Methods to Assess Co-Benefits of California Climate Investments

Accelerated Implementation of Technology

Center for Resource Efficient Communities, UC-Berkeley
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I. Background

Under California's Cap-and-Trade program, the State's portion of the proceeds from Cap-and-Trade auctions is deposited in the Greenhouse Gas Reduction Fund (GGRF). The Legislature and Governor enact budget appropriations from the GGRF for State agencies to invest in projects that help achieve the State's climate goals. These investments are collectively called California Climate Investments (CCI).

Senate Bill 862 requires the California Air Resources Board (CARB) to develop guidance on reporting and quantification methods for all State agencies that receive appropriations from the GGRF. Guidance includes developing quantification methodologies for greenhouse gas (GHG) emission reductions and other social, economic, and environmental benefits of projects, referred to as "co-benefits."

This document is one of a series that reviews the available methodologies for assessing selected co-benefits for CCI projects at two phases: estimating potential project-level co-benefits prior to project implementation (i.e., forecasting of co-benefits), and measuring actual co-benefits after projects have been implemented (i.e. tracking of co-benefits). The assessment methodology at each of these phases may be either quantitative or qualitative. As with CARB's existing GHG reduction methodologies, these co-benefit assessment methods will be developed to meet the following standards:

- Apply at the project level
- Align with the project types proposed for funding for each program
- Provide uniform methods to be applied statewide, and be accessible by all applicants
- Use existing and proven tools or methods where available
- Use project level data, where available and appropriate
- Reflect empirical literature

CARB, in consultation with the State agencies and departments that administer CCI, has selected ten co-benefits to undergo methodology assessment and development.

This document reviews available empirical literature on the ***accelerated implementation of technology*** co-benefit and identifies:

- the direction and magnitude of the co-benefit,
- the limitations of existing empirical literature,
- the existing assessment methods and tools,
- knowledge gaps and other issues to consider in developing co-benefit assessment methods,
- a proposed assessment method for further development, and
- an estimation of the level of effort and delivery schedule for a fully developed method.

II. Description of co-benefits

California is known today as a hotbed of innovation, particularly in the technology sector. California is also leading the nation in addressing climate change. As part of effectively addressing climate change, California is supporting the development and spread of innovative technology to reduce GHG emissions and achieve other resource-use efficiencies, both within the state and throughout the nation.

The "accelerated implementation of technology" co-benefit is defined as any situation in which a CCI contributes to the development or diffusion of a given technology faster than it would have occurred in the absence of the CCI. This can occur in three types of situations. Some CCI, such as the Low Carbon Transportation Advanced Technology Freight Demonstration Projects, are directly investing in the development of new technology. Other CCI technology investments, such as high-speed rail, already exist in other parts of the world, but still may be new to California or the United States, and would not likely be implemented in the absence of a CCI. Still others, such as low-emission transit vehicles, already exist even in California, but will proliferate more rapidly as a result of the incentives that CCI projects provide beyond market forces. This literature review is contained to the diffusion of equipment and infrastructure technologies and does not evaluate the role of CCI in the adoption of specific land management practices and behaviors if they do not involve such technologies.

Each of these situations involves comparing the potential results of a CCI project to a counter-factual situation in which such investment had never occurred. For this reason, any quantification of the extent of acceleration of technology implementation would involve estimation or modeling of relevant economic and institutional forces in these counterfactual scenarios. For example, quantification of the acceleration of deployment of high speed rail technology would require estimation of when, if ever, a high speed rail would be constructed in California in the absence of the CCI program. Because estimations of this sort rely on factors that are uncertain or unknowable, assessment of this co-benefit must remain qualitative.

CCI can result in the accelerated implementation of technology through three pathways that can occur in any of the three situations described above:

1. directly investing in development of new low carbon or resource-efficient technologies.
2. providing funding for purchase of innovative technologies by project applicants,
3. expanding market access for innovative technologies through rebates or other mechanisms to reduce barriers to technology diffusion,

The CCI programs that result in the accelerated implementation of technology are shown in Table 1 below.

