This Decade's Solar Photovoltaic Emergence: a cross-sectorial investigation of conditions that foster solar photovoltaic electricity production.

Master Thesis

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Abstract:

The sun represents a clean, non-exhaustible source of energy. However, until recently the high cost of solar photovoltaic technology has not allowed it to be economically competitive with traditional, fossil fuel sources. Recent developments, and reductions in the cost of solar cells has allowed for solar photovoltaic to become much more economically competitive. This decade has seen a serious increase in the global installed capacity as countries aim to reduce their dependence on fossil fuels and begin the transition to a more sustainable, low carbon future. This transition is essential to make good on the benchmarks set at the 21st installment of the Conference of Parties and the resulting Paris Agreement; which called for an ambitious target of limiting atmospheric temperature increase to 2° Celsius above pre-industrial levels. However, the Nationally Determined Contributions that have been communicated by individual countries in their efforts to transition away from fossil fuels has to this point in time fallen far short of the necessary reductions to ensure that the 2° Celsius barrier is not eclipsed. It is therefore imperative that the worlds top solar photovoltaic promoting countries at this point in time are analyzed in a cross-sectorial macro setting to gain insights into which various combination of variables have come together to drive this decades solar photovoltaic boom—as to highlight the potential pathways that countries outside the scope of this analysis can take in the future to ensure that solar photovoltaic technology begins to be implemented—so to guarantee that the potential of solar photovoltaic technology to provide a clean, non-exhaustible source of energy is truly realized.

VIII. Discussion of OUTCOME 1: Total installed photovoltaic capacity.

IX. Discussion of OUTCOME 2: Percentage of solar radiation harnessed

Acronyms

GDP	Gross Domestic Product
GHG	Greenhouse gas
CO2	Carbon dioxide
COP	Conference of Parties
INDC	Intended Nationally Determined Contributions
NDC	Nationally Determined Contributions
UNFCCC	United Framework Convention on Climate Change
MW	Megawatt
GW	Gigawatt
kWh	Kilowatt-hour

List of Figures

List of Tables

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Chapter I. Introduction

The current decade will be remembered as the time that photovoltaic power production began to gain traction around the world. This photovoltaic boom comes to light when you consider that, in 2010; globally there was an addition of 19 gigawatts of photovoltaic (PV) power (Lins, 2014). A significant amount, considering this is equal to the cumulative amount of PV power installed since the commercial inception of the technology in the 1970s (Reichelstein, 2013). The subject and pertinence of variable renewable energy has never been more at the forefront of decision makers' minds, and will be a principle component in reducing greenhouse gas emissions, a negative externality associated with fossil fuel combustion. Variable renewable energy, especially solar harnessing technologies, has vast potential to become a dominant player in global electricity production, "solar power is the one source of energy for which potential capacity vastly exceeds any reasonable estimate of humanities future demands for energy" (Patt, 2015). However, the reality of the situation is that we are harnessing a very small fraction of the incoming solar power that strikes the surface of the earth.

Although solar photovoltaic technology has been available since the late 1950's the technology has not been widely applied until the beginning of this decade. The overarching goal of this work will be to determine which factors have been paramount in driving the solar photovoltaic boom taking place this decade. An investigation of the world's greatest solar photovoltaic promoting countries in terms of, 1) Total installed capacity, or 2) percent of incoming solar radiation harnessed and used to generate electricity at the end of 2015. The results will lend insights into the factors that have come together on a macro level to better understand the solar photovoltaic boom currently taking place.

Despite the current and projected growth in global PV capacity, multi country comparisons, especially in an interdisciplinary setting where total installed solar photovoltaic is set as the dependent variable under investigation are practically non-existent. In fact, several authors have actually pointed out that there is a lack of empirical work in this field (Schaffer and Bernaur, 2014). Most studies have focused on renewable output and shares (Jenner et al., 2012a; Marques et al., 2010; Smith and Urpelainen, 2013; Steinhilber et al., 2011), renewable policies (Ward and Cao, 2012, Jenner, 2012a), or the effectiveness of a specific policy instrument, such as an energy tax or feed-in tariff (Jenner, 2012b). Consequently, the literature contains very little previous work with a cross-sectorial structure with an aim of comparing and analyzing the worlds leading solar photovoltaic countries to gain insights as to where similarities and differences arise across a multitude of socioeconomic and geographic conditions. A cross country comparison of the countries with the greatest installed photovoltaic capacity will lend insights into the various paths the countries have taken to integrate PV into their existing electricity sectors. Additionally, a comparative analysis will be able to provide insights and highlight the potential paths other countries can take in their pursuits to transition to a sustainable, low carbon society. Therefore, this thesis will focus on a variety of factors derived from a range of backgrounds, such as: socioeconomic, physical (geographical), and policy-related conditions which in combination can paint a clearer picture, and give new insights into which combination of macro-level factors have lead these countries to their current standing at the top of the PV capacity list. The underlying desire and primary aim of this work is guided by the following research question: which socio-economic, policy-related and physical characteristics are typically present in the world's top photovoltaic promoting countries at the end of 2015? To this point in time, photovoltaic and other renewable energy technologies have been supported by government policies, allowing them to be economically competitive, albeit still more expensive than its fossil fuel alternatives and for this reason these various government support policies have been taken as a given and will not factor into the analysis.

The thesis will have the following structure; first the context and the motivation for undertaking this work with regard to climate change and the international cooperation taking place to mitigate and begin the transition to low carbon societies that will be sustainable for generations to follow. Next the current solar photovoltaic landscape will be discussed, specifically how Europe originally took the photovoltaic reigns but the demand landscape has recently transitioned east to Asia Pacific. The 4th section focuses on the sustainability framework, which is used to designate arguments, conditions and is the guiding theory for this undertaking. The sustainable development framework has been used as the theoretical guide for this work. The following methods section will draw focus to the primary analytical tool used, Qualitative Comparative Analysis. There are 16 independent variables that have been plucked from the sustainability framework, which are then compounded into 6 combined sets and tested on the two outcomes under investigation. Two result sections will follow, one for each outcome under investigation. The first outcome pertains to the total installed capacity of the world's top 16 promoting countries at the end of 2015. The second outcome will investigate which of these top 16 countries in terms of installed PV capacity are doing the most with their available solar resource. The results will be followed by, two complementary discussion sections that will lend insights and provide explanations of the results. The conclusion section will provide the most important insights gained from the following analysis of the world's top solar photovoltaic promoting countries and what other countries with similar, sustainable ambitious can do to follow suit.

Chapter II. Motivation

2.1 Why this matters

Climate scientists have observed through measurements that carbon dioxide (CO_2) concentrations have been steadily increasing throughout the century when compared to the pre-industrial level of about 280 parts per million (ppm). In 2015, for the first time in the instrumental record, the average concentration of CO_2 in the atmosphere eclipsed 400ppm, as shown in figure 1. Measurements regarding the concentration of carbon dioxide present in the atmosphere began in 1958 at the Mauna Loa Observatory in Hawaii. At that point in time the observed carbon dioxide measurements indicated a level of 310 parts per million (ppm). Comparing the levels of carbon dioxide observed in the atmosphere today with those at the beginning of Keeling's measurements, is indicative of a nearly 30% increase in less than 60 years. This rate of carbon uptake by the atmosphere far outpaces any natural phenomenon observed in Earths history. Earths climate has continuously shifted between glacial and interglacial cycles, but on the order of tens of thousands of years, as opposed to decades (Archer, 2000).

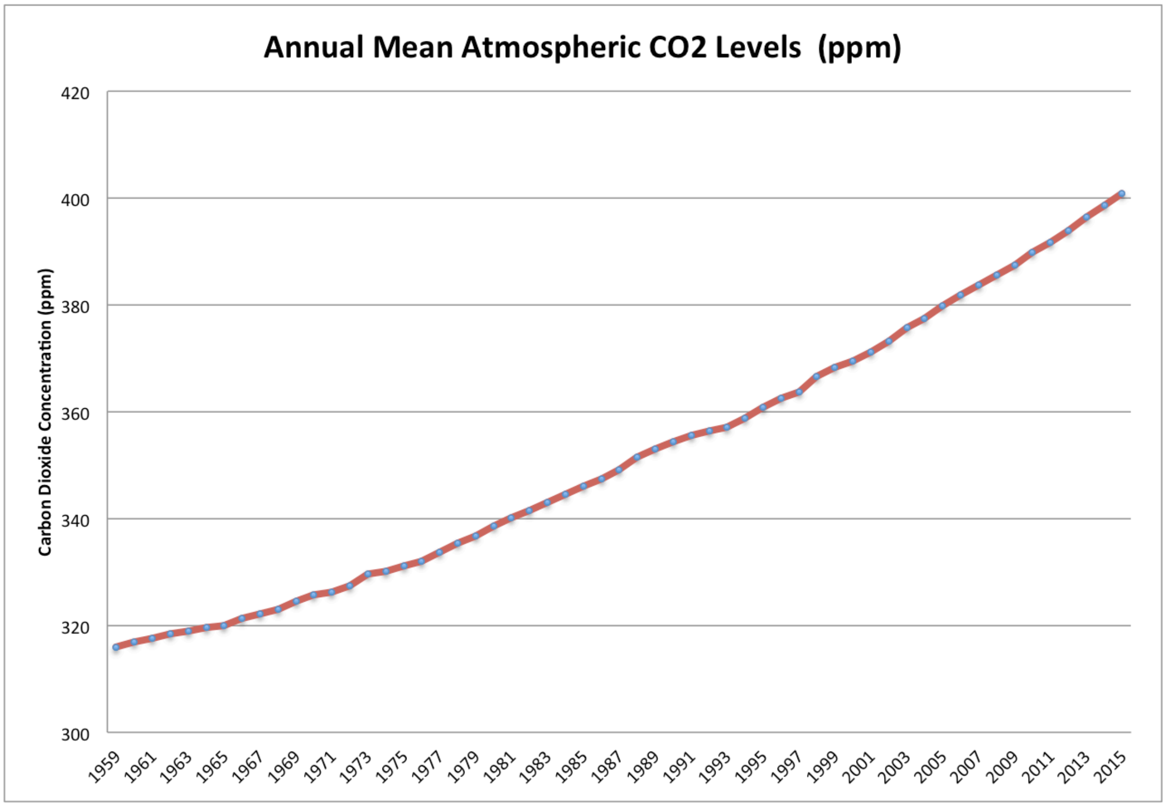


Figure 1: Annual mean atmospheric CO2 levels (parts per million); Data: Worldbank, 2016; Image: own illustration

This is not to say; that there have also been significant increases in the levels of other greenhouse gases, such as, methane (CH_4) and nitrous oxide (N_2O) (IEA, Key CO_2 Emissions Trends, 2016). However, the most common anthropogenic GHG is carbon dioxide and two largest sources are electricity and heat production, accounting for 32% of emissions. (Solanghi et al, 2011. The presence of carbon dioxide and other greenhouse gases is the primary reason the world has seen its average temperature increase by roughly 1 degree Celsius since the turn of the century (Rosenzweig et. al, 2008). These numbers also represent the serious opportunity that solar photovoltaic and other alternative renewable sources have in reducing these pollution intensive sectors reliance on carbon based sources as global climate change concerns begin to be addressed in earnest around the world.

