DEVELOPMENT OF A GENERAL METHODOLOGY FOR EVALUATION OF CARBON SEQUESTRATION ACTIVITIES

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Introduction

The United States may soon be focusing national attention on processes and activities that mitigate the release of CO_2 to the atmosphere and, in some cases, may remove CO_2 from the atmosphere. As we invest national resources to these ends, it is important to evaluate options and invest wisely. How can we apply consistent standards to evaluate and compare various CO_2 sequestration technologies? A standard methodology that considers all the carbon impacts is needed. This would be useful for policy makers to understand the range of options and for technology developers and investors to guide investment decisions. It would also serve as a source of information for calculations or estimations of carbon credits in a future credit trading system.

The performance objective for a sequestration technology is not necessarily zero emission of CO_2 but rather a reduction compared with the baseline of current practice. To make sure that all carbon aspects are considered, care must be taken to ensure that there are no hidden emissions when making an alteration from the baseline. The fundamental question underlying an analysis of merit of a process or alteration of a process is as follows:

How much CO_2 is generated as a result of the sequestration process, and what is the sequestered carbon's ultimate fate?

Both inputs and outputs must be considered to obtain a total picture. When we speak of carbon sequestration in this manuscript, we refer to all greenhouse gas sequestration measured in carbon dioxide or carbon equivalence (CE). The carbon dioxide equivalence is also called the Global Warming Potential (GWP). A complete list of GWP values has been prepared by IPCC.[1]

To address our objective, we have developed and elaborated on the following concepts:

- All resources used in a sequestration activity should be reviewed by estimating the amount of greenhouse gas emissions for which they historically are responsible. We have done this by introducing a quantifier we term *Full-Cycle Carbon Emissions* (FCCE), which is tied to the resource or product.[2]
- The future fate of sequestered carbon should be included in technology evaluations. We have addressed this by introducing a variable called *Time-Adjusted Value of Carbon Sequestration* (TVCS) to weigh potential future releases of carbon, escaping the sequestered form.
- The *Figure of Merit* of a sequestration technology should address the entire life cycle of an activity. The figures of merit we have developed relate the investment made (carbon release during the construction phase) to the lifetime sequestration capacity of the activity.[2] To account for carbon flows that occur during different times of an activity, we incorporate the *Time Value of Carbon Flows*.

In this short preprint we limit ourselves to discussing the development of TVCS and how it relates to FCCE.

Results

Future carbon emissions occurring from sequestered carbon should be considered when evaluating different sequestration approaches. To determine the FCCEs for streams that will cause carbon emissions in the future, we introduce the Time-Adjusted Value of Carbon Sequestration (TVCS). One way to estimate this value is to employ our global climate models to predict changes in atmospheric CO_2 levels as a result of sequestration and future release from sequestered carbon. This would be a labor-intensive task. Moreover, if an individual sequestration effort is moderate, it will be considered merely as noise in existing global models. We propose another approach—to start by defining a sequestration duration goal that will serve as a metric for future reference. For example, we may chose to use 200 years as our goal for sequestration. In this scenario, if we sequester 2 megatons of carbon (2 MtC = 7.4 Mt of CO_2) today and are able to keep it sequestered for at least 200 years, we should receive full value (100%) for the activity. If we have partial or full release in less than 200 years, we are not doing as well and the value is less. The question is this: how do we evaluate different carbon release profiles and determine their proper values?

Consider the graphs in Figure 1a–1d, in which several value curves have been constructed based on the instantaneous release of 2 Mt of sequestered carbon sometime in the future. We will later consider partial release over time. Figure 1a shows a scenario that does not give any value (or credit) to a sequestration of less than 200 years. Figure 1b takes a more gradual approach by applying a straight-line model. Here, if we instantaneously release all the carbon at any time before 200 years (e.g., 150 years), we would get fractional credit (e.g., 150/200×2=1.5 MtC). To give proportionally more credit to longer sequestration periods, we can construct a curve as in Figure 1c. Here we emphasize that there is increasingly more value in focusing on technologies that will keep the carbon sequestered longer, thus discouraging activities with potential quick release. It is clear that this third approach is very sensitive to prior knowledge about the future release, especially for the years close to year 200. To counter this, we may choose to use a fourth approach (Figure 1d) which suggests that we should consider short-term solutions favorably while recognizing that future predictions are hard to make. In all the cases, we have chosen to give full credit, or value, to sequestration past 200 years (or whatever metric we select as a goal).

It should be pointed out that all the curves drawn in Figure 1 were constructed using the same basic equation, namely (for $y \le Y$)

$$Value = (Amount\ of\ Carbon\ Released) \times \left[\frac{(1+i)^y - 1}{(1+i)^Y - 1} \right] , \quad (1)$$

where i is the penalty interest rate, y is the number of years sequestered, and Y is the sequestration goal (expressed in years). This equation is of the same type as interest rate functions but has been normalized by the expression in the denominator so that the function takes a value of 1 (one) when $y = Y$. The different curve shapes constructed in Figure 1 were obtained by changing the penalty interest rate from 500% to 0.01% to 3% to –3% for Figure 1a, 1b, 1c, and 1d, respectively. We propose the following abbreviated expression for the modifier:

$$V = R \times TVCS(i, y, Y) , \quad (2)$$

where V is the value of carbon sequestration and R is the amount of carbon released.