Table 1. *CCI programs affected by co-benefit*

Program	Project	Likely direction of co-benefit (+ = beneficial change)
Sustainable Communities and Clean Transportation		
HSRA	*High Speed Rail*	+
CalSTA	*Transit and Intercity Rail Capital Program (TIRCP)*	+
Caltrans	*Low Carbon Transit Operations (LCTOP)*	+
CARB	*Low Carbon Transportation*	+
SGC	*Affordable Housing and Sustainable Communities (AHSC)*	+
	Transformative Climate Communities (TCC)	+
Energy Efficiency and Clean Energy		
CSD	*Low-Income Weatherization Program*	+
	Community Solar	+
CDFA	*Alternative Manure Management Program*	+
	State Water Efficiency and Enhancement Program (SWEEP)	+
DWR	*Water-Energy Efficiency Program*	+
CARB	*Woodsmoke Reduction*	+
Natural Resources and Waste Diversion		
CNRA	*Urban Greening Program*	+
CalRecycle	*Waste Diversion Program*	+

III. Directionality of co-benefits

Research indicates that projects that involve new and advanced technology also generally promote its implementation and diffusion. CCI projects that adopt new technologies through any of the three pathways identified above will promote technology diffusion – a ***positive co-benefit****.*

IV. Magnitude of the co-benefit

The magnitude of this co-benefit varies by the types of technologies, their current distribution in the California economy, and the magnitude of CCI funding of technology development, purchase, or incentivization. Projects that require large amounts of capital investment may experience more technology implementation acceleration from CCI funding than other types of projects, as the level of investment required may otherwise be cost-prohibitive for the project proponents. Also, new technologies that are currently at the beginning of market penetration may benefit more from investment, as success in implementation could bring popularity to the new technologies. High Speed Rail (HSR), for example, is both new in the United States (despite its successful operation in Asia and Europe) and also requires a large capital investment. Kamga and Yazici (2014) have argued that a successful HSR project in the US may help the country shift to a more diverse and sustainable travel pattern. Eventually technologies may reach a point of market saturation and decline as newer technologies are introduced into the market, but this not likely to occur for current innovative technologies until many years after a CCI is made.

For all of the CCI programs listed in Table 1 above, acceleration of technology is likely to be significant at the project level, compared to what would likely happen in the absence of the CCI. This is because these CCI are either directly funding development, deployment or adoption of novel technologies, or are financing the acquisition of equipment that is relatively expensive compared to more carbon-intensive alternatives (e.g. low-emission buses for a transit agency, high-efficiency stoves for an applicant to the Woodsmoke Reduction program). In either case, it is reasonable to assume that these technologies would not be deployed in these situations if it were not for the availability of CCI funds.

The literature that applies to accelerating the implementation of technology is diverse, and can be mainly divided into two major research lines, the first on innovation generation, and the second on technology adoption. To assess the acceleration of the implementation of technology by government investment and policy, research on technology adoption is more relevant.

Most research on technology implementation focuses on the theory, rather than the practice, of technology or innovation diffusion, and the factors that motivate it (Geroski 2000m Kufafka et al 2003, Dyk and Liezl 2014, Luttmer 2012). In theory, adoption and diffusion can both be used to describe the processes governing the utilization of innovations (Luttmer 2012). They are treated with slight differences in empirical research.

Studies of adoption behavior emphasize factors that affect if and when a particular individual, firm or entity will begin using an innovation (Sunding and Zilberman 2001). Measures of adoption may assess both the timing and extent of new technology utilization. This type of research usually applies a multivariate methodology, such as discrete choice models, to analyze the factors impacting people’s choice of a new technology, including attributes of the people who may adopt it, their beliefs and interactions with others and with their environment, or attributes of the technology itself. For example, Angst et al. (2010) looked at the adoption of electrical medical records in US hospitals, from 1975 to 2005. They found that larger and older hospitals were more likely to adopt new technology, and their prominence was instrumental in spreading the technology. That is, one of the most important factors was the identity of the early adopters.

