of periodic data, however, extrapolations will be preliminary and the data point will be recalculated at a later stage.

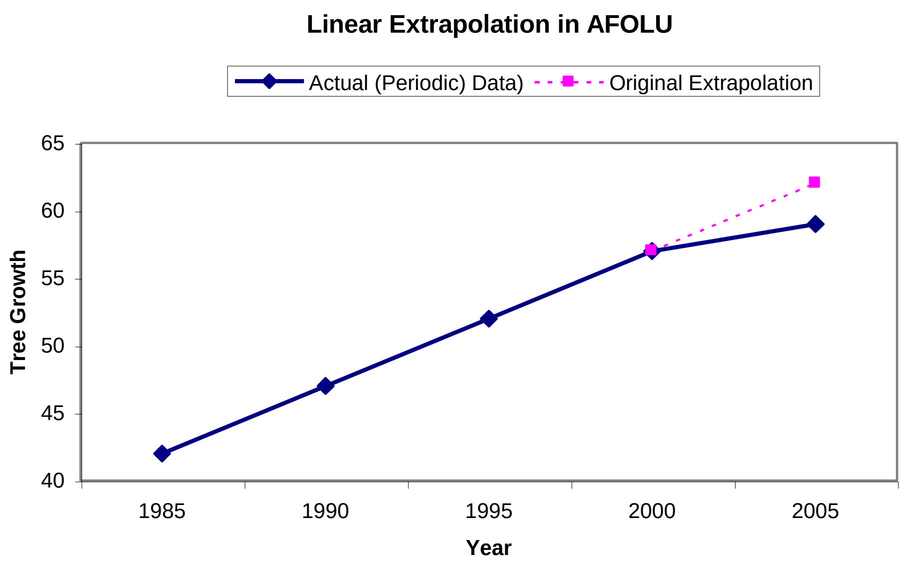
Box 2 in this section shows an example in which activity data for forests are available only at periodic intervals, and data for the most recent years are not yet available. Data for recent years can be extrapolated on the basis of a consistent linear trend, or on the basis of appropriate surrogate data. It should be noted, however, that the uncertainty of the extrapolated estimates increases in proportion to the length of time over which the extrapolation is made. Once the latest set of periodic data becomes available, it will be necessary to recalculate the part of the time series that had been estimated using trend extrapolation.

The example in Box 1-2 assumes a linear extrapolation, which is likely to be appropriate for the forest land category.

Box 1-2 Case study on periodic data, using extrapolation

Consider a case in which a national forest inventory is conducted every 5 years. Estimates of several types of required data (e.g. tree growth) will therefore be obtained only at certain intervals. On the assumption that growth is on average reasonably stable between years, inventory estimates for the years after the last available data should be made using extrapolations of past estimates (i.e. tree growth trends). As shown in Figure 1-4, a biomass estimate for 2005 for a plot is obtained in this way, although the latest measurement was made in 2000. The trend between 1995 and 2000 is simply extrapolated linearly. In practice, a log scale might be used to accommodate exponential behaviour, but this is not considered for this simple example. In addition, extrapolation can be improved using surrogate data or more sophisticated modelling that takes into account parameters influencing the parameter we want to extrapolate.

Figure 1-4 Linear extrapolation in agriculture, forestry and land use



Unlike periodically available data, when data are not available for the first years in the time series (e.g. base year and pre-base year data on, for example, waste disposal and land use), there is no possibility of filling in gaps with future surveys. Trend extrapolation back in time is possible but should be done in combination with other splicing techniques, such as surrogate data and overlap. Some countries that have undergone significant administrative and economic transitions since 1990 do not have consistent activity data sets for the entire time series, particularly if national data sets covered different geographic areas in previous years. To extrapolate backwards in these cases, it is necessary to analyse the relationship between different activity data sets for different periods, possibly using multiple surrogate data sets.

