**Exergy and the City**

The Solar potential of a city and its implications on urban policy

Hugh Byrd and Anna Ho

The University of Auckland

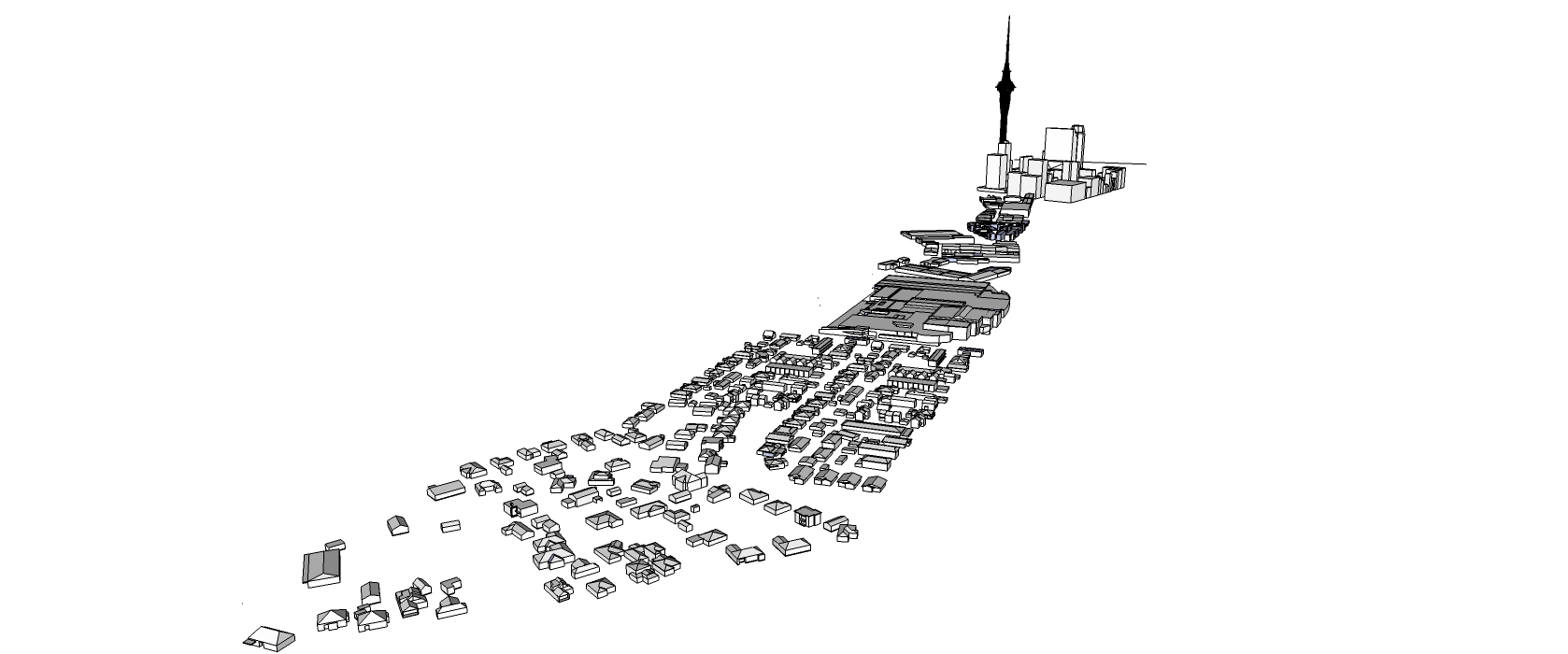
Exergy is synonymous with the availability of energy and, in the context of this research, is the availability of energy generated by photovoltaics (PVs) mounted on roofs across a city. The research was carried out on Auckland City with the aim of answering the questions:

1. How much energy could be produced if a city fully utilised its rooftops in a practical and efficient manner?
2. If there is any excess energy produced, how could this best be used?
3. What implications will this have on the shape of cities?