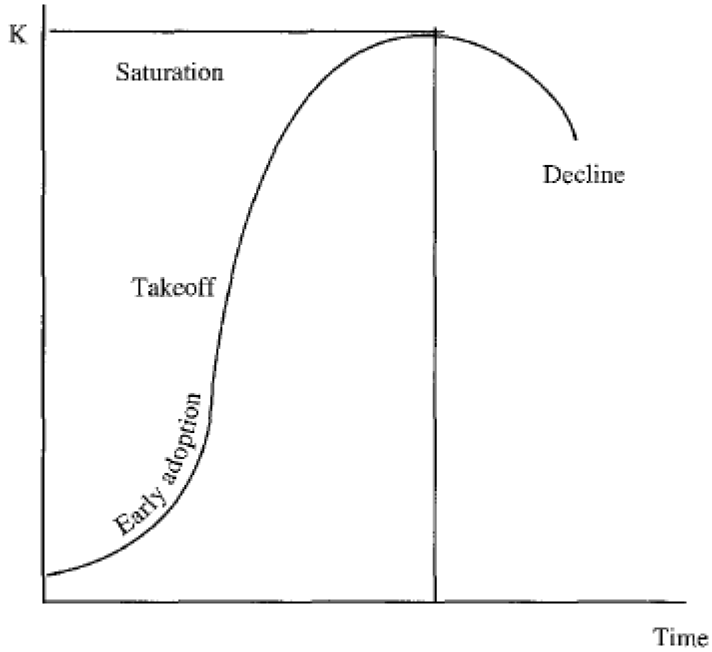
Another type of technology adoption research is focused on diffusion. Diffusion can be interpreted as aggregate adoption. Diffusion studies depict an innovation that penetrates its potential market (Sunding and Zilberman 2001). As with adoption, there may be several indicators of diffusion of a specific technology, but studies of diffusion tend to focus on the aggregate behavior of an entire marketplace, rather than the behavior of individual entities. Figure 1 summarizes the theory and models for technology implementation and diffusion from the literature.

Figure 2. *List of theories on technology diffusion*

Theory	Explanatory variable	Definition
Diffusion of Innovation	Attributes of the innovation	
	Relative advantage	Degree to which it is perceived to be better than what it supersedes
	Compatibility	Consistency with existing values, past experiences, and need
	Complexity	Difficulty of understanding and use
	Observability	Degree to which technology generates results that are observable
	Triability	Degree to which it can be experimented with on a limited basis
	Communication channels	Amount/type of interaction taking place within and among levels of employees within an organization
	Innovator characteristics	Five adopter categories each with defining characteristics
Theory of Reasoned Action	Behavioral Intention	Perceived likelihood of performing the behavior
	Attitude	
	Behavioral beliefs	Belief that behavioral performance is associated with certain outcomes
	Evaluations	Value attached to that behavioral outcome
	Subjective Norm	
	Normative beliefs	Belief about whether each referent approves/disapproves of the behavior
	Motivations to comply	Motivation to do what each referent thinks
Theory of Planned Behavior	In addition to the constructs included in the TRA	
	Perceived behavioral control	
	Control belief	Perceived likelihood of occurrence of each facilitating or constraining condition
	Perceived power	Perceived effect of each condition in making behavioral performance difficult or easy
Technology Acceptance Model	Perceived ease of use	Degree to which a person believes that using a particular system would be free of effort
	Perceived usefulness	Degree to which a person believes that using a particular system would enhance job performance
Social-Cognitive Theory	Environment	Factors physically external to the person
	Situation	Person's perception of the environment
	Self-efficacy	Person's confidence in performing a particular behavior
	Outcome-Expectations	The value that the person places on a given outcome
	Reciprocal determinism	The dynamic interaction of the person, the behavior, and the environment in which the behavior is preformed
	Reinforcements	Responses to a person's behavior that increase or decrease the likelihood of reoccurrence
Task-Technology Fit Model	Task-Technology Fit	
	Tool Functionality	Definitions for these constructs are still evolving.
	Task Requirements	

Many researchers use a model of technology diffusion that is called the epidemic or imitation model, which follows an S-curve (Figure 2). Initially, there is a low adoption rate, and then a takeoff period when the innovation rapidly spreads to the potential market. During these periods, the rate of change is high. Then the market reaches saturation, and, in most cases, a decline follows, as the technology is replaced by something newer. This model assumes that that the main barrier to technology diffusion is the lack of information about the new technology, which may be a result of cost, distance, or communication (Mansfield 1963).

