The Importance of Precision in Greenhouse Gas Emissions Inventories: Comparing Simple and Precise Data Collection Models

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Abstract As the connection between anthropogenic greenhouse gas (GHG) emissions and climate change becomes more widely recognized and better understood, many municipalities, businesses, non-profit organizations, and universities are voluntarily inventorying their GHG emissions in the hopes of identifying opportunities for GHG mitigation. While the GHG inventory should strive for accuracy, the data collection process should not be so rigorous that it postpones the implementation of mitigation projects or makes the inventory infeasible with limited resources. Despite the potential burdens of an overly rigorous data collection process, little research has quantified the impact of precision in data collection on the accuracy of inventory results. Thus, this study uses municipal operations data from Contra Costa County, California to compare the results derived by a *precise* data collection model (based on activity data obtained from multiple external organizations) with those derived by a *simple* model (based on internal financial records and price assumptions). The similarity of the results derived by the two models indicates that the simple model is a good predictor of the precise model, which suggests that simplifying the data collection process can save time and money without significantly compromising the accuracy of the results.

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) (2007a, 2007c), a number of diverse scientific observations indicate that atmospheric temperatures are progressively increasing, with reverberating effects on natural ecosystems and human society. Climate change raises sea level, amplifies extreme weather events, and disrupts natural ecosystem functioning (IPCC 2007a). Climate change also harms economic and social sectors through impacts on public health, food and water supply, and rural livelihoods (IPCC 2007a). The IPCC (2007c) expresses high confidence that recent climate change is largely due to greenhouse gas (GHG) emissions from human activities. The human impact on climate change is escalating as anthropogenic GHG emissions continue to increase (IPCC 2007c).

IPCC projections of future GHG emissions vary greatly depending on the emissions scenario, which is based on assumptions about human energy use, consumption, and production levels (IPCC 2000). This dependence on human activities indicates that reductions in anthropogenic GHG emissions can have significant impacts on the extent of future climate change. The IPCC (2007b) affirms that human society has great potential to mitigate climate change through behavioral changes and improved management practices. Thus, GHG reduction programs and policies hold great importance for climate change mitigation.

As the connection between anthropogenic GHG emissions and climate change becomes more widely recognized and better understood, many municipalities, businesses, non-profit organizations, and universities are voluntarily quantifying their GHG emissions in the hopes of identifying opportunities for GHG mitigation (CCAR 2007). Many of these organizations are also motivated by a desire to improve their public image or by a need to meet regulation standards (Gillingham *et al*. 2006). This quantification is generally accomplished through a GHG inventory based on *activity data*, which reflect usage amounts, and *emissions factors*, which reflect GHG emissions per unit of activity (IPCC 2006). For example, an inventory of GHG emissions from the transportation sector would use vehicle fuel consumption (*activity data*) and a coefficient reflecting the GHG emissions per unit of fuel consumed (an *emissions factor*) to generate a total GHG emissions number.

The GHG inventory should be designed for accuracy in order to inform management decisions to reduce emissions; however, it should also be designed to minimize the "reporting burden" of the time and effort required to gather and analyze inventory data (CCAR 2007:1).

While increasing precision in the data collection process may increase accuracy in the results, it may also create barriers for many organizations that do not have access to the resources necessary for a precise analysis. A rigorous GHG inventory process generates costs associated with membership fees paid to organizations that provide direction and assistance in the data collection process, the organizational resources used to collect activity data, and the third-party inventory certification that is required by some organizations (CCAR 2008). Experts estimate that organizational resource use in data collection for one annual GHG inventory costs between $15,000 and $30,000 for local governments, and this number could reasonably be much higher for corporations with multiple local offices (LGO Protocol Advisory Group 2008, pers. comm.). Additionally, membership fees range up to $8,000 for local governments and $10,000 for businesses, and the costs of third-party certification vary depending on the reporting and certifying organizations (CCAR 2008, ICLEI 2008). This yields a total inventory cost around $25,000 to $50,000 for each GHG inventory. Thus, precision in data collection requires large financial and labor inputs, but GHG inventories often must be conducted with limited financial and human resources (DOE 2007e). As a result, the United States Department of Energy (DOE) (2007e) advises that reporting organizations aim to use the most accurate method that their resources allow, focusing on major emissions sources and excluding minor sources when only limited resources are available. While substantial research by many organizations has searched for the most accurate method of quantifying GHG emissions, little research has focused on determining what level of precision is actually necessary to make informed decisions to lower emissions.