2.2 Energy use and growth

The Fifth Assessment Report from the Intergovernmental Panel on Climate Change (Working Group I) states that human influence on the climate system is clear (IPCC, 2013). Among the many human activities that produce greenhouse gases, the use of energy represents by far the largest source of emissions. Smaller shares correspond to agriculture, producing mainly methane and nitrous oxide from domestic livestock and rice cultivation respectively (IEA, Key CO$_2$ Emissions Trends, 2016). Increasing demand for energy comes from worldwide economic growth and development. This is evident when you consider that between 1971 and 2014 the global total primary energy supply increased by nearly 150% and still heavily dependent on fossil fuels to power development. Figure 2 highlights the fact that five major emerging national economies are primarily responsible for the worldwide carbon dioxide increase since the middle of the 1990's. The red line titled 'BRICS' in figure 2 encompasses these five emerging economies: Brazil, Russia, India, China and South Africa, highlighting the fact that carbon based fossil fuel sources have been the primary driver of this recent, rapid development.

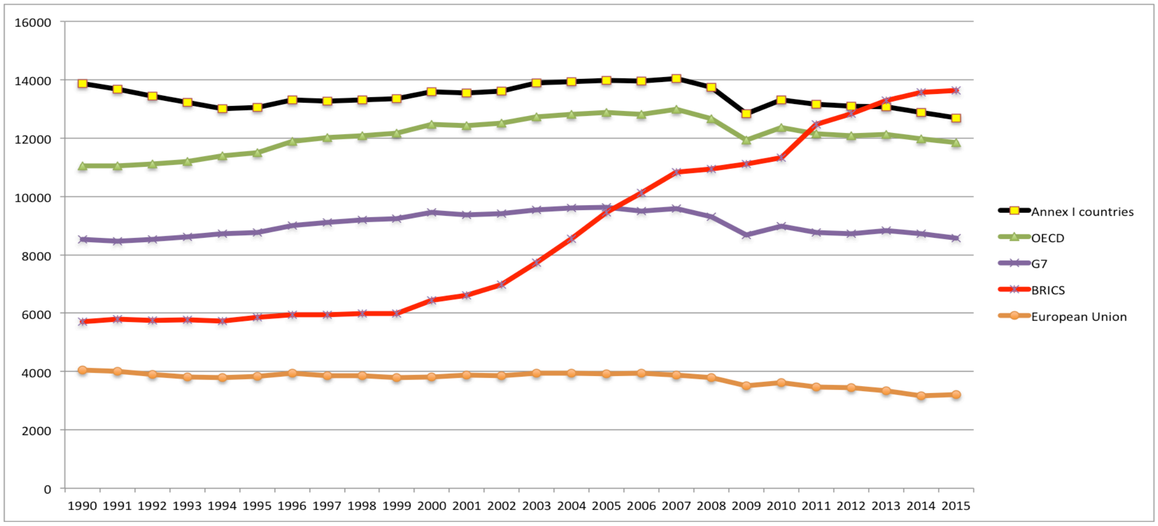


Figure 2: CO2 emissions from fuel combustion (MtCO2); Data: Worldbank, 2016. Image: own illustration

It’s clear that while these major emerging economies were using fossil fuels to power their economic and social development, other, already developed countries such as some of those listed as Annex I parties to the Kyoto Protocol (e.g. black line in figure 2) had already begun to take the necessary measures to curb their carbon dioxide emissions as to honor their pledges to the first commitment period under the protocol.

2.3 1992 Earth Summit and formation of UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty negotiated at the Earth Summit in Rio de Janeiro in June 1992. The treaty entered into force on March 21, 1994. Article 2 of the UNFCCC states;

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*
>
> *–Article 2 United Nations Framework Convention on Climate Change.*

The framework set no binding limits on greenhouse gas emissions for individual countries and contains no enforcement mechanisms. Rather the framework outlines how specific international treaties, called protocols or agreements, may be negotiated in an open format, which allows for maximum participation by developed and developing countries alike. Hope being, that a non-legally binding format will open dialogue between nations and create an environment, which fosters inclusion, opposed to strict legally binding rules, which would be disinviting for the majority of developing economies. Although there have been and always will be people who question the human influence on the climate, the precautionary principle, which was formed as part of the 1992 Rio declarations, pulled from the shadows the anthropogenic emission problem and spotlighted efforts to combat climate change. Principle #15 from the Rio declarations noted, “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations, 1992). The principle was a major influencing factor as to why the majority of countries endorsed and ratified past climate agreements, such as, the Kyoto Protocol formulated in 1997. Since 1995 the parties of the convention have met annually to assess the various aspects of climate change. As of December 2015, the UNFCCC has 197 parties and enjoys broad legitimacy due to its nearly universal membership.

2.4 International cooperation: climate specific protocols and agreements.

Berlin 1995 signified the first time that the Conference of Parties (COP) met upon behave of the UNFCCC to discuss and outline specific emission reduction targets. Two years later at the COP held in Kyoto, Japan, the Parties agreed to broad outlines of emission targets. Commonly referred to as the Kyoto Protocol, the international treaty commits State Parties to reduce greenhouse gas emissions based on the premise that global warming exists. More specifically, anthropogenic sources of carbon dioxide, and not natural phenomena, are responsible (Rosenzweig et. al, 2008) (Solomon, 2009). The Protocol is based on the principle of *common but differentiated responsibilities*: it puts the obligation to reduce current emissions on developed countries on the basis that they are historically responsible for the current levels of greenhouse gases in the atmosphere. Article 2 of the Kyoto Protocol states;

> *"Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall: (a) Implement and/or further elaborate policies and measures in accordance with its national circumstances…"* (United Nations, 1998)

The Kyoto Protocol, while in theory great, in practice and implementation there were a number of shortcomings. None greater than the fact that although there were a number of developed, predominantly European countries, which were on board with the economy wide emission reductions, for they were classified as Annex I countries, and had already reaped the benefits of unregulated development over the past century with the onset of the industrial age which fostered a century plus of largely unregulated development and growth without worry of potential consequences. In layman terms, the protocol may have sparked dialogue but the protocol itself failed in the sense that a number of developed, capable, and pollution intensive countries were never required to reduce their emissions and is evident in figure 3 which highlights the percentage increase or decrease in GHG emissions in the years 2000, 2006 and 2012 when compared to 1990 levels. Figure 3, highlights the leading role that European countries have taken in reducing their GHG emissions as well as the general discrepancies in emission trends that exist between the developing and developed countries.

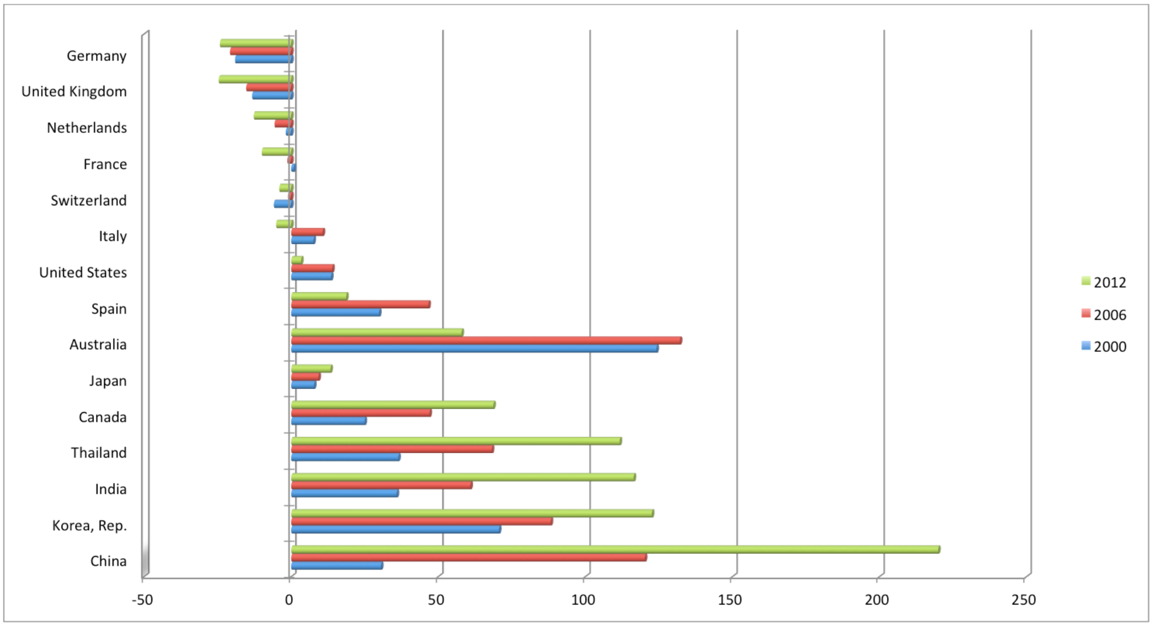


Figure 3: Total GHG emissions percent change for the years 2000, 2006 and 2012 compared to 1990 base year. These are the top 16 countries in terms of PV capacity at the end of 2015 and representative of the cases that will be used for the QCA analysis; Data: WorldBank, 2016; Image: own-illustration

This is the first time in the fight against climate change that the *free-rider problem* came to fruition. The term 'free-rider' was originally used in economic theory of public goods, and has been written about since the late 1970's (Groves and Ledyard). The free-rider problem occurs when benefits are gained with no incurred cost and are common in public and non-excludable goods. By this definition the Kyoto Protocol was suspect on may fronts to fall akin to this free-rider problem for it involved negotiations that ultimately concerned the world's atmosphere, a global non-excludable public good. The fact that the Kyoto Protocol failed to get a number of developed countries to agree to, or ratify the protocol, and in effect created the free-rider phenomenon, compromised the effectiveness of the protocol from its inception. It failed to bring pollution intensive, developed parties such as the United States to ratify, or even support the emission reduction conditions laid forth by the Kyoto Protocol. For this reason, the protocol is often criticized for being a toothless tiger, for it can't force any action, or conjure punishment for inaction. Although the Kyoto Protocol was adopted on December 11, 1997, it did not enter into force until February 16, 2005 when two-thirds of the participating countries had ratified it. Therefore, the Kyoto Protocol's first commitment period was for the period of 2008-2012 in which participating countries were required to reduce domestic emissions 5% relative to 1990 levels. Despite extensive participation, by 192 countries the Kyoto Protocol was limited in its potential to address global emissions for The United States remained outside of the Protocol's jurisdiction, and developing countries faced absolutely no emission reduction targets. When these merits are considered than the overall success of the protocol must be called into question, for only 18% of global emissions fell under the Kyoto umbrella (European Commission, 2017). The developed world had a real opportunity to spark the practice of sustainable development in their assistance of the developing world, to ensure that the same developmental, fossil fuel driven mistakes would not be repeated. However, in reality, in their haste to catch up with the developed world, large developing, export oriented economics such as China were allowed to become equally, if not more so dependent on the cheap, greenhouse gas intensive forms of fuel, specifically coal to spark and drive their developmental accession. Unfortunately this is the same pollution intensive blueprint laid forth by the developed world over a century ago and while ultimately leading to development, the negative byproduct has not been remediated but is rather exactly what these Protocols and Amendments put forth by the UNFCCC attempt to address.

