The Sustainability Benefits of the Connected Workplace

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Executive Summary

Dell's Legacy of Good program includes a commitment to learn how to measure the positive outcomes arising from the use of our technology. This is an important enabler to our top-level goal of demonstrating that the good that comes from our products and services is ten times what it takes to create and operate them. As part of this effort, Dell chose to study our Connected Workplace program and other related work-from-home initiatives. While these programs are known for their effectiveness at improving work-life balance for Dell employees, they also have sustainability-related benefits - employees who work from home, or another remote location, do not need to commute to a Dell facility, potentially reducing both their fuel consumption and related vehicle carbon emissions. In addition, enabling the remote workforce is a goal not only for Dell, but also for many of our customers. The more we learn about this trend, and its implications, the better support and guidance we can provide for our customers as they look to deploy similar programs.

The core methodology for the study was based off of work completed by the Global e-Sustainability Initiative (GeSI, The Boston Consulting Group, 2010). The GeSI report provided a base protocol to use for our study and analysis, though we did have to modify the process somewhat to meet the needs of our work. In addition to the GeSI report, we looked at a number of other studies – both with respect to process and results – in order to find an approach appropriate for our work. The result was a comprehensive list of potential outcomes and impacts. These included rebound effects, such as increased home electricity use during the day, as well as indirect effects, such as additional non-business-related vehicle trips.

Environmental Benefits

Over 1300 Dell U.S. employees provided us with data on their commute patterns and fuel usage. Through their data, we found that they are making significant use of our work-from-home initiatives.

- The average Dell U.S. employee works from home over 9½ times per month. While this number includes Dell employees that are 100% customer-facing, it is still well above the average of 2.3 times per month as reported by Gallup (Gallup, 2015).
- The associated fuel and emissions savings are significant. Even after taking into account rebound effects and the footprint of IT, we're helping our employees reduce their footprint by over one metric ton of CO_2e per year. Over the entirety of the Dell U.S. employee base, this means that our employees have collectively, seen a reduction in their carbon emissions footprint of ~35,000 metric tonnes of CO_2e per year. When we add the savings seen directly by Dell, the benefits rise to 40,000 metric tonnes. The magnitude of these benefits are comparable to what others have found in their studies of work-from-home.
- Dell employees, however, benefit from our work-from-home initiatives in other ways as well. These programs provide better work-life balance. In addition, by telecommuting, Dell U.S. employees have reduced their gasoline consumption by an average of 175 gallons per year. Collectively, the Dell employee base saves over twelve million dollars a year in fuel costs.

Table 1: Summary of study results (Pflueger, Gibson, & Normand, The Sustainability Benefits of the Connected Workplace, 2016)

Effect	Per employee effect	Comments
Mitigated emissions	1.80 mT CO_2e	Handprint
Emissions increases due to rebound effects	-0.65 mT CO_2e	Negative handprint
Emissions increases due to ICT footprint	-0.0057 mT CO_2e	Solution footprint
Net Mitigated Emissions	**1.15 mT CO_2e**	**Dell and Dell employees**

Broader Impacts

While the impact within Dell is significant, the benefits are even more impressive when scaled across the United States. The Gallup data suggests that the U.S. workforce avoids 2.7 billion round-trips per year by telecommuting. This is equivalent to a reduction in commuting footprint of 30 million metric tonnes CO_2e of per year. It's important to recognize, as well, that these are not numbers representing potential, but are actual realized savings.

A conservative estimate of Dell's market share suggests that our technology plays a direct role in over 20% of this savings (or > 6 million tonnes of CO_2e avoided annually). This is a significant fraction of our overall carbon impact. As a result, our study of the sustainability-benefits of work-from-home initiatives is our first work that shows benefits that, when scaled-up, have a measureable impact on our top-level Legacy of Good goal.

At the same time as we estimate these benefits, however, we must recognize that Dell is not wholly responsible for these savings. It takes an entire value chain to enable these solutions – including other hardware, connectivity and software suppliers. Still, this is great progress on both our measurement goal and our top-level goal of demonstrating that the good from our technology and services is ten times its impact.

In addition to its own interest in enabling work-from-home, Dell has seen more and more of its customers considering similar programs. This work clearly demonstrates that these organizations may be helping their employees reduce their environmental footprint as well as improve their work-life balance.

Dell will continue to study our work-from-home initiatives and use that work as a stepping-off point for studying other IT-based solutions. We look forward to sharing our work with others, learning from them as well.

Introduction

The top goal of Dell's 2020 Legacy of Good Plan states that "by 2020, the good that will come from our technology will be 10x what it takes to create and use it". Not only is this ambitious and aspirational, it is also challenging from a definition and measurement perspective. While we know a great deal about measuring product impacts, we have very little on how to measure the 'good' that results from a technology.

Our approach has been to start small, with studies focusing on specific solutions comprised of, or enabled by, Information and Communications Technologies (ICT). The reduction in scope affords us the opportunity to go into more depth on identifying and measuring the positive outcomes, while at the same time limiting the investigation of impacts or 'footprint'.

This study looks at the carbon mitigation effects of work-from-home programs, using Dell's direct experience as a source for data on organizational and employee benefits.

Dell and the Connected Workplace

The concept of telecommuting is not new; its origins go back to the early 1970's. These days, however, terms such as telecommuting, telework, remote work, work-from-home, and flexwork are frequently treated synonymously – though there are some differences. They all, however, share the trait that they describe programs that support employees' capability to perform their work at sites other than a company's traditional offices.

IT enabled greenhouse gas (GHG) abatement has been a popular subject of study in recent years, and a number of studies have shown that telecommuting has an especially high abatement potential. Dell's telecommuting solution for its employee base is reflected in its Connected Workplace program. To date, not only has this program had a positive effect on Dell's operational and energy footprint[1], evidence suggests that our employees have seen their carbon footprint go down as well. Fewer trips to the office means fewer car-miles driven and less gasoline consumed. Of course, this also may mean that, during those hours they otherwise would have been at a Dell office, our employees see increased energy consumption at home.

Dell's Connected Workplace program is an excellent mechanism for building our capability to measure the environmental benefits of IT-based solutions. Our solution has been in place for some time, with a good number of employees taking advantage of the program to work from home. We also have access to IT usage data to help identify application footprint. In addition, the data produced by the study will not only support our Legacy of Good program, it will also help our HR team understand the value its offering has to Dell's employee population. It is our hope to take what we learn from this

[1] In its fiscal year 2015 Corporate Responsibility report, Dell stated that it has saved $21 million in real estate expenses and reduced its greenhouse gas emissions by 9800 metric tons as a result of its Connected Workplace program.

study and apply it to quantifying the benefit of other Dell technologies, bringing us closer to realizing our 10x20 goal.

Prior Work on the Environmental Impact of Telecommuting

The last decade has seen several studies published on the GHG abatement potential of various ICT solutions. As part of our preliminary research, we reviewed a number of these studies based on their similarities to the goals of our Connected Workplace study.

Findings of our research indicated that some degree of GHG abatement potential is likely to exist as a result of telecommuting. However, the complexities of the telecommuting system are far from being completely understood. We have therefore used the results from this prior work to guide our process, identify areas where we can add additional detail and depth and as results that can be compared against our own findings to help establish broader patterns linking remote work and positive environmental outcomes.

Study Process

To guide the study process, we are leveraging the assessment methodology created by the Global e-Sustainability Initiative (GeSI) for evaluating the carbon-reducing impacts of Information and Communication Technologies (ICT) (The Boston Consulting Group, 2010).

GeSI's methodology defines three main steps. As our study is somewhat different than a typical GeSI study, we will have to slightly amend their process:

- Define the goal(s) and scope of the study, including specification of the purpose of the study as well as its intended audience
    - The GeSI methodology mainly focuses on comparing a potential scenario with a current scenario. As we are looking backwards to capture benefits from an existing solution, we will identify baseline and current scenarios ('before' and 'after')
- Limit assessment by identifying those impacts that are material and should be included, as well as those impacts that may be obvious focal points for study, but which are unlikely to materially affect results
    - Identify solution boundaries and establish potential sources of energy use, emissions generation or other positive or negative effects
    - This also includes identification of main study components, as well as the conditions under which the components are relevant – i.e. what is, and isn't, in scope for the study
    - During this step, we will also categorize effects by type of effect and whether the effect is primary (direct) or secondary (indirect)
- Assess relevant effects and interpret net results
    - We will review the relevant effects and identify data sources and data collectors for each
    - We will then aggregate, analyze and interpret the results.

Study Goals

The purpose of this study is to measure the sustainability-related benefits of Dell's initiative to enable employees to work from home. While this includes Dell's formal Connected Workplace program, many Dell employees have taken advantage of our corporate remote work goals on an informal basis.

This work has several intended audiences:

- Stakeholders interested in Dell's 10x20 and measurement sustainability goals
- Dell's Human Resources organizations
- Dell employees
- Those Dell customers considering creation or expansion of similar initiatives
- Policy-makers and regulators interested in commute patterns and climate change

As this is the first study Dell has performed on the topic, we caution readers not to use the findings of this work for product or solutions comparisons. If comparisons are possible in the future, it will be because studies performed on other organizations provide additional data as to the relationship between program and organizational characteristics, and commute patterns.

Baseline and Current Scenarios

As we are studying the relative impact, handprint and footprint, of work-from-home initiatives, our baseline scenario will be a work environment where employees commute to and from their office on those normally scheduled workdays that do not otherwise include a visit to a customer, supplier or partner. The current scenario considers that employees commute to and from their office on an as-needed basis or work-from-home on a pre-arranged schedule.

Table 2: Baseline and current scenarios

Baseline Scenario	Current Scenario (Connected Workplace)
• **Employee commutes to and from the office on all normally scheduled workdays not including a visit to a customer, supplier or partner**	• **Employee commutes to and from the office on an-needed basis or on a pre-arranged schedule**

Study Scope and Solution Boundaries

Dell is a global company with sizeable employee populations in the Americas, Europe and Asia. Due to significant differences in commute patterns and work locations, as well as available data, we are going to focus this study on U.S. employees only. Also, within the U.S. employee base, Dell has a number of employees who are designated as 'remote' workers, but whose job responsibilities and commute patterns require work away from a Dell office. We will not be focusing on these employees. Instead, we will specifically focus on those employees whose commute patterns have changed as a result of

Dell programs. The focus on U.S. employees also means that we will be looking at Dell U.S. facilities only.

Other items within scope are those IT applications and services that are required to support work-from-home. To be considered within the study, these applications and services must see some material change in usage patterns as a function of employee location. We will also exclude applications and services that focus on providing support for Dell contractors or other non-Dell personnel; the study is considering Dell U.S. direct workers only.

