# CHAPTER 5

# TIME SERIES CONSISTENCY

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# 5 TIME SERIES CONSISTENCY

**ELABORATION OF VOLUME 1, CHAPTER 5 OF THE 2006 IPCC GUIDELINES.**

## 5.1 INTRODUCTION

No refinement.

## 5.2 ENSURING A CONSISTENT TIME SERIES

### 5.2.1 Recalculations due to methodological changes and refinements

Elaboration of Section 5.2.1 of the *2006 IPCC Guidelines*.

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, so that resulting animal categories are more homogenous or applies a more accurate emission factor. 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 greenhouse gas inventories, it is expected that data availability will improve.[1]
- *The previously used method is not consistent with the IPCC guidelines for that category*: Inventory compilers should review the guidance for each category in Volumes 2-5.
- *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 substitute HFCs and PFCs for ozone depleting substances being phased out under the Montreal Protocol. 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 or removals in a transparent manner. Where the previously used methods are insufficiently transparent, it is *good practice* to change or refine them. See Section 5.2.3 for further guidance.
- *The capacity for inventory preparation has increased*: Over time, the human or financial capacity (or both) to prepare inventories may increase. If inventory compilers increase inventory capacity, it is *good practice* to

[1] Sometimes collection of data may be reduced which can result in a less rigorous methodological outcome.

change or refine methods 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 monitor directly more types of emission sources.
- *Availability of new EFs in the IPCC Guidelines that could be different from previous IPCC guidelines*: From time to time, the IPCC greenhouse gas inventory guidelines are to be subjected to a refinement process 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 recent available IPCC guidelines 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 might consider the appropriateness of the EF in relation to changes in the emission rate for specific periods of the time series. Changes in emission rates might be triggered by changes in process/technology changes. In such cases, it is possible for the inventory compiler to apply the old EFs in one set of the time series and the latest EFs for other parts of the time series.
- *Correction of errors*: It is possible that the implementation of the QA/QC procedures described in Chapter 6, Quality Assurance and Quality Control and Verification, 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.

**BOX 5.1**
**RECALCULATION IN THE AGRICULTURE FORESTRY AND OTHER LAND USE (AFOLU) SECTOR**

It is anticipated that the use of recalculation techniques in the AFOLU Sector will be particularly important. The development of inventory methods and interpolation/extrapolation tools (models) for this sector is ongoing and it is anticipated that changes to the methods of many countries will occur over time due to the complexity of the processes involved. In simple cases, sampling or experimentation may provide country-specific emission factors, which might require a time series recalculation. Situations that are more complicated can also arise. For example:

- The instruments used to collect activity data may change through time, and it is impossible to go back in time to apply the new instrument. For example, land-clearing events can be estimated by the use of satellite imagery, but the satellites available for this work change or degrade through time. In this case, the overlap method described in Section 5.3.3.1 is most applicable.
- Some data sources such as forest inventories required for AFOLU categories may not be available annually because of resource constraints. In this case, interpolation between years or extrapolation for years after the last year with measured data available may be most appropriate. Extrapolated data may be recalculated when final data become available (see Sections 5.3.3.3 and 5.3.3.4 on interpolation and extrapolation).
- Emissions and removals from AFOLU typically depend on past land use activity (*GPG-LULUCF 2003*). Thus, data must cover a large historical period (20-100 years), and the quality of such data will often vary through time. Overlap, interpolation or extrapolation techniques may be necessary in these cases.
- The calculation of emission factors and other parameters in AFOLU may require a combination of sampling and modelling work. Time series consistency must apply to the modelling work as well. Models can be viewed as a way of transforming input data to produce output results. In most cases where changes are made to the data inputs or mathematical relationships in a model, the entire time series of estimates should be recalculated. In circumstances where this is not feasible due to available data, variations of the overlap method could be applied.

## 5.2.2 Adding new categories

Elaboration of Section 5.2.2 of the *2006 IPCC Guidelines*.