In addition, there have been 38 countries that have also agreed to make economy wide emission reduction commitments under a second commitment period, which runs from 2013 to 2020 (UNFCCC, 2016a). The Doha Amendment to the Kyoto Protocol, would bring this second commitment period into force, but requires ratification by two-thirds of the participating parties, specifically 144 countries. As of March 29, 2017 only 75 parties had ratified the Doha Amendment (UNFCCC, 2016a). Fact of the matter is that the protocols second commitment period targets imply action on less than 13% of global CO2 emissions in 2014, which clearly signifies the Protocols lack of inclusion on a global scale.

However, In addition to the Kyoto second commitment period arose both the Copenhagen and Cancun Accords in which developed and developing countries submitted voluntary emission reduction pledges for 2020. Opposed to the 13% global CO2 emission inclusion rate from second commitment period under the Kyoto Protocol, the latest emission reduction Accords capture 80% of global CO2 emissions, these Accords have been lauded for increasing participation and getting developed and developing countries alike to strive towards creating a sustainable future. The short arm of the Kyoto Protocol as well as the greater encompassing reduction commitments put forth under the Copenhagen Accords can clearly be seen in Table 1. It is common practice for Annex I Parties to submit absolute emission reduction targets (e.g. 20% below 1990 levels), while many developing, non-Annex I Parties such as China and India have submitted ‘nationally appropriate mitigation actions’, many of which are intensity-based targets, focusing on reducing their CO2 intensity by creating the same amount of value with less pollution intensive combustion (GDP/CO2 emissions). In addition, a number of these developing country targets are conditional on international support – either requiring support to be implemented or to achieve greater levels of ambition and GHG emissions reductions.

Although the ambition of these pledges is insufficient to limit temperature rise to 2°C above pre-industrial levels, the breadth of participation in mitigation commitments marked a significant improvement to the coverage of the Kyoto Protocol, and laid the groundwork for the Paris Agreement.

Table 1: CO_2 emission reduction targets if applicable and recorded observations

Cases under investigation	Kyoto Commit CO_2 equivalent (1990 base)	1990-2013 CO_2 percent change	Kyoto 2nd Commit (2005 base)	Copenhagen Accord Pledge
China	NONE	333.1%	NONE	- 40% CO2 intensity (2005)
Germany	- 21%	- 20%	- 14%	- 20-30% (1990)
Japan	- 6%	14%	- 3.8%	- 25% (1990)
United States	NONE	7.8%	NONE	- 17% (2005)
Italy	- 6.5%	- 17.3%	- 13%	- 20-30% (1990)
UK	- 12.5%	- 20.3%	- 16%	- 20-30% (1990)
France	1990 levels	- 7.3%	- 14%	- 20-30% (1990)
Spain	+ 15%	9.6%	- 10%	- 20-30% (1990)
Australia	+ 8%	43.2%	- 0.5%	- 5 -15% (2000)
India	NONE	198%	NONE	- 20% CO2 intensity (2005)
Korea	NONE	156%	NONE	- 4% (2005)
Belgium	- 7.5%	- 15.9%	- 15%	- 20-30% (1990)
Canada	- 6 %	23%	NONE	- 17% (2005)
Netherlands	- 6%	3.6 %	- 16%	- 20-30% (1990)
Thailand	NONE	188%	NONE	- 7-20% BAU
Switzerland	- 8%	- 7.4%	- 15.8%	- 20-30% (1990)

Kyoto Data: http://unfccc.int/kyoto_protocol/items/3145.php;
Copenhagen Accord: http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php
http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php
Emission Data: http://data.worldbank.org/indicator/EN.ATM.CO2E.PC
Olivier, J. et al, *Trends in global CO2 emissions 2013 report*.

2.5 Paris Agreement: international action beyond 2020

The theme of common but differentiated responsibilities continues in the latest climate agreement, which came into force November of 2016, and was negotiated and bears the title, The Paris Agreement. The main focus of the 21st installment of negotiations at the COP regarding climate change focused on the post 2020 mitigation contributions, of individual nations, depending on their capabilities and for each to self determine. More than 170 countries submitted Intended Nationally Determined Contributions (INDCs) prior to COP21, representing more than 90% of the energy related CO2 emissions (IEA, Energy and Climate Change, 2015).

The Paris Agreement was adopted by consensus on 12 December 2015 because of the growing amount of evidence that links the byproducts of development and humans' everyday lifestyles to the negative externalities currently being observed throughout the world's natural habitats. Paris emphasized the fact that we must transition our world away from the fossil fuel age. Article 2 of the Paris Agreement states:

1. *This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty (…)*
2. *This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.*

The Paris Climate Agreement pg. 25

The expectations that are highlighted by the underlining Articles of the 2015 Paris Agreement, such as, Article 2 must be considered as a focusing event for the entire renewable energy community. The fact that 196 nations did *not* disagree that something must be done to limit global warming is an important first step to acknowledging the issue; 'the success of the COP21 in Paris at the end of 2015 couldn't have had a better resonance than the announcements that PV could contribute significantly to decarbonizing the electricity mix of the planet, sooner than expected and at a reasonable cost' (IEA 2015 Snapshot of Global PV market, 2016).

However, it must be noted that the Paris Agreement did not highlight which mechanisms or strategies would be implemented to ensure we do not eclipse these temperature benchmarks. Additionally, the current sum of all the submitted INDCs are insufficient in ensuring that the 2 °C target is not eclipsed. As stated in the opening remarks of the Paris Agreement; 'Emphasizing with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C" (The Paris Agreement pg. 1). For this reason, the INDC that were submitted can be resubmitted in the future, but only with stronger emission reduction targets. While it is not possible to recede on a past commitment, an INDC is not legally binding, therefore there would be no punishment for non-compliance or failure to meet said commitment. As made clear in the opening remarks of the Paris agreement, it is evident that greater emission reduction pledges are required to ensure that the temperature increase thresholds are not eclipsed. Scenarios put forth by the International Energy Agency predict that emissions from the energy sector need to peak around 2020 if there is to be a reasonable chance of limiting the temperature increase to below 2°C (IEA, Energy and Climate Change, 2015).

With this in mind, what The Paris Agreement did ensure is that the UNFCCC will take stock in progress and convene a facilitative dialogue among Parties in 2018. This will be followed by a formal global stock take of progress in 2023 and every five years thereafter, ahead of setting each successive round of Nationally Determined Contributions (NDCs). The agreement determined that a single framework would be developed to track progress of NDCs, barring in mind the built-in flexibility mechanisms for the Parties' involved. All Parties will report regularly on emissions, progress towards NDCs, adaptation actions, and means of implementation. The Paris Agreement entered into force on 4 November 2016, thirty days after the date on which at least 55 Parties to the Convention accounting for roughly 55 % of the total global greenhouse gas emissions have 'deposited their instruments of ratification, acceptance, approval or accession with the Depositary' (UNFCCC, 2016b).

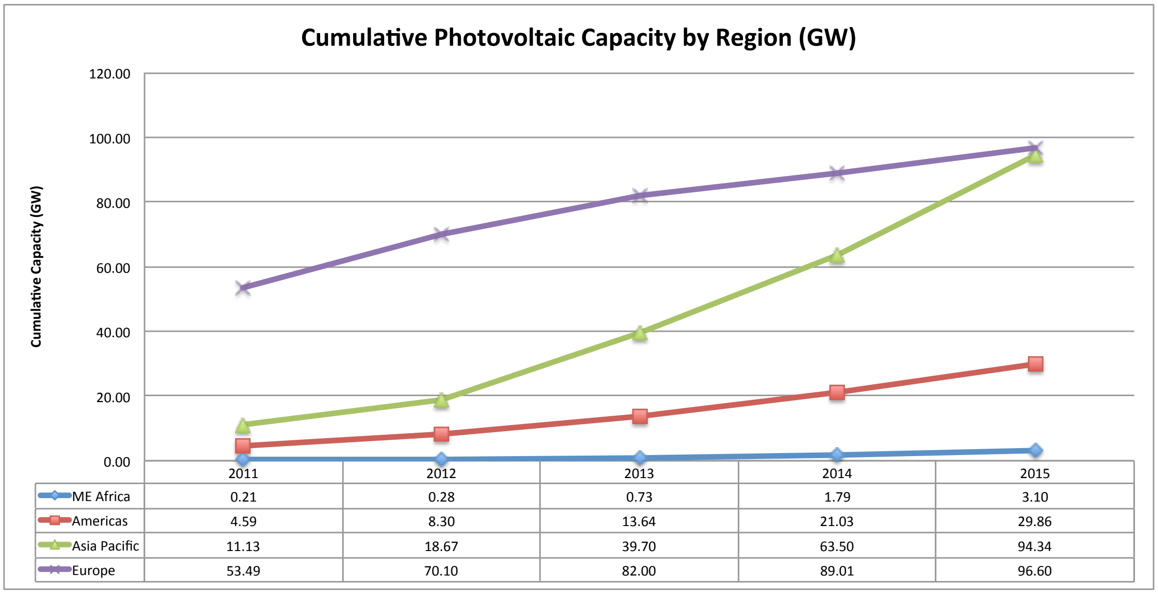
Although not specifically outlined within The Paris Agreement, renewable energy has a serious role to play in driving sustainable development and highlights a key pathway to achieving the ambitious but to this point unjustifiable temperature target outlined by the Paris agreement. Only with strong political determination and recognition that a transition to low carbon societies is as much a political, social and cultural endeavor as it is a technological undertaking. For policymakers this implies that the low carbon energy transition requires an increase in strategic policy intelligence, openness to experimentation and policy learning as well as the development of strategies to manage resistance to the de-carbonization of the existing energy system (OECD, 2015). The Paris Agreement has ushered in a new era in which de-carbonization, focusing on energy demand reduction and increasing energy efficiency will become the 'new normal', thereby leading to a new paradigm in thinking about governing energy transitions (Kern, 2016). It is argued that the global signal sent out by the Paris Agreement has the potential to significantly accelerate the de-carbonization of the global energy system—and with the recent plunge in solar panel costs, the technology now has an opportunity to be an integral player in the transition.

Chapter III. Context with Regard to Solar Photovoltaic Development

3.1 Photovoltaic boom

The sun provides $3.6\ x\ 10^4$ terawatts (TW) of usable power to our Earth's surface every year, while our global demand is currently 16 TW (Hosenuzzaman, 2015). These numbers signify the immense potential of solar energy to power the continuously growing energy needs of today and in the future. The challenge is to eloquently make the transition in solar harnessing technologies, from a highly promising yet previously expensive option to a highly competitive player in electricity industries around the world (Brazilian et. al, 2013). In 2010, the global PV capacity was 19 GW, and forecasts by US market research company GTM Research (Green Tech Media) suggest that by the end of 2016, global PV capacity will reach 321 GW, with a projected 64 GW of PV to be added in 2016. These numbers highlight the fact that this decade will be remembered as the era of the photovoltaic boom.