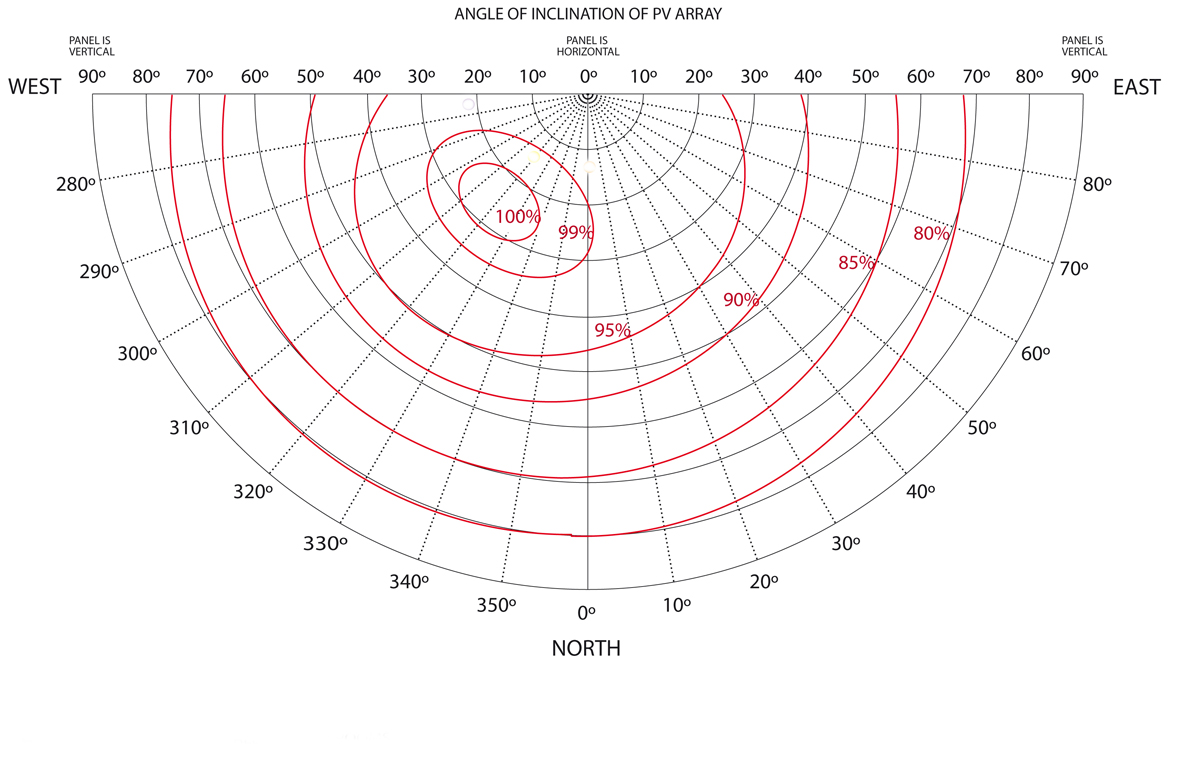
The purpose of looking at the full potential is that it provides a starting point from which to backcast and predict the impact of PVs as they increase penetration into the building stock.

The study took a large sample (3 million sqm of floor area) of various types and uses of buildings form high rise city centre developments through to low density suburbs and everything between.

Figure 1 illustrates the sample that was analysed and from which the performance of the whole city was extrapolated.

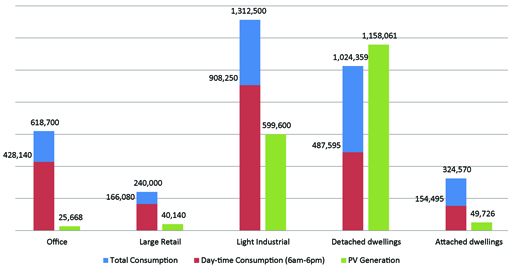


The first stage of the research was to establish the amount of energy available. This involved an analysis of rooftops in order to filter out the optimum orientation and tilts for solar collection. Figure 2 illustrates a solar protractor for Auckland that measures the percentage efficiency based on tilt and orientation. For the purposes of this study, only roofs within 95% of the optimum angle were selected.



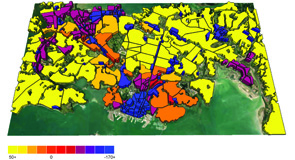
High rise buildings performed worse with little available roof area and vertical surfaces that are relatively inefficient. The roofs are cluttered already and PVs on vertical surfaces can reduce daylight; a more valuable form of solar energy for commercial buildings. Industrial type buildings have the most appropriate roof forms but the overall area of these in the City is significantly smaller than suburban roof forms which, although more complex in shape, offer the largest potential surface area.