The need for accuracy must be balanced with the need for feasibility and for timely action. Gustavsson *et al*. (2000) explains that there are four principles necessary for a useful GHG inventory: accuracy, comprehensiveness, conservativeness, and practicability. Gustavsson *et al*. (2000) asserts that practicability (which is defined to express simplicity and feasibility) is at odds with—and must be balanced with—the other three principles. An inventory model that overemphasizes the need for accuracy, comprehensiveness, or conservativeness could bring the cost of the inventory so high as to make it infeasible (Gustavsson *et al*. 2000). Furthermore, Gottinger (1995) perceives a tension between two opposing strategies for addressing climate change mitigation: improving the accuracy of scientific research or acting immediately to reduce GHG emissions. He explains that a strategy that waits for scientific certainty will risk great damage in the time it takes to reach this certainty (Gottinger 1995). Arvai *et al*. (2006) also explores the relationship between climate change research and policy interventions. He explains that the complexity of the climate change problem requires that policymakers implement mitigation policies despite a lack of scientific certainty (Arvai *et al*. 2006). Thus, there is also a trade-off between accuracy and timely action. The ultimate goal of a GHG inventory is to identify opportunities for GHG mitigation, but the time burden of precision in data collection postpones the implementation of GHG mitigation projects and policies. To be a useful tool for mitigating an organization's GHG emissions and, thus, its contributions to climate change, the inventory process must be feasible given limited financial and human resources, timely, and accurate.

There has been growing discussion about the data requirements for GHG inventories in the planning process for implementation of the California Global Warming Solutions Act of 2006, or Assembly Bill 32 (AB32), which requires California to reduce its GHG emissions to 1990 levels by 2020 and will require periodic statewide GHG inventories to track progress toward this target (Nunez 2006). The implementation of AB32 may also place GHG reporting requirements on industry and local governments in California, and this transition from voluntary to mandatory action would create an additional burden for many organizations and local governments (ARB 2008, LGO Protocol Advisory Group 2008, pers. comm.). The California Air Resources Board (ARB) has been tasked with the development of statewide standard protocols for AB32 implementation, a process which has included extensive discussion with local governments and other stakeholders. Preliminary discussion reveals that these protocols will offer two approaches to GHG inventory data collection, a *recommended method* and multiple *alternate methods* (ARB 2008, LGO Protocol Advisory Group 2008, pers. comm.). The recommended method will require precise data, while the alternate methods will offer additional approaches for organizations that lack the resources necessary for the recommended method (ARB 2008, LGO Protocol Advisory Group 2008, pers. comm.).

While these studies and policy discussions address the potential benefits and burdens of a precise data collection process, little research has actually quantified the impact of precision in data collection on the accuracy of results. Thus, this study will use municipal operations data from Contra Costa County, California to compare the results derived by a *precise* data collection model (based on activity data obtained from multiple external organizations) with those derived by a *simple* model (based on internal financial records and price assumptions). Specifically, can a *simple* data collection model predict the total emissions[1] (and the subtotals by emissions source) derived by a more *precise* model within an acceptable tolerance range of three percent[2]?

The simple model is straightforward and inexpensive, as it estimates activity data from financial records that can be obtained internally and fuel price data that is publicly available from the DOE. The precise model, on the other hand, requires data from electricity providers, landfill managers, and multiple County departments, but it relies on fewer assumptions. Thus, the precise model will serve as the most accurate baseline against which the accuracy of the simple model will be measured. If the simple model can predict the results derived by the precise model within an acceptable tolerance range of three percent, it may serve as a preliminary indicator of mitigation opportunities and it may suffice when precise analysis is infeasible due to limited financial or human resources. This would allow limited resources to be focused on mitigation, so more organizations could begin mitigation efforts sooner.

Furthermore, if precision does not have a large effect on inventory results, an organization's time and money may be better spent on implementing programs and policies that actually reduce GHG emissions. This management approach currently exists in relation to LEED green building standards, as in the case of the planned UC San Francisco Mission Bay medical center. The medical center will be built in accordance with LEED green building standards, but the money that would be spent on LEED certification will instead be spent on the construction of sustainable building features (Sustainable Industries 2007). This GHG study could inform the same type of management decision—specifically whether funds should be directed toward research and certification or toward actual project implementation. Thus, the findings of this study may have important implications for the nature and scope of future GHG mitigation efforts.

I hypothesize that the simple model will be able to predict the GHG emissions values of the precise model within a tolerance range of three percent. To evaluate this hypothesis, the error of

[1] As different GHGs have different relative impacts on climate change, GHG emissions numbers will be expressed as a single amount of *carbon dioxide equivalent*. This represents the amount of carbon dioxide emissions that would have the same effect on climate change as the actual emissions makeup (which contains multiple GHGs).

