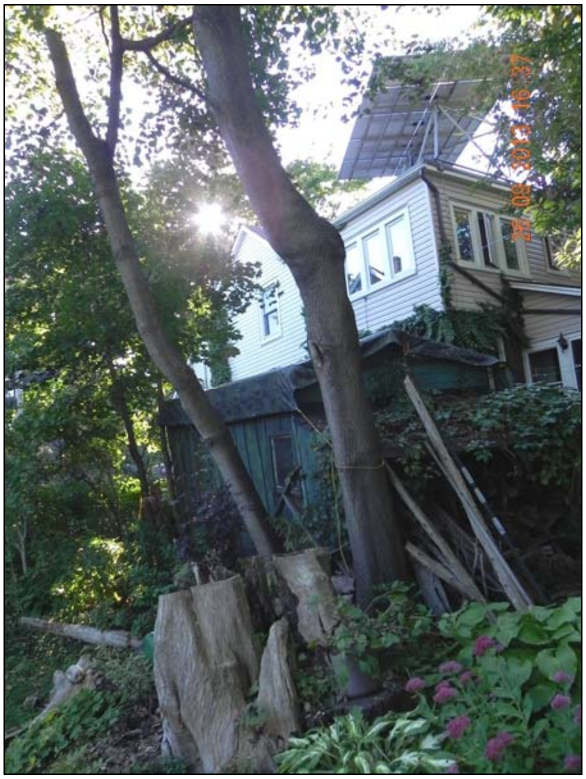
The Ravina Project

Think Globally – Act Locally

A Simple Model for Energy Policy Makers



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An Introduction to The Ravina Project

The Ravina Project, conceived in late spring 2006 and up and running in November of that year is a household-focused engineering science project. We are collecting high fidelity data and writing formal papers on such topics as: household cooling and heating efficiencies, solar PV efficiencies versus ambient heat and sun angles, solar PV Capacity Factor, the invention and use of a new solar PV efficiency standard, household resiliency, household thermodynamics, and how 'livable' a lower carbon emission lifestyle can be, among other things.

Our high fidelity databases are large and growing, totaling over 100,000 pieces of data. They allow us to validate or falsify various speculative hypotheses. They also allow us to anchor our published papers in data rich analysis. Some papers rely upon the analysis of several thousands of observations.

Our programmable dynamic solar array structure is unique. It is specifically designed to enable the collecting surface to tilt and compensate for the sun's altitude in the sky on an hourly basis. This ability is critical here at 43.7 degrees latitude where for about 90 days a year, the sun does not get above 30 degrees in altitude above the horizon at noon, sun time. As a bonus the dynamic array produces observations which allow us to calculate a solar array's aperture. For those areas outside the Tropics, the calculations we have made help us define the best algorithms for low cost, simple, hand operated 2-axis sun tracking systems which lose little in potential harvested energy due to poor sun angles upon the collecting surface.

In addition to the science and data gathering, The Ravina Project is conceived and built as a prototype upgrade to an existing and very common housing type in the Greater Toronto Area. We are testing the integration of various sub-systems over an extended number of years to determine their compatibility both with each other and with the people, plants and pets making up the household. Our modified 1920s era house allows us to empirically test out our resiliency, especially Grid resiliency, as real world disruptive events occur. We understand that technology is changing and the particular technologies we are using to provide resilience will be obsolete in future years. However, we see the resilience functionality we have created being incorporated into future technologies which will be more powerful, compact and probably cheaper in real dollars to adopt. It is our view that future events will create market demand to the extent that Grid resilience is either designed into new houses or provided as an upgrade package to current householders at much lower cost than a new bathroom. Refurbished and reconfigured used electric automobile batteries may provide a key piece among the technologies included in the future Grid resilience packages available to householders.

We envision a future in which the availability of electrical Grid power and carbon based fuels will be, of necessity, much lower than today. Due to growing climate disruption/global warming, residential Grid power supply may become intermittent on a regular basis as it is today in many parts of the Second and Third Worlds. When resiliency to Grid interruptions are built into housing infrastructure, such interruptions will not be as catastrophic as they would be in present day First World neighbourhoods. On a city wide level household Grid resilience allows utilities to build smaller scaled, lower carbon, centralized power supplies because they have the option of disconnecting whole neighbourhoods during peak power demand.