Table 3: Study components and scope

	In Scope	Out of Scope
Dell Facilities	U.S. Facilities	Non-U.S. Facilities
Employees	U.S. Employees Employees not designated as "Remote" Employees designated as "Remote" whose commute patterns have changed as a result of Dell's program	Non-U.S. Employees Employees designated as "Remote" whose commute patterns have not changed as a result of Dell's program
IT Applications and Services	IT applications and services required to support work from home IT applications and services that see material changes in use patterns due to employee location	IT applications and services that support remote work for Dell contractors and outsource personnel. IT applications and services that see no material changes in usage based on employee location
IT Hardware	Additional on-site networking equipment required to support remote employees when they are working at a Dell facility IT hardware required to support in-scope IT applications and services	Client systems (laptops, desktops, etc…) that would be in service required of work location IT equipment at employees' home used for networking and connectivity
Home Energy Use	Energy and electricity consumption during hours when the employee would otherwise be working at Dell	Energy and electricity consumption outside of normal Dell business hours

Identification of Material Effects

Through our review, we identified twelve material effects to be reviewed within the study. The analysis leading to this selection is presented in Appendix A. Table 10 provides a mapping between the different effects and the type of effect. This information is carried forward into the Data Analysis section of this paper.

Data Collection

Due to the wide variety of greenhouse gas emissions effects material to the study, we had to collect data from a number of sources. These are listed, along with the specific effects to which they are mapped, in Appendix B, Table 11.

Data Analysis

We are going to look at the outcomes from Dell's Connected Workplace program in two different ways. First, we will use a more traditional approach, similar to GeSI's protocol, where we look at decreases and increases in emissions to calculate an average GHG abatement (in tons CO_2e) attributable to a single telecommuting employee over a specific timeframe. Second, we will consider a different approach where we look at the 'investment' in carbon emissions required to produce a 'return' in positive outcomes in order to calculate an environmental rate-of-return.

Table 4: Calculation of emissions decreases per employee

Effect	Emissions decrease per employee	Comments
Potential decrease in employee GHG emissions due to reduced use of vehicle by employee	1.56 mT CO_2e	Results from Dell Connected Workplace employee survey
Potential decrease in Dell facility energy use due to reduced employee presence	0.12 mT CO_2e	Calculated from Dell facility data
Potential decrease in facility lifecycle emission footprint through mitigation of new construction	n/a	No specific instances were found that could be attributable to work-from-home
Potential decrease in lifecycle emissions due to less wear on employee vehicle	0.12 mT CO_2e	Based on mfg. LCA of 6mt per vehicle, avg vehicle life of 200K miles and annual travel reduction of 3850 miles
Total	**1.80 mT CO_2e**	

Table 5: Calculation of emissions increases per employee (rebound effects)

Effect	Emissions increase per employee	Comments
Potential increase in home electricity use or emissions due to increased use of appliances while at home (e.g., heating or cooling equipment)	0.45 mT CO_2e	Results from Pecan Street study
Non-immediate increase in vehicle usage during business hours for local errands / trips	0.20 mT CO_2e	Results from analysis of Zhu-Mason data
Increase in air travel on behalf of employees who work for Dell but are not near a Dell facility	Not calculated	Data not available from survey
Potential increase in energy use due to increased number of employees supported per facility	n/a	Work-from-home has reduced, rather than increased, Dell facility energy consumption
Total	**0.65 mT CO_2e**	

Calculating the Per-Employee GHG Reduction Factor

Table 4, Table 5 and Table 6 summarize the findings of the study for emissions decreases, emissions increases due to rebound effects and emissions increases due to IT footprint. Together, these are rolled up into the overall results, presented in Table 7.

This shows that, overall, Dell work-from-home programs mitigate approximately 1.15 metric tonnes of CO_2e per employee per year, with most of the decrease being related to employee GHG emissions and a smaller percentage attributable to Dell GHG emissions. Given that the Dell IT solution emissions footprint driven by the solution is approximately 0.0065 metric tonnes of CO_2e per employee per year, the ratio of handprint[2] to footprint for Dell's work-from-home initiatives is well over 150:1.

This shows that, overall, Dell work-from-home programs mitigate approximately 1.15 metric tonnes of CO_2e per employee per year, with most of the decrease being related to employee GHG emissions and a smaller percentage attributable to Dell GHG emissions.

[2] The solution handprint includes positive benefits minus any rebound effects. Footprint is measured as the resources required to manufacturing and operate the solution.

Notes on Calculating IT Solutions Footprint

Looking at all aspects of the study, calculating the IT footprint was by far the most difficult. While initial investigations into the IT footprint associated with work-from-home provided some data, a complete dataset, however, proved difficult to build. Some of the challenges included:

- Identification of applications or services that see a change in use based on worker location
- Measurement of the usage of relevant applications or services
- Measurement of the portion of an application or service used by remote workers that is shared with other solutions
- Accommodation of the variety of hosting models possible for applications or services, including those applications hosted within virtualization environments
- Estimation of the usage of storage or networking equipment that supports relevant applications and services but is shared with a large number of other solutions

Despite the difficulties in data collection, however, all discussions with Dell's IT organization suggested that the impact, from an IT perspective, is very small – and likely immaterial to the results of this study. Accordingly, we looked to establish a conservative upper bound for IT impact. This would then allow us to check the assumption that IT impact was not material to the overall findings of the study.

Table 6: Calculation of ICT emissions increases per employee

Effect	ICT emissions increase per employee	Comments
Potential increase in data center energy use due to increased employee use of data center resources	0.0035 mT CO_2e	Based on upper bound for SonicWALL and Lync energy consumption
Potential increase in home electricity use directly due to increased use of ICT equipment at home	Not calculated	This is incorporated into the home electricity use number.
Potential increase due to increased usage of networking and telecommunications equipment	0.0022 mT CO_2e	Based on estimates for audio and video stream usage, as well as public data on data transfer energy intensity
Potential increase in equipment lifecycle emissions due to purchase of additional ICT equipment	n/a	Emissions estimates for IT equipment manufacturing and logistics have been rolled into the data center estimate
Total	**0.0057 mT CO_2e**	

The full estimate, considering both application footprint and network traffic footprint, is roughly six-thousandths of a metric ton of CO2-equivalent per Dell U.S. employee. This is less than 1% of the benefit measured in other parts of the study, backing up our original hypothesis that the IT-related footprint of work-from-home is immaterial compared to the measured benefits.

Table 7: Summary of study results

Effect	Per employee effect	Comments
Mitigated emissions	1.80 mT CO_2e	Handprint
Emissions increases due to rebound effects	-0.645 mT CO_2e	Negative handprint
Emissions increases due to ICT footprint	-0.0057 mT CO_2e	Solution footprint
Net Mitigated Emissions	**1.15 mT CO_2e**	

Comparison with Results of Prior Work

While most studies conclude that telecommuting results in a positive environmental impact, we noted wide variation in nearly all other aspects. Some studies provided detailed numerical analysis, while others were strictly qualitative. Some studies employed complicated statistical simulations, while others relied on simple algebraic calculations. Studies also varied greatly in geographic scope, assumptions, and timeframes.

Most of the studies included in our review are macro-level assessments considering the combined GHG abatement potential of numerous ICT solutions. Telecommuting (or variations such as flexiwork and decentralized business) is included as an individual ICT solution in all of these studies. While varying methodologies made comparison between studies difficult, the findings of our preliminary research were still useful as a means to guide our methodology and validate assumptions.

All but two of the studies we reviewed came to a definitive conclusion that telecommuting has a positive impact on the environment. The first exception is a study by Erdmann and Hilty, which argues that the impact of telecommuting on GHG emissions is negligible due to rebound effects which will compensate for any environmental benefit achieved through second-order effects (Erdmann & Hilty, 2010).

Table 8: Previous studies on the environmental impacts of telecommuting

Study Name	Year	Geographic Scope	Environmental Impact
BT's Net Good 3:1 Carbon Abatement Methodology	2014	U.K.	Positive
Measuring the Energy Reduction Impact of Selected Broadband-Enabled Activities Within Households	2012	France, Germany, Italy, Spain, U.K., U.S.	Positive
Towards a High Bandwidth, Low Carbon Future	2007	Australia	Positive
Scenario Analysis: Exploring the Macroeconomic Impacts of Information and Communication Technologies on Greenhouse Gas Emissions	2010	EU 15	Negligible
The Potential Global CO_2 Reductions from ICT Use	2008	EU	Positive
Saving the Climate @ the Speed of Light	2006	EU 25	Positive
BT Agile Worker Energy and Carbon Study	2009	30 BT Employees in London	Positive
Broadband and Telecommuting: Helping the U.S. Environment and the Economy	2011	U.S.	Positive
The Impact of Telecommuting on Personal Vehicle Usage and Environmental Sustainability	2014		Negative

The other exception is a study by Zhu and Mason [need to include reference] which asserts that telecommuters drive more miles in a personal vehicle than traditional workers, leading to a negative environmental impact. We consider this study to be significant enough that we have reviewed it in detail. Our findings on this study are presented in Appendix J:.

Although the majority of studies argue that telecommuting is beneficial for the environment, these exceptions highlight the importance of considering rebound effects in the calculation of GHG abatement.

Our study differs from previous studies in a number of ways. First, the scope of this study is more focused than that of other studies. Rather than considering all telecommuters in a specified region, this study only focused on U.S. based Dell employees. The narrow scope simplified data collection, improved data accuracy, and allowed us to focus on making our methodology as detailed and transparent as possible. Second, we collaborated with Pecan Street Project, an Austin-based organization researching residential energy use, to collect direct data on rebound effects. Most other studies have not had access to this level of data, having to estimate the effects of changing home energy use patterns, or omit it from their calculations. Finally, we also considered the GHG emissions resulting from the IT equipment hosting the applications and services that enable work-from-home initiatives.

Conclusions and Further Work

Characteristics and Benefits of Dell's Work-from-home Initiatives

The primary conclusions from this study are that the estimated sustainability-related of work-from-home, including our Connected Workplace program, are significant and in line with the findings of other studies (on the order of one metric ton of CO_2e per year per employee). The benefits persist and remain material even when rebound effects such as home electricity use and non-business-related personal trips during the day are taken into account.

In addition to the sustainability-benefits, though, we also learned a lot about the commute patterns of Dell's U.S. employee base. We found that, although employee participation in Dell's formal Connected Workplace program is significant[3], the true adoption rate of remote work is greater than our formal data would suggest. Our survey data suggests that, at any one point in time, over 45% of Dell's U.S. employee base is working remotely[4].

At the same time, from the analysis, it is clear that carbon emissions benefits from work-from-home will vary over time. Factors such as the increasing adoption of electric vehicles may mitigate some of the benefit. In addition, as certain regions develop a richer energy mix, with respect to renewables such as wind and solar, both potential benefits and rebound effects will change. Last, some of the literature suggests that providing remote work capabilities may incent some employees to live further away from their hosting offices than they might under other circumstances. Existing data does not seem to be sufficient to size the potential impact from this.