Figure 3 illustrates a simplified version of the analysis which shows (in green) the potential energy available from rooftops across the whole City. The ‘detached dwellings’ category, which is largely comprised of suburbia, is the largest collector of energy. The ‘attached dwellings’ category, generally compact and higher density house forms, is disappointingly low due to the smaller roof areas and also due to the assumption in the study that all households would install solar water heating prior to PVs. In Auckland, solar water heating offers greater energy savings as a typical household uses 25% of energy on hot water heating.



Having established the generation potential, this can then be compared with energy demand by the buildings. From data of energy demand of different building types and uses, a profile of both daytime and night-time electricity use was established. This is illustrated in figure 3 with the brown bars measuring daytime electricity use and the blue, night-time use. The interesting result of this chart is that the excess electricity generated by suburbia is almost the same as the electricity demand, during the daytime, of the rest of the city. In theory, suburbia could power the city.

Figure 3 is effectively a ‘net-metering’ chart and can be used to map net metering spatially across a city. This is demonstrated in figure 4 where the orange areas of the City indicate equal supply to demand (zero net energy), the blue areas have a net demand and the yellow areas have a net supply. Not surprisingly, yellow is suburbia and all the compact development is in various shades of blue with little contribution of energy to the city.



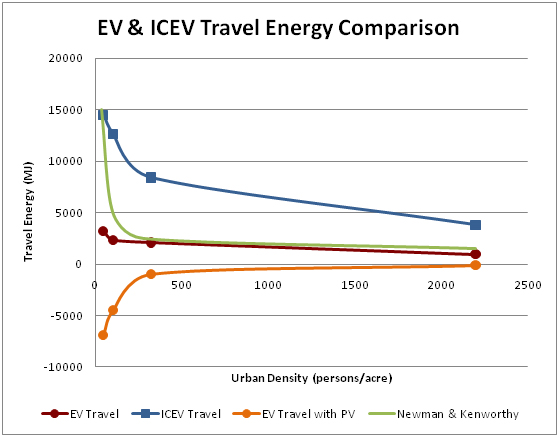
Having established the spatial distribution of energy generation by PVs and the magnitude of the supply, the next question is how to best utilise this surplus generated in the suburbs. New Zealand does not have a subsided feed-in tariff (FiT) and internationally they are likely to be phased out. Therefore, this study did not take account of FiTs. In many cities the logical step would be to utilise the excess electricity by feeding in to the grid and thereby reducing electricity demand by conventional sources. This would also have the benefit of reducing the quantity of greenhouse gases produced by conventional electricity generation.

However, in New Zealand, about 75% of electricity is generated from renewable sources such as hydro, geothermal and wind. Most carbon in the city is produced from the internal combustion engine. Auckland is a car dependent city and with almost half of the country’s total energy use being oil for transport, displacing the use of oil would be a preferable option for PV generated electricity.

The next stage of the study was to investigate the energy required for transportation within the city and evaluate the contribution that could be made by electric vehicles (EVs) charged by PVs.

Extensive data on travel patterns in Auckland was analysed. Interestingly, in Auckland, ‘work to main job’ travel is only 22% of a ‘vehicle driver’s mean travel distance in major urban areas’. The remaining 78% is for recreation, shopping, social visits, education and other activities that frequently happen outside peak PV generating times, which means that cars can be at home during the day if there are reasonable alternatives for travel to work.

Energy use for travel was then related to the net density of housing which is, in turn, related to the distance from the city centre. Figure 5 shows the relationship between travel energy and city density. The green curve is the curve produced by Newman and Kenworthy in their comparison of travel energy and different density (gross density) cities. The blue curve is Auckland’s relationship between travel and net density using internal combustion engine vehicles (ICEVs). The red curve illustrates travel energy in Auckland if the car fleet were all EVs charged by the grid (EVs are approximately 4 times more efficient than ICEVs). However, if they are charged by PVs, there is still surplus energy available after all travel is accounted for. Hence the orange curve becomes negative.



The conclusions of this are that the emerging technologies of PVs, EVs and smart meters have a synergy that can reduce New Zealand’s dependence on oil. Furthermore, in the case of Auckland, a compact city is not necessarily either an energy efficient or low carbon form. Finally, policy decisions on urban form should be based on the technologies of the future and not those of the past or present.

The authors are grateful to The University of Auckland who funded this research through the “Transforming Cities” thematic research initiative and also acknowledge the support from Professor Harvey Perkins and Charlotte Sunde.