1.4 Non-linear extrapolation

In some cases, particularly for emission categories influenced by economic activity, time series consistency is best represented by multiplicative (exponential) rather than additive (linear) relationships. In these cases, it is better to construct a polynomial through all the given data points. The resultant polynomial can be used to fill data gaps in the time series. There are a number of non-linear methods for interpolating within a set of known data. For example, inventory compilers can apply the Newton's interpolation method or the Lagrange's interpolation method. Both methodologies are widely available in the literature and yield the same interpolating polynomial. The Richard extrapolation and Padé approximation methods can also be applied for trend extrapolation. Inventory compilers should exercise caution when applying trend extrapolation methods. For example, a high-order polynomial may provide a very good fit to a data set over its range of validity. However, if higher powers than needed are included, the polynomial may diverge rapidly from smooth behaviour outside the range of the data. When countries use models or measurements to estimate GHG emissions, the chi-squared statistical method would be useful for testing discrepancies between samples, to understand whether a difference is caused by chance or by an underlying relationship. Such testing would help to increase the accuracy and time series consistency of imputed data.

An example of filling data gaps with a non-linear trend is given in Volume1, Chapter 5 of the IPCC 2019 refinement, where a polynomial is used to generate data for missing years.

1.5 Other techniques

In some cases, it may be necessary to develop a customised approach to best estimate the emissions over time. For example, the standard alternatives may not be valid when technical conditions are changing throughout the time series (e.g. due to the introduction of mitigation technology). In this case, it will be necessary to carefully consider the trends in all factors known to influence emissions over the period. Where customised approaches are used, it is good practice to document them thoroughly, and in particular to give special consideration to how the resultant emissions estimates compare with those that would be developed using the more standard alternatives.

1.6 Selecting the most appropriate technique

The choice of splicing technique involves expert judgement, and depends on an expert assessment of the volatility of the emission trend, the availability of data for two overlapping methods, the adequacy and availability of surrogate data sets and the number of years of missing data. Table 1-2 summarises the requirements for each technique and suggests situations in which they may or may not be appropriate. Countries should use Table 1-2 as a guide rather than a prescription.

Table 1-2 Summary of splicing techniques

Approach	Applicability	Comments
Overlap	Data required to apply both the previously used and the new method must be available for at least 1 year, preferably more	• Most reliable when the overlap between two or more sets of annual estimates can be assessed • If the trends observed using the previously used and new methods are inconsistent, this approach is not good practice
Surrogate data	Emission factors, activity data or other estimation parameters used in the new method are strongly correlated with other well-known and more readily available indicative data	• Multiple indicative data sets (singly or in combination) should be tested to determine the most strongly correlated • Should not be used for long periods, unless the correlation with the surrogate can be clearly supported across all of the time span.
Interpolation	Data required for recalculation using the new method are available for intermittent years during the time series	• Estimates can be linearly interpolated for the periods when the new method cannot be applied

		• The method is not applicable in the case of large annual fluctuations
Trend extrapolation	Data for the new method are not collected annually and are not available at the beginning or the end of the time series	• Most reliable if the trend over time is constant. • Should not be used if the trend is changing (in this case, the surrogate method may be more appropriate) • Should not be used for long periods
Non-linear trend analysis (inter/extrapolation)	In cases in which time series consistency is best represented by multiplicative (exponential) rather than additive (linear) relationships	• Most reliable for trend analysis of model outputs • Should not be applied for long periods • Applicable in the case of large annual fluctuations
Other techniques	The standard alternatives are not valid when technical conditions are changing throughout the time series (e.g. due to the introduction of mitigation technology)	• Document customised approaches thoroughly • Compare results with standard techniques

2 Reporting and documentation of trend information

If the same method and data sources are used throughout the time series, and there have been no recalculations, then following the reporting guidance for each category should be sufficient to ensure transparency. Generally, countries should explain inventory trends for each category, giving particular attention to outliers, trend changes and extreme trends. Countries should provide additional documentation if they have recalculated previous estimates and if they have used the techniques in this chapter to splice methodologies.