Still, it should be noted that the full benefits from remote work go significantly beyond those tied to sustainability topics. Work-from-home improves employee work-life balance, and is becoming an expected feature of the workplace by the millennial workforce.

Scalability of Benefits

While we are very interested in what we are enabling within our own employee base, we are also interested in the broader question of the overall impact that our technology is having in this area. Fortunately, available data on the commute patterns of the U.S. workforce as a whole are sufficient for us to calculate both an estimate of the current benefits that remote work provides, as well as an

[3] For FY15, Dell reported that one of every four of eligible employees were enrolled in its Connected Workplace program (Dell, 2015).

[4] Based on an estimate of an average of 9.7 remote work days per month per Dell U.S. employee.

estimate for additional benefits possible as adoption of work-from-home comes closer to its saturation point.

Global Workplace Analytics provides regular updates on telework statistics. These statistics (Global Workplace Analytics, 2016), together with recent poll data from Gallup (Gallup, 2015) provide strong insight into the state of telework today in the United States. Their data suggests that, in a given year, U.S. workers are now managing to avoid over two-and-a-half billion roundtrips commutes per year.

Given Dell's U.S. market share for both servers and for client systems (desktops, notebooks, tablets and thin clients), Dell technology is playing a significant role in these solutions nationwide and globally. We have set a very conservative estimate for Dell's participation at a little over 20%. Including this share and nationwide emissions factors, we believe Dell's technology is a participant in solutions that are avoiding over six million metric tonnes of CO_2-equivalent per year. It is important to note, however, that Dell cannot and will not take full credit for this. Telework solutions require participation across a wide value chain, including software and services providers, other hardware and communications providers and, last but not least, the efforts of a large number if IT professionals. All of these components must work together to enable an employee to work from a remote location.

Measurement of IT Solutions

While measuring the sustainability benefits of work-from-home was the major focus of the study, one of the other primary goals of this study was to advance Dell's capabilities with respect to measuring the positive social and environmental outcomes from the use of our technology. Some prior art was available – most notably the Global e-Sustainability Initiative's 2010 measurement methodology (GeSI, The Boston Consulting Group, 2010). While this was necessary to our work, it was not sufficient. The GeSI work focused on a methodology for estimating the potential of a given technology solution, as opposed to measuring actuals in terms of benefits and footprint. Other prior art provided suggestions for how to conduct studies on telecommuting, but not the more general problem of estimating the net benefit of an IT-based solution.

One area provided significant challenges – measuring the IT footprint of a solution. The nature of IT is such that specific resources may be dedicated to one purpose or application or may be shared across a wide range of services and end-users. While we were not able to generate a complete dataset of actuals for IT footprint, we were able to estimate an upper bound. Through this estimate, we were able to show that the IT footprint, in this instance, was not material to overall results. Having an upper bound on footprint also enabled us to put a lower bound on the ratio of net outcomes to footprint for work-from-home solutions. This number was significant – over 150:1. While it is significant, it is also not surprising. IT provides huge leverage for some classes of solutions.

Regardless of the issues pertaining to methodology, either overall of specifically for IT, we consider the study to be successful from the perspective of learning how to measure the net benefits of these classes of IT-based solutions.

Suggestions for Further Work

There are a number of areas where we see future work in this space. First, Dell and its employee base still have additional opportunity where telecommuting is involved. Second, we are planning to investigate other IT-based solutions with positive social and environmental benefits. The work and methods we develop here provide a great starting point for future work.

Our work-from-home analysis is based on an initial survey of the Dell U.S. employee base. We are very interested, however, in how adoption is evolving internally, and where we might be able to take these initiatives. In addition, the survey work we have done has been solely focused on the U.S. employee base. Dell, however, has a large number of employees in other regions, including substantial populations in Europe, India and China. We do not expect to see the same potential for mitigating carbon emissions in these areas, however, we would like to understand commute patterns for our employees worldwide.

Our success in establishing a minimum ratio for impact bodes well for future studies of IT-based solutions that generate positive social and environmental outcomes. Through this study, we were able to document a methodology for future, similar work. This will give us, and others, a better starting point for other measurement efforts. There is still a lot to learn in this area, but this is a great start. In addition, even though measurement of the IT footprint of work-from-home was challenging, this study afforded us an invaluable opportunity to build-out a draft process for future IT footprint measurement.

We expect to document and publish both our work on an overall process for conducting net benefit studies, as well as our specific thoughts on measuring the IT footprint of an IT-based sustainability solution within groups such as the Net Positive Project. It is our hope that, as we make this work and our processes public, others will use and expand this work.

Appendix A: Primary and Secondary Effects of Work-from-home on Carbon Emissions

Solution Boundaries, Assessment Requirements and Limitations

A review of the study components listed above suggests that five separate environments comprise the solution boundaries:

- Dell offices
- Dell data centers
- Employee personal vehicles
- Employee homes
- 3rd party networking and telecom equipment and facilities

To set a plan of attack for this study, we must look at each environment and identify and assess potential emissions sources.

- Dell Office Facilities (not including equipment)
  - We will only consider operational energy consumption and greenhouse gas emissions for Dell office facilities. While it is possible that, in the long-term, Dell's office facility portfolio may be affected by our remote work program, in the short-term and medium-term it will remain the same.
  - In addition, many Dell facilities in the U.S. purchase 100% of their electricity through renewable sources today. These decisions were not a consequence of our remote work program, and will reduce associated emissions for both the baseline and the studies cases. While we will establish baseline energy consumption for Dell office facilities, we will only establish baseline emissions numbers for those facilities purchasing significant quantities of energy from non-renewable sources.
  - Data on energy consumption and emissions for Dell facilities will be provided from previous studies.
- Dell Data Centers (not including equipment)
  - This category includes the data center, itself, as well as that equipment required to power and cool the IT equipment running those applications and services supporting our remote work solution. It does not include the IT hardware (servers, storage equipment and networking equipment) required for those applications and services).
  - As with Dell office facilities and for the same reasons, we will consider only operational energy consumption and greenhouse gas emissions.
  - Only those data centers hosting IT equipment relevant for this study will be considered.
  - Data center energy consumption and emissions pertinent to this study will be calculated as an 'uplift' to the calculated IT power consumption. This uplift will be determined by multiplying an average Power Usage Effectiveness (PUE) for the data center (subtracting 1 to account for IT

power consumption) by an emissions factor appropriate for the facilities' location and the percentage of non-renewable power purchased at that locations.

- Dell Enterprise IT Equipment
  - This category includes servers, storage equipment, networking equipment and any data center appliances required to support those applications and services relevant to the study.
  - In some cases, we anticipate having to apportion energy consumption and emissions from IT equipment based on the fraction of a piece of equipment that an application or service uses or the fraction of the use of the application or services that applies to remote workers, compared to on-site workers.
  - IT equipment emissions will be calculated from the IT energy consumption, as well as an emissions factor appropriate for the location of the host data center and the percentage of non-renewable power purchased at that location. Note that, in a number of cases, operational emissions may be minimal as many of our U.S. data centers purchase a significant fraction of their electricity through renewable sources.
  - Although previous studies have shown that, for enterprise servers, the majority of footprint occurs during product use, we are going to consider manufacturing footprint as well – for those servers (or other equipment) identified within the study to be additional (i.e. production required to support the initiative).
- Dell Office-based Equipment
  - This category includes additional equipment required for the initiative within the office environment. This predominantly includes networking equipment required at Dell sites to support employees that are not hardwired into the Dell network given the employees' predominantly remote status. We will be considering both operational and manufacturing footprint for this equipment.
  - Operational energy consumption and emissions from office-based equipment will not be included in calculations for the hosting office environment.
- Employee vehicles
  - While we expect the majority of impact from employees' vehicles to be operational, some evidence suggests that the manufacturing footprint of automobiles is a material fraction of an automobile's overall footprint. We will look into existing literature on automobile product carbon footprint to determine if this is material to the study.
  - For the business-as-usual case, we will assume that those employees relevant to the study would have been commuting to Dell roughly 20 days per month.
  - The number of commutes reduced through the remote work initiative, as well as the average distance per commute and expected vehicle miles driven per gallon of gasoline will be calculated from a survey of Dell employees to be conducted during the first and second quarters of Dell's FY16.
- Employee home and appliances
  - We expect heating and cooling equipment to be the predominant drivers of energy consumption and associated carbon emissions when the employee is working from home. Accordingly, we will be looking at operational energy consumption of this equipment. As we

have neither a model nor data on wear-and-tear on this equipment as a result of greater employee presence at home, we will not be considering manufacturing footprint of these appliances.

  - We are partnering with Pecan Street, a research and development organization focused on residential energy consumption, to help us estimate the rebound effects on home electricity and energy use from remote work. We will also be looking to previous studies for guidance and information on these effects.

- 3rd-party outside networking and telecommunications equipment
  - There are potential rebound effects from the use of networking and telecommunications equipment to transmit data between the employee's home and the Dell network. We do not, however, have direct data on this usage. If we are able to estimate these rebound effects, it will have to be through data we can collect through prior work.

With this comprehensive list of potential effects, we can build a table that sorts these according to the type of effect (decrease, increase due to ICT, or increase due to rebound effects) and directness of effect (primary / direct or secondary / indirect). Table 10 provides the categorization of the effects to be considered within the study.