We understand that reducing a household's carbon footprint is vital to reducing overall atmospheric carbon release. We are looking closely at our attitudes and lifestyle for insights into such areas as: household carbon accounting, using software rather than hardware defined devices, carbon based functional analysis of both the technology we employ and the consumer products we purchase. These changes are our attempt to modify our attitudes and desires so that we may decouple ourselves from the current and prevalent consumption based modernity. However, we also know that high technology, applied correctly, will allow for this decoupling on a massive scale.

As the changed lifestyle part of the experiment unfolds today, it becomes apparent we are living a future lifestyle in an old house modified for tomorrow.

All our data and papers are published on our WEB site at: www.theravinaproject.org

Regards,

Susan and Gordon Fraser
Directors

The Ravina Project

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Abstract

The origin of the phrase, “Think Globally – Act Locally” is murky. There are at least three names associated with its first use going back to the 1960s and ‘70s. The concept, found in Patrick Geddes 1915 book, “Cities in Evolution” is verging on 100 years of age.

Today the phrase is used as a short form for the process of considering the global consequences when planning at the local level. The ‘local level’ is quite elastic extending from the national/regional to the city/town right down to the neighbourhood and household.

Over the last eight years The Ravina Project, a Toronto based, privately funded household research project has been focused on energy use at the household level among other things. We want to use our large databases to build a model and make some comments upon how, “Think Globally – Act Locally” should be applied by energy policy makers here in Toronto and Ontario in general.

Introduction

Let’s look at the global situation. We, like most people, can make a list of challenges facing humankind. We want to focus on one issue, CO2 pollution. We see CO2 pollution as one of global impact, one requiring a global solution and one that is an existential threat to our high energy, modern civilization. We could burn ourselves right off this planet if our worldwide mitigation efforts fail. Worldwide abrupt climate changes have happened several times before promoting massive species extinctions. This time will be no different if CO2 pollution is left unchecked. So we will focus on a reduction of CO2 pollution as the ‘global’ part of, “Think Globally – Act Locally”.

Decarbonization and the Global Carbon Accounting Balance Sheet

There are many models which demonstrate the effects of CO2 pollution over the rest of this century. Their outcomes vary because each is based upon different aspects and starting conditions. All agree though, that CO2 reduction by humans must occur. We also know from these models that a dramatic decarbonization of our civilization over the next 30 years is a requirement if we want to limit the damage that climate change will cause as the century progresses.

Globally one of the greatest sources of CO2 pollution involves the generation of electricity. On one hand we have the polluters burning coal, natural gas and oil and on the other we have non-polluters harvesting the energy of the wind, sun, water and the atom.

So what does this global CO2 threat tell us about what we should do locally? Let’s build a simple model and see what it tells us. In this model we will have an extra million dollars to spend on a local electrical energy generation project. We can upgrade, retrofit, or build new but at the end of the day we must spend all our money on an electrical generator of some kind. In every scenario we consider, the criteria for success for failure will depend upon whether our project reduces or increases the production of CO2 on a global level. The touchstone will be a global Carbon Accounting Balance Sheet. On one side we have the global total of non-polluting generation and on the other we have the global total of polluting generation. Our goal is to increase the global non-polluting generation and reduce the polluting generation.

Immediately, without considering any particular project we might spend our money on, it becomes clear that any non-polluting generation already in place becomes very valuable: it's already built and producing. Why is this the case? It is the case because the resources: financing, raw materials, supply chains, factories, labour force, installation force, and commissioning needed to place this new clean generation capacity on-line will be astronomical.

Really? So what kinds of worldwide numbers are we talking about?