The preceding example showed how to penalize (or discount) the maximum sequestration value for discrete releases of the sequestered carbon; however, it is more likely that future carbon release from an activity is predicted via a mathematical expression (e.g., a half-life constant). In this case, Equation 2 is modified to yield the time-integrated value,

$$V = S_C - \int_0^Y R(y) \times (1 - TVCS(i, y, Y)) dy , \quad (3)$$

where S_C is the net amount of carbon initially sequestered and *R(y)* is the release profile. The carbon release profile could, for example, be from the use of slowly decomposing ammonium carbonate fertilizer.

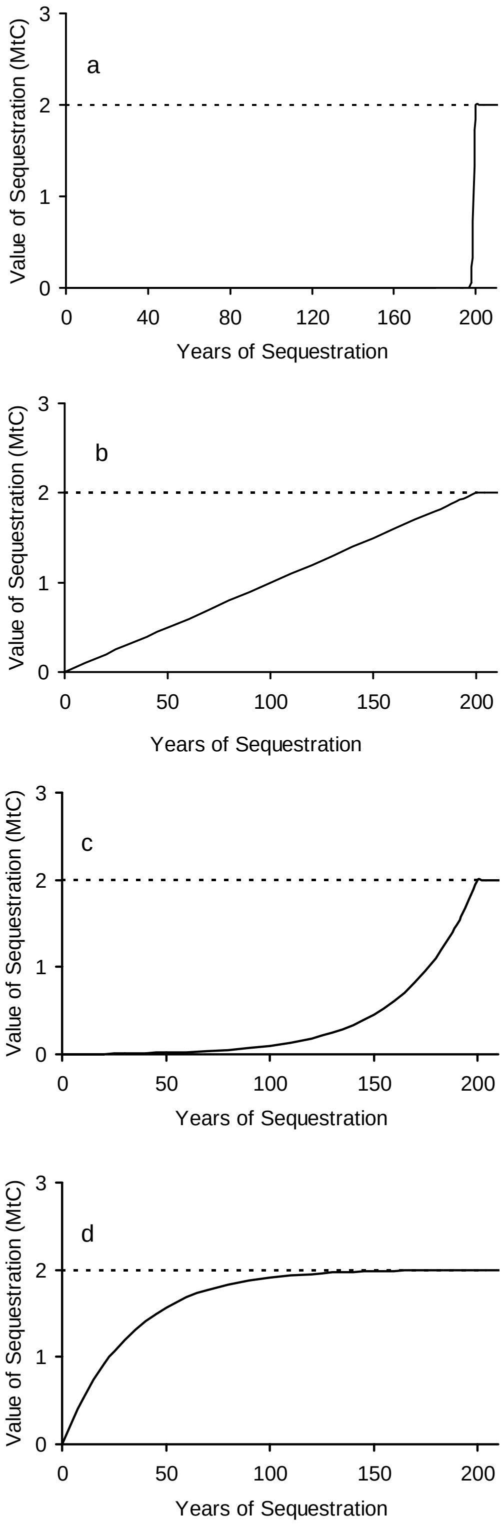

Figure 1. Several potential profiles for calculation of the time value of carbon sequestration.

We have discussed the future release of carbon from a sequestration activity. We should also consider that energy and materials might be needed in the future for "maintenance" to retain the carbon in its sequestered form. Intuitively, we can say that the use of energy and materials in the future should be limited. Because we expect that their use generate CO_2, we need to incorporate this knowledge in the value of sequestration. To keep with the approach that we have taken concerning TVCS, we would value delayed use of energy more than early use. The easiest way to visualize this it to realize that any maintenance in the future will generate CO_2, and this amount must be added to that potentially released from the sequestered carbon. Thus, *R* in Equations 2 and 3 represent the total CO_2 (or CE) released in the future, whether from captured CO_2 itself or from any CO_2-generating activity associated with the captured carbon. Incorporating maintenance activities into the projected scenario creates a situation that would cause some sequestration technologies to have a negative value, indicating a poor carbon management strategy.

The FCCE of the sequestered carbon stream is the amount of carbon equivalents of future emissions related to this stream. In introducing the TVCS, we have acknowledged that emissions may occur in the future from the sequestered carbon and we have also incorporated a projected value to address future releases. Thus, the time-adjusted FCCE is the right-hand part of the expression in Equation 3,

$$FCCE = \int_0^Y R(y) \times \left(1 - TVCS(i, y_j, Y)\right) dy \, . \tag{4}$$

Conclusions

Our objective was to develop a general methodology for evaluation of carbon sequestration technologies. We wanted to provide a method that was quantitative but also structured to give robust qualitative comparisons despite changes in detailed method parameters—that is, it does not matter what "grade" a sequestration technology gets, but a "better" technology should always achieve a higher score. We think that the methodology we have begun to develop provides this capability.

- This is a methodology that will assist in evaluation and comparison of well-defined sequestration activities.
- This is a methodology that should be used to address long-term merit prior to engaging in an activity.
- This is a methodology that treats a sequestration activity as an engineering process of which we have knowledge and control.
- This is a methodology that addresses carbon sequestration in life-cycle terms.

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References

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