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 or removals 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 5.3.3 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 or removal activity is occurring**: Some emission processes, particularly in the IPPU Sector, only occur as a result of specific technological processes. For example, the use of substitutes for ozone-depleting substances (ODS substitutes) has been phased in at very different rates in different parts of the world. Some applications may only now be starting to occur in some countries.
- **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 IPCC categories**: The *2006 IPCC Guidelines* contain some categories and subcategories that were not covered in the *1996 IPCC Guidelines* (IPCC, 1997). 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**: In cases where the *2006 IPCC Guidelines* and its *2019 Refinement* do not provide guidance on allocation and methodological guidance for a specific category and country deems the category to be significant (according to its national definition) to its national emissions total (e.g. $CH_4$ emissions and removals from agricultural soils).
- **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, or if a category previously regarded as insignificant (see Section 4.1.2 in Chapter 4, Methodological Choice and Identification of Key Categories, for reasons for not estimating emissions/removals from an existing source/sink) 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.

## 5.2.3 Tracking increases and decreases due to technological change and other factors

Elaboration of Section 5.2.3 of the *2006 IPCC Guidelines*.

Emission inventories can track changes in emissions and removals 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 typically will 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 so 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/removals 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, an aluminium plant manager who introduces measures to reduce the frequency and intensity of anode effects 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 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. 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. Changes in process/management practices/technologies can be used as a guide to trigger 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 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 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, a land cover map for the latest time step in the time series might be developed from a new satellite imagery product with higher imagery resolution and different image processing procedures to derive land cover classes compared to the satellite imagery used to generate a land cover map in the base year or other year within a time series. This implies that different land cover maps produced for the time series will have varying resolution and methods for deriving land cover classes. Differences in these attributes (imagery resolution and image processing procedures, etc.) might introduce inconsistencies and errors in activity data derived from various land cover maps used in the time series. Livestock management techniques will have an impact on annual emissions and assumptions and EFs. These technologies and management practices may be applied to different levels for different years but have to be applied appropriately across the time series. Therefore, the inventory compiler has to apply appropriate data extrapolation methods to ensure that such inconsistencies are limited as far as feasible.

***Capture, destruction, or combustion 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 capture and storage (e.g., $CO_2$), destruction (e.g., HFC-23) or combustion (e.g., $CH_4$). These activities do not necessarily change the average emissions generated per unit of activity, and therefore it is not *good practice* to use different emission factors for different years. Instead, the inventory compiler should estimate total emissions generated and emissions reduced separately, and then subtract reductions from the total generation to arrive at an estimate for total emissions to the atmosphere.

# 5.3 RESOLVING DATA GAPS

## 5.3.1 Issues with data availability

Elaboration of Section 5.3.1 of the *2006 IPCC Guidelines*.

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 and waste 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 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 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 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. Box 5.2 presents an example of time series consistency associated with using available industrial reporting information.

**BOX 5.2**

**TIME SERIES CONSISTENCY WHEN USING FACILITY LEVEL DATA FROM NEW LEGISLATION (E.G. DATA FROM EMISSIONS TRADING SCHEME, OTHER NATIONAL DATA REPORTING PROGRAMMES)**

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 Scheme, the European Pollutant Release and Transfer Register, other facility monitoring programs in Australia and the USA etc. Therefore, inventory compilers will 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. And 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 ensured to the extent feasible.

Something to check is whether the sectoral coverage of the category to be estimated is complete and the data collected have undergone a validation process before communication.

Then the expert should decide how to integrate these data in 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 the older one 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 apply also to the past. For instance, discrepancies from old and new emission factors may be justified by the change in technologies and/or best practises, 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 time series relevant techniques should be selected to ensure the consistency of the time series (or the appropriate documentation has been provided to justify the trend, e.g. change in technical conditions due to the introduction of mitigation technology/recovered emissions).

This issue is relatively common in the IPPU sector. 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 deriving from this collection may also be applied to the time series backward (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.