Table 9: Potential sources of energy use or emissions generation within solution boundaries

Energy use or emissions generation environment	Source of emissions	Potential effects
Dell office	Dell office electricity use	Potential decrease in Dell facility energy use due to reduced employee presence Potential increase in energy use due to increased number of employees supported per facility Potential decrease in facility lifecycle emission footprint through mitigation of new construction
Dell data center	Dell data center energy use Dell enterprise equipment manufacturing emissions	Potential increase in data center energy use due to increased employee use of data center resources (including power dist. and cooling) Potential increase in equipment lifecycle emissions due to purchase of additional ICT equipment
Employee Vehicle	Vehicle fuel use Vehicle manufacturing	Potential decrease in employee GHG emissions due to reduced use of vehicle by employee Potential decrease in lifecycle emissions due to less wear on employee vehicle Non-immediate increase in vehicle usage during business hours for local errands / trips Increase in air travel on behalf of employees who work for Dell but are not near a Dell facility
Employee Home	Home electricity use	Potential increase in home electricity use directly due to increased use of ICT equipment at home Potential increase in home electricity use or emissions due to increased use of appliances while at home (e.g., heating or cooling equipment)
3rd Party Outside Networking and Telecom	Communications equipment use	Potential increase due to increased usage of networking and telecommunications equipment

Table 10: Summary of potential effects of Work-at-home programs on carbon emissions

	Primary Effects	Secondary Effects
Enabling (decrease emissions)	Potential decrease in employee GHG emissions due to reduced use of vehicle by employee Potential decrease in Dell facility energy use due to reduced employee presence	Potential decrease in facility lifecycle emission footprint through mitigation of new construction Potential decrease in lifecycle emissions due to less wear on employee vehicle
Direct ICT emissions (increase emissions)	Potential increase in data center energy use due to increased employee use of data center resources Potential increase in home electricity use directly due to increased use of ICT equipment at home Potential increase due to increased usage of networking and telecommunications equipment Potential increase in equipment lifecycle emissions due to purchase of additional ICT equipment	*No material secondary direct ICT emissions*
Rebound (increase emissions)	Potential increase in home electricity use or emissions due to increased use of appliances while at home (e.g., heating or cooling equipment)	Non-immediate increase in vehicle usage during business hours for local errands / trips Increase in air travel on behalf of employees who work for Dell but are not near a Dell facility Potential increase in energy use due to increased number of employees supported per facility

Appendix B: Data Sources and Collectors

The most critical data sources for the study will be three distinct efforts looking at the commute patterns of Dell employees, rebound effects resulting from home energy and electricity use and the energy and emissions footprint of the IT applications and services required to support the program. We will supplement this with existing data on Dell facilities and publically-available material, including prior remote work studies.

Table 11: Data Sources and Related Greenhouse Gas Emissions Effects

Data Sources and Related Greenhouse Gas Emissions Effects
The Dell "Connected Workplace" Employee Study
Potential decrease in employee GHG emissions due to reduced use of vehicle by employee
Potential decrease in lifecycle emissions due to less wear on employee vehicle
Increase in air travel on behalf of employees who work for Dell but are not near a Dell facility
Rebound Effects from Home Energy Use (Pecan Street)
Potential increase in home electricity use directly due to increased use of ICT equipment at home
Potential increase in home electricity use or emissions due to increased use of appliances while at home (e.g., heating or cooling equipment)
Dell IT Remote Work Support Study
Potential increase in data center energy use due to increased employee use of data center resources (including power dist. and cooling)
Potential increase in equipment lifecycle emissions due to purchase of additional ICT equipment
Existing Dell facility data
Potential decrease in Dell facility energy use due to reduced employee presence
Potential increase in energy use due to increased number of employees supported per facility
Potential decrease in facility lifecycle emission footprint through mitigation of new construction
Publically-available reference material, including prior studies on remote work
Non-immediate increase in vehicle usage during business hours for local errands / trips
Potential increase due to increased usage of networking and telecommunications equipment

Appendix C: The Dell "Connected Workplace" Employee Study

The primary sustainability-related benefit expected from Dell's work from home program is reduced employee fuel consumption with associated reduced carbon emissions as a result of less travel to and from Dell. In order to calculate these benefits, we collected sample commute and vehicle data from a survey sent to 7500 Dell employees during the spring of 2015.

Once the survey data was collected, we were able to calculate average commute and emissions statistics across four distinct populations of Dell employees. This enabled us to estimate total and average vehicle commute emissions statistics across the entire Dell U.S. employee base.

Employee Commute and Vehicle Data Survey

Our survey instrument was sent to employees representing four distinct populations within the Dell U.S. employee base:

- Texas employees, designated as remote[5] workers
- Texas employees, not designated as remote workers
- U.S., non-Texas employees, designated as remote workers
- U.S., non-Texas employees, not designated as remote workers

The survey included questions about the employee's home location, commute patterns, commute transportation, as well as heating and cooling use while working from home. The survey asked about a number of different work locations, including:

- A Dell facility near the employee
    - This is the traditional work model
- A customer, supplier or partner location
    - This is also part of the traditional model and is most common for those employees with sales or services responsibilities
- The employee's home
- Other non-Dell locations
    - For example, a coffee shop, conference space, or shared office space
- Dell facilities outside the employee's local area

For each work location, the survey asked as to the number of days per month the employee worked at that location, as well as location and transportation data for sites other than the employee's home (which is resolved at the beginning of the survey).

[5] The 'remote' worker designation is a Dell H.R. flag for identifying those employees that are participating in a formal remote work program such as Dell's Connected Workplace initiative.

It is important to note that the sum of the total number of days worked at each site may be greater than the number of days the employee works in a month. This is a result of employees who work from more than one location during the business day.

The part of the survey focused on commuting transportation included questions as to the mode of transportation typically used by the employee, as well as information pertaining to the employee's personal vehicle – if it was used to commute to any work location.

Study Methodology

Calculating average mitigated emissions per employee over the Dell U.S. employee population is a two-step process:

1st For each of the four respondent populations, calculate the average greenhouse gas commuting emissions per respondent for both the current scenario (work-from-home enabled) and the baseline scenario (no work-from-home) from employee commute and vehicle data (Figure 1).

2nd For each of the four respondent populations, multiply the average respondent GHG emissions (reported, baseline and mitigated) by the number of employees in that population. Sum these, then divide them by the total number of Dell U.S. employees to calculate an estimate for the average employee's mitigated CO2e emissions (Figure 2).

In addition to our emissions calculations, we also needed to address two issues with the dataset. While a little under 1500 employees responded, not all of the returned surveys were completed. After incomplete responses were discarded, we were left with 1372 useful responses.

In addition, the initial survey request, sent to 5000 employees, did not identify respondents' 'remote' or 'non-remote' designation. In order to address this, we sent survey requests to an additional 2500 employees using several data collectors to keep responses from the different populations separate. From the second set of responses, we developed a model that would allow us to assign a remote designation to specific respondents from the first set. This model included a small set of criteria estimated to be 80% accurate on assignment[6].

The number of contacted employee population along with the number of respondents, is broken down into geography and designation in Table 12.

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[6] Respondents in the first dataset were designated as remote workers if they resided in a state without a nearby Dell facility, were Texas employees reporting that they worked from home 15 days or more a month, or non-Texas, U.S. employees reporting that they worked from home 10 or more days a month.

Table 12: Survey population and response data

Employee population	Total employee base[7]	Surveyed employees	Percentage of base surveyed	Total Respondents	Survey Response Rate	Response percentage of base population
Texas, non-remote	13138	2000	15.2%	443	22.2%	3.37%
Texas, remote	2838	1000	35.2%	216	21.6%	7.61%
U.S. (ex. Texas), non-remote	12247	2000	16.3%	259	13.0%	2.11%
U.S. (ex. Texas), remote	7114	2500	35.1%	454	18.2%	6.38%

Calculation of average GHG emissions per respondent by population

As mentioned earlier, the first step in the analysis process was to calculate the greenhouse gas emissions for each population's survey respondents. This includes not only the current greenhouse gas emissions given actually commute data, but also an estimate of emissions assuming employees were required to work at Dell.

The general approach to the calculation is shown in Figure 1. For each respondent, we calculated an annual commute distance to Dell, based on the number of monthly commutes reported by the employee and the one-way commute distance to Dell. We then divided that distance by a vehicle fuel efficiency number (miles per gallon). In many cases, survey respondents provided an estimate of the fuel efficiency of their vehicle. Where they did not provide an estimate, we used an average fuel efficiency across all respondents in the study[8]. To calculate average fuel consumption per respondent, we divided the total fuel consumption by the number of respondents in the population.

[7] These are the employee base population numbers used in the study, these numbers will change on a regular basis.

[8] Average reported fuel efficiency over all respondents was 23.1 miles per gallon.

Using a standard fuel emissions factor, we then calculated the average GHG emissions for the population[9]. We did not calculate either commute miles or emissions for those employees not using a personal vehicle to commute to work[10].

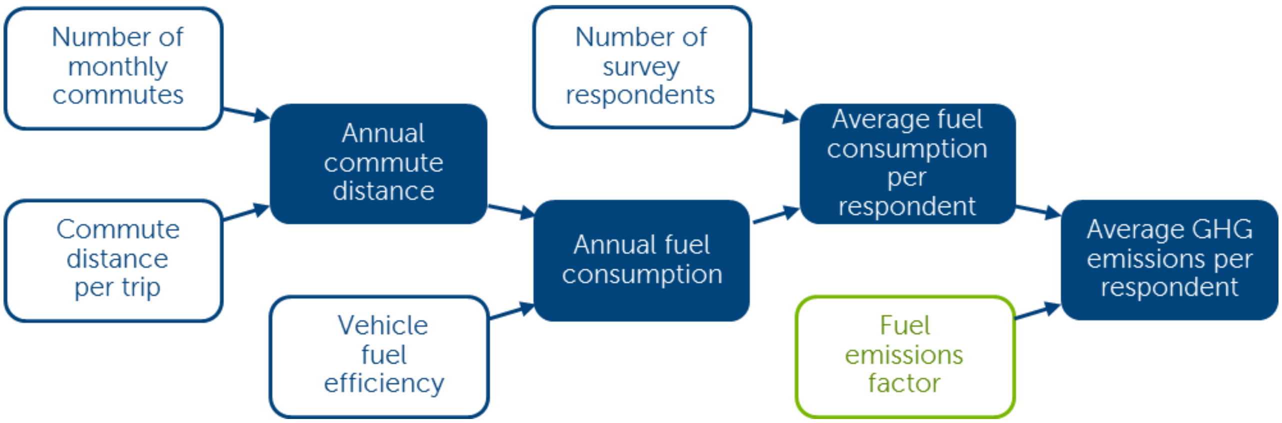

Figure 1: Calculation of average GHG emissions for a population and scenario[11]

To generate an estimate of the emissions that would be generated through the baseline scenario, we calculated an expected maximum number of commutes for each respondent, were they to have to commute to Dell for each workday. For those Dell employees identified as customer-facing, traveling to a customer, supplier or partner more than ten times per month, this number was identical to the number of commutes they reported in the current environment (i.e., we did not add any additional commutes for customer-facing employees). For all other employees, the maximum number of expected commutes under the baseline scenario was the number of workdays per month reported by the employee minus the number of days per month they were at a customer, supplier or partner facility.

[9] 0.00889 metric tonnes of CO_2e per gallon of gasoline (http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results)

[10] A small percentage of employees reported using either mass-transit or self-propelled means (biking, walking) to commute.

