
Category	Title
General guidance	Time series consistency
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1 Time series consistency

1.1 Introduction

This guidance has been adapted from the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). The basic methods and principals are the same unless otherwise indicated. The time series is a central component of an air pollutant inventory because it provides information on historical emissions 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 emissions 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 method 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.

This chapter describes good practice in ensuring time series consistency. Subsection 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 2 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 QA/QC of time series consistency is given in Sections 3 and 4.

1.2 Ensuring a consistent time series

1.2.1 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 new use of a higher Tier method instead of a Tier 1 default method for an industrial category because a country has obtained site-specific emission measurement data that can be used directly or for development of national emission factors.

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. An example of a refinement would be if new data permit further disaggregation of a livestock enteric fermentation model. Resulting animal categories could then be more homogenous 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 higher quality data could be introduced, due to improved data collection methods.

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

- *available data have changed.* 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. As countries gain experience and devote additional resources to preparing air pollutant inventories, it is expected that data availability will improve ⁽¹⁾;

⁽¹⁾ 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 key.* A category might not be considered *key* in a previous inventory year, depending on the criteria used, but could become *key* in a future year. For example, many countries are only beginning to calculate emission inventories for PM_{2.5} and becoming aware of the impact of the use of biofuels on PM emissions. Although current emissions from this category are low, they could become *key* in the future based on trend or level. Countries anticipating significant growth in a category may want to consider this possibility before it becomes *key*;
- *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 change in emissions in a transparent manner. Where the previously used methods are insufficiently transparent, it is good practice to change or refine them. See subsection 1.2.3 of the present chapter for further guidance;
- *the capacity for inventory preparation has increased.* Over time, the human or financial capacity (or both) necessary to prepare inventories may increase. If inventory compilers increase 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;
- *new inventory methods become available.* In the future, new inventory methods may be developed that take advantage of new technologies or improved scientific understanding. For example, remote-sensing technology improvements in emission monitoring technology may make it possible to directly monitor more types of emission sources;
- *correction of errors.* It is possible that the implementation of the QA/QC procedures described in Chapter 6, Inventory management, improvement and QA/QC, 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.

1.2.2 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 2 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.** Some emission processes, particularly in the Industrial Processes Sector, only occur as a result of specific technological processes;
- **rapid growth in a very small category.** A category that previously was too small to justify resources for inclusion in the national inventory could experience sudden growth and should be included in future inventories;
- **new NFR categories.** The *EMEP Emission Reporting Guidelines* contain some categories and subcategories which 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;

- **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.

If a new emission-causing activity began after the 'base year' ⁽²⁾, or if a category previously regarded as insignificant (see subsection 1.2.1 of the present chapter regarding methodological choice for reasons for not estimating emissions from an existing source) has grown to the point where it should be included in the inventory, it is good practice to document the reason for not estimating the entire time series.

1.2.3 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, fuel switching 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 to 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. Since a general assumption is that emission factors or other estimation parameters do not change over time unless otherwise indicated, 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.

Abatement of emissions

Larger point sources such as chemical manufacturing facilities or power plants might generate emissions but prevent them from being released to the atmosphere through abatement and control. In these cases it is good practice to account for these measures and to apply different emission factors for different years and to document the reasons why these factors are different.

⁽²⁾ Within the UNFCCC/IPCC (United Nations Framework Convention on Climate Change/Intergovernmental Panel on Climate Change) approach the 'Base Year' is a year upon which targets are based and often represents the start year of the inventory.

1.3 Resolving data gaps

1.3.1 *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 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 fifth or tenth year, or region-by-region, implying that national level estimates can only be directly obtained once the inventory in every region has been completed. When data are available less frequently than annual, 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 producing inventories for years after the last available data point and before new data are available. In this case, new estimates should be extrapolated based on 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 programs 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.

1.3.2 *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, Data collection. Countries should not use different collection periods within the same time series because this could lead to a bias in the trend.

2 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 2-1.

2.1 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 between the results of the previously used and 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 ⁽³⁾.

Equation 1:

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

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 through 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.

⁽³⁾ Overlap Equation 1 is preferred to the equation described in Good Practice Guidance for National Greenhouse Gas Inventories (IPCC, 2000):

$$y_0 = x_0 \cdot \left(\frac{\sum_{i=m}^n y_i}{\sum_{i=m}^n x_i} \right)$$

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 2-1 shows a hypothetical example of a consistent overlap between two methods for the years in which both can be applied. In Figure 2-2 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 overlap. For example, a constant 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.