## 5.3.2 Non-calendar year data

No refinement.

## 5.3.3 Splicing techniques

Elaboration of Section 5.3.3 of the *2006 IPCC Guidelines*.

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 ensuring time series consistency are summarised in Table 5.1.

### 5.3.3.1 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 or removal 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 or removals associated with the new method are estimated according to Equation 5.1:[2]

**EQUATION 5.1**
**RECALCULATED EMISSION OR REMOVAL ESTIMATE COMPUTED USING THE OVERLAP METHOD**

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

Where:

$y_0$ = the recalculated emission or removal estimate computed using the overlap method;

$x_0$ = the estimate developed using the previously used method;

$y_i$ and $x_i$ are 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 only one year may lead to bias and it is not possible to evaluate trends.

Figure 5.1 shows a hypothetical example of a consistent overlap between two methods for the years in which both can be applied. In Figure 5.2, 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 or removals 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 5.1 is preferred to the equation described in *Good Practice Guidance for National Greenhouse Gas Inventories* (*GPG2000*, IPCC, 2000):

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

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 5.1 Consistent overlap**

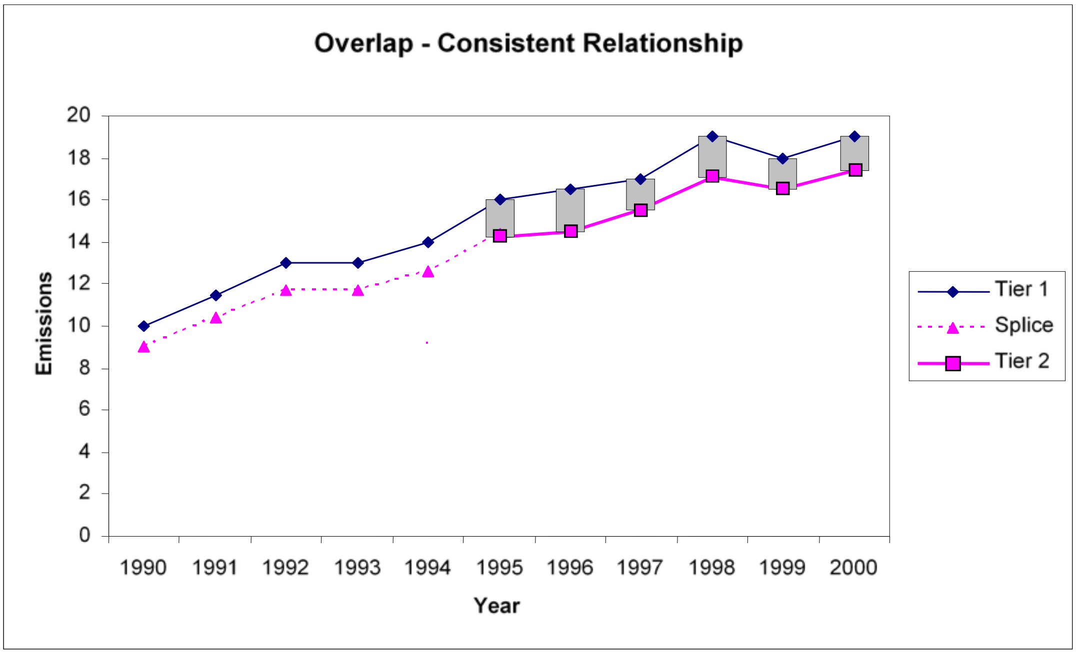
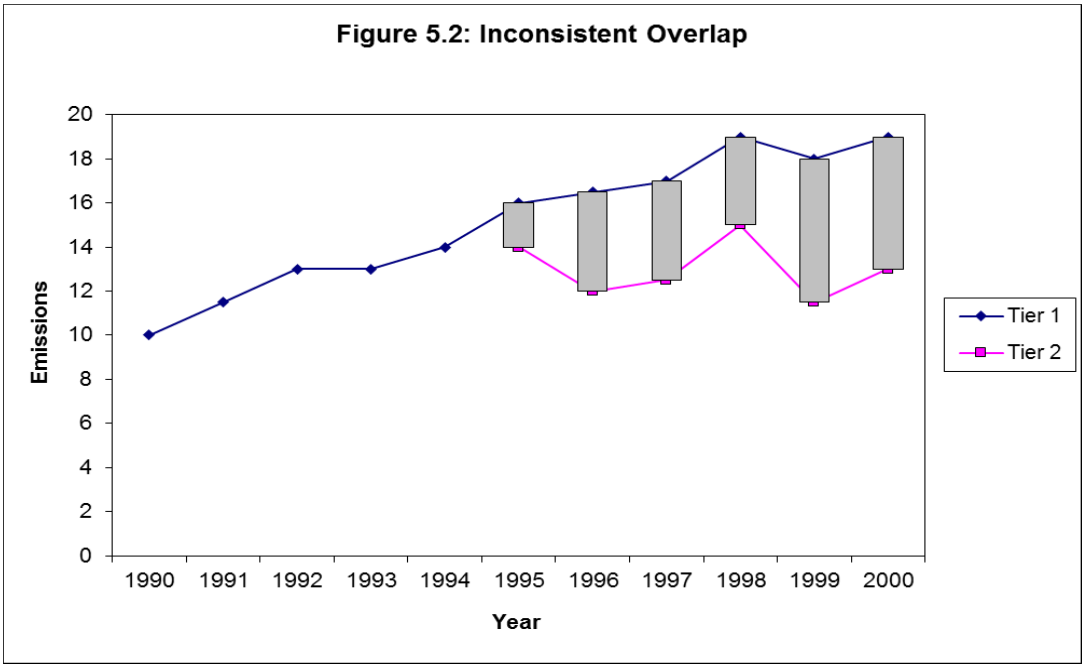