[11] For each diagram, elements in blue outline represent survey respondent information, elements in green outline are data from outside the study, elements in solid blue represent intermediate and final calculations

Table 13: Respondent fuel consumption and CO_2e emissions

Employee population	Average baseline fuel consumption (gallons)	Average baseline annual CO_2e emissions (metric tonnes)	Average reported fuel consumption (gallons)	Average reported annual CO_2e emissions (metric tonnes)	Average mitigated CO_2e emissions (metric tonnes)
Texas, non-remote	386	3.43	252	2.24	1.19
Texas, remote	420	3.74	41	0.36	3.38
U.S. (ex. Texas), non-remote	342	3.04	247	2.19	0.85
U.S. (ex. Texas), remote	321	2.85	12	0.11	2.74

Table 14: Population Commute Statistics

Employee population	Reported work days per month	Local Dell facility commutes per month	Work-from-home days per month	Other commutes per month[12]	Total commutes plus work-from-home days per month[13]
Texas, non-remote	19.6	14.2	7.1	1.3	22.7
Texas, remote	19.6	1.9	17.7	1.9	21.5
U.S. (ex. Texas), non-remote	19.5	14.3	6.1	2.1	22.5
U.S. (ex. Texas), remote	19.6	0.4	17.3	4.6	22.4
All, non-remote	19.6	14.3	6.6	1.7	22.6
All, remote	19.6	0.8	17.4	3.9	22.1
All U.S. Employees	**19.6**	**10.5**	**9.7**	**2.3**	**22.4**

[12] These commutes may be to a customer / supplier / partner facility, a remote Dell facility or a non-Dell location such as a coffee shop or shared conference space.

[13] This is typically more than the total number of work days in a month as some employees will work from more than one location in a given day.

Once we had specified an expected number of baseline commutes for employees, we followed the same procedure as for current commutes to calculate annual greenhouse gas emissions for the population. Average fuel consumption and emissions, as well as mitigated emissions, are listed for each population in Table 13.

In addition to emissions calculations, we also calculated additional results on the average number of commutes to each type of location addressed in the survey, on a per population basis, for all employees designated as remote workers, all employees not designated as remote workers, and the Dell U.S. employee base in its entirety. These results are presented in Table 14.

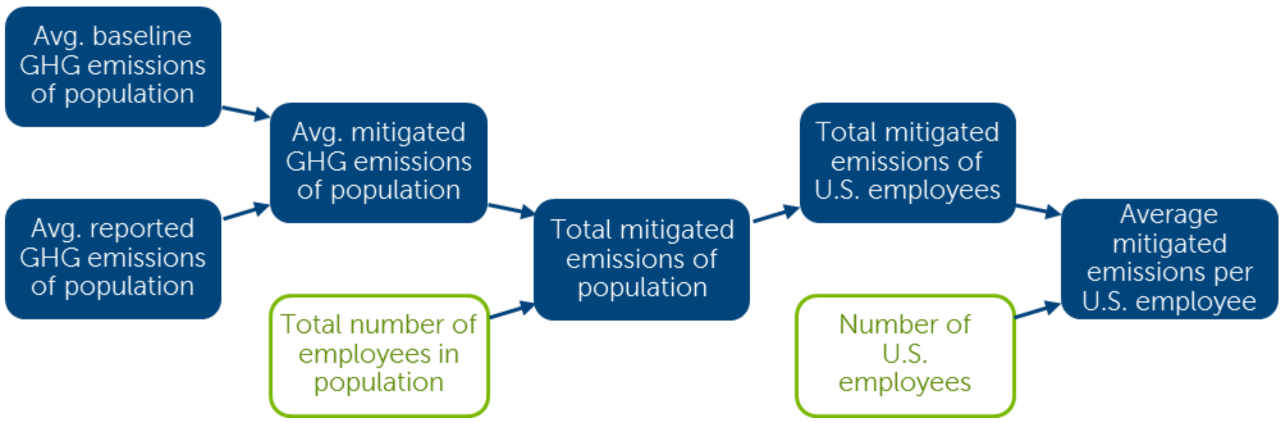

Figure 2: Calculation of average mitigated emissions for Dell U.S. employees

Calculation of average GHG emissions across Dell U.S. employee base

The second step in the analysis process was to use the data from the first step to calculate an estimate of the average mitigated emissions of the respondents in each population. We then multiplied this by the number of Dell U.S. employees in each population to calculate an estimate for the total mitigated emissions within that population. By summing across all populations, we then calculated an estimated for the total mitigated emissions over the entirety of the Dell U.S. employee base. Dividing this number by the total number of U.S. employees gave us an estimate of the average mitigated emissions per employee over the U.S. employee base. This process is described in Figure 2 and the resulting calculations are summarized in Table 15 and Table 16.

Table 15: Dell U.S. employee base fuel consumption and CO_2e emissions

Employee population	Average baseline fuel consumption (gallons)	Average baseline annual CO_2e emissions (metric tonnes)	Average reported fuel consumption (gallons)	Average reported annual CO_2e emissions (metric tonnes)	Average mitigated CO_2e emissions (metric tonnes)
Texas, non-remote	5,070,000	45,000	3,306,800	29,400	15,600
Texas, remote	1,190,000	10,600	115,600	1,030	9,600
U.S. (ex. Texas), non-remote	4,190,000	37,300	3,021,400	26,860	10,400
U.S. (ex. Texas), remote	2,280,000	20,300	85,400	760	19,500
All Dell U.S. Employees	**12,730,000**	**113,200**	**6,529,200**	**58,040**	**55,150**

Table 16: Dell U.S. employee average baseline, reported and mitigated emissions

Employee population	Baseline CO_2e Emissions (metric tonnes per employee)	Annual CO_2e Emissions (metric tonnes per employee)	Mitigated CO_2e Emissions (metric tonnes per employee)
Texas, all	3.48	1.90	1.58
U.S. (ex. Texas), all	2.97	1.43	1.55
All U.S. Employees	**3.20**	**1.64**	**1.56**

Appendix D: Automotive Lifecycle Emissions

A complete picture of the relationship between automobile emissions and employee commuting requires not only a calculation of the emissions resulting from fuel use, but also the mitigated emissions from automobile manufacturing occurring as a result of reduced vehicle wear-and-tear.

The calculation of mitigated automobile manufacturing emissions is fairly straightforward. From the Dell employee commute data analysis, we have an estimate of the mitigated travel distance. If one assumes a service lifetime for the automobile measured in miles, then the mitigated emissions are the fraction of the mitigated miles over service lifetime miles times an estimate of the greenhouse gas emissions generated during manufacturing of the vehicle.

Specific numbers for manufacturing emission s by model type were hard to find. A Carbon Trust study in 2011, though, suggests 6 metric tonnes per vehicle is a reasonable estimate (Carbon Trust, 2011). Similarly, data on average vehicle service life in miles is hard to find. High-level estimates, however, range around 200,000 miles per vehicle (Ford, 2012). With these numbers, and an estimated reduction in commute-related travel by employees, we estimate savings of 0.12 metric tonnes of CO_2e per employee from reduced vehicle usage.

Table 17: Calculation of mitigated automobile manufacturing emissions

Automobile manufacturing emissions	6 metric tonnes per vehicle (Carbon Trust, 2011)
Average avoided vehicle travel per employee per year	3850 miles per vehicle
Average automobile service life	200,000 miles per vehicle (Ford, 2012)
Percent of automobile service life	1.9%
Mitigated automobile manufacturing CO_2e	**0.12 metric tonnes per employee per year**

Appendix E: Rebound Effects from Home Electricity Use

To estimate the rebound effects associated with home electricity use, Dell contracted with the Pecan Street Project to provide an estimate based on Pecan Street's residential energy use dataset and a dedicated survey to Pecan Street participants. This work was conducted during the spring and summer of 2015.

Annual Emissions Estimation

Twenty-five of Pecan Street's residential participants responded to their survey, with a mix of work-from-home patterns. For each of the responding participants, Pecan Street looked at residential energy data over a full year, from June 1, 2014 through May 31, 2015. From this data, Pecan Street concluded that for an average participant, working from home resulted in an increase in electricity usage of 6.34 kWh per day worked.

The study also attempted to look at other potential energy use. The most common energy source aside from electricity was natural gas. This was predominantly used for heating during colder weather. Pecan Street could not find a statistically significant increase in natural gas use as a result of work-from-home for their participants.

To calculate a per employee number, we multiplied the average number of work-from-home days per month per employee by the expected uplift in home electricity consumption. We then converted this to an annual number and multiplied by an EPA emissions conversion factor for electricity use to get to an annual estimate for additional emissions.

Key Assumptions and Concerns

While Pecan Street's data applies to Dell employees in Central Texas, we are using the data as if it applied nationally. Data from the U.S. Energy Information Administration (U.S. Energy Information Administration, 2013) suggests that home electricity usage in Texas averages around 14,000 kWh per year, while the U.S. average is around 11,000 kWh per year. It should be noted, however, that all home **energy** use (excluding transportation) in Texas is about 14% less than the national average.

In order to calculate an average for all employees across the U.S., we calculated a total additional kWh for all Texas employees and for other U.S. employees separately. We then multiplied the U.S. number accordingly to compensate for the additional expected energy use. This led to a final number of **0.44 metric tonnes of CO_2e per employee per year**.

Appendix F: Dell IT Remote Work Support Study

To understand the impact of Dell's work-from-home initiatives from an IT perspective, we have to consider three primary environments – employee residences, Dell offices, and Dell data centers. For each of these environments, we can look to the basic IT commodities of compute power, storage and networking to identify potential impacts.

Table 18: Potential increases in manufacturing and operational greenhouse gas emissions

Environment	Compute power	Storage	Networking
Employee residence	*Work-related desktops, laptops or other client systems*	*N/A*[14]	*Personal routers and cable modems* ISP networking equipment
Dell office	*Work-related desktops, laptops or other client systems*	*N/A (see above)*	*In office wireless routers, access points and networking equipment*
Dell data center	Data center servers	Storage systems	Data center networking equipment

We believe the items noted in italics can be neglected as immaterial to this study. This includes emissions resulting from client systems, storage in client systems or personal routers and cable modems. From a manufacturing perspective, work-related client systems are issued to Dell employees regardless of work location. In addition, the operational energy use and associated greenhouse gas emissions of these products is included in the residential energy consumption data from Pecan Street. Similarly, emissions resulting from the use of personal routers and cable modems would either be incurred regardless or are considered within the residential data. Emissions resulting from client storage are included in the client systems (desktops, laptops, tablets, phones). So, these can be neglected as well.

In addition, discussions with individuals in Dell's IT organization suggest that the effect of work-from-home on office environment networking equipment is negligible. While it is the case that hoteling employees (who would otherwise work from home) do make greater use of office networking equipment, the process of engineering a solution to increase office network bandwidth resulted in identifying inefficiencies in the previous networking implementation. Net: addressing the inefficiencies in the legacy networking environment provided the additional capabilities needed with no meaningful net change in hardware.

[14] In almost all cases, storage used for client systems is part of the client system.

This leaves four types of solution components as items of interest: servers, data center storage equipment, data center networking equipment, and 3rd-party / ISP networking equipment. The first three components are part of the data center, while the latter is the communication system enabling data transfer between the data center and remote worker's location.