Worldwide Terawatts of Non-polluting Buildout

The *U.S. Energy Information Administration's International Energy Outlook 2012* tells us that in 2010 the world used 523.9 Quads (Quadrillion British Thermal Units [BTUs]) of energy. The world power generation output to support that energy use in 2010 is 17.5 Terawatts (TW). Of that 17.5 TW, 14 Terawatts were generated by the world's fossil fuelled power supplies. That 17.5 TW will increase to about 27 TW by 2040 because of the huge expected energy use increase by non-OECD countries. Over the next 30 years the world has to build at least 7 TW of non-polluting power supply to support the world wide decarbonization effort. If that's our goal, what does it mean in real terms, that is, in terms of numbers of solar panels, wind turbines, power dams or the like?

Let's confine ourselves to building and installing just one Terawatt (1 TW = 1,000,000,000,000 Watts) of clean power output using solar, wind, dams, geothermal and nuclear. Using solar PV panels the area covered by 20% efficient panels working at a yearly average capacity factor of 17% is about 29,412 square kilometers. If we build and install 5 Megawatt (MW) wind turbines working at an annual average capacity factor of 34% we will need about 588,235 units. If we chose to build out dams like Sir Adam Beck 2 with a maximum capacity of 1,463 megawatts and run them at an annual average capacity factor of 80% we will need to build about 854 dams. If we use 100 MW geothermal plants working at an annual capacity factor of 80% we will need 12,500 such plants. And finally, if we use the next generation nuclear powered electrical generators like the one currently being designed in Mississauga and we limit them to modules of 100 MW each with an annual capacity factor of 90% we will need about 11,111 units.

If these numbers make your head spin then you are like us. Just building out one TW of non-polluting power supply is a huge task even over 30 years. How about the world building out 7 TW over 30 years? Are we pushing the limits, even the theoretical limits of the world's ability to produce, install and finance these generators? It is in this context that you can understand our statement above that any current non-polluting generation is worth its 'weight in gold'. It looks like all our resources will be required to build our way out of this global CO2 pollution problem. We'll have nothing extra to play around with existing carbon free generation except to extend its lifetime. More on that below …

Green Project Evaluation

So now we understand the magnitude of our global problem let's return to our model. Here are some scenarios we might consider when we spend our million dollars on local electrical power generation.

Let's upgrade a large solar generator of some kind to better more efficient solar panels. How would we evaluate this expenditure in light of global CO2 pollution? The new generator would produce more energy but only marginally so. The global non-carbon side of the balance sheet is only marginally increased and if we are lucky there will be some trivial decrease on the carbon side. From our accounting point of view this is a poor investment. It provides us with a negligible return on our investment dollar in either increased non-polluting generation or reduced CO2 pollution.

Let's invest our funds into a project that will shut down a local nuclear powered electrical generator and bring in hydro power from some distance away. We are playing with clean generators but not changing the global numbers because we are swapping out one clean generator for another. And we break one of our corollaries mentioned above that existing non-carbon generation is very valuable. There is a net loss globally to the amount of clean generation available. Before the replacement we have two sources of non-polluting power generation and after we have only one. This is a poor investment.

Let's invest in extending the lifetime of a local CO2 free generator so it can provide clean energy for a decade or two into the future. This is an easy call. Existing clean generation is very valuable now and into the future so extending its lifetime is a good investment. But if we look at our balance sheet nothing changes. Why is this different than the rejected scenario above where we replaced the solar panels? What's different is that without the upgrades the clean generator would disappear reducing the amount of clean energy available on the global balance sheet. This is a good investment.

One of the upgrades we hear about today is a swap out from coal generation to natural gas. On our spreadsheet this tends to reduce the amount of pollution per unit of generation but the global total of polluting generators is not reduced, that is, swapping one gigawatt (GW) of coal generation for one GW of natural gas generation is zero sum. This status quo investment means it prolongs the lifetime of CO2 pollution which, in light of the need for rapid decarbonization, is a negative investment. That being said this particular upgrade has other profound social benefits, like for instance, public health would be greatly helped with this swap. But our model does not include public health as a criteria, just the global balance sheet of clean and polluting generation. This is a poor investment.

If we use our one million to invest in new non-polluting generation then we have a good investment. It increases the amount of non-polluting generation on our world wide balance sheet.

The Decarbonized Household

Let's look at the household in light of this carbon accounting model.