**Figure 5.2 Inconsistent overlap**




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 able to understand the differences so that to be sure that the new method actually improves the accuracy of emission estimates.

Box 5.3 provides a practical example were the inventory compiler should evaluate the application of the overlap approach to estimate GHG emissions for the years 2001–2003.

**BOX 5.3**
**CASE STUDY OF OVERLAP METHOD**
**METHANE EMISSIONS FROM CHARCOAL PRODUCTION IN GODONIA**

Consider the example below where we should evaluate the application of the overlap approach to estimate 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: 4790/5000 = 0.96):

| | 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 |
| Ratio Tier 2 : Tier 1 | | | | 0.96 | 0.96 | 0.90 | 0.90 | 0.90 | 0.92 | 0.96 |

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

- average = 0.93;
- standard deviation = 0.027 (low variability → overlap approach seems appropriate).

Step 3. Apply average to calculate missing data:

- year 2001: 4,000 * 0.93 = 3,713;
- year 2002: 4,000 * 0.93 = 3,713;
- year 2003: 4,100 * 0.93 = 3,806.

| | 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 | **3,713** | **3,713** | **3,806** | 4,035 | 4,598 | 4,410 | 4,500 | 4,320 | 4,513 | 4,790 |
| Ratio Tier 2 : Tier 1 | | | | 0.96 | 0.96 | 0.90 | 0.90 | 0.90 | 0.92 | 0.96 |