[2] The acceptable tolerance range of three percent is based on *de minimis* guidelines provided by the DOE (2006), which allow the reporting organization to omit (or treat more leniently) any source that represents less than three percent of the total inventory from future inventories. These *de minimis* guidelines suggest that a difference of three percent will not greatly impact inventory analysis. This concept will be addressed further in the methods section.

the simple model in predicting the GHG value generated by the precise model is calculated using the formula $|N_S-N_P|/N_P$ (where N_S represents the GHG emissions value generated by the simple model and N_P represents that of the precise model) for the total emissions and for each emissions source. Since a tolerance range of three percent is set to compare the two models, the null hypothesis is that $|N_S-N_P|/N_P > 0.03$, and the alternative hypothesis is that $|N_S-N_P|/N_P \leq 0.03$. If $|N_S-N_P|/N_P \leq 0.03$ for the emissions total and some or all of the emissions sources, this result could have important management implications for GHG mitigation.

Methods

To test this hypothesis, financial data was collected for the simple model, activity data was subsequently collected for the precise model, and emissions factors were applied to generate GHG emissions numbers for both models. The error of the simple model in predicting the results of the precise model was calculated for the total emissions and for each emissions source.

Data was collected according to two data collection models: a simple model and a precise model. Both the simple and precise models yield activity data, but the precise model collects activity data directly, while the simple model uses financial data and price assumptions to estimate activity data (Fig. 1).

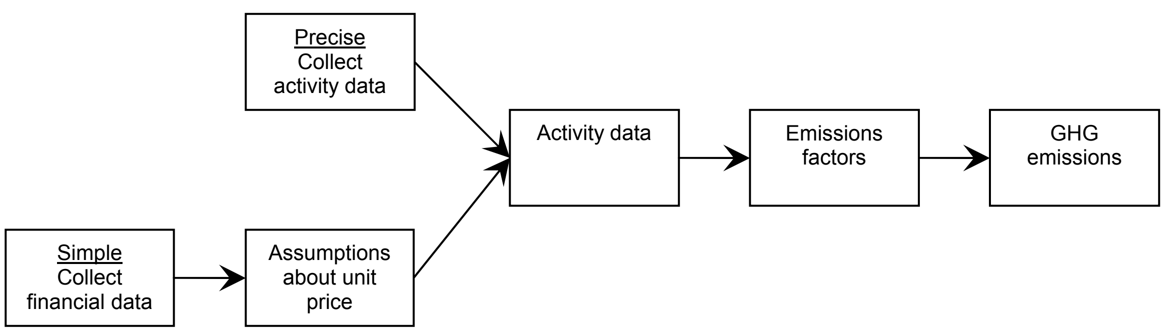

Figure 1. Data collection processes for the precise and simple models

For example, the simple model would use two pieces of information—the total amount of money paid for electricity use (financial data) and an assumption about the price paid for each kilowatt hour of electricity (price assumption)—to estimate the total number of kilowatt hours of electricity used (activity data). Financial data was collected for the simple model before activity data was collected for the precise model in order to minimize bias in the assumptions made in the simple model.

Data was collected for three major emissions sources: energy use, vehicle fleet fuel use, and waste disposal. These sources were selected in accordance with the methods of ICLEI – Local Governments for Sustainability (formerly known as the International Council for Local Environmental Initiatives), of which Contra Costa County is a member. Table 1 describes the specific data that was collected for each model and emissions source.

Table 1. Data collection methods for the simple and precise models

Emissions source	Precise model		Simple model	
	Data	Source	Data	Source
Energy use	Fuel use	Pacific Gas & Electric Company	Money paid to fuel providers & California fuel price averages from the DOE	Internal accounting computer software
Vehicle fleet fuel use	Fuel use	Fleet Services Department	Vehicle fuel purchases & California fuel price averages from the DOE	Internal Accounting Department records
Waste disposal	Solid waste tonnage sent to landfill	Haulers, transfer stations, and landfills	Money paid to waste haulers and transfer stations & a per ton hauling fee estimate based on County bills	Internal accounting software and website

Activity data for the precise model was acquired from Pacific Gas & Electric Company, five waste hauling facilities, three transfer stations, two landfills, and the County Fleet Services and Facilities Maintenance Departments. Financial data for the simple model was obtained directly from the County's accounting website and computer software whenever possible. When financial data was not available from these sources, it was obtained from an account clerk in the County's Accounting Department. Price assumptions for the simple model were obtained (in the form of annual California averages) from public records provided by the DOE. The simple model also required specific assumptions to improve its accuracy and applicability, which were identified in conversations with County staff. For example, it was assumed that ten percent of charges on energy bills represent taxes and fees rather than usage charges, based on the Utility User's Tax in Contra Costa County (Smart Voter 2004). Thus, ten percent of the total money spent in the building energy use sector was subtracted before the unit price assumptions were applied. Furthermore, the County government does not pay excise taxes on vehicle fuels, so federal and California excise taxes were subtracted from California average prices for vehicle fuels before the unit price assumptions were applied. A detailed description of the methods and assumptions for the simple and precise models is included in Appendix A.