Figure 2-1 Consistent overlap

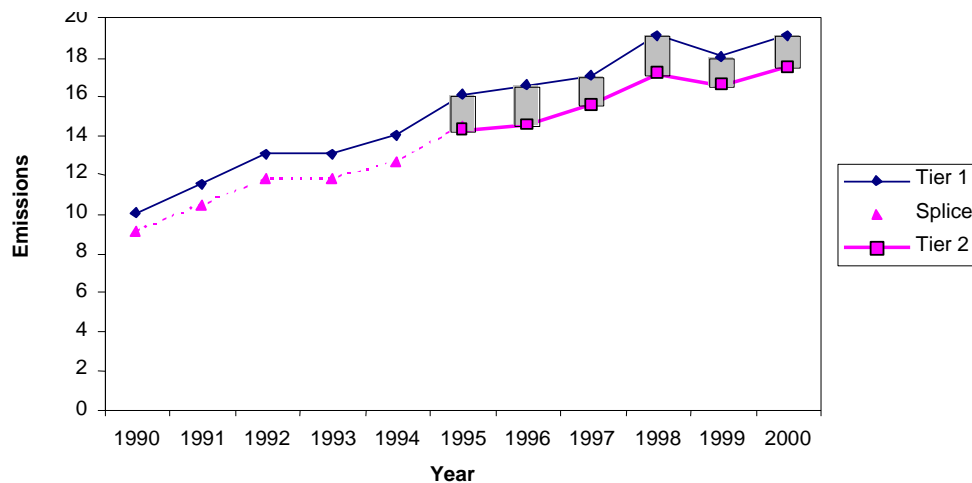
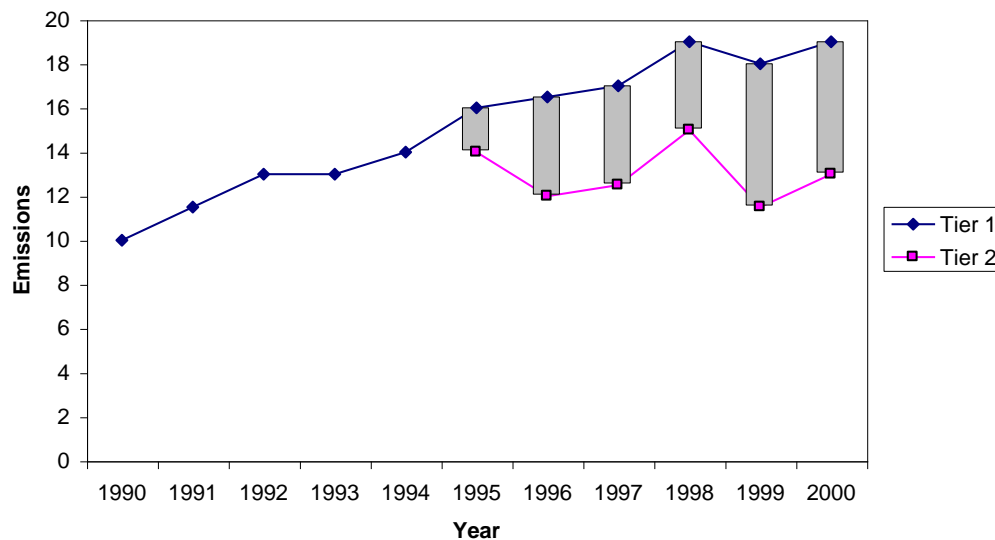


Figure 2-2 Inconsistent overlap



2.2 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 vehicle distances travelled, emissions from domestic wastewater may be related to

population, and industrial emissions may be related to production levels in the relevant industry. See Chapter 3, Data Collection.

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

$$y_0 = y_t \bullet (s_0 / s_t) \tag{2}$$

where:

y = the emission estimate in years 0 and t

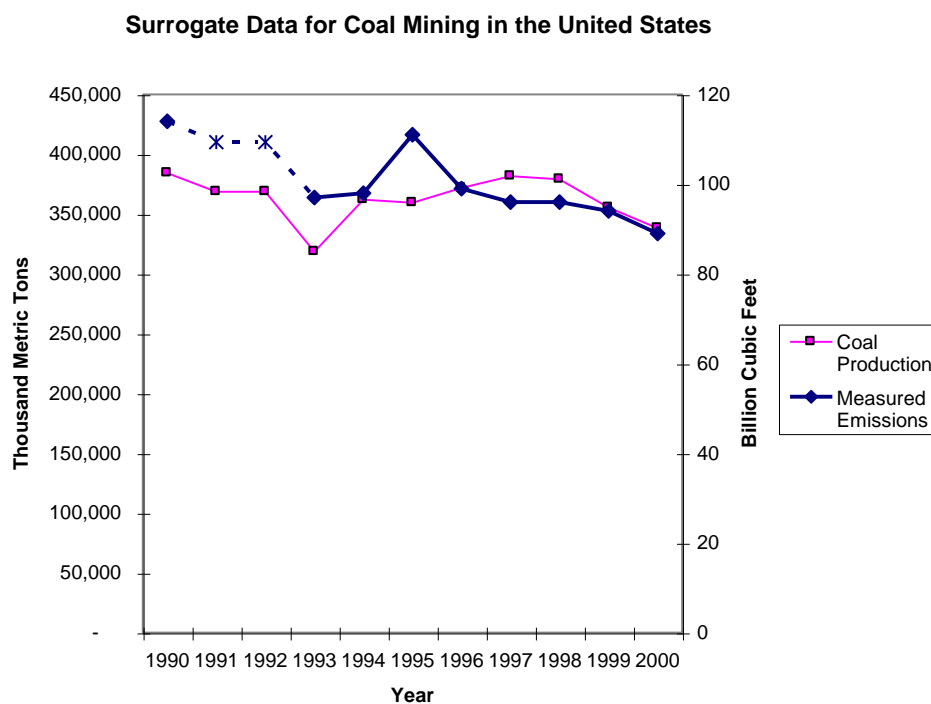
s = the surrogate statistical parameter in years 0 and t

Although the relationship between emissions and surrogate can be developed on the basis of data for a single year, the use of multiple years might provide a better estimate.

Box 1 provides an example of the use of surrogate data for estimating methane emissions from underground coal mining in the United States. 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.

Box 1 — Case study of surrogate data**Methane emissions from underground coal mining in the United States**

On a quarterly basis, the U.S. Mine Safety and Health Administration (MSHA) measures methane emissions levels at underground mines with detectable levels of methane in their ventilation air. USEPA uses these measurements as a basis for calculating national emissions from underground coal mining. These data were not available for the years 1991–1992, however, because of restructuring within the Department of Labor. To estimate emissions for these years, USEPA used total underground coal production as a surrogate data set. The graph below shows the relationship between underground coal production and measured emissions, which are closely but not perfectly correlated. Differences reflect the fact that individual mines vary greatly in their emission rates, and as production levels at mines change over time, the weighted average emission rate also changes. USEPA applied Equation 2 to estimate emissions for 1991 and 1992 using Tier 3 emissions data and coal production for 1990. These data points are crossed by the dashed line in the graph. Note that this procedure is very similar to the Tier 1 method because coal production is the recommended activity data for Tier 1. Comparison of implied emission factors from estimates using surrogate data with Tier 1 default factors would be a useful QA/QC check.



Source: USEPA (2004)

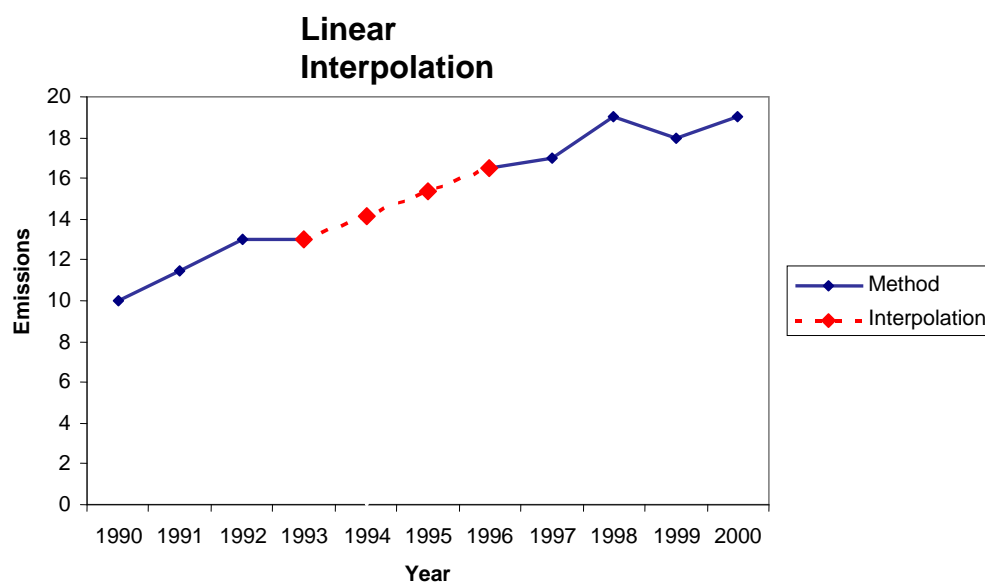
2.3 Interpolation

In some cases it may be possible to apply a method intermittently throughout the time series. For example, necessary detailed statistics may only be collected every few years, or it may be impractical to conduct detailed surveys on an annual basis. In this case, 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 2-3 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 1993–1996. 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 will not be according to 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 2-3 Linear interpolation