### 5.3.3.2 SURROGATE DATA

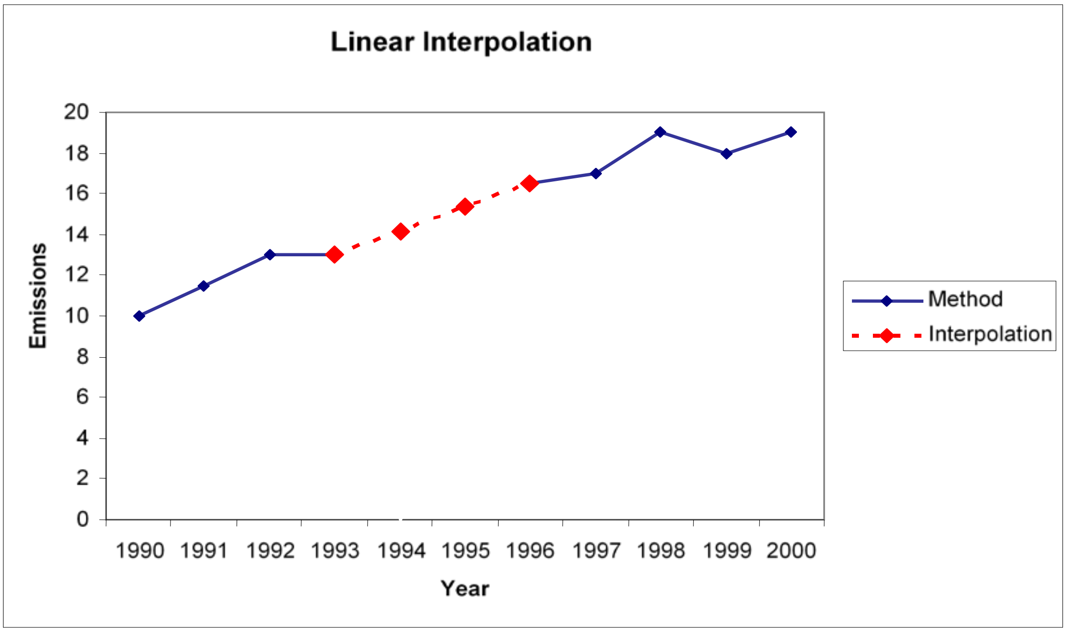
No refinement.

### 5.3.3.3 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 5.3 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 5.3 Linear interpolation**



**BOX 5.4**

**CASE STUDY OF INTERPOLATING DATA**

**CARBON DIOXIDE EMISSIONS FROM FOSSIL WATER INCINERATION IN GODONIA**

Annually, the Statistical Office of Godonia collects activity data on the amounts of fossil liquid waste incinerated by all industrial waste incineration companies. The Statistical office uses this activity data to estimate carbon dioxide ($CO_2$) emissions from incineration of fossil liquid waste. However, these data were not available for the years 2004-2006 due to temporary closure of the unit with the Statistical Office responsible for collecting waste data. Hence, the time series emission estimates for this category is incomplete in the national GHG inventory of Godonia and requires that a data gap filling method is applied. The steps involved in filling the data gaps in the time series are described below.

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GHG emission source x | 3,800 | 3,920 | 4,030 | 4,135 | 4,235 | | | | 4,655 | 4,770 | 4,880 | 4,975 |

Step 1. Determine whether any factors might have affected the activities that gives rise to emissions for the emission category of interest. This step is important to ensure that the interpolation method is not applied in cases where the activity was prohibited for certain years of the time series (e.g. due to legislation prohibiting certain activities, disruptions such as conflicts/economic performance, etc).

Step 2. Analyze data and assess applicability and type of interpolation technique desired. This exercise can be achieved by fitting a trend line on the data and assessing the value of R2 (the regression coefficient). The closer to unity the regression coefficient is, the more appropriate the interpolation methodology is. In the example above, fitting a linear trend line is more appropriate as the time series shows a linear time series.

Step 3. Calculate difference in GHG emissions between last year before the gap and first year after the gap:

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GHG emission source x | 3,800 | 3,920 | 4,030 | 4,135 | 4,235 | | | | 4,655 | 4,770 | 4,880 | 4,975 |

4,655 (2007) – 4,235 (2003) = 420

Step 4. Calculate the length of the gap: 2007 – 2003 = 4 years.

Step 5. Calculate average change in emissions per gap year = 420/4 = 105 $GgCO_2$.