The simple model has potential pitfalls in its dependence on accurate assumptions. An effective simple model must include accurate price assumptions and must identify organization-specific circumstances such as those described above. It must account for charges other than usage costs in financial records (such as baseline fees and taxes) and for special circumstances that impact prices. This can only be accomplished through informed research in the data collection process.

After the necessary activity and financial data was collected and price assumptions were used to estimate activity data for the simple model, emissions factors from Clean Air – Cool Planet's (2005) public carbon emissions calculator were used to calculate GHG emissions from activity data for each model and emissions source. All financial data, price assumptions, activity data, and emissions factors are included in Appendix B. As different GHGs have different relative impacts on climate change, GHG emissions numbers were expressed as a single amount of *carbon dioxide equivalent*. This represents the amount of carbon dioxide emissions that would have the same effect on climate change as the actual emissions makeup (which usually contains multiple GHGs).

Since this project is a case study, it represents only one "data point" and, therefore, data was not analyzed using statistical analysis. Rather, an acceptable tolerance range of three percent was set to compare the two models. Many GHG reporting organizations, including the California Climate Action Registry (2007), set a *de minimis* threshold of five percent, which allows the reporting organization to omit (or treat more leniently) any source that represents less than five percent of the total inventory from future inventories. The *de minimis* threshold is meant to reduce the burden of data collection in the face of limited resources (CCAR 2007). The IPCC (2006) recommends that limited resources be focused on *key categories*, which by one definition add up to 95-percent of the total inventory (therefore allowing the omission of five percent). However, after much debate, the DOE (2006) guidelines set a *de minimis* threshold of three percent for GHG inventories. To be conservative, three percent was set as an acceptable margin of error based on the guidelines provided by the DOE (2006). These *de minimis* exceptions suggest that a difference of three percent will not greatly impact inventory analysis.

The error of the simple model in predicting the GHG value generated by the precise model was calculated using the formula $|N_S-N_P|/N_P$ (where N_S represents the GHG emissions value generated by the simple model and N_P represents that of the precise model) for the total emissions and for each emissions source. Since an acceptable tolerance range of three percent was set to compare the two models, the value of $|N_S-N_P|/N_P$ fell into two categories: less than or equal to 0.03 or greater than 0.03. A value of $|N_S-N_P|/N_P$ that was less than or equal to 0.03 indicated that the simple model was able to predict within the acceptable tolerance range of three percent.

Most organizations, in conducting a GHG inventory, aim to identify their most significant emissions sources in order to prioritize mitigation efforts. Thus, a more informative metric is the fractional composition of the total GHG emissions number by emissions source, which illustrates the relative impact of different emissions sources. The results of the two models for the fractional inventory composition by emissions source were also compared to assess the ability of the simple model to predict the results of the precise model.

The time and money spent on each model were also monitored to compare the difference in resource requirements between the two models. The analysis of financial resource requirements was based on the monetary value of staff time spent on the inventory process, as well as the membership fee paid to ICLEI for assistance in the precise data collection methods.

Results

The simple and precise models generated very similar results for the emissions total and the subtotals by emissions source, including energy use, vehicle fleet fuel use, and waste disposal (Fig. 2).