Figure 2. *The S-curve of technology adoption*



The S-Curve model is widely accepted across researchers, and it is helpful to measure the co-benefits that a CCI project can bring. For example, if a CCI program involves technology that is at “early adoption” stage, the successful implementation of this program may possess the potential to accelerate the diffusion of such technology, to bring it to the level of “takeoff” up the diffusion curve. The reason behind this is that the S-Curve model assumes that lack of information is the main barrier of implementation of new technology (Sunding and Zilberman 2001), and the successful implementation would greatly improve the spread of information, thus accelerating the diffusion process. In this model, programs that involve technology at lower diffusion stages have more potential to accelerate technology implementation than programs with technology that is at a higher diffusion level, if all else is equal.

VI. Limitations of current studies

The major limitation of current studies is that most focus on the economic and social theories of technology diffusion—how new technologies spread and why people adopt them—not on how to assess any potential acceleration in the rate of technology adoption. As a result, these studies contain no predictive methods that would enable the estimation of rates of technology adoption under varying scenarios. In addition, though a CCI may reduce a given barrier to implementation of new technology (such as lowering cost through a rebate program) there may be multiple barriers to the wider implementation of a technology in the rest of the economy. These can include not only cost, but also issues such as risk aversion, lack of information/familiarity, or previous commitment to an existing technology. Which barrier is the strongest limiting factor on implementation will likely vary by technology, and there is no method available in the literature for making generalizations in this regard, especially at the project level.

In addition, there is little research indicating how to quantify levels of technology use. There is research about technology incubators and their role in facilitating innovation, as well as the mechanism of acceleration of technology diffusion through information, but these lines of research are generally descriptive in nature and provide no guidelines for measuring and evaluating the potential effect of, or for, individual projects (Colombo and Delmastro 2002, Mian 1996, Phillips 2002, Morgenstern and Al-Jurf 1999).

Finally, studies of technology adoption and diffusion generally take a panoramic view of entire markets or industries, and less often analyze the factors influencing, or the effects of, individual technology implementation decisions, such as those undertaken by CCI projects. Any method useful to individual CCI project applicants and funding recipients must take account of the limited information about the potential market for a given technology that would be available to these applicants.

VII. Existing quantification methods and tools

To assess the potential for technology implementation at the level of individual decision-makers, previous literature has developed only qualitative methods. Two of these methods, drawn from the literature summarized above, are the Level of Technology Implementation (LOTI) approach developed for schools, and the E-Health Readiness Framework, initially developed for public health services.

LOTI framework

The LOTI framework was first developed to assess the implementation of classroom teaching technologies in individual schools (Moersch 1995). It identifies seven levels, from non-use (level 0) to refinement (level 6) (Figure 3). In the original case from which the framework was developed a series of changes occur in the classroom as a teacher progresses from one level of technology use to the next. Teaching and technology shift from being separate (the computer lab vs. the classroom) to being integrated, and technology better supports more of the teaching. At the highest level, technology provides a “seamless medium” for problem solving and inquiry by students.

This framework could potentially be adapted to assess the use of technology to support other goals, such as the reduction of GHG emissions. CCI projects could potentially be evaluated based on the level of technology use they propose to foster along an adapted version of the LOTI framework.