Step 6. Calculate total emissions for gap year by adding the average change per year.

Step 7. Use results obtained in step 6 to calculate the missing emissions data in the time series:

- year 2004: 4,235 + 105 = 4,340 Gg $CO_2$;
- year 2005: 4,340 + 105 = 4,445 Gg $CO_2$;
- year 2006: 4,445 + 105 = 4,550 Gg $CO_2$.

Step 8. Transparently report results:

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GHG emission source x | 3,800 | 3,920 | 4,030 | 4,135 | 4,235 | **4,340** | **4,445** | **4,550** | 4,655 | 4,770 | 4,880 | 4,975 |

## 5.3.3.4 TREND EXTRAPOLATION

No refinement.

#### 5.3.3.5 NON-LINEAR TREND ANALYSIS

New guidance in Section 5.3.3.5 of the *2019 Refinement*.

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 literature and yield the same interpolating polynomial (Ouyed & Dobler, 2010). 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 range of the data. When countries use models or measurements to estimate GHG emissions the $X^2$ statistical method would be useful for testing of discrepancies between samples to understand whether difference is caused by chances or underlying relationship. Such testing would help to increase accuracy and time-series consistency of imputing missing data.

An example of filling data gaps with a non-linear trend is given in Box 5.5. In this example, there is one year of missing data for direct soil $N_2O$ emissions from manure on non-federal grasslands. However, a plot of the data indicates that a linear trend fit is clearly inappropriate. Therefore, a polynomial will be fit to the data and used to impute the missing year.

**BOX 5.5**
**CASE STUDY OF NON-LINEAR TREND DATA**
**DIRECT SOIL $N_2O$ EMISSIONS FROM MANURE ON NON-FEDERAL GRASSLANDS**

The annual greenhouse gas inventory requires direct soil $N_2O$ emissions in kt $N_2O$-N from manure on non-federal grasslands to be part of the accounting. This annual greenhouse gas inventory is calculated for the years 1990 to the most recent year and is reported to the United Nations Framework Convention on Climate Change. However, the time series for $N_2O$ emissions below is missing data for 2002. To fill this data gap a non-linear trend analysis is conducted. All of the steps required to complete the time series are described below.

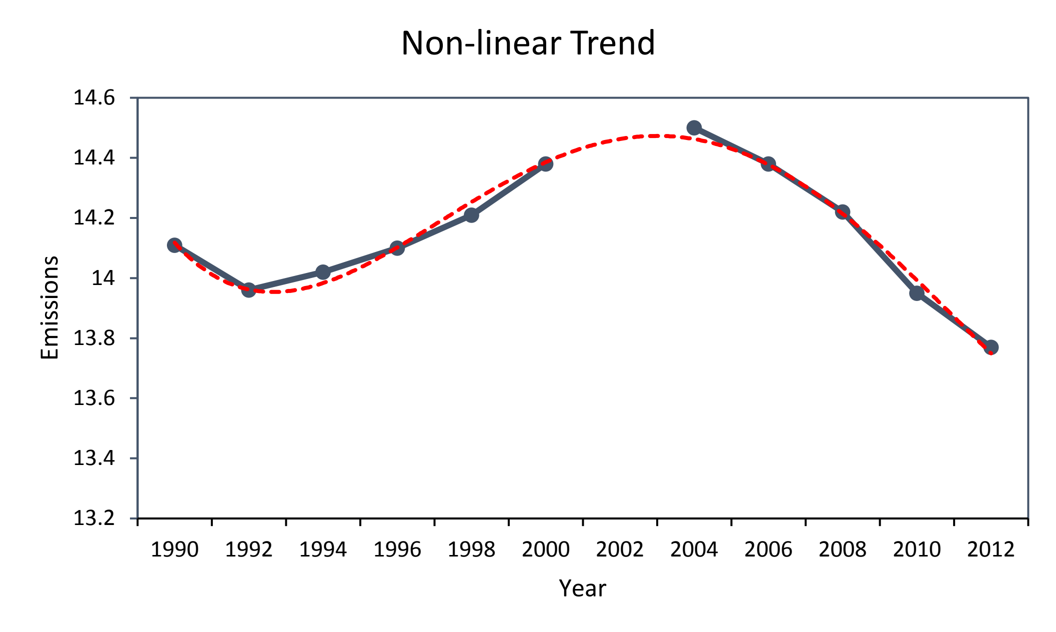
Step 1. Plot the known data to determine the most appropriate gap-filling method to apply. The figure below contains a plot of the data. However, the data do not follow a linear trend, but a polynomial should fit the data well.