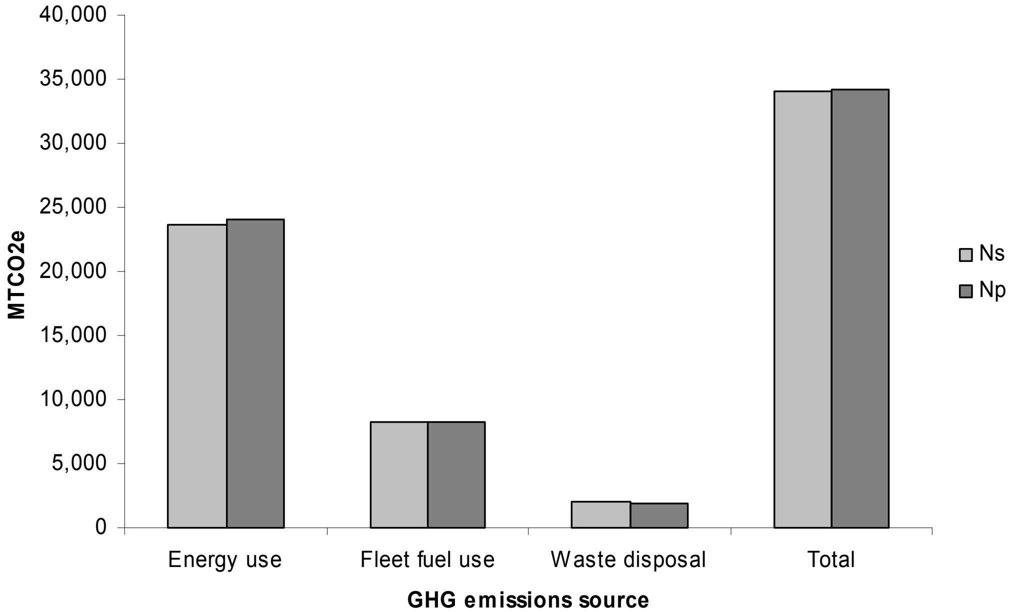

Figure 2. Comparison of the results derived by the simple and precise models for the emissions total and the subtotals by emissions source. N_S represents the GHG value generated by the simple model and N_P represents that of the precise model. MTCO2e, or *metric tons of carbon dioxide equivalent*, represents the amount of carbon dioxide emissions that would have the same effect on climate change as the actual emissions makeup (which contains multiple GHGs). Source data is displayed in Appendix B.

Ability to Predict Within a Three Percent Tolerance Range The simple model was able to predict the results of the precise model within three percent for the emissions total and for the energy use and vehicle fleet subtotals, but failed to predict within three percent for the waste disposal subtotal (Table 2). The emissions subtotals are further broken down into sub-subtotals, and the simple model was unable to predict the results of the precise model within three percent for six of the eight sub-subtotals (Table 2). While the error in the sub-subtotals ranged from less than 1% to 42%, the error in the subtotals ranged from only 1% to 9%, and the error in the total was less than 1%.

Table 2. Error of the simple model in predicting the results of the precise model. N_S represents the GHG value generated by the simple model and N_P represents that of the precise model. MTCO2e, or *metric tons of carbon dioxide equivalent*, represents the amount of carbon dioxide emissions that would have the same effect on climate change as the actual emissions makeup (which contains multiple GHGs). The total and source subtotals are displayed in bold text, while the sub-subtotals are listed beneath the subtotals in non-bold text. Sources for which the simple model could not predict the results of the precise model within three percent are marked with asterisks*. Source data is displayed in Appendix B.

GHG emissions source	N_S (MTCO2e)	N_P (MTCO2e)	$\|N_S-N_P\|/N_P$
Energy use	**23,662**	**24,034**	**0.02**
*Electricity	16,770	16,110	0.04
*Natural gas	6,690	7,714	0.13
Propane	186	182	0.02
*Stationary diesel	16	28	0.42
Vehicle fleet fuel use	**8,305**	**8,216**	**0.01**
Gasoline	7,203	7,186	0.00
*Diesel	799	696	0.15
*B20 biodiesel	239	228	0.05
*Compressed natural gas	65	106	0.39
***Waste disposal**	**2,075**	**1,902**	**0.09**
Total	**34,042**	**34,152**	**0.00**

Fractional Inventory Composition by Emissions Source The two models derived very similar results for the fractional inventory composition by emissions source, with only small differences in two sub-subtotals (Table 3). All three subtotals and all but two sub-subtotals show variance of less than 1%, and the largest variance is 3% in the natural gas sub-subtotal.

Table 3. Inventory composition by emissions source for the simple and precise models. The total and source subtotals are displayed in bold text, while the sub-subtotals are listed beneath the subtotals in non-bold text.

GHG emissions source	**Simple model** (% of total)	**Precise model** (% of total)
Energy use	**70%**	**70%**
Electricity	49%	47%
Natural gas	20%	23%
Propane	1%	1%
Stationary diesel	0%	0%
Vehicle fleet fuel use	**24%**	**24%**
Gasoline	21%	21%
Diesel	2%	2%
B20 biodiesel	1%	1%
Compressed natural gas	0%	0%
Waste disposal	**6%**	**6%**

Financial And Labor Resource Requirements The financial and labor resource requirements for the two models were also monitored and compared. The labor requirements for the precise model included 40 days of staff labor (from one full-time staff person) to collect inventory data, while the simple model required only two days of staff labor for data collection. However, some of the staff labor time associated with the precise model included timing delays while waiting for response from external organizations. The financial resources associated with this staff labor time included salary paid to project and support staff as well as associated office resource costs. These costs are proportional to the amount of staff labor time for each model. Thus, data collection for the simple model required only five percent of the financial and labor resources necessary for the precise model. Additional financial requirements for the precise model included almost $6,000 in membership fees paid to ICLEI for assistance with the precise data collection methods, as well as the staff time required to request and secure funding to pay this membership fee (ICLEI 2008). The County did not pay for third-party inventory certification because, while required by other organizations, verification is not required by ICLEI. As no assistance (and, therefore, no membership fee) was necessary for the simple data collection methods, the simple model actually required less than five percent of the financial and labor resources necessary for the precise model.