We consume carbon based natural gas to heat our house and electricity from the grid, our batteries and solar panels to power our household. We can also use electricity to heat our house using space heaters.

So from our carbon accounting model is it better to heat our house with natural gas or with electricity?

From our extensive databases we find that over 3,192 contiguous days our all inclusive cost per cubic meter of natural gas is $0.60. Also from our database of 2,498 contiguous days of billed electricity we pay an all inclusive $0.15 per kilowatt hour. Since every cubic meter of natural gas is equivalent to 10.35 kilowatt-hours the cost of gas per kilowatt-hour is $0.60 divided by 10.35 equals $0.058. As you can see the cost of electricity is about 3 times the cost of natural gas per kilowatt-hour of energy used. As I write this today, in Ontario, 5% of our electricity is coming from fossil fuels (natural gas) with 65% from nuclear, 24% from hydro, 6% from wind and the rest from solar and the like. There is only 5% carbon content in our electricity. However, when we burn natural gas to heat our house the energy we get from it has 100% carbon content.

From the global carbon accounting model we have been using, it behooves us to heat our house with electricity only, and if we can't, then we must at least partially, heat our house with electricity. Doing so will dramatically reduce our carbon emissions. But there is a catch. We will have to spend twice as much to heat our house as we do now plus pay for the current usage of electricity. From our database we used 22,244 cubic meters over that 3,192 days at a cost of $13,384.56. If we used electricity in place of natural gas it would have cost us $0.15 times 22,244 cubic meters times 10.35 kilowatt hours per cubic meter of gas equals $34,533.81 or about $3,950 a year. Add in a year of regular electrical usage at $1.87 a day or $682.55 the yearly all electric total is $4,632.55. Contrast this with $1,530.50 plus $682.55 equals $2,213.55 when we use both electricity and natural gas.

From a global carbon accounting perspective the pricing is counter productive by a long shot. A 5% carbon release using electricity versus a 100% carbon release with natural gas means electricity is 20 times more carbon efficient whilst being about three times more expensive. This means we can get a huge drop in our household heating carbon use by going to an all electric house. It also means that rapid decarbonization must include electrical household heating in the Greater Toronto Area. Come to think of it, a price on carbon would bring the price differential closer together here.

Note that if we were not in Ontario, a region that has spent huge amounts of taxpayer dollars on creating a nuclear powered electrical generation infrastructure these numbers would be entirely different. In areas where electrical generation is entirely coal based, there would be no carbon accounting advantage to using electrical energy to heat our house.

Suppose we take on the task of deeply decarbonizing a city with houses as energy efficient as ours. We have upgraded our project house and tracked the improvements in heating efficiencies with each upgrade. Let's use our numbers to get an idea of the electrical load our house would provide to the grid if we were to go all electric. Summer time natural gas usage is used for domestic hot water only so we will eliminate that usage from the workhorse wintertime natural gas usage.

Between the heating seasons of 2004-05 and 2011-12, eight years in total, the house insulation was upgraded and the wintertime natural gas used for heating dropped from 2,411 to 1,271 cubic meters. Note that some of this drop in natural gas usage was the result of warmer winters. From our data the house's heating efficiency increased by almost 40%. That 1,271 cubic meters of natural gas translates into 13.2 MWh of energy. If we used only electricity for heating we would be using an extra 13.2 MWh each year and if our current electrical usage is counted in we would use in total about 17.8 MWh of energy. One hundred thousand upgraded houses like ours would use 1.78 Terawatt-hours or about 13.9 percent of the full rated output of Adam Beck 2 for a year (12.8 TWh). Ontario's hydro generation capacity is 8,119 MW. 100,000 all electric homes like ours would use 2.5% of the total hydro yearly energy generation capacity of 71.1 TWh (running at 100% capacity).

Conclusion

A 30 year rapid decarbonization here in Ontario, Canada will place huge stress on our current non-carbon polluting electricity generation infrastructure plus it will require an unprecedented clean generation build out.

In summation we have demonstrated that a simple model based upon the maxim, 'Think Globally – Act Locally' has the potential to clarify some complex energy choices we face as we go forward this century.