Solar PV harnessing technology has been around for over half a century, yet has only recently become economically competitive with government support to earnestly enter mature markets (Meneguzzo, 2015). Solar PV was initially used on satellites in the 1950's, but due to high economic cost and relatively low climate implicating concerns or considerations at the time, the technology was not widely deployed until after the first major international climate change conference and protocols were in place with the turn of century.



	2011	2012	2013	2014	2015
ME Africa	0.21	0.28	0.73	1.79	3.10
Americas	4.59	8.30	13.64	21.03	29.86
Asia Pacific	11.13	18.67	39.70	63.50	94.34
Europe	53.49	70.10	82.00	89.01	96.60

Figure 4: Maturation of photovoltaic market in terms of global installed capacity (GW) Data, PVPS, 2016.

Solar PV demand and global installations were once dominated by European Union member states as is evident by figure 4, however, 2012 marked a change in the PV demand landscape. In 2004, the worldwide installed photovoltaic capacity in was a mere 2.6 Gigawatts (GW); by the end of 2013 the global PV capacity had grown to 139 GW (Lins et. al, 2014). This near 60-fold growth in a ten-year span is impressive considering where the technology was in terms of installed global capacity just a few years prior, however, more impressive has been the addition since the end of 2013, thanks in large part to the Asian Pacific emergence in the market.

3.2 Europe initially dominates solar PV market.

Figure 4 highlights that prior to the 2012 PV boom in Asia Pacific, the European continent's capacity was much greater than any other region in the world. Thanks in large part to the European Unions determination to stand by emission reduction commitments when other developed, Annex I countries to the Kyoto Protocol did not in earnest attempt to scale back their domestic emissions. It could be argued that photovoltaic capacity growth within European countries corresponds well with the reduction targets under the first commitment period of the Kyoto Protocol, this can be seen in Table 2, the countries with the greatest carbon dioxide reductions between 1990 and 2013 (Germany, UK and Italy) are also representative of the European parties with the greatest photovoltaic capacity.

Europe had the strongest commitments under the Kyoto Protocol and its noticeable in the portion of oil, gas, and coal used to generate electricity, which has been diminishing across all countries since the Kyoto Protocol came into force in 2005 (Worldbank, 2016).

Table 2: Share of oil, gas or coal used in electricity production.

	1990	2007	2014	'90-'07 abs.	'07-'14 abs.	' 90-'07 % change	07-'14 % Change	2015 PV Cap.
Belgium	37.81	39.45	33.40	1.64	-6.05	4.16	-15.33	3.25
France	11.29	9.99	5.11	-1.31	-4.88	-13.07	-48.84	6.58
Germany	68.02	62.79	56.28	-5.23	-6.51	-8.32	-10.37	39.70
Italy	83.60	83.63	56.25	0.03	-27.38	0.04	-32.74	18.91
Netherlands	93.47	87.19	82.95	-6.27	-4.24	-7.19	-4.87	1.57
Spain	46.81	62.08	38.73	15.28	-23.35	24.61	-37.62	5.44
Switzerland	1.37	1.38	1.15	0.00	-0.23	0.29	-16.59	1.36
UK	77.45	78.46	60.65	1.01	-17.81	1.29	-22.70	8.78

Data: Worldbank, 2016; source: 'own-illustration'

Table 2 shows the share of oil, gas and coal used to generate electricity in the individual years of 1990, 2007 and 2014 as well as the absolute and percent change between those years. It is clear that some European countries (e.g. France and Switzerland) have already decarbonized their electricity generation sectors, while other countries, albeit overall reduction in the share of fossil fuel sourced electricity since 1990 are still largely dependent, as is the case with the Netherlands. European countries that are still largely dependent on fossil fuels can implement measures to decarbonize their electricity sectors in their quests to meet emission reduction commitments. However, it creates the dilemma for other countries whose energy sector has largely rid itself from fossil fuels, such as Switzerland or France. These countries often have to look at options outside the energy sector to honor their commitments to international climate negotiations. The European Commissioner for Climate Action has said:

> *The European Union is clearly delivering on its Kyoto commitments. The EU has reduced its emissions significantly since 1990 while expanding its economy. This further demonstrates that climate policy can be implemented in a way that fosters jobs and growth. The 20% reduction target for 2020 is also within reach thanks to new climate and energy legislation. And through additional policies, the EU is actually on track to overachieve its targets. (European Commission, 2013)*

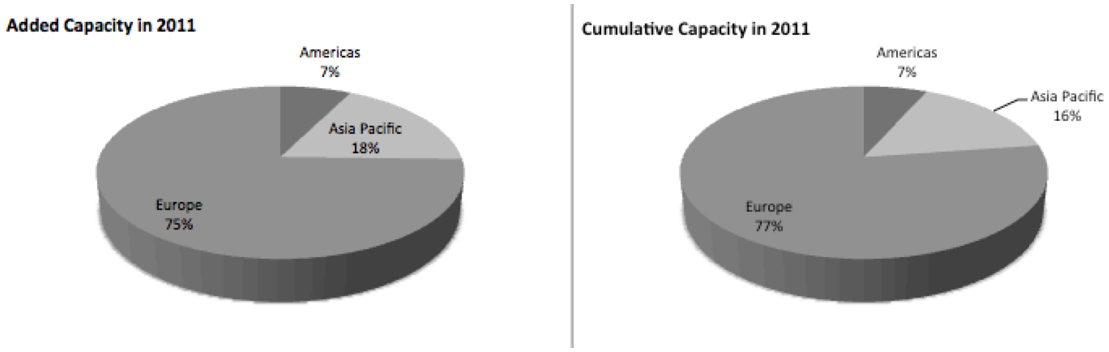


Figure 5: Share of installed PV capacity by world region in 2011: Left pie chart shows added capacity by region in the year 2011. The pie chart on the right indicates the total installed photovoltaic capacity by world region at the end of 2011. Data: IEA, PVPS Annual Report, 2012. Image: own-illustration

As the left pie chart in figure 5 clearly exemplifies, the European community was responsible for three-quarters of the worldwide installed photovoltaic capacity at the end of 2011. At the end of 2013, 58% of the global PV capacity had been installed in Europe (Lins, 2014). The global emergence of PV can be traced back to 2010, a year in which there was an additional 19 GW installed globally (Lins, 2014). This number is put in perspective and truly gains relevance when considering that this is nearly equal to the cumulative amount of solar PV installed since the commercial inception of the technology in the 1970's (Reichelstein, 2013).

3.3 Asia's emergence in the market

The growth of the solar photovoltaic sector within China in 2016 was rather extraordinary and has cemented the countries position as the worlds leading solar photovoltaic promoter in terms of installed capacity. The transition from the European dominated market to Asia Pacific, can be traced back to 2014 when China installed more solar PV than all of Europe combined (Sharma, 2015) In 2014, China accounted for 28.9% of the global 45.3 GW added photovoltaic capacity (Sharma, 2015). In 2015 the PV market continued its rapid expansion, and China maintained its position as the leader, accounting for 14.4 of the total 59 GW of globally added capacity (Sharma, 2015). However, these numbers are bland in comparison with the amount of new solar PV China installed in the year 2016. According to a report from the National Energy agency, China more than doubled their PV capacity in 2016; now having a total installed capacity of 77.42 gigawatts (Reuters, 2017). To illustrate the significance of this, China's new additions in 2016 are equal to a doubling of the added capacity across all European countries between 2012 and 2015. Although solar plants in China produced 66.2 billion kilowatt-hours of power in 2016, this still only represents 1% of the total power generated. However it highlights the beginning of a crucial transition in reducing the dependence on fossil fuels as China strives to increase their share of renewables from 11% today to 20% by 2030 (Reuters, 2017).

Crystalline silicone, an essential material for the production of solar cells housed within the photovoltaic module was once believed to be a limiting factor in the cost reduction potential of photovoltaic technology (Srinivasan and Rajamani, 2016). The worldwide production of crystalline silicon was ramped up and as figure 6 highlights how the price of solar photovoltaic panels correspondingly decreased.

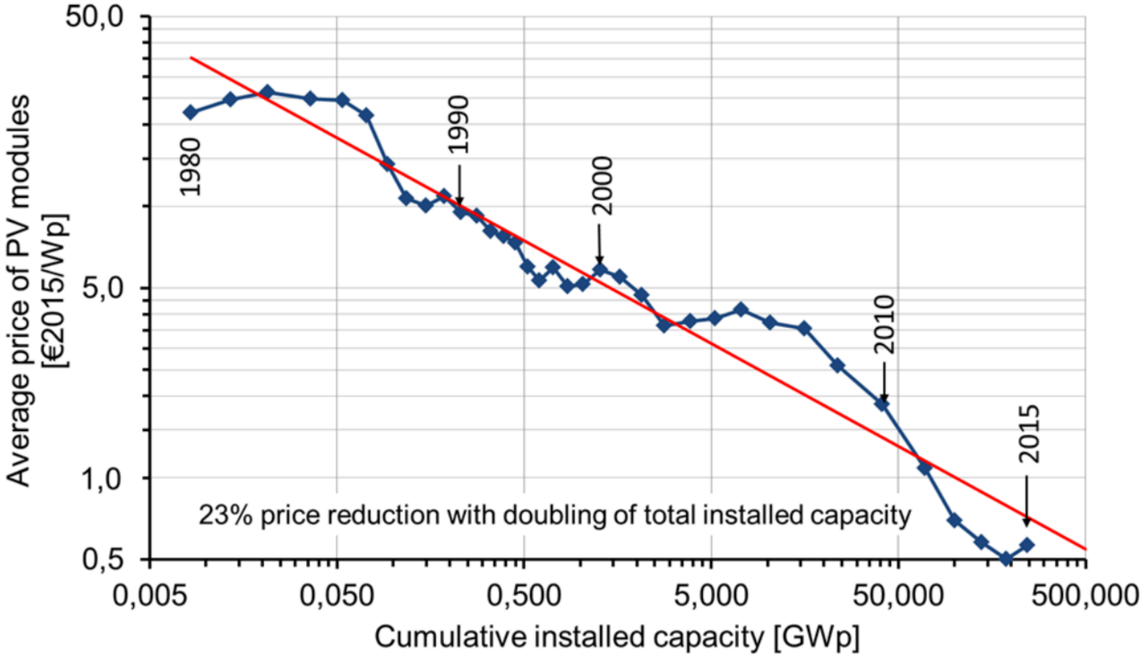


Figure 6: Historical price development of PV modules (Wirth, 2016)

Large investment, especially by the Chinese have driven down the price if solar modules into unprecedented territory, below 50 cents per watt as of May 2015 (Meneguzzo et al. 2015). At this price a true “generation parity” with the cheapest energy source, namely coal, is now being approached. In addition, the Chinese firms were able to develop a competitive edge in the global solar PV market due to their flexibility in responding to orders, as a result of less-protective labor laws and agglomeration of support industries, and their ability to reduce costs across the manufacturing process (Gallagher 2014). With easy access to low-cost capital and a soaring international demand, the firms in China had a strong financial case for ramping up solar PV module production capacity across the manufacturing value chain (Nair, 2014). Figure 7 highlights the shift in the photovoltaic landscape with more photovoltaic power generation capacity being installed in the Asian Pacific region than any other part of the world in the calendar year of 2015.