Discussion

The simple and precise models generated almost identical values for the emissions total and for the fractional inventory composition by emissions source, creating similar portrayals of the GHG inventory. The GHG inventory is a tool used by organizations to inform management decisions to reduce emissions, so the most important factor in comparing the simple and precise models is whether or not they would lead to similar management decisions. The emissions total and the inventory composition are the most informative metrics for management, as the emissions total illustrates magnitude and the inventory composition informs the selection of emissions sources on which to target mitigation efforts. The similarity of the results for the emissions total and the inventory composition suggests that the two models would lead to similar management decisions. However, the simple model was not a perfect substitute for a more precise analysis. Examination of each emissions source reveals interesting patterns in the discrepancy between the two models.

In general, the greatest discrepancies between the two models occur in the smallest emissions sources. The smallest of the subtotals, the waste subtotal, exhibits the largest discrepancy between the two models (Table 2). The inability of the simple model to accurately predict the results of the precise model for the waste sector is largely due to a lack of reliable public price records (like those that exist for fuel sales) for waste hauling fees. Similarly, the largest error out of all of the emissions values occurs in the two smallest sources: the sub-subtotals for the stationary diesel used in the County's emergency generators and the compressed natural gas (CNG) used by the County's vehicle fleet (Table 2). The large error for these two sources can be explained by rough assumptions and incomplete records. The stationary diesel fuel consumption estimate in the simple model is based on a rough assumption made by County staff that 50-percent of the fuel purchased for the emergency generators is actually consumed in routine testing and emergencies. County staff also explained that the County's CNG fueling station was built very recently, so tracking has yet to be standardized and all CNG fuel purchases outside of the County's fueling station may not be reflected in financial records.

This illustrates a tendency for smaller emissions sources to have casual internal recordkeeping, casual or nonexistent external tracking, and fewer informative statistics available to the public. The sources with the lowest emissions are generally also the sources with the lowest financial costs, and organizations tend to focus their budgeting and recordkeeping efforts on more costly activities. As a result, the ability of the simple model to accurately predict the results of the precise model is limited for smaller emissions sources. This analysis suggests that, for any given organization, the simple model will yield the greatest error in the smallest emissions sources, as these will be the areas with the lowest cost and, therefore, the most lenient recordkeeping. Thus, the simple model has the greatest error in the areas that are least important to the overall results of the inventory. For example, despite error as large as 42% in the smaller sub-subtotals, the error in the emissions total is less than 1% (Table 2). Furthermore, the insignificance of the error in small emissions sources is illustrated in a comparison of the results of the two models for the inventory composition by emissions source. Despite the large error in the waste subtotal and the stationary diesel and natural gas sub-subtotals, the results generated by the two models for these sources in the inventory composition differ by less than 1% (Table 3). Thus, the tendency for larger error in smaller emissions sources has only a minimal impact on the ability of the simple model to generate the same management decisions as would be generated by a more precise analysis.

Current literature acknowledges that the achievable level of precision in data collection will depend on the availability of human and financial resources; however, this literature does not explore the possibility that the perceived correlation between precision in data collection and accuracy in results (and, thus, ability to make informed decisions) is not actually as strong as might be expected (IPCC 2006, DOE 2007e). This study investigates this connection between precision in data collection, accuracy of results, and ability to make informed decisions to reduce emissions. The comparison of the results generated by the two models for each emissions source (Table 2) quantifies the impact of precision on accuracy, and the comparison of the results generated by the two models for the fractional inventory composition by emissions source (Table 3) investigates the impact of precision on the ability to make informed decisions to reduce emissions. The similarity of the results generated by the two models for both metrics questions the assumption that increasing precision in data collection will always lead to better management decisions, especially when increasing precision is costly and postpones implementation of projects that would actually reduce emissions.

The results of this study suggest that a simple model can predict the results of a more precise analysis with acceptable accuracy and with less than five percent of the time and money. Existing patterns of organizational recordkeeping are generally not conducive to the requirements of the precise model, but most organizations are highly motivated to keep accurate records of financial expenditures. Many organizations are also required by law, governing boards, or investors to create budgets and track spending. Thus, a simple model based on financial records can be completed with records that are kept internally. The simple model avoids the staff time that would be spent to acquire external data which may or may not be available and accessible. It also avoids the payment of a membership fee for assistance in data collection (although membership with organizations like ICLEI holds additional benefits beyond assistance in the data collection process). Furthermore, as the simple model requires only two days of staff labor time, it could be completed by an existing staff person—avoiding the staff time necessary to hire and secure funding for a new staff person. These avoided costs can make the inventory feasible in the face of limited resources and could translate to funding for the implementation of GHG reduction projects. Based on the expert inventory cost estimates mentioned previously, a 95-percent reduction in resource use could save up to $47,500 for local governments (and potentially much more for larger organizations and corporations) in funds that could be allocated for GHG mitigation (CCAR 2008, ICLEI 2008, LGO Protocol Advisory Group 2008, pers. comm.). The simple model can also be used for annual inventory reevaluations, which allow an organization to monitor the impact of reduction projects and progress toward a reduction target.