Appendix A

There are lots of calculations in this essay. In what follows we want to show the reader how we crunched our numbers.

One Quad equals 1,000,000,000,000,000 BTUs or 1.0 to the power of 15 BTUs (1.0^15) but it also equals 1.055^12 megajoules. One megajoule equals 0.277777778 kilowatt-hours (kWh). 1.055^12 megajoules equals 1.055 times 0.2778^12 kWh or 2.9308^11 kWh. 2.9308^11 kWh expressed in TWh equals 2.9308^11 times 1.0^-9 equals 293.08 TWh (Terawatt-hours).

By these calculations one Quad is equal to 293.08 TWh of energy consumed worldwide for a year so for 523.9 Quads, we must multiply 293.00 TWh times 523.9 Quads equals 153,544.6 TWh. But this is worldwide total energy usage over the whole year of 8,760 hours. How big a world wide power supply running at 100% power output each hour do we need to produce this total energy output over a year? We need 153,502.7 TWh divided by 8,760 hours in a year equals 17.528 TW or 17.5 TW (rounded).

1 TW Solar Panel Area Calculation

For the calculation regarding the area of solar panels required to generate an average of 1 TW of power each hour of the year we assume that a 20% efficient solar photovoltaic panel can make 200 Watts of electricity per square meter when illuminated with 1000

Watts of light energy through a defined atmosphere. Therefore 5 square meters of these panels will generate 1000 Watts of electricity. But since we are looking for an output of 1000W every hour of the day on average over the course of a year, we must consider Capacity Factor which will allow us to calculate the total area of 20% panels required to produce that average 1000W. Here in Toronto the Capacity Factor is about 17% more or less. That means the calculation must be modified so that if 5 square meters of panels gives us 1000W at 17% Capacity factor then 5 divided by 0.17 equals 29.4 square meters of 20% solar PV panels will give us on average 1000W (1 kW) every hour for a year. A TW is 1,000,000,000 kilowatts so the surface area of panels producing 1 TW on average every hour of the day is 1,000,000,000 multiplied by 29.412 and divided by 1,000,000 (square meters in a square kilometer) or, to make it simpler, 29.4 times 1000 equals 29,412 square kilometers (11,356 square miles or 7,267,840 acres) of 20% solar panels. This area is the size of Belgium with no spacing allowed between the panels.

1 TW Wind Turbine Calculation

Each wind turbine has a capacity of 5 million Watts (5 MW) but it only produces power one third of the time. We use a Capacity Factor of 34%, a commonly accepted yearly average value for wind turbines. Each turbine on a yearly basis will produce on average 5 MW times .34 or 1.7 MW of power output each hour of the year. Therefore to produce 1 TW of power output the number of turbines required is 1,000,000 MW divided by 1.7 MW equals 588,235 turbines.

1 TW Sir Adam Beck 2 Calculation

Sir Adam Beck 2 has a rated capacity of 1,463 MW. We use an accepted Capacity Factor of 80% for hydro plants. The 1,463 becomes 1463 times .8 equals 1,170.4 MW. The number of plants required to produce 1 TW of full time power on average for a year is 1,000,000 MW divided by 1170.4 equals 854 Sir Adam Beck 2s.

1 TW Geothermal Calculation

A 100 MW geothermal plant has an accepted Capacity Factor of 80% so its average output over the course of a year is 80 MW. To provide 1 TW of power output on average over the year we will need 1,000,000 MW divided by 80 MW per plant equals 12,500 100 MW geothermal plants.

1 TW Nuclear Reactor Calculation

Many of the modern designs for nuclear reactors, like those the Mississauga firm Terrestrial Energy are designing, are modular in nature with proposed modules between 80 and 600 MWth (Megawatts Thermal) that are designed to work together to make a much larger electrical generator. We use a 100 MW module as a building block in our calculation and we set its Capacity Factor at 90% which is on par with the existing base of nuclear power plants. The number of these modules to provide TW of continuous power on average over a year is 1,000,000 MW divided by (100 times .9) equals 11,111.

"If we knew what we were doing, it would not be called research."
- A. Einstein

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