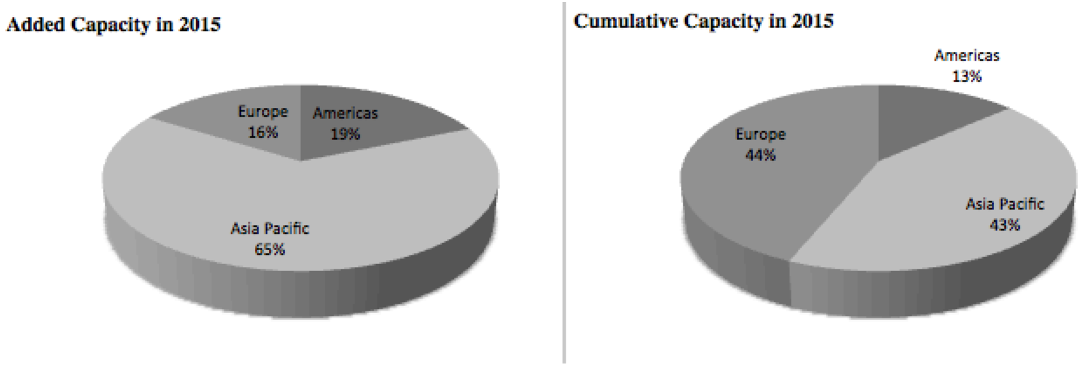


Figure 7: Share of installed PV capacity by world region in 2015. Left pie chart shows added capacity by region in the year 2015. Right, total installed photovoltaic capacity by world region by the end of 2015; Data: IEA PVPS Annual Reports, 2016. Image: own illustration

China is making significant strides to curb their business as usual approach of the past into more climate friendly policies, in regards to energy production. The State Council has set up the National Leading Group on Climate Change, which is composed of multiple relevant departments, and it has released the *China’s National Climate Change Programme*. The Standing Committee of the National People’s Congress (NPC) has endorsed the *Resolution on Tackling Climate Change*, by which the active response to climate change is one, which includes major strategies for economic and social development. In the *12th Five-Year Plan for National Economic and Social Development* reviewed and approved by NPC, it clearly states that low-carbon development is an important guiding policy, and for the first time the reduction of CO_2 emissions per unit of GDP is set as a binding target at -17% (Second National Communication on Climate Change of the Peoples Republic of China, 2012). The deployment of renewable energy technology forms an important component of meeting the targets put forth and ultimately transitioning to a low carbon economy. There have been great advances of the solar photovoltaic sector within China over the past two decades but the pathway has been very erratic. There have been a number of reasons for this erratic pathway, these include national support policies such as rural electrification, the *Western Development Strategy*, and a clean energy manufacturing industry as well as external events such as the explosion in terms of international demand for PV, the 2008 financial crisis and trade disputes with the United States and Europe (Zhang et. al, 2014). China's growing demand for energy has been intertwined with its rapid development for the past 30 years. Since 1978, Chinas average annual GDP growth rate has reached 10% while the growth of the average annual energy consumption has grown at rate of 5.8% (Zhao et. al, 2013). At this rate of growth, China will demand 4.8 billion tons of standard coal by 2020; however, the traditional energy resources can only meet 70% of this demand. In this unsustainable setting, in which the demand grows and the traditional resources are limited, it is imperative to accelerate the development of the solar harnessing and other renewable energy technologies. Thankfully, China is rich in renewable resources and provides massive developmental potential. According to projections, by 2050, the renewable energy capacity in China will be equivalent to the total primary energy consumption in 2000, which was 1.3 billion tons of standard coal (Zhao et. al, 2013). China has four types of renewable energy readily available for commercial production of electricity: hydroelectric, wind, biomass and solar. Of these four sources, solar power has the greatest potential within China (Zhao et al, 2010). Solar is a renewable, safe, reliable, quiet technology that besides the manufacturing process doesn't produce any emissions and therefore an integral component in successfully transitioning China to a low-carbon, sustainable society.

3.4 Dependent variable: cumulative solar photovoltaic capacity.

The previous background information that has been outlined in this section, lends insight into the maturation of the global solar photovoltaic market. It has been determined that the total installed solar photovoltaic capacity of each country is of the upmost importance and therefore will be the dependent variable under investigation with regard to outcome 1. Additionally the degree to which each country harnesses the available solar radiation within their territory will be tested to pay respect to the efforts put forth by smaller, less resource intensive populations whose efforts otherwise would have gone unnoticed if only the cumulative capacity were to be taken into consideration. The total installed solar photovoltaic capacity is influenced by a host of independent variables, which originate from one of the three mutually reinforcing sustainable development pillars— Economic, Ecologic and Societal. How these various independent variables interact and come together to influence the cumulative installed solar photovoltaic capacity of each country under investigation is the primary objective of the following analysis.

Chapter IV. Guiding Theory and Research Design

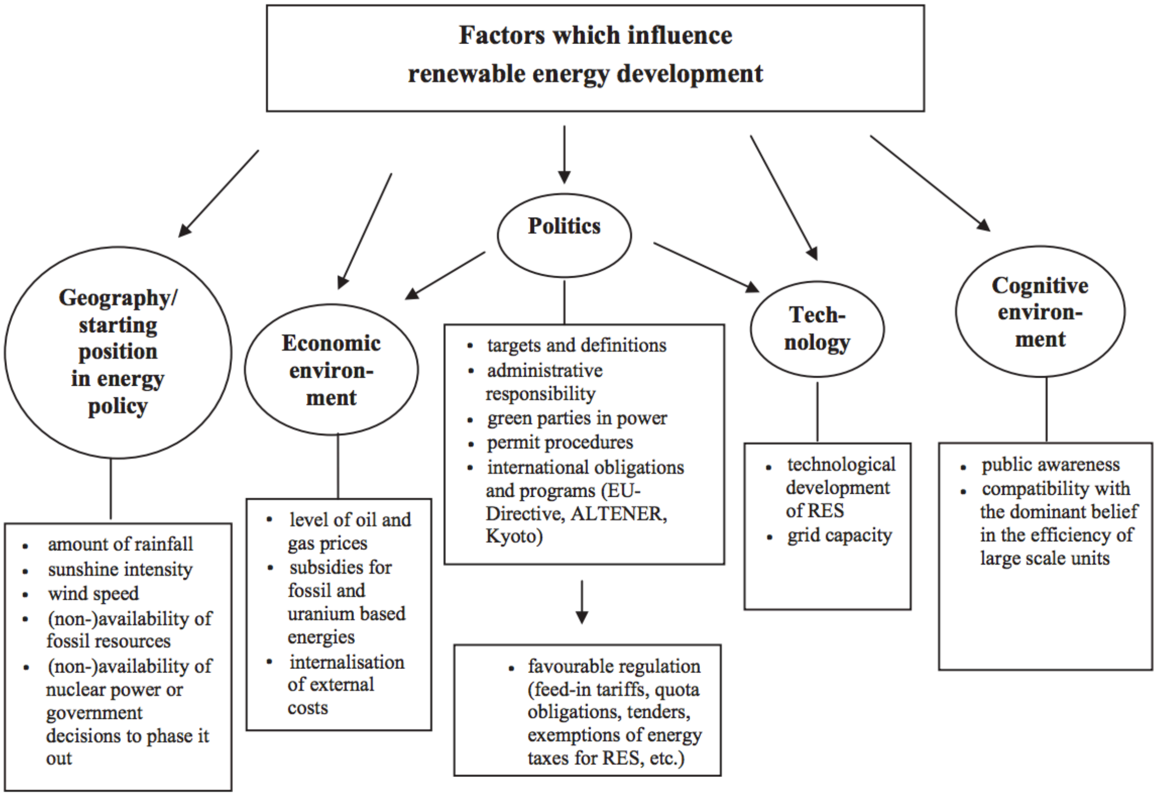
4.1 Sustainable development framework

The modern concept of Sustainable Development is rooted in the undertakings of the 1987 Brundtland Commission and the resulting work, titled *Our Common Future*. Sustainable development roots in the concept of a sustainable society and in the management of renewable resources and will work as the guiding theory and framework around which the rest of this work revolves. The notion of sustainable development was adopted by the World Council for Environment and Development in 1987 and by the Rio Conference in 1992 as ‘a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations’ (WCED, 1987: 46). Traditionally, the notion of sustainable development has been supported by three primary pillars—economy, ecology, and society—allowing for a schematic categorization of development goals within one of these independent yet mutually reinforcing pillars on which the platform for sustainable development can take shape. More concretely, sustainable development addresses concerns in regard to the interrelationship between human society and nature; working to establish a developmental strategy in which the current level of societal welfare does not compromise or undermine the environment, natural resource allocation, or the intertemporal social welfare of future generations. An intertemporal choice is an economic notion, which describes how an individual’s current decisions affect what options become available in the future. Theoretically, by not consuming today, consumption levels could increases in the future, and vice versa (Howard and Richard, 1990). Sustainability has thus been acknowledged as a major normative regulation principle for contemporary society, which includes this intertemporal aspect, specifically a long-term ethical relationship of present generations with those of the future (Laws et al. 2004; Scholz 2011) (Hansmann et. al, 2012). Essentially, sustainable development ‘meets the needs of the present without compromising the ability of future generations to meet their own needs.’ This definition is based on the previously mentioned ethical imperative of equity within and between generations. Moreover, apart from meeting the basic needs of all, sustainable development implies sustaining the natural life-support systems on Earth, and extending to all the opportunity to satisfy their aspirations for a better life (Hediger, 2000). In an unsustainable setting some dimensions must be compromised at the expense of another, for instance, achieving ecological aims in the present, through strict ecological regulations and conservation of natural resources would most likely have positive effects on the economic situation of future generations, even though it may hamper short-term economic growth (Hansmann et. al, 2012). Often times, one dimension, in this example economic growth, is sacrificed to ensure environmental protection. Additionally, equity within generations is often considered an intrinsic component of sustainable development linked to the social pillar (IPCC, 2014). An ideal medium must be found to balance the consumption of natural resources today with the preservation of the environment, which together determine the amount of societal welfare that a society experiences—and the tool to achieve this intertemporal balance is sustainable development.

4.2 Interactions between sustainable development and renewable energy

Renewable energy is any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. Renewable energy utilization is defined as sustaining natural capital as long as the resource use does not reduce the potential for future harvest. Figure 10 highlights the relationship between renewable energy and the concept of sustainable development that can be viewed as a hierarchy of goals and constraints that involve global, regional and local considerations. Although the exact contribution of renewable energy to sustainable development must be evaluated on a country-specific context, it offers the opportunity to contribute to a number of important sustainable development goals: (1) social and economic development; (2) energy access; (3) energy security; and (4) climate change mitigation and the reduction of environmental and health impacts (IPCC, 2011). These goals can be linked to the three-pillar model, while sustainable development concepts provide a useful framework for policymakers to assess the contribution of renewable energy to the notion of sustainable development and to formulate appropriate economic, social and environmental policies (IPCC, 2011). The mitigation of dangerous anthropogenic climate change is a strong driving force behind the increased use of renewable energy worldwide (IPCC, 2015). Historically, economic development has been strongly correlated with increasing energy use and growth of GHG emissions; renewable energy can help decouple that correlation, contributing to sustainable development (IPCC, 2011). There are a number of independent variables that arise from the sustainable development framework that can be drivers of renewable energy integration, in this case specifically solar photovoltaic energy production. The dependent variable under investigation, the total installed solar photovoltaic capacity of a country at the end of 2015 can be influenced by a number of independent variables that fall from this sustainable development umbrella, for example: population growth, per capita energy consumption, gross domestic product per capita, countrywide greenhouse gas emissions, ambient concentration of air pollution in urban areas, percent of urban population living in coastal areas as well as the share of renewable energy sources as a share of consumption.