Estimating data center footprint

The challenges of data collection

Surprisingly, estimating the impact of IT has been the most difficult task within all of our studies of IT-based solutions. IT, as an industry, has built significant capabilities around measuring the footprint of an entire data center. When looking at the part of a data center focused on a specific solution, however, there is very little prior art, and what does exist is highly proprietary.

Initial investigations into the IT footprint associated with work-from-home provided some data. A complete dataset, however, proved difficult to build. Some of the challenges include:

- Identifying applications or services that see a change in use based on worker location
- Measuring the usage of relevant applications or services
- Measuring the portion of an application or service used by remote workers that is shared with other solutions
- Accommodating the variety of hosting models possible for applications or services, including those applications hosted within virtualization environments
- Estimating usage of storage or networking equipment that supports relevant applications and services but is shared with a large number of other solutions

Despite the difficulties in data collection, however, a number of discussions internal to Dell have suggested that the impact, from an IT perspective, is very small. So small, in fact, that the IT professionals interviewed considered the impact to be immaterial from the data center's point-of-view – i.e. too small to measure.

General modeling approach

Difficulties aside, unless we have a model that estimates relative size of the impact, we're not going to have full confidence that the overall solution is Net Positive from an environmental perspective. As a result, we will take an approach whereby we look to identify a maximum expected footprint. We will then compare this to the overall benefits to assess whether or not IT impact is material to the overall analysis.

The first step in the process is to identify known applications or services that see different usage patterns, based on an employee's work location[15]. We'll then investigate those applications to put an upper bound on application impact. This will include either identifying or estimating the number of servers required to support these apps and services. This is, in part, determined by the relationship between the application or service and the IT solutions, as well as the relationship between the application or service and the underlying hardware on which it is hosted.

Once we know the relationship between deployed servers and those key applications and services supporting the IT solution, we can then estimate the energy consumption of the supporting IT equipment. Once we have server energy estimates, we'll use existing energy consumption profiles for data centers to estimate power required for storage and networking systems. Then we can use information on a data center's Power Usage Effectiveness (PUE) to add the uplift resulting from power and cooling infrastructure.

Last, we'll convert the energy data to emissions data using internal data on energy purchases to get an overall impact.

Identification of applications and services supporting Dell's work-from-home initiatives

With respect to work-from-home initiatives and capabilities, we believe that only a small number of types of applications are relevant:

- Applications and services that provide, manage and control access to the Dell network from outside the Dell network
- Applications and services that enable or support employee communication, including e-mail and phone services

To identify applications and services relevant for the Connected Workplace study, we started with an interview of individuals associated with project management for deployment of the program. This identified SonicWALL Secure Mobile Access and Aventail Connect as Dell's primary solution for enabling employees secure access to Dell IT applications and services from outside the Dell firewall. Dell's SonicWALL / Aventail solution provides employees outside the Dell firewall secure access to applications and services inside the Dell firewall through a Virtual Private Network (VPN).

Dell uses Microsoft Exchange as its primary mail server, Outlook as its email client and personal information manager, and Lync as its primary communications server. During interviews with representative from Dell IT, we determined that, of the three of these applications, Lync is likely the only application that sees a difference in use based on employee location.

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[15] We are defining 'Applications' as those programs used directly by the employee. 'Services' are programs with which the employee does not directly interact, but which provide features and capabilities required by other applications and services.

While there are likely to be other applications that see some change in use based on employee locations, SonicWALL / Aventail and Lync are the most commonly used by Dell employees. We are comfortable that, in focusing on these, we are measuring the majority of the impact.

These two applications, however, must be treated differently. Our VPN solution (SonicWALL Secure Mobile Access with Aventail Connect) is explicitly to support remote access to the Dell IT environment. Lync, however, is used both by employees working remotely and employees working on site. In addition, some of the use of Lync while an employee is remote would have been required regardless of employee location. For example, an employee who uses Lync to communicate with a vendor or supplier could be either remote or on premises.

Dell work-from-home footprint associated with SonicWALL Secure Mobile Access

Whereas Dell IT's overall SonicWALL Secure Mobile Access (SMA) implementation is comprised of approximately 50 appliances, 21 are used for direct support of our work-from-home programs for U.S. employees. The balance includes appliances supporting our EMEA and APJ employee populations, as well as supporting development and customer-facing activities. We will count all 21 of these for footprint.

In addition to the emissions from use of the product, however, we must also look at the emissions generated as a result of product manufacturing and logistics (moving product from point of manufacture to point-of-use inside Dell). The closest comparative data we have on manufacturing-related emissions is product carbon footprint data resulting from an analysis of a 12th generation 2U Dell server (Stutz, Comparing the Carbon Footprints of 11G and 12G Rack Servers from Dell, 2013).

In addition, for proper accounting we have to amortize the manufacturing and logistics phase emissions over the expected lifetime of the product. Based on the original study, we will use an expected service lifetime of four years – though in many cases, for data center appliances, service lives are significantly longer.

Calculating an upper bound for data center footprint associated with Lync

Supporting employee communications is, obviously, another important enabler of work-from-home. Dell's end-to-end internal solution for Unified Communications is Microsoft Lync 2013[16].

Estimating the percentage of Dell's Lync implementation that is driven by our Connected Workplace and related work-from-home initiatives is tricky. Most conversations and messaging, even those occurrences where one or more participants are working remotely, would be managed through Lync regardless. In some cases, a conversation enabled by Lync would be managed in person if the participants were working in relative proximity. This, however, is a small fraction of all usage.

[16] As of April 2015, Microsoft Lync is Skype for Business.

Regardless, we still need to provide an estimate in order to assess overall footprint. So, for purposes of this exercise, we will assign a percentage of Lync usage equal to the average percentage of employees who are working remote at any time. In other words, we will assume that *all* Lync use by remote employees is driven by work-from-home.

To calculate this, we will allocate a percentage of the footprint that is commensurate with the rate at which Dell U.S. employees work remote (roughly 9.7 times per month). This will be a very conservative estimate as the majority of employee interactions with Lync are not driven by employee location. Employees only use Lync's remote communications and messaging capabilities as a substitute for in-person conversations or engagements.

So, in order to get an estimate for the footprint associated with Lync and our work-from-home initiatives, we'll use the following process:

- Identify an appropriate equipment set for a 5000 user Lync solution deployment using a standard Dell reference architecture (Dell, 2015)
- Calculate annual energy consumption for equipment set using Dell's Energy Smart Solution Advisor tool (Dell, 2014)
- Apply appropriate emission factor to determine CO2 impact
- Scale solution for Dell U.S. employee population
- Estimate percentage of application use driven by Dell work-from-home initiatives
- Calculate estimated emissions footprint for Lync part of solution

The Dell reference architecture for Lync for a 5000 user deployment leverages Dell's PowerEdge R630 and R430 servers (Dell, 2015) in addition to other components. This equipment is typical of rack-mounted servers deployed in data centers. As the reference architect includes a complete solution inclusive of server, storage and networking components, we will not have to develop a separate estimate for usage of these resources. As we calculate results for this solution, we will multiply by eight to approximate the equipment required for a population of the size of the Dell U.S. employee base[17].

To estimate manufacturing and logistics-related carbon emissions, we will use the per-server footprint used for the SonicWALL appliances. While this is not ideal comparison, it should provide a rough estimate and, in any event, we are looking to establish an upper bound on footprint.

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[17] Scaling up the 5000 user solution provides a conservative estimate for footprint. A solution engineered specifically for 35,000 to 40,000 users would likely require a smaller equipment set.

Table 19: Estimation of work-from-home-related carbon emissions resulting from IT applications and services

SonicWALL Secure Mobile Access:	
Number of supporting appliances	21
Expected annual energy consumption of appliances	~54,000 kWh
Expected annual carbon emissions (CO_2 equivalent) from operation	30.45 metric tonnes CO_2e [18]
Expected annual manufacturing and logistics related carbon emissions ($CO2_e$)	16.49 metric tonnes CO_2e
Total SonicWALL-related carbon emissions	46.94 metric tonnes CO_2e
Lync:	
Number of servers	35
Number of data center networking and storage systems required	28
Expected annual energy consumption of implementation	~196,900 kWh
Expected annual carbon emissions (CO_2 equivalent) from operation	110.6 metric tonnes $CO2_e$
Expected annual manufacturing and logistics related carbon emissions ($CO2_e$)	49.5 metric tonnes CO_2e
Average number of work from home days per month for Dell U.S. employees	9.7 (out of 20 maximum)
Work-from-home Lync-related carbon emissions (48.5% allocated)	77.30 metric tonnes CO_2e
Total application-related carbon emissions	**124.24 metric tonnes CO_2e**
Annual application-related carbon emissions per Dell U.S. employee	**0.0035 metric tonnes CO_2e per Dell U.S. employee per year**

Summary of application footprint

Table 19 provides a summary of the estimates and calculations for the IT-related emissions from deployment and operation of both SonicWALL and Lync. Even taking into account the very conservative assumptions with respect to model parameters and assignment of Lync usage, the total emissions are still very small. The final results, under 4/10ths of 1% of a metric ton of CO2 per year per employee is significantly below the benefits employee see from commuting. The conclusion is that, while IT footprint should not be neglected, it is overall immaterial to the final results of the study.

Estimating communications footprint

The last component of IT footprint to be measured as part of this study is the communications infrastructure that enables information to move between the data center and the location from which an employee is working. While specific information on data transfer between data centers and residences is not available, there is general information as to the energy intensity of network traffic. Since 2011, AT&T has been measuring and reporting on this metric as one of its key Energy Management performance indicators (AT&T, 2015). For 2014, AT&T reported an energy intensity of 189 MWh per Petabyte of network traffic.

To calculate an estimate of data networking footprint, however, we'll also need an estimate of the amount of data traffic driven by remote work. Once again, we can investigate this through Microsoft Lync.

Microsoft recommends that, to ensure optimal media quality, Lync deployments should be provisioned with 65 kilobits per second (Kbps) per expected audio stream and 500 kilobits per second per expected video stream. This information, combined with a Lync use model for the average Dell employee[19], gives an expected annual energy footprint for network traffic of 142 MWh / year.

Summary of emissions results

The sum of the two impact categories is provided in Table 21. Together, application-related and network-related emissions are a little over six-thousandths of a metric ton of CO_2-equivalent per Dell U.S. employee per year.

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[18] Based on U.S. average of 5.62×10^{-4} metric tonnes of $CO2_e$ per kWh.

[19] The employee use model is based on an average of 48% of Dell U.S. employees working remotely, with an 8 hour per day workload, 240 workdays per year, using audio streams during 40% of the workday and video streams during 5% of the workday (conservative estimates).