On the other hand, the use of a simple model by some organizations would complicate efforts to encourage a standardized approach in order to facilitate comparability across jurisdictions and organizations. However, the ARB lists harmonization, consistency, and comparability as its major goals in implementation of AB32, but allows the use of multiple alternate methods for GHG inventory data collection—including the use of financial records (ARB 2008, LGO Protocol Advisory Group 2008, pers. comm.). While the ARB was tasked with the development of a standard California protocol for AB32 implementation, the inclusion of alternate methods in the draft protocol acknowledges the need for flexibility in data requirements and suggests that these alternate methods will produce results that meet the standards of state policy (ARB 2008, LGO Protocol Advisory Group 2008, pers. comm.).

As this is only one case study, further research on additional institutions will be necessary to verify that these findings are generally applicable. The accuracy of the simple model is largely dependent on the quality of the assumptions that are made to generate activity estimates—which depend on access to accurate public data and knowledge of organization-specific circumstances. Although less rigorous than the precise model, the simple model still includes many variables, all of which introduce opportunities for error. Thus, only further research can verify whether this simple model is reliable. Whether or not this exact simple model is generally applicable, the results of this study suggest a need for more extensive consideration of the baseline data requirements for GHG inventories, especially given the potential burdens of an overly rigorous data collection process. There are two avenues to streamlining the data collection process: to design a reliable simple model that is based on data that is already easily accessible, or to improve the accessibility of precise data in order to decrease the resource requirements for the precise model. While this study focuses on the first strategy, further research should investigate both strategies. In other words, the solution may not be to change the GHG inventory methodology, but instead to change the focus of organizational recordkeeping systems. When accurate records of resource usage are held only by the external organizations that provide these resources, and individual organizations track only their financial expenditures, a rigorous GHG inventory data collection process or rough assumptions become necessary. Further research could investigate recordkeeping systems that would be more conducive to GHG inventories—and what resources and training would be required to maintain these systems. If the implementation of AB32 does in fact place GHG reporting requirements on industry and local governments, a discussion of inventory data requirements and the future role of assistance organizations like ICLEI will become even more pertinent.

The results of this study suggest that streamlining the data collection process can decrease the burden of the inventory and save time and money for project implementation without significantly compromising the accuracy of results. Thus, a simple model for GHG inventory data collection may suffice in the face of limited resources, and it may actually be preferable in order to act immediately to reduce emissions and to save resources for project implementation. To effectively facilitate GHG reductions, the inventory must be useful to the organizations that it targets. Thus, feasibility and timely action must be considered in addition to accuracy in the development of protocols for GHG inventories.

Acknowledgements

Thank you to the following individuals for their help in the data collection process: Richard Battersby, Robin Bedell-Waite, Sam Cuzzocrea, Deidra Dingman, Andy Green, Terry Mann, Maria Martinez, and Doug Parker of Contra Costa County; Brooke Lee, Xico Manarolla, Alex Ramel, and Ayrin Zahner of ICLEI – Local Governments for Sustainability; Michelle Bennett of Contra Costa Transfer and Recovery Station; Jon Carlson of City of Brentwood; Sal Coniglio of Garaventa Enterprises; Janna Coverston of Richmond Sanitary Service; Bill McLaren of Pacific Gas & Electric Company; Chanel Patterson of Allied Waste Services; and the instructors and students of U.C. Berkeley's Environmental Sciences senior thesis course.

Appendix A. Methods and Assumptions

Table 4 illustrates the methods and assumptions of the simple and precise models.