Range of Factors that Influence Renewable Energy Development



Source: (Reiche, 2002).

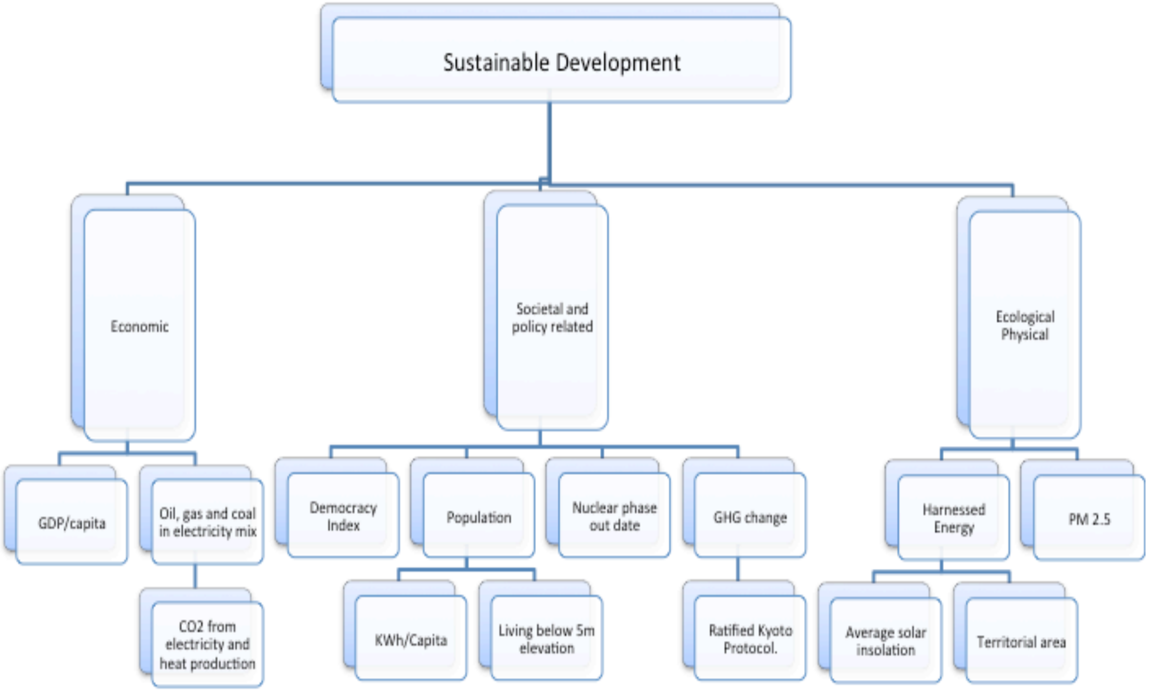
Figure 8: This diagram depicts the various factors that can influence renewable energy development as well as highlighting the diverse background from which the factors can be influenced.

As is evident from figure 8, there are a host of factors, which influence renewable energy development, spanning across all three foundational pillars of sustainable development, economic, ecological and societal. This highlights the argument that the development of solar photovoltaic and other renewable energy technologies is rooted in the notion of sustainable development. Figure 8 is representative of a similar framework used in a publication discussing the policy differences in the promotion of renewable energies in EU member states and reinforced the selection of independent variables used in the following analysis. Reliable access to energy, whether from renewable or non- renewable sources, is closely correlated with a societies measure of development; this is particularly true for countries at earlier stages of development (Gaye, 2016). This being said it comes as no surprise that countries at different stages of development have varying motivations to advance renewable energy. There are an assortment of incentives for developing countries to encourage the deployment of renewable energy, for instance: access to energy, creating employment opportunities in the formal economy, which is legally regulated and taxable, and reducing the costs of energy imports, or, in the case of fossil fuel rich countries, prolonging the lifetime of their natural resource base (IPCC, 2011). On the other hand, the primary reasons for developed countries to push for integration of renewable energy into their existing energy infrastructures are: reducing carbon emissions to mitigate climate change, enhancing energy security, and actively promoting structural change in the economy, such that job losses in the declining manufacturing sectors of developed countries are softened by new employment opportunities that come about from building up a new 21st century, renewable energy based infrastructure (IPCC, 2011). There are a number of individual factors that influence renewable energy development that appear in figure 8 which are one to one correlation in terms of independent variables, commonly referred to as conditions, used in the following analysis. The factors that influence renewable energy development that appear in figure 8 should be compared with figure 9 on page 22; which provides a detailed breakdown and assortment of the independent variables derived for this analysis and filed into the sustainable development framework. When the two figures are compared the bipartisanship of the factors is evident and reinforces the independent variables that were selected, discussed and used in the following analysis. Nevertheless, it must be recognized that any framework, by itself, is an imperfect tool for organizing and expressing the complexities and interrelationships encompassed by sustainable development. The notion of sustainable development has been used to guide and assist in deducing different conditions (independent variables) to test on the outcomes pertaining to photovoltaic capacity of countries under investigation.

4.3 Three pillars of sustainability: Societal, Economical and Ecological.

The three primary pillars on which sustainable development takes shape allow for a schematic categorization of development goals within one of these independent yet mutually reinforcing pillars: Societal, Economical and Ecological on which the platform for sustainable development can take shape. Sustainable development indicators were selected and tested as a way of being able to measure, compare and quantify the various facets of development to track progress, set goals and create paths to ensure that future practices are indeed alleviating pressure on the natural system and becoming more sustainable in the process. The potential for renewable energy to play a significant role in alleviating poverty and driving development in communities across the world has created an opportunity to boost the societal welfare of the current community without compromising the welfare of future generations. Figure 9, is an attempt to categorically divide the independent variables that are used in the following analysis into the sustainable development framework and its three underlying, mutually reinforcing pillars.

Independent Variables for Following Analysis Under Sustainable Development Framework



Source: Self-created

Figure 9: Hierarchical Diagram of the three pillar model of the sustainable development framework and how the following conditions pertaining to the QCA analysis fall within this three pillar framework.

As is evident from figure 9, there are a number of conditions that fall under each pillar, some conditions sprouting from the existence of others, which then tie back into the overarching family pillar. For example kilowatt-hour consumption of energy and the percentage of the population living below 5 meters elevation sprout from the overarching population condition which is just one of a number of conditions under the societal pillar that arises from this sustainable development framework, in which the three independent, yet mutually reinforcing pillars merge in an effort to ascertain development in a sustainable fashion.

None of the below listed conditions will be expected to stand alone in the analysis, however, describing each underlying sustainable development indicator and/or condition in and of itself by giving a short explanation as to why these variables are considered pertinent in determining the extent to which solar photovoltaic has been integrated in the shape of overall installed solar photovoltaic capacity at the end of 2015 for each case under investigation.

Societal pillar: sociopolitical conditions pertaining to sustainable development indicators

Percent of total population living in coastal areas

Coastal ecosystems provide important economic benefits, such as fisheries, tourism and recreation. They are also important for biodiversity, which is recognized by the Convention on Biological Diversity (CBD) as having its own intrinsic value as well as importance for human life and sustainable development (UN DESA, 2007). High population concentrations within the 100-kilometer coastal zone can dramatically affect the coastal ecosystem through habitat alteration and increased pollution. On the other hand, coastal areas with good access to internal, regional, and international trade appears to be favorable for economic development (UN DESA, 2007). For the analysis, the data available from the Worldbank is the percent of the urban population living below 5 meters elevation. Reason being that these countries and/or populations would be exposed and susceptible to future climate change externalities such as global sea level rise that could infringe upon these exposed populations and therefore have incentive to mitigate now to limit future damage. Although the sustainable development indicator and condition are not identical they are inherently similar. There could be an interrelationship with solar PV, for it could be argued that a nation, with a large portion of its population exposed to future sea level rise would be active in trying to limit their greenhouse gasses to ensure the future welfare of their population isn't compromised by the combustion of fossil fuels. Although there is no guarantee, one could argue that a population at risk is most plausible to take action.

Democracy Index

Desired to create a condition, which captured the sort of government that is in place for the various countries under investigation. To determine if one specific type of government, in this case democratic countries combined with the wealth of the population would have a specific effect on the solar photovoltaic capacity of a country. With respect to the interrelationship with PV, no direct relationship is expected between government type and the PV capacity of a country. However, democratic states with adequate financial resources are typically indicative of nations in which the will of the people is usually met with corresponding policies of what they desire.

Population Growth

Agenda 21 came to fruition at the 1992 Earth summit in Rio de Janeiro and explicitly deals with sustainable development; within it population growth is identified as one of the crucial elements affecting long-term sustainability. Population growth, at both national and subnational levels, represents a fundamental indicator for national decision-makers (United Nations, Department of Economic and Social Affairs, Indicators of Sustainable Development: Guidelines and Methodologies, 2007). Its significance must be analyzed in relation to other factors affecting sustainability. However, rapid population growth can place strain on a country's capacity for handling a wide range of issues of economic, social, and environmental significance, particularly when rapid population growth occurs in conjunction with poverty and lack of access to resources (UN DESA, 2007). With respect to the interrelationship with PV, a growing population concurrently will require more energy and electricity to power their development. Additionally growing populations are typically found in developing countries with a newfound appetite to consume natural resources in their drive to development. Therefore, it’s imperative that this growing economies harness the potential of renewable energy

Economic pillar: economic conditions pertaining to sustainable development indicators

Gross Domestic Product (GDP) per capita

By allocating total production to each unit of population, the extent to which the rate of individual output contributes to the development process can be measured (UN DESA, 2007). GDP per capita is a powerful indicator of the economic state of development; although it is not a direct measure of sustainable development it is very important measure for the economic and developmental aspects of sustainable development, including people's consumption patterns and the use of renewable resources (UN DESA, 2007). One of the often-cited limitations of GDP is that it does not account for the social and environmental costs of production, and is therefore not a good measure of the level of overall well being. With respect to the interrelationship of GDP/capita and PV, countries that have relatively wealthy populations in terms of GDP per capita are in a favorable position to undertake and push for policies that the underlying society desires. Being a wealthy society does not automatically guarantee a higher rate of photovoltaic or other renewables are integrated into the existing electricity mix, but is symbolic of financial flexibility and a society that would have the resources to implement renewables.