Table 20: Estimation of annual network traffic emissions footprint

Expected annual data transfer requirements for Lync for Dell U.S. employees	752 Terabytes / year
Network energy intensity (AT&T, 2015)	189 MWh / Petabyte
Annual carbon emissions from network traffic	78.8 mT $CO2_e$
Annual carbon emissions from network traffic per Dell U.S. employee	**0.0022 metric tonnes CO_2e per Dell U.S. employee per year**

Table 21: Estimation of overall annual IT footprint

Annual application-related carbon emissions per Dell U.S. employee	0.0035 metric tonnes CO_2e
Annual carbon emissions from network traffic per Dell U.S. employee	0.0022 metric tonnes CO_2e
Total annual IT-related carbon emissions	**0.0057 metric tonnes per employee per year**

Appendix G: Dell Facilities Savings from Remote Work Initiatives

For companies the size of Dell, a real estate portfolio is a constantly varying list of facilities. In addition, any given facility may be owned or leased, acquired by direct purchase or brought on board through an acquisition. Similarly, facilities may be frequently sold, left or sub-let. This makes analysis of the savings resulting from changes in a real estate portfolio occurring as a result of Dell's work-from-home initiatives a challenging task. That being said, one particular Dell real estate transaction stands out as having a direct relationship to Dell's work-from-home initiatives.

In calendar year 2013, Dell divested itself of Building 1 on its South Parmer campus in Austin, Texas. This building was comprised of 320,000 ft^2 of various spaces, including office and lab facilities. This single transaction makes up slightly more than half of the total square footage Dell has divested during the work-from-home initiative. We believe that by focusing on this facility for our energy savings calculations, we will be providing a conservative lower-bound for the full figure.

During the last full year in which PS1 was fully occupied, fiscal year 2011, energy consumption for this facility was approximately 7.7 million kWh. Allocated over the Dell U.S. employee base, this gives an estimated savings (lower-bound) of **0.121 metric tonnes of CO_2e per employee per year**.

Appendix H: Notes on the BT and Yankee Group / ACEEE Telecommuting Studies

This section provides a closer look at two existing studies which influenced our work on the Sustainability Benefits of the Connected Workplace. Although our methodology differed from that which was used in these prior studies, they are presented in this appendix as a basis for comparison.

In 2012, the Global e-Sustainability Initiative commissioned a study which took a novel approach to quantifying the regional energy reduction potential of eight broadband-enabled consumer activities. Telecommuting is one of the activities included in the study. The energy reduction potential of each activity was evaluated independently of the others, allowing us to limit our research to the sections concerning telecommuting. The study itself was a joint effort between the Yankee Group and the American Council for an Energy-Efficient Economy.

Two years after publication of the Yankee Group / ACEEE study, British Telecom released a similar report on their methodology for quantifying the greenhouse gas reduction potential of their products and services. This report is supplementary to BT's Net Good goal which states that by 2020, BT's products and services will enable customers to reduce carbon emissions by at least three times the end-to-end carbon impact of BT's business. Much like in the Yankee Group / ACEEE study, telecommuting is one of several ICT enabled solutions independently analyzed in the report.

BT referenced the Yankee Group / ACEEE study as the source of the methodology used in their report. For this reason, the methodology and results of BT's study are discussed here in context of the methodology and results from the Yankee Group / ACEEE study.

Yankee Group / ACEEE Methodology

At a basic level, the calculation model of the Yankee Group / ACEEE study includes a set of ten key variables which could either positively or negatively impact the energy reduction potential of telecommuting. Each variable was assigned a range of possible values, and a corresponding set of formulae relate these values to an expected change in energy consumption. The range of values assigned to each variable was selected based on a mix of Yankee Group survey data, publicly available statistics, prior studies, and expert opinions. The Yankee Group's survey on consumer broadband-related activities queried more than 1,000 consumers across two regions of interest, the United States and the EU-5.

The Yankee Group performed a Monte Carlo analysis through 10,000 model iterations, randomizing the key variables according to their identified low, mid, and high values. By doing so, they arrived at low, mid, and high values for the energy reduction potential of telecommuting in the two regions studied.

BT's Modifications to Existing Methodology

BT's study on telecommuting followed a methodology similar to that used by the Yankee Group/ACEEE, with only slight modifications to data inputs to reflect a more focused geography. The scope of BT's study was BT-enabled telecommuters in the UK. BT applied a fairly loose definition to the term “BT-enabled telecommuting” which includes all telecommuters wherever BT provides a physical broadband line, even if BT is not the end service provider.

The Monte Carlo analysis was used to arrive at a per-telecommuter emissions reduction factor. This factor was multiplied by the number of BT-enabled telecommuters in the UK to arrive at an estimated emissions reduction potential that can be attributed to BT.

Accounting for Rebound Effects

The Yankee Group took steps to account for two commonly identified rebound effects of telecommuting: increased home energy use, and increased vehicle use for personal errands during the workday. This was accomplished through the inclusion of home energy use and personal trip deflator variables. These deflator variables produce an opposite effect compared to the other eight variables, effectively eroding the energy reduction achieved through reduced commuting miles and energy use. The Yankee Group assumed, based on TIAX, that personal trips could erode commuting savings by 15 to 50 percent. They also assumed that increased electricity use per home as a result of telecommuting could range from 15 to 50 percent of business consumption.

Since BT used the same methodology to compute their results, rebound effects of increased home energy and personal vehicle use are automatically accounted for in their study. BT did not expand their study to include additional effects.

Results of Both Studies

BT determined the expected annual energy savings due to telecommuting to be 0.95 metric tons CO_2e per telecommuter. These results are specific to BT-enabled telecommuters in the UK, meaning the geographic scope of the BT study is not entirely consistent with our own. However, their results, which are normalized per-telecommuter, are easily comparable to the results from the Connected Workplace study.

The Yankee Group/ACEEE presents their estimated energy savings due to telecommuting in units of million barrels of oil equivalent. They provide separate figures for the EU-5 and the US. Since the Connected Workplace study is focused on US-based Dell employees, we are most concerned with the US results. The Yankee Group/ACEEE study found that for the average case, telecommuting could lead to annual energy savings of 214.6 million barrels of oil equivalent in the US. This is significant as it is equivalent to a little under 20 million metric tonnes of CO_2e per year.

While interesting, the results from the Yankee Group study are not easily compared to our Connected Workplace study. Their results are based off a large set of Monte Carlo simulations that are, in turn, leveraging a chart of expected low, medium and high estimates for a number of factors deemed material to telecommuting impact. As such, this is a model of combined impact, as opposed to a measurement of actual individual impact. It is interesting to note, however, that the Yankee Group’s assumptions with respect to the rebound effects of home electricity use and personal trips taken during the day are similar to the findings of our study.

Appendix I: Other Studies

The Energy and Greenhouse Gas Emissions Impacts of Telecommuting and e-Commerce

About the Report

This report was commissioned by the Consumer Electronics Association (CEA) in 2015 as an update to a nearly identical study conducted by TIAX in 2007. It is of particular interest to us because its analysis of telecommuting is more granular than what we found in many similar studies. In addition to the typical variables considered in a telecommuting study, Fraunhofer took into account lighting and HVAC energy use, printing and paper impacts, and reductions in building floor space. Since we are not including all of these variables in our study on the Connected Workplace program, it is beneficial for us to see them analyzed in this study, in some cases providing more solid grounds for us to consider them immaterial.

On the downside, this report is lacking in a clear description of methodology. Intermediate values are provided, data sources are cited, and the overarching premise of "lifecycle analysis" is explained. However, much is left to be assumed when it comes to the details behind the calculations. This report is useful in influencing how we treat certain variables, and provides some intermediate and final values which we can compare to our own. Yet, it is clear that our methodology differs significantly from theirs, limiting the usefulness of certain comparisons.

Scope of the Study

The geographic scope of the study is the U.S. Telecommuting system boundaries include commuting vehicle-miles traveled (VMT), personal VMT, home and office ICT energy, home and office lighting energy, home HVAC energy, and reduced office floor space.

Summary of Methodology

The environmental impact of telecommuting was analyzed separately for a number of different cases. The average frequency of telecommuting was varied between 1 and 5 days per week. In the case of 3, 4, and 5 times per week, an additional "organizational" case was analyzed, where telecommuting leads to actual reductions in office building floor space.

Fraunhofer used data from the 2009 National Highway Transportation Survey (NHTS) (Although I'm pretty sure this is the National Household Travel Survey). Their analysis focused on people who worked from home an average of at least one day per month. They sorted these people into five bins: 1-5, 6-10, 11-15, 16-20, and 20+ days per month. For each bin, they evaluated the average daily VMT for the telecommuting and non-telecommuting cases. For analysis of home energy consumption, data from the 2012 DOE/EIA Residential Energy Consumption Survey was used.

Appendix J: Zhu and Mason Study on the Impact of Telecommuting on Personal Vehicle Usage

Of all of the prior work on the sustainability benefits of telecommuting, one study stood out with a contrary conclusion challenging the claim of positive environmental benefit. This is a 2014 study conducted by Pengyu Zhu and Susan Mason at Boise State University (Zhu & Mason, 2014). The study concluded

Study Background and Methodology

The Zhu Mason study used data from the 2001 and 2009 National Household Travel Surveys to estimate the relationship between telecommuting and vehicle miles traveled during a day (U.S. Department of Transportation, Federal Highway Administration, 2009). The NHTS provides an inventory of the nation's daily travel. Surveys included a list of trips taken on one randomly chosen day over a one-year range. For each trip, the respondents were asked to provide data on that trip, including, but not limited to, the purpose of the trip, as well as time the trip took place, mode of transportation and trip length. Each survey also requested additional household data, but did not ask for specific locations, costs of travel or specific routes.

Zhu and Mason then identified a number of different factors that could affect vehicle miles traveled in order to isolate any differences resulting from whether or not the respondent was a telecommuter.

Study Conclusions

The conclusions from the Zhu Mason study were strikingly different from the majority of other studies looking at telecommuting and greenhouse gas emissions. Their primary finding was that, based on the 2009 survey data, the marginal effect of telecommuting was to increase vehicle miles travelled by 45.3 miles per day. Further calculations from their study estimated that the median telecommuter drove **over 16,000 miles more per year** than the media non-telecommuter in 2009, with over 90% of that figure being attributable to travel to/from work, or work-related business travel.

Concerns

While our sample size is much smaller than that of the NHTS, our results are in significant opposition to the conclusions of Zhu and Mason. Using Zhu and Mason's threshold of defining telecommuters as those employees commuting one or more times per week, we estimate ~68% of all Dell U.S. employees are telecommuters. In addition, the data from our employee survey suggests an average **reduction of ~3550 commute miles per year** as compared to those Dell U.S. employees not considered to be telecommuters. Notably, however, this is strictly personal vehicle miles travelled and does not include modes such as air travel or mass transit. Our study also does not include additional personal trips employees may take as a result of the flexibility afforded to them through Dell's support for remote work.