Figure 3. *LOTI framework for teaching assistance technologies*

The LoTi Framework

Level	Category	Description
0	Nonuse	A perceived lack of access to technology-based tools or a lack of time to pursue electronic technology implementation. Existing technology is predominately text-based (e.g., ditto sheets, chalkboard, overhead projector).
1	Awareness	The use of computers is generally one step removed from the classroom teacher (e.g., integrated learning system labs, special computer-based pullout programs, computer literacy classes, central word processing labs). Computer-based applications have little or no relevance to the individual teacher's instructional program.
2	Exploration	Technology-based tools serve as a supplement to existing instructional program (e.g., tutorials, educational games, simulations). The electronic technology is employed either as extension activities or as enrichment exercises to the instructional program.
3	Infusion	Technology-based tools, including databases, spreadsheets, graphing packages, probes, calculators, multimedia applications, desktop publishing applications, and telecommunications applications, augment isolated instructional events (e.g., a science-kit experiment using spreadsheets/graphs to analyze results or a telecommunications activity involving data-sharing among schools).
4	Integration	Technology-based tools are integrated in a manner that provides a rich context for students' understanding of the pertinent concepts, themes, and processes. Technology (e.g., multimedia, telecommunications, databases, spreadsheets, word processors) is perceived as a tool to identify and solve authentic problems relating to an overall theme/concept.
5	Expansion	Technology access is extended beyond the classroom. Classroom teachers actively elicit technology applications and networking from business enterprises, governmental agencies (e.g., contacting NASA to establish a link to an orbiting space shuttle via the Internet), research institutions, and universities to expand student experiences directed at problem solving, issues resolution, and student activism surrounding a major theme/concept.
6	Refinement	Technology is perceived as a process, product (e.g., invention, patent, new software design), and tool to help students solve authentic problems related to an identified real-world problem or issue. Technology, in this context, provides a seamless medium for information queries, problem solving, and/or product development. Students have ready access to and a complete understanding of a vast array of technology-based tools.

E-Health Readiness Framework

The E-Health Readiness Framework was developed to assess the degree to which an individual community is prepared to participate and succeed in a "telehealth" service (health care using telecommunications technologies; Dyk and Liezl 2014). It evaluates the level of technology use in a community before the program starts. Khoja et al. (2007) first developed a complete set of tools to measure the level of technology readiness in a country, using the following five categories (Khoja 2007):

1) Core readiness: measures aspects of planning and integration;
2) Technological readiness: measures the availability, reliability, and affordability of the technology;
3) Learning readiness: addresses programs and resources available for training people to use the technology;
4) Societal readiness: considers the interaction between the institution and other institutions in the region and beyond;
5) Policy readiness: assesses whether government and institutional policies are in place to address common issues).

Each of these levels of readiness are assessed using a questionnaire. The questionnaire for "core readiness" is shown below as an example.

Figure 4. *Core readiness statements*

Statements:	*Score* 1	2	3	4	5	D/K
Identification of Needs for future changes, which the proposed telehealth/ e-health project will address:						
1. Organization has properly identified its needs	1	2	3	4	5	D/K
2. Organization has properly prioritized its needs	1	2	3	4	5	D/K
Dissatisfaction with status quo on the prioritized needs (related to the proposed project):						
1. There is general dissatisfaction with current handling of issues that could be addressed through telehealth/e-health	1	2	3	4	5	D/K
2. Solutions other than telehealth/e-health have been explored.	1	2	3	4	5	D/K
Awareness about telehealth/e-health in the organization:						
1. Awareness of ICT and internet's role in healthcare exists among the planners	1	2	3	4	5	D/K
2. Awareness of ICT and internet's role in addressing the prioritized needs exists among the planners.	1	2	3	4	5	D/K
Comfort with technology:						
1. There is general comfort in using ICT/internet among users of the proposed telehealth/e-health project.	1	2	3	4	5	D/K
2. There is general comfort among staff in using ICT/internet for storing patient information.	1	2	3	4	5	D/K
3. There is general comfort among staff in using ICT/internet for the purpose of patient care and education.	1	2	3	4	5	D/K
Trust on the use of ICT:						
1. All the policymakers and senior administrators trust new technology as a solution to the identified problems	1	2	3	4	5	D/K
2. All the staff members trust new technology as a solution to the identified problems	1	2	3	4	5	D/K
3. There are plans in place to increase staff's trust and confidence in the new technology	1	2	3	4	5	D/K
Planning for the new telehealth/e-health project:						
1. An individual or a group has taken responsibility for planning.	1	2	3	4	5	D/K
2. All the user groups among staff and other stakeholders have been involved in planning	1	2	3	4	5	D/K
3. There is an appropriate plan for implementation of telehealth/e-health initiative	1	2	3	4	5	D/K
4. The implementation plan includes proper budgeting and identification of resources.	1	2	3	4	5	D/K
5. There is an appropriate plan for evaluation of telehealth/e-health initiative, including option for external evaluation	1	2	3	4	5	D/K
Overall satisfaction and willingness:						
1. The proposed technology is appropriate according to the conditions within the organization	1	2	3	4	5	D/K
2. There is a willingness among staff to implement the technology for its intended purpose	1	2	3	4	5	D/K
Integration of technology:						
1. Integration of technology with the current services has been considered in the planning process	1	2	3	4	5	D/K
2. There is a plan in place to integrate telehealth/e-health with the current services	1	2	3	4	5	D/K