Energy use per capita

Energy is a key factor in industrial development and in providing vital services that improve the quality of life. Since the onset of the industrial revolution energy has been regarded as the engine of economic progress. Traditionally, however, its production, use, and byproducts have put major strain on the environment, both from a resource use and pollution point of view. The decoupling of energy use from development represents a major challenge of sustainable development. The long-term aim is for development and prosperity to continue through gains in energy efficiency rather than increased consumption and a transition towards the environmentally friendly use of renewable resources. On the other hand, limited access to energy is a serious constraint to development in the developing world, where the per capita use of energy is less than one sixth that of the industrialized world (IEA, Energy and Climate Change, 2015). The actual value of the indicator is strongly influenced by a multitude of economic, social and geographical factors. When using it as an indicator of sustainability the indicator has to be interpreted in connection with other indicators of economic development and energy use, as smaller or larger values of the indicator do not necessarily indicate more or less sustainable development (UN DESA, 2007). With respect to the interrelationship between energy consumption and the amount of solar PV installed, there is a definite yet convoluted correlation. The range of energy consumption between societies with similar characteristics can be staggering. Some developed countries use drastically less energy per capita than otherwise similar developed countries in terms of economic and societal similarities, for example the European Union member nations compared with the United States or Canada. Typically after economies have developed their per capita energy consumptions begin to decline as they transition to a more services geared economy, although this relationship can be complex for the wealthier a society becomes the more energy they typically require to power their lives. As the world's economies continue to develop their underlying societies and populations likewise develop and in the process the demands for energy will grow to newfound heights and solar harnessing technologies will play a serious role in supplying this ever-increasing demand.

Renewable energy sources as a share of consumption

Chapter 4 of Agenda 21 calls for an improvement of efficiency in the energy sector as well as a transition towards low carbon societies. Dependence on non-renewable resources can lead to a multitude of short and long-term consequences and is unsustainable in the long term. Renewable resources, on the other hand, can supply energy continuously under sustainable management practices while simultaneously acting as a mitigating agent in the context of climate change. The ratio of non-renewable to renewable energy resources represents a measure of a country's sustainability (UN DESA, 2007). This sustainable development indicator is essentially the inverse of the condition used in the analysis, which gives the share of electricity produced from oil, gas or coal sources. This sustainable development indicator and inverse of the condition used in the analysis helps to show how pollution intensive each countries energy supply is. The higher the share of fossil fuels in a countries electricity mix the greater is the opportunity for PV to enter the market, while countries with a relatively small fossil share may have already incorporated solar PV or other renewable energy options.

Ecological Pillar: physical conditions pertaining to sustainable development indicators

Ambient concentration of air pollutants in urban areas

Provides a measure of the state of the environment in terms of air quality and is an indirect measure of population exposure to air pollution which can lead to health complications to people living in urban areas. Air pollution, from households, industry power stations and transportation are typically the greatest sources of air pollution (Seinfeld and Spyros, 2016) As a result, the greatest potential for human exposure to ambient air pollution and subsequent health problems occurs in urban areas. Improving air quality is a significant aspect of promoting and improving sustainable human settlements. The relevance and relation to solar PV is the fact that it is representative of a clean source of electricity, opposed to the combustion of fossil fuels, which release carcinogenic pollutants into the surrounding atmosphere. Particulate Matter (PM) in particular effects more people than any other pollutant (Seinfeld and Spyros, 2016). The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water (Schauer, 1996). It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. The most health-damaging particles are those with a diameter of 10 microns or less, which can penetrate and lodge deep inside the lungs (Schauer, 1996). Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer (WHO, 2016). World Health Organization, air quality guidelines estimate that reducing annual average particulate matter (PM_{10}) concentrations from levels of 70 $\mu g/m^3$, which are common values for many cities in developing economies, closer to the neighborhood of WHO guideline level of 20 $\mu g/m^3$, then air pollution related deaths could be reduced by around 15%. However, even under the WHO guideline levels PM has a negative effect on human health, highlighted by the fact that in the European Union, where PM concentrations in many cities do comply with guideline levels, it is estimated that average life expectancy is 8.6 months lower than it would be without the anthropogenic sourced micron pollutants (WHO, 2016)

Harnessed Energy

This condition was created to determine the extent to which countries were harnessing the available incoming solar insolation and converting it into electricity, considering how much land (surface area) is available within their territory. Essentially the result of the following equation will become the condition and shows the percentage of the yearly incoming solar radiation that is harnessed by solar photovoltaic and converted to electricity.

Percent of a countries incoming solar insolation converted to electricity =

$$\left(\frac{PV\ capacity\ (kilowatt)\ *\ 8760\ hours}{\text{Area (m2)}\ *\ \text{avg. yearly insolation kwh/m2}}\right) * PV\ eff * 100$$

PV eff = PV efficiency or capacity factor =

$$\left(1-\frac{PV\ potential\ (TWh)\ -\ PV\ output\ (TWh)}{PV\ potential\ (TWh)}\right) * 100$$

*PV potential = installed photovoltaic capacity in 2014 * 8760 hours*
PV output = photovoltaic electricity production in 2014

* These are equations are self-formulated.

There is not necessarily an expectation with regard to this condition, for some countries in the top-5 in terms of installed capacity are territorially large countries, such as the United States and China and therefore harness a very minute fraction of the available solar radiation within their territory. However, European countries, with their typically smaller territorial size harness a greater fraction of the available incoming solar radiation.

Emission of Greenhouse Gasses

Greenhouse gases contribute in varying degrees to global warming depending on their heat absorptive capacity and their lifetime in the atmosphere. The global warming potential (GWP) describes the cumulative effect of a gas over a time horizon (usually 100 years) compared to that of carbon dioxide (Lashof and Dilip, 1990). For example, the global warming potential of methane is 21, meaning that the global warming impact of one kilogram of methane is 21 times higher than that of one kg of carbon dioxide. Prior to the industrial revolution the amount of greenhouse gases present in our atmosphere remained relatively constant over the past two thousand years (MacFarling Meure et. al, 2006). 2015 marked the first time in the instrumental record that the average concentration of CO2 in the atmosphere eclipsed 400ppm. The amount of carbon dioxide observed in the atmosphere today is indicative of a nearly 30% increase in less than 60 years (MacFarling Meure et. al, 2006). With respect to the interrelationship with PV, the more a country integrates renewable energy; such as solar photovoltaic and other options the total amount of GHG emissions that are emitted will begin to decline (once the energy required to produce the PV modules is offset from the fossil free technology). The percent change of GHG emissions in 2014 when compared to 1990 also gives an idea of individual countries commitments to past climate agreements as well as the trajectory of their economy.

<u>Conditions not directly related to sustainable development</u>

Nuclear phase out date

This condition works in conjunction with the nuclear efficiency condition. Reason being, that while the majority of countries with the technology have their nuclear power facilities operating, according to my calculations, at an efficiency greater than 70% there are a number of countries that have decided to phase out nuclear in the coming years. It is obvious, that for the countries adopting this nuclear phase out strategy (Germany, Switzerland, Belgium) additional sources of capacity will have to be added to the grid to ensure a smooth transition, and opens the door for renewables, such as solar photovoltaic to help replace the supply shortcomings created by the outgoing nuclear technology. There is a relation to solar PV for countries that are actively planning to phase out nuclear power from their electricity mix will be hard pressed to replace it with non fossil fuel alternatives. Therefore, there is real opportunity for PV to further penetrate these markets and help make up for the discrepancy created by the removal of the nuclear sector from the electricity mix.

Nuclear Efficiency or capacity factor

This condition was selected, to gauge which countries were fully utilizing their nuclear capacity. I created this condition to counter the fact that there are some countries in the world, specifically Japan, which have a large installed nuclear capacity (40.3 GW) yet generate almost zero electricity from their 43 nuclear power plants after the Fukushima accident. This condition came to life in the form of an equation:

$$\left(1-\frac{nuclear\ potential-nucelar\ output}{nuclear\ potential}\right)*100$$

The reasoning for this condition is similar to that for that nuclear phase-out date, but trying to capture perhaps aging facilities and potentially the next wave of countries to steer away from nuclear power generating options, opening the door for renewable alternatives such as solar PV.

Share of carbon dioxide emissions from electricity and heat production

This condition came to light when considering how to highlight which countries had a real, and in a sense easy opportunity to lower their emissions by decarbonizing their electricity infrastructure. The price of photovoltaic technology has been diminishing and for the first time is approaching grid parity, on par with the cost of coal. For this reason solar harnessing technologies have for the first time become a real and legitimate option from an economical standpoint to phase out fossil fuel power plants. There is a relation to solar PV for nations with a high fraction of their carbon dioxide being sourced from either electricity or heat production, are most likely symbolic of countries that have a fossil fuel intensive electricity mix. These are the countries were PV has a real opportunity to reduce domestic emissions associated with electricity and heat production and assist in complying with Nationally Determined Contributions laid forth as part of the Paris Agreement in December 2015.

Annex I countries that ratified the Kyoto Protocol

Desired to create a condition that captured a States sincere and earnest international commitment to combating climate change. Primarily by agreeing to take the costly steps towards mitigation by implementing new technologies or coming up with new practices to reduce emissions. This condition highlights, which industrialized countries were serious about combating climate change and which nations refused to part with economic development at all costs. International emission reduction targets should have a positive impact on solar PV capacity.

In the following methods section all of these independent variables that primarily come from the sustainable development framework will be molded into 6 combined sets. These combined sets can be thought of as independent variables, which will be tested against the set dependent variables better known as the outcome under investigation. The dependent variable that will be tested will either be the total installed solar photovoltaic capacity at the end of 2015, or the fraction of available incoming solar radiation that is harnessed by each country.

4.5 Case Selection

Because the primary purpose of this undertaking is to determine which previously described conditions that have come from within the previously described sustainability framework are responsible for this decade's solar photovoltaic boom. It is necessary to determine which conditions are essential and in which combination the conditions have previously taken form in the worlds top solar photovoltaic capable countries to gain insights into how other countries in the future can take similar routes in their pursuits of sustainability. For this reason our case selection will focus on the top-sixteen countries in terms of photovoltaic capacity by the end of 2015. At the end of 2015, the countries that had the greatest installed photovoltaic capacity were: China (43.5 GW), Germany (39.7 GW), Japan, (34.4 GW), United States (25.6 GW) and Italy (18.9 GW) (Snapshot of Global PV Markets, 2016). There is a considerable drop off in terms of cumulative capacity after the top 5, Great Britain ranks sixth on the list with a total of 8.8 GW (Snapshot of Global PV Markets, 2016).

Table 3: Total installed photovoltaic capacity and annually added capacity (GW). Data: IEA, PVPS 2016.

Country	2014 Added Capacity (GW)	2014 Total Capacity (GW)	2015 Added Capacity (GW)	2015 Total Capacity (GW)
China	10.64	28.33 (2)	15.2	43.54
Germany	1.9	38.25 (1)	1.5	39.7
Japan	9.74	23.4 (3)	11.0	34.41
U.S.	6.21	18.32 (5)	7.3	25.62
Italy	0.424	18.62 (4)	0.3	18.91
UK	2.3	5.1 (8)	3.5	8.78
France	0.939	5.68 (6)	0.879	6.58
Spain	0.023	5.38 (7)	0.056	5.44
Australia	0.904	4.13 (9)	0.935	5.07
India	0.8	2.94 (11)	2.0	5.05
Korea	0.909	2.39 (12)	1.01	3.43
Belgium	0.079	3.16 (10)	0.095	3.25
Canada	0.632	1.9 (13)	0.6	2.5
Netherlands	0.4	1.12 (15)	0.45	1.57
Thailand	0.475	1.29 (14)	0.121	1.43
Switzerland	0.305	1.06 (16)	0.3	1.36

As is evident from table 3 there is major variance in the total installed solar capacity among the world's top photovoltaic promoters. Because there is such a large variance in the installed capacity it has been decided that it would be best to again test these top photovoltaic countries with regard to how well they harness the solar radiation available within their territory. This second outcome that will be tested gives precedent to the cases that do not require as much energy for they support smaller and/or less resource intensive populations and gives credence to their efforts to integrate solar photovoltaic technology which would have gone unrecognized under the criteria which simply took the absolute installed capacity into consideration.