Step 2. Determine the order of the polynomial most appropriate for the data. The goal is to find a polynomial with the lowest order that still adequately fits the data. Start by fitting a polynomial of order 2 then incrementally increase the order until an adequate fit is found. Beware of overfitting the data. Statistical tests comparing the $n^{th}$ and the $(n+1)^{th}$ order polynomial fit can be useful. For these data, a fourth order polynomial is the most appropriate fit.

Step 3. Use the polynomial determined in Step 2 to estimate the missing data. The polynomial obtained via least-squares regression is given by: $14.4005 - 0.2872\, t + 0.0544\, t^2 - 0.0031\, t^3 + 0.0001\, t^4$:

| | 1990 | 1992 | 1994 | 1996 | 1998 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emissions | 14.11 | 13.96 | 14.02 | 14.10 | 14.21 | 14.38 | 14.49 | 14.50 | 14.38 | 14.22 | 13.95 | 13.77 |

Step 4. Transparently report results:



#### 5.3.3.6 OTHER TECHNIQUES

No refinement.

#### 5.3.3.7 SELECTING THE MOST APPROPRIATE TECHNIQUE

A number of splicing techniques are presented below to address time series consistency issues. 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 5.1 summarises the requirements for each technique and suggests situations in which they may or may not be appropriate. Countries should use Table 5.1 as a guide rather than a prescription.

**TABLE 5.1**
**SUMMARY OF SPLICING TECHNIQUES**

| Splicing Technique | 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. | • Most reliable when the overlap between two or more sets of annual estimates can be assessed.<br>• 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 in order to determine the most strongly correlated.<br>• 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. | • Estimates can be linearly interpolated for the periods when the new method cannot be applied.<br>• 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.<br>• Should not be used if the trend is changing (in this case, the surrogate method may be more appropriate).<br>• Should not be applied for long periods. |
| Non-Linear Trend Analysis (Inter/Extrapolation) | In cases where time series consistency is best represented by multiplicative (exponential) rather than additive (linear) relationships | • Most reliable for trend analysis of model outputs.<br>• Should not be applied for long periods.<br>• 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.<br>• Compare results with standard techniques. |

## 5.4 REPORTING AND DOCUMENTATION OF TREND INFORMATION

Elaboration of section 5.4 of the *2006 IPCC Guidelines* (only applies to the information contained in Table 5.2).

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 Volumes 2-5, 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 5.2 provides an example of how recalculations can be documented either for reporting purposes or for internal tracking.

**TABLE 5.2**
**CATEGORY-SPECIFIC DOCUMENTATION OF RECALCULATIONS**

| **Category/Gas** | **Emissions and Removals (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 application of time-series techniques (e.g. gap-filling, revised AD, new methodology).
- Data source used.
- Selection and justification of the method employed.
- Assumptions used to reconstruct time series (e.g. rationale for choice of surrogate data).

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 5.3 can be useful tools for documenting and explaining the application of splicing techniques.

**Mitigation**: The category-specific guidance in Volumes 2-5 provide 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.

# 5.5 TIME SERIES CONSISTENCY QA/QC

No refinement.

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[3] Available at https://www.coursehero.com/file/23549186/Ouyed-Chapter-4-Interpolation-Extrapolation-Techniques/.