Recalculations. In addition to following the category-specific guidance on each category provided in the sectoral volumes, countries should clearly document any recalculations. The documentation should explain the reason for the recalculation and the effect of the recalculation on the time series. Countries can also include a graph that shows the relationship between the previous data trend and the new data trend. Table 2-1 provides an example of how recalculations can be documented either for reporting purposes or for internal tracking.

Table 2-1 Category-specific documentation of recalculations

Category/gas	**Emissions (Gg)**										
	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Previous data (PD)											
Latest data (LD)											
Difference in percentage =100 × [(LD-PD)/PD]											
Documentation (reason for recalculation):											

Splicing techniques. Countries should provide documentation of any splicing techniques used to complete a time series. The documentation should identify the years in which data for the method were not available, the splicing technique used and any surrogate or overlap data used. Graphical plots, such as those shown in Section 1.2.4 of this chapter, can be useful tools for documenting and explaining the application of splicing techniques.

Mitigation. The category-specific guidance in the sectoral volumes provides targeted guidance on specific information that should be reported for each category, including mitigation and reductions. Generally, countries should document the approach used to track mitigation activities and provide all relevant parameters such as abatement utilisation, destruction efficiency and updated emission factors.

3 Time series consistency quality assurance/quality control

The most effective way to ensure the quality of a time series is to apply both general and category-specific checks to the entire time series (see Chapter 6, on inventory management, improvement and QA/QC). For example, the outlier and implied emission factor checks in Chapter 6 will help to identify possible inconsistencies in the time series. Category-specific checks are particularly important because they target unique features of each category.

As described above, plotting and comparing the results of splicing techniques on a graph is a useful QA/QC strategy. If alternative splicing methods produce different results, countries should consider which result is most realistic. In some cases, additional surrogate data can be used to check the spliced time series.

A side-by-side comparison of recalculated estimates with previous estimates can be a useful check on the quality of a recalculation. This can be done through a tabular comparison, as shown in Table 2-1, or as a graphical plot. It is important to note, however, that higher tier methods may produce trends different from those of lower tier methods because they more accurately reflect actual conditions. Differences in trends do not necessarily suggest a problem with the recalculated estimate.

Where it is possible to use more than one approach to track the effects of mitigation activities, countries should compare the results of multiple approaches. If the results differ by more than would be expected, it is good practice to explain the reason for the differences and evaluate whether or not a different approach should be used. For disaggregated higher tier estimates, implied emission factors can be a useful tool for checking the consistency of the trend and the plausibility of mitigation estimates.

In some cases, activity data collection may have been interrupted or drastically changed. This situation causes challenges for time series consistency. In this situation it is good practice to examine closely the documentation of the previous data collection system, to get a good understanding of how changes in data collection, including definitions and delimitations, have affected the data used in the inventory and of any implications for inconsistencies in time series. If appropriate documentation is not available, an alternative is to compile indicators (e.g. emissions per unit production or emissions per car) and to compare the indicators for different countries with a similar economic structure, across time series and in the overlap of the two data collection methods.

In some cases a country may have undergone changes in geographical coverage, e.g. a country may have divided into two or more new countries. In this situation it is good practice to compare the inventory data with estimates from regional statistics for the years prior to the split. It can also be recommended to collaborate with other countries that were once part of the same country to ensure completeness and to avoid double counting. If regional statistics are not available and such collaboration is not possible, it is good practice to compare appropriate indicators, as described above, for the country before a split with the data used in the inventory.

If inconsistencies are identified, it is good practice to correct them and, if necessary, apply appropriate splicing techniques as described in this chapter.

4 References

IPCC, 2000, *Good practice guidance and uncertainty management in national greenhouse gas inventories,* Intergovernmental Panel on Climate Change National Greenhouse Gas Inventories Programme, Institute for Global Environmental Strategies, Hayama, Japan (www.ipcc-nggip.iges.or.jp/public/gp/english/) accessed 7 June 2019.

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5 Point of enquiry

Enquiries concerning this chapter should be directed to the co-chairs of the Task Force on Emission Inventories and Projections (TFEIP). Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current co-chairs.