VIII. Discussion of knowledge gaps and other issues to consider in development co-benefit quantification methods

The main gap in empirical studies is their focus on theories of technology diffusion, or factors affecting technology adoption by individuals, rather than how to accelerate effective technologies. Existing methodologies for assessing adoption readiness are relatively straightforward qualitative checklist approaches, but information on the current level of technology diffusion is an important limiting factor in successfully employing these methods. To use these methods for either predicting or tracking benefits, applicants to CCI programs would need to be able to assess the current level of implementation of the technology, either within California or nationally. This is likely more feasible for CCI programs or implementing agencies than for project applicants. These methodologies would also need to be modified for assessing the level of technology implementation, particularly to represent the different levels of the S-curve of technology diffusion. Finally, these methodologies tend to be forward-looking, in the sense that they attempt to assess the potential for future implementation of a technology by an organization or entity, but the extent of conformance with the S-curve in a given technology's diffusion is only evident in retrospect.

IX. Proposed method/tool for use or further development

Overall, existing methods to assess technology adoption and diffusion are inadequate for assessing the accelerated implementation of technology from CCI. Development of an assessment framework that would function effectively at the project level and that would make meaningful comparisons between CCI program areas (transportation, energy and natural resources), and to scenarios of what would have happened in the absence of a given CCI, would require applicants to provide information and make judgments on matters that are largely unknown to them and beyond their control. Asking applicants to assess their own readiness for new technology implementation is feasible but unenlightening given that (in relevant cases) they are already demonstrating their interest in, and readiness for, new technology by applying for CCI funding.

In most of the programs listed in Table 1, it is true almost by definition that the implementation of low-emission and resource-efficient technologies is accelerated by CCI. In that sense, there is little doubt that the accelerated implementation of technology is a co-benefit of CCI. However, the *applicants* for these funds, as opposed to the program agencies or others that observe market-wide technology dynamics, are not in a position to know the fate of these technologies, or the potential pace of their implementation, in the absence of CCI projects.

Assessment of the accelerated implementation of technology is more feasible for CCI programs or implementing agencies than it is for project applicants, given the latter's lack of relevant information and ability to develop and assess alternative scenarios for future technology development. A good example of the former is the Low Carbon Transportation Program's 2016-17 Funding Plan, which examines the progress of the Heavy Duty Vehicle and Off-Road Equipment investments in promoting the demonstration, commercialization and transition to market maturity of these advanced technologies (CARB 2016, figure 3, p.46). The same document also examines the progress toward a "self-sustaining ZEV [zero-emission vehicle] market" pursuant to SB 1275 (CARB 2016, p.116) with explicit reference to theories of technology diffusion (Rogers 2003, Moore 1991). Future assessments of the accelerated implementation of technology co-benefit of CCI could consult these analyses as models for how agencies or programs might assess the magnitude of these co-benefits.

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