Table 4. Methods and assumptions for the precise and simple models

Source	Precise Model	Simple Model
Energy use: electricity and natural gas	Usage data from PG&E.	Cost data from accounting software. The average price of electricity in California in 2006 was $0.1328/kWh and that of natural gas was $1.182/therm (DOE 2007b, 2007c). Assume that 10% of the electricity and natural gas cost represents taxes and fees, based on a Utility User's Tax of about 8% in Contra Costa County (Smart Voter 2004).
Energy use: propane	Usage data from accounting computer software.	Cost data from accounting software. 2006 propane price derived from averaging the price on a January bill ($2.50/gallon) and a November bill ($2.70/gallon) to generate $2.60/gallon. Assume that 10% of the propane cost represents taxes and fees.
Energy use: diesel emergency generators	Usage data from Facilities Maintenance.	Diesel cost data from account clerk. The average price of diesel in California in 2006 was $2.922/gallon (DOE 2007d). Facilities Maintenance estimates that about 50% of the total purchased emergency fuel is actually consumed for routine testing and emergencies.
Vehicle fleet fuel use	Fuel consumption data from Fleet Services.	Cost data from account clerk. The average price of gasoline in California in 2006 was $2.855/gallon and that of diesel was $2.922/gallon (DOE 2007d). The average price of B20 biodiesel in the U.S. in 2006 was $2.740/gallon and that of CNG was $1.887/GGE (DOE 2007a). According to the DOE, California biodiesel prices were generally about $0.25 higher than the U.S. average in 2006, which yields a B20 biodiesel price of $2.990/gallon. However, according to Fleet Services, the County Government is exempt from all state and federal excise taxes, which are included in these price averages. The total of state and federal excise taxes for gasoline in California in 2006 was $0.364/gallon, that for diesel was $0.424/gallon, that for B20 biodiesel was $0.224/gallon after a federal tax credit of $0.20/gallon, and that for CNG was $0.0984/GGE (CEC 2007).
Waste disposal	Routine waste data from hauling facilities. Illegal dumping data from transfer stations, landfills, and internal records. When only volume data is available (rather than tonnage data), ICLEI advises to assume a waste density of 600 lbs/cubic yard to estimate tonnage data.	Cost Data from accounting software and internal accounting website. Recovery rates from the Solid Waste Program Manager with supporting annual summaries, with advice to assume 50% when unknown. From County bills, the average fee for hauling waste is about $65/ton.

Appendix B. Source Data and Results for the Precise and Simple Data Collection Models

Tables 5a,b illustrate the source data and results of the precise and simple models, respectively.

Table 5a. Source data and results for the precise model. Emissions factors were taken from Clean Air - Cool Planet's (2005) public carbon emissions calculator. MTCO2e, or *metric tons of carbon dioxide equivalent*, represents the amount of carbon dioxide emissions that would have the same effect on climate change as the actual emissions makeup (which contains multiple GHGs).

Emissions Source	Activity data		Emissions factors		MTCO2e
	amount	units	amount	units	
Energy					24,034
Electricity	52,253,717	kWh	0.0003083	MTCO2e/kWh	16,110
Natural gas	1,455,394	therms	0.0053000	MTCO2e/therm	7,714
Propane	33,790	gallons	0.0054000	MTCO2e/gallon	182
Stationary diesel	2,835	gallons	0.0099900	MTCO2e/gallon	28
Fleet					8,216
Gasoline	824,031	gallons	0.0087200	MTCO2e/gallon	7,186
Diesel	69,670	gallons	0.0099900	MTCO2e/gallon	696
B20 biodiesel	28,563	gallons	0.0079920	MTCO2e/gallon	228
CNG	17,561	GGE	0.0060473	MTCO2e/GGE	106
Waste	11,761	tons	0.1617091	MTC02e/ton	1,902
Total					34,152

Table 5b. Source data and results for the simple model. The activity per dollar metric is the inverse of the unit price assumptions collected in the simple model. Emissions factors were taken from Clean Air - Cool Planet's (2005) public carbon emissions calculator. The emissions factor for B20 biodiesel (which contains 20% biodiesel and 80% diesel) was generated by subtracting 20% from the diesel emissions factor. MTCO2e, or *metric tons of carbon dioxide equivalent*, represents the amount of carbon dioxide emissions that would have the same effect on climate change as the actual emissions makeup (which contains multiple GHGs).

Emissions Source	Total cost ($)	Subtract fees ($)	Activity/$		Activity data		Emissions factors		MTCO2e
			amount	units	amount	units	amount	units	
Energy									23,662
Electricity	8,026,452	7,223,807	7.530	kWh/$	54,396,136	kWh	0.0003083	MTCO2e/kWh	16,770
Natural gas	1,657,789	1,492,010	0.846	therm/$	1,262,276	therms	0.0053000	MTCO2e/therm	6,690
Propane	99,341	89,407	0.385	gal/$	34,387	gal	0.0054000	MTCO2e/gal	186
Stationary diesel	9,582	-	0.342	gal/$	1,640	gal	0.0099900	MTCO2e/gal	16
Fleet									8,305
Gasoline	2,057,518	-	0.401	gal/$	825,981	gal	0.0087200	MTCO2e/gal	7,203
Diesel	199,716	-	0.400	gal/$	79,950	gal	0.0099900	MTCO2e/gal	799
B20 biodiesel	82,635	-	0.362	gal/$	29,875	gal	0.0079920	MTCO2e/gal	239
CNG	19,224	-	0.559	GGE/$	10,748	GGE	0.0060473	MTCO2e/GGE	65
Waste	833,990	-	0.015	tons/$	12,831	tons	0.1617091	MTC02e/ton	2,075
Total									34,042

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