2.4 Trend extrapolation

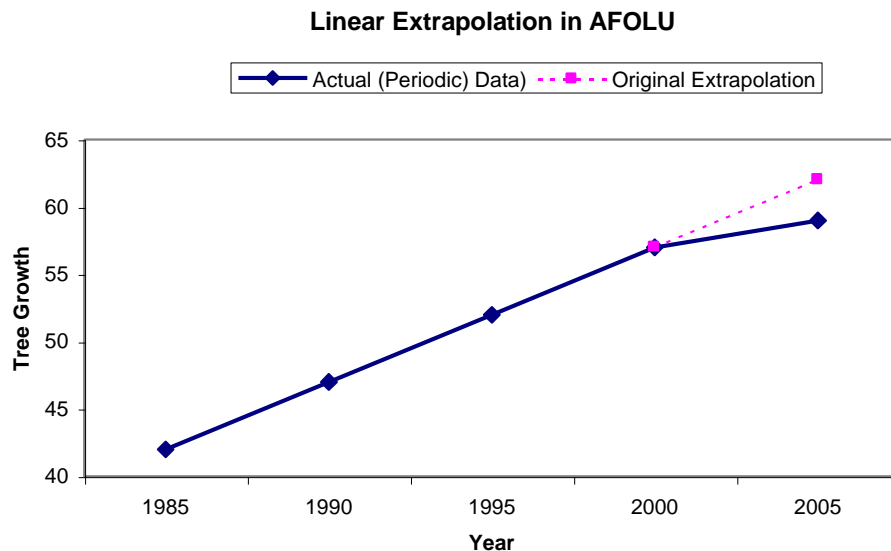
When detailed estimates have not been prepared for the base year or the most recent year in the inventory, it may be necessary to extrapolate from the closest detailed estimates. Trend extrapolation is conceptually similar to interpolation, but less is known about the actual trend. Extrapolation can be conducted either forward (to estimate more recent emissions) or backward (to estimate a base year). Trend extrapolation simply assumes that the observed trend in emissions during the period when detailed estimates are available remains constant over the period of extrapolation. Given this assumption, it is clear that trend extrapolation should not be used if the change in trend is not constant over time. In this situation it will be more appropriate to consider using extrapolations based on surrogate data. 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 trend, or on the basis of appropriate 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 2 assumes a linear extrapolation, which is likely to be appropriate for the forestland category. Non-linear extrapolations are possible, and may be more appropriate given an observed trend, (e.g. exponential growth in the use of ODS (ozonosphere damaging substances) substitutes). Countries using non-linear extrapolation should provide clear documentation for the choice and explain why it is more appropriate than linear extrapolation.

Box 2 — Case study on periodic data, using extrapolation

Consider a case where a national forest inventory is conducted every five years. Estimates of several types of required data (e.g. tree growth) will therefore only be obtained 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 the figure below, 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. Also, extrapolation can be improved using surrogate data or more sophisticated modelling taking into account parameters influencing the parameter we want to extrapolate.



NB: AFOLU = 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.

2.5 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 to those that would be developed using the more standard alternatives.

2.6 Selecting the most appropriate technique

The choice of splicing technique involves expert judgement, and depends on an expert assessment of the volatility of emissions 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 2-1 summarises the requirements for each technique and suggests situations in which they may or may not be appropriate. Countries should use Table 2-1 as a guide rather than a prescription.

Table 2-1 Summary of splicing techniques

Approach	Applicability	Comments
Overlap	Data necessary to apply both the previously used and the new method must be available for at least one year, preferably more.	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> Multiple indicative data sets (singly or in combination) should be tested in order to determine the most strongly correlated. Should not be done for long periods.
Interpolation	Data needed for recalculation using the new method are available for intermittent years during the time series.	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> 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 done for long periods.
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).	<ul style="list-style-type: none"> Document customised approaches thoroughly. Compare results with standard techniques.

3 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 3-1 provides an example of how recalculations can be documented either for reporting purposes or for internal tracking.

Table 3-1 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 percent =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 subsection 2.1 of the present 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, updated emission factors, etc.

4 Time series consistency QA/QC

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, 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 are targeted to 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 3-1, or as a graphical plot. It is important to note, however, that higher Tier methods may produce different trends than 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 in tracking 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 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 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 compare these between 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 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 prior to 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.

5 References

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6 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.