Key Takeaways

The NHTS data on which the Zhu Mason study is based is very comprehensive. Parts of Zhu and Mason's analysis, however, includes assumptions that are not supported by our survey data. Other parts of the analysis, in addition, may be looking at data that is not pertinent to the Dell employee study.

The relationship between telecommuting and commute distance

One example is the potential relationship between telecommuting and distance from work. Zhu and Mason describe this potential as an endogeneity problem with the telecommuting status variable. In addition, Zhu and Mason did not look at how the frequency of telecommuting over-and-above the threshold of one day per week affects results.

In looking at the Dell employee data, we find that we can support a conclusion that there is a relationship between commute distance and frequency of telecommuting. In addition, not only does our sample suggest the relationship, but it shows results very similar to the daily work-related trip data from Zhu Mason.

Table 22: Comparison of Dell and Zhu Mason VMT results

Meets Zhu-Mason threshold for telecommuting (one or more days per week)	Daily work-related vehicle miles travelled per Zhu-Mason (2009 survey data)	Average daily commute distance (Dell U.S. employee sample)
No	28.2 miles	32.2 miles
Yes	39.5 miles	41.5 miles

We do not believe, however, that our results establish a causal relationship. It is possible that, in the long-term, employees considering a move in residence will be more likely to consider a location further from their office if they are allowed to telecommute. In addition, it is also very plausible that a longer travel distance between the employee and their office incents increased adoption of telecommuting. Without additional specific work in this area, we cannot size any rebound effects resulting from this; further work will be required. In addition, even with longer travel distances, whether the net effect is positive or negative will depend on remote work frequency. In the extreme case, where the employee never needs to work in the office, total commute travel is zero, regardless of commute distance.

In addition, the relationship between telecommuting and commute distance suggests that there may be a break-even point for telecommuting activity. In other words, in order for telecommuting to be beneficial from an employee carbon emissions point-of-view, the employee may need to meet / exceed a threshold for number of work-from-home days per month. Using the Dell employee statistics above, we can estimate expected vehicle miles travelled as a function of work-from-home days and compare that to the expected vehicle miles travelled for the non-telecommuting worker.

Figure 3 is a scatter-diagram that shows estimated vehicle miles travelled (VMT) to and from work for those Dell employee survey respondents who were not identified as customer-facing, who provided commute distance data and who identified their primary commute transportation as a personal vehicle. We have overlaid the scatter diagram with a line denoting the average monthly commute VMT.

As expected, the Dell survey data shows that, despite the fact that there seems to be a relationship between frequency of telecommuting and commute distance, VMT goes down as telecommuting increases.

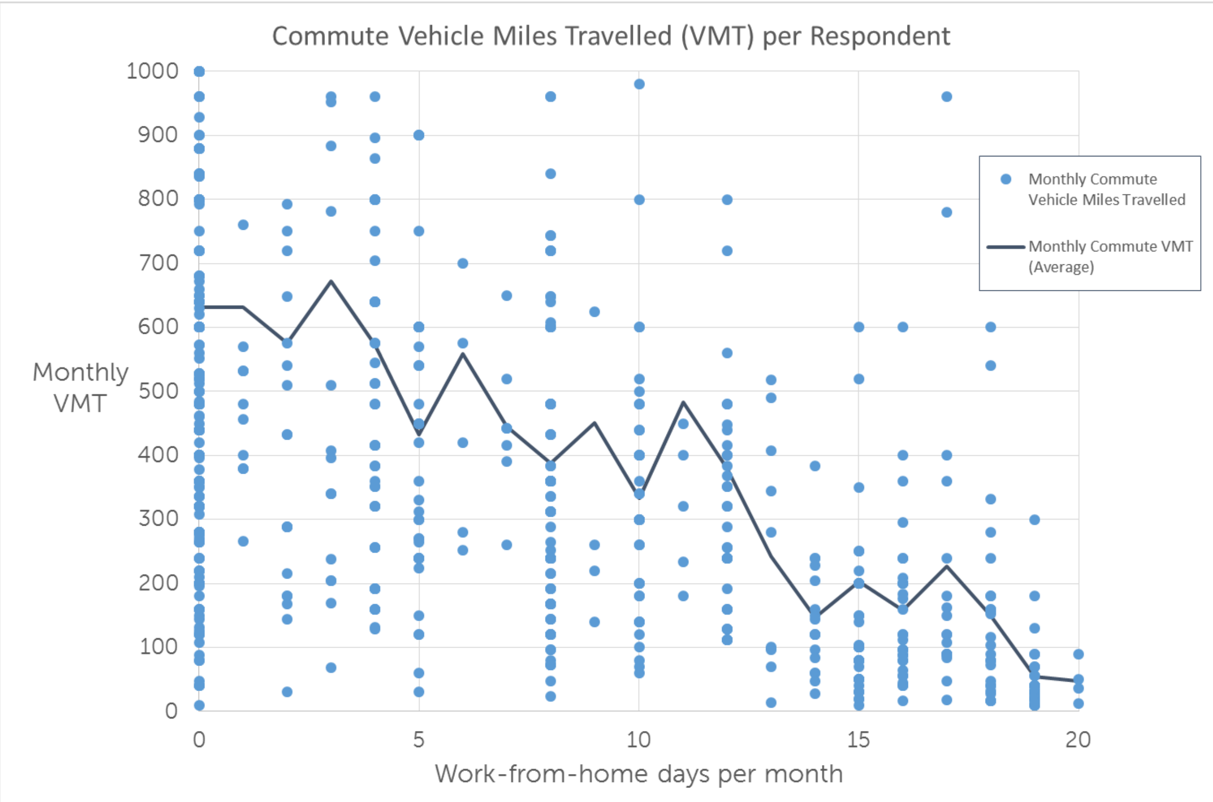

Figure 3: Commute Vehicle Miles Travelled by Respondent

The relationship between telecommuting and additional non-business-related travel

Analysis of the Zhu Mason study also suggests that those employees that telecommute are more likely to take non-business-related trips on work days than non-telecommuting employees. This is also plausible and is, in fact, a stated benefit from a human resources perspective. Allowing employees greater flexibility in their schedules affords them opportunities to improve their work-life balance.

Table 23 shows a comparison of the percentage of survey respondents reporting various types of non-business-related travel. Three specific types of trips look significant: shopping, other family / personal business and other social / recreational. Note, however, it is not possible from the Zhu Mason study to extract out data from those days that were not work-days (i.e. weekend days for those workers with Monday-to-Friday schedules).

Table 23: Frequency of non-business-related trips (based on 2009 survey data)

Type of trip	Observed non-telecommuters reporting trip	Observed telecommuters reporting trip
Shopping	34.7%	**38.3%**
Other family/personal business	31.6%	**37.5%**
School/church	7.9%	6.7%
Medical/dental	4.5%	5.1%
Visit friends/relatives	9.9%	9.5%
Other social/recreational	28.2%	**36.0%**
Any non-business-related trip	**67.6%**	**74.1%**

Accordingly, while we believe there is, in fact, extra non-business travel associated with working from home, it is a challenge to estimate the rebound effect. But the data suggests that the number of these trips are material and must be considered.

To calculate the potential rebound effect, we will need estimates for the number of additional trips taken by telecommuting employees and multiply that by the average trip distance.

Using the Zhu Mason data for percent likelihood that a telecommuter will take a particular trip, we can get an estimate of the extra number of trips each month per individual. We can then use the Zhu Mason data for average trip length to get an estimate of the additional miles attributable to that type of trip. Summing these up over all trip types will give us an estimate of additional miles travelled for those employees that meet the Zhu Mason threshold for telecommuter.

With this, we get an estimate, per telecommuter, of an extra 760 miles travelled for non-business related trips per year. Further analysis converts this to a rebound effect of **0.20 metric tonnes of CO_2e per employee.**

Appendix K: Scaling work-from-home sustainability benefits across the U.S.

Dell's study of its Connected Workplace program and more generally, work-from-home, is part of its Legacy of Good program of corporate goals. As the top-level goal, Dell's 10x20 goal, is focused on the positive social and environmental outcomes resulting from the use of our technology, we'd like to estimate the sustainability-related benefits of work-from-home as it applies to the use of Dell's technology across the entirety of the U.S. workforce.

Fortunately, there are significant recent datasets on the telecommuting workforce. Global Workplace Analytics, a research-based consulting firm, focuses on helping its clients build strategies around workplace flexibility. In addition to its tools for estimating the benefits of remote work, GWA provides frequent updates on the state of remote work in the U.S. This data (Global Workplace Analytics, 2016), along with results from a Gallup poll on telecommuting in August of 2015 (Gallup, 2015) and an American Community Survey analyzing data from the U.S. Census Bureau (McKenzie, 2015) give us an estimate of the total number of times per year the average U.S. employee works from home.

Table 24: Calculation of Total Number of Annual U.S. Employee Commutes Avoided

Total number of U.S. workers	128.4 million	GWA
Number of telecommutes per *month* per worker	2.3	Gallup
Percentage of solo trips in a private vehicle	76.4%	ACS
Total number of trips avoided *yearly* through telecommuting	**2.7 billion**	

Given that the Gallup poll questions specifically asked about employees who work from home using their computer to communicate, we estimated Dell's participation by looking at Dell's market share in two markets: client systems, such as notebooks and desktops, and server systems[20]. Both of these type of systems are required for employees to work remotely. We used the lesser of these two numbers in our calculations in order to estimate impact.

With these numbers, we estimate that Dell technology has participated in the avoidance of over 617 million round-trip commutes per year. It is clear that Dell cannot take credit for this alone. Enabling work-from-home requires not only not only notebooks, desktops and servers, but also storage and networking systems, software, communications and other IT infrastructure, as well as supportive company policies and implementation. We are proud, however, that our technology has played a role in helping this value chain avoid the production of over 6.1 million metric tonnes of CO_2-equivalent on an annual basis.

[20] This data was provided in private communications with IDC.

Table 25: Estimate of Avoided Annual Impact

Annual commute round-trips avoided	617 million	Previous data + IDC
Average round-trip commute distance	24.2 miles	National Household Travel Survey (U.S. Department of Transportation, Federal Highway Administration, 2009)
Average light vehicle fuel efficiency	21.6 miles per gallon	Dept. of Transportation (Bureau of Transportation Statistics, n.d.)
Emissions factor for gasoline	8.89 kg CO_2e per gallon	EPA (U.S. Environmental Protection Agency, 2014)
Annual CO_2e emissions avoided	**6.1 million metric tonnes**	

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