Chapter V. Method

In this study, the top 16 countries in terms of installed photovoltaic capacity at the end of 2015 will be compared using fuzzy-set Qualitative Comparative Analysis (QCA). The starting point for any QCA is to select a sample of cases, set an outcome that you wish to test and a selection of conditions that are expected to explain differences regarding the outcome between the cases under investigation (Berg-Schlosser and De Meur, 2009). QCA is a fairly new set-theoretic research method that is specifically suited for an intermediate number of cases (n=5-50) and strikes a balance between qualitative and quantitative analysis (Rihoux, 2006). Furthermore, QCA is a technique that uses Boolean algebra to implement principles of comparison used by scholars engaged in the qualitative study of macro level social phenomenon. Because of the interdisciplinary nature of this study a fuzzy-set QCA is an ideal tool to perform the necessary analysis; with a number of independent variables, from here on out referred to as conditions, being tested to determine their effects on the dependent variable under investigation, better known as the outcome. Initially there was a very broad spectrum of potential conditions, which were sub-grouped into one of the three underlying and primary pillars on which the sustainable development framework is built. The most important conditions were selected from a review of academic literature, government and independent agency reports. In the end the overarching intent is to be able to determine which conditions or combination therefore create the most robust markets for photovoltaic capacity or which countries are harnessing the greatest fraction of available solar radiation striking their territorial area. Insights will be beneficial for determining which factors are paramount, and which are not principally necessary for future photovoltaic integration into a countries existing energy mix to ensure that fossil fuel based energy production is ultimately phased out and ideally replaced entirely—creating a pathway for economic and social development in a sustainable manner.

5.1 Fuzzy set Qualitative Comparative Analysis

Qualitative Comparative Analysis (QCA) belongs to the group of case study methods and can be considered the most systematic form for case comparisons, when it comes to the various analysis techniques. When using the Qualitative Comparative Analysis technique, the first order of business is deciding whether to use a conventional 'crisp' or 'fuzzy-set' calibration method. A conventional (or 'crisp') set is dichotomous, meaning that each and every case under investigation is either 'in' or 'out' of a set, for example, the set of 'Ratified Kyoto Protocol'. In this crisp-set example, a binary output would be generated, with cases taking on either the value of 1, or 0. Values of 1 would be representative of cases that are 'in', for example countries that had ratified the Kyoto Protocol and 0 'out' for countries that had not ratified the Kyoto Protocol. The corresponding output, or results produced by QCA provide detailed information about which (combinations of) factors were sufficient for the outcome in a certain group of cases; due to its focus on complex causal structures, which distinguishes QCA from statistical techniques, it offers more precise insights about which further steps could be undertaken in subsequent (comparative) case studies (Schneider and Wagemann, 2010).

A fuzzy set, by contrast, permits membership scores that fall anywhere within the interval 0-1, meaning more fine grain information about cases can be contained (Schneider and Wagemann, 2010), while retaining the two qualitative states of full membership and full non-membership (the values of 1 and 0 respectively). This is similar to the crisp set technique, however fuzzy set goes beyond 'fully in' and 'fully out' and integrates all other possibilities along the 0-1 interval. For example, certain cases may be 'almost fully in' the set, membership score = .90, or 'almost fully out' of the set, membership score = 0.1. Something which is unique to the fuzzy set technique would be the notion of a 'crossover point' when the membership score = 0.5, meaning that the case is neither 'more in' nor 'more out' of the set under investigation and therefore the point is ambiguous and should always be avoided because the case looses its power to draw conclusions if it lies on the 'crossover point'. It is up to the researcher to set the three calibration thresholds, which ultimately determine the fuzzy set membership scores. For this reason it is imperative that this procedures is open, explicit and thorough so that other scholars can easily evaluate the results.

The overarching goal of QCA analysis is to support the researcher in their attempt to arrive at a meaningful interpretation of the patterns displayed by the cases under investigation. More specifically, it is an examination of set theoretic relationships between causally relevant conditions and a clearly specified outcome. In the case of this study, the outcome for which we are testing is either having over 10GW installed photovoltaic capacity at the end of 2015; or which cases had harnessed over 0.2% of the incoming solar radiation striking their territories. These set-theoretic relationships are then interpreted in terms of sufficiency and necessity. More precisely, as figure 10 highlights a condition can be interpreted as sufficient, if the condition is always present when the outcome is also present. Consequently, the sufficient condition is sub-set of the outcome. By contrast, a necessary condition is one that, whenever the outcome is present the condition is also always present. Therefore, the necessary condition is a super-set of the outcome and must be present every time the outcome is observed. (Ragin 2000).

Figure 10: Example of two sufficient and one necessary condition in terns of subset (Bol, 2009).
Source: *own illustration*

However, two problems frequently appear when we analyze empirical cases comparatively: first, very often, we do not find any conditions that are sufficient or necessary for all cases under examination. In addition, it is common that conditions are sufficient and necessary only in combination with other conditions commonly referred to conjunctural causality or configurational causality (Thomann, 2016). Additionally there is the possibility for there to be equifinal causation or equifinality, which implies that it is possible for there to be multiple paths that lead to the same outcome, each representing an alternative path that may apply to some cases but not to others (Thomann, 2016). This implies that there can be various combinations of conditions that lead to the outcome.

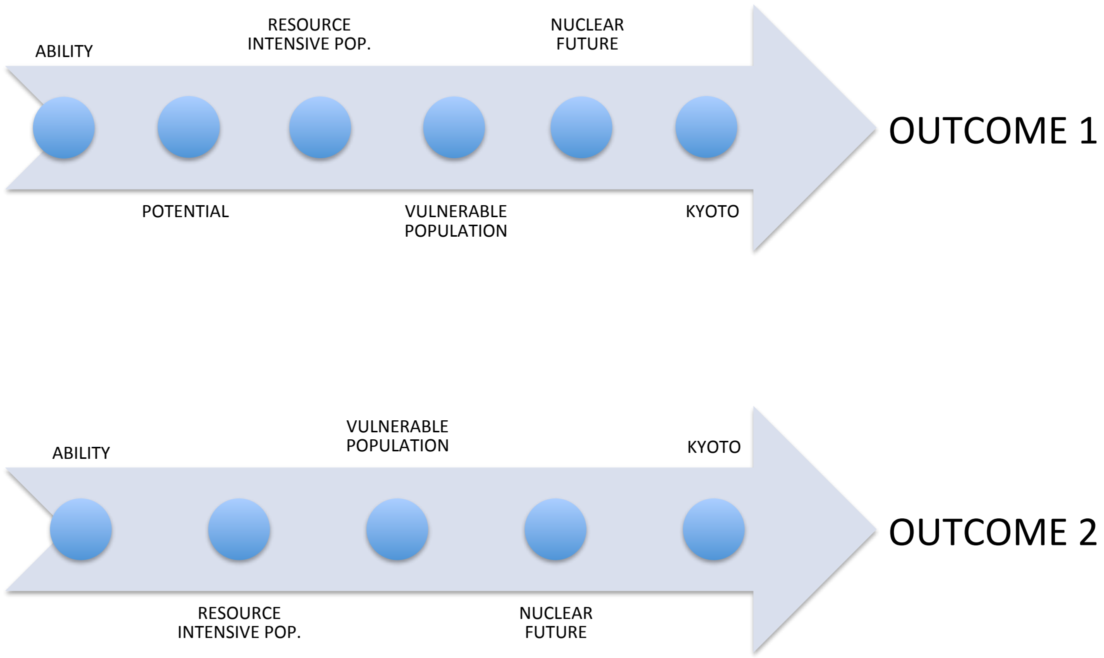


Figure 11: Illustration of the individual conditions that will be tested for the specified outcome.
Source: own illustration.

As mentioned before QCA is a configurational method, and therefore produces results that highlight this interplay between conditions to explain the outcome under investigation (Schneider and Wagemann, 2010). For this reason, it should be noted that when it comes to interpreting the results the entire set of conditions should be considered in unison, for an overt focus on individual conditions isolated from one another goes against the epistemological foundation of QCA (Schneider and Wagemann, 2010). At times a researcher is able to conclude from an analysis that a perceived important condition is neither a necessary or sufficient condition; this does not imply it can be neglected, but rather this per say invisible condition might be an INUS condition— that is, it is only casually relevant in some cases and only in combination with other conditions (Mahoney 2008, Wagemann and Schneider 2009). With these notions and realizations in mind, the next section focuses on the calibration of the individual conditions as well as both outcomes to be tested in the following analysis.

5.2 Calibration of the variables under investigation – The Outcomes

The dependent variable, from here on out referred to as the outcome, is of the upmost interest and at the center of the analysis. In this case we are interested in determining which conditions are sufficient or necessary to ensure that a country has over 10 gigawatts of installed photovoltaic capacity at the end of 2015; or which countries are already harnessing 0.2% of the incoming solar radiation available in their territory. The reason for the two different outcomes under investigation is that while one takes into account total capacity in absolute terms it fails to capture the efforts put forth by smaller countries that don't consume nearly as much electricity as the big industrial economies. Therefore, the second outcome was created to test which countries are doing the most with their available solar resource with respect to their geographical constraints.

Case	Photovoltaic Capacity (GW)	Fuzzy set score	Harnessed Solar Energy (%)	Fuzzy set score
China	43.54	0.993	0.0307	0.035
Germany	39.7	0.988	0.9799	0.946
Japan	34.41	0.973	0.5207	0.765
U.S.	25.62	0.909	0.0202	0.028
Italy	18.91	0.788	0.5855	0.805
UK	8.78	0.402	0.1728	0.370
France	6.58	0.246	0.0903	0.104
Spain	5.44	0.184	0.1062	0.137
Australia	5.1	0.166	0.0041	0.021
India	5.05	0.165	0.0078	0.022
Korea	3.43	0.104	0.2394	0.536
Belgium	3.25	0.099	0.9826	0.947
Canada	2.50	0.079	0.0022	0.020
Netherlands	1.57	0.060	0.2651	0.560
Thailand	1.43	0.057	0.0195	0.028
Switzerland	1.36	0.056	0.2317	0.529
Lower bound	1		0.05	
Crossover Point	10		0.2	
Upper bound	30		1.0	

Table 4: Raw data and calibrated fuzzy scores for the two OUTCOMES.

Table: self-created.

5.3 Calibration and combination of conditions into combined sets.

The following figure gives an overview of how the previously described sustainable development indicators and other conditions pair together with other conditions to form the combined sets that will be used for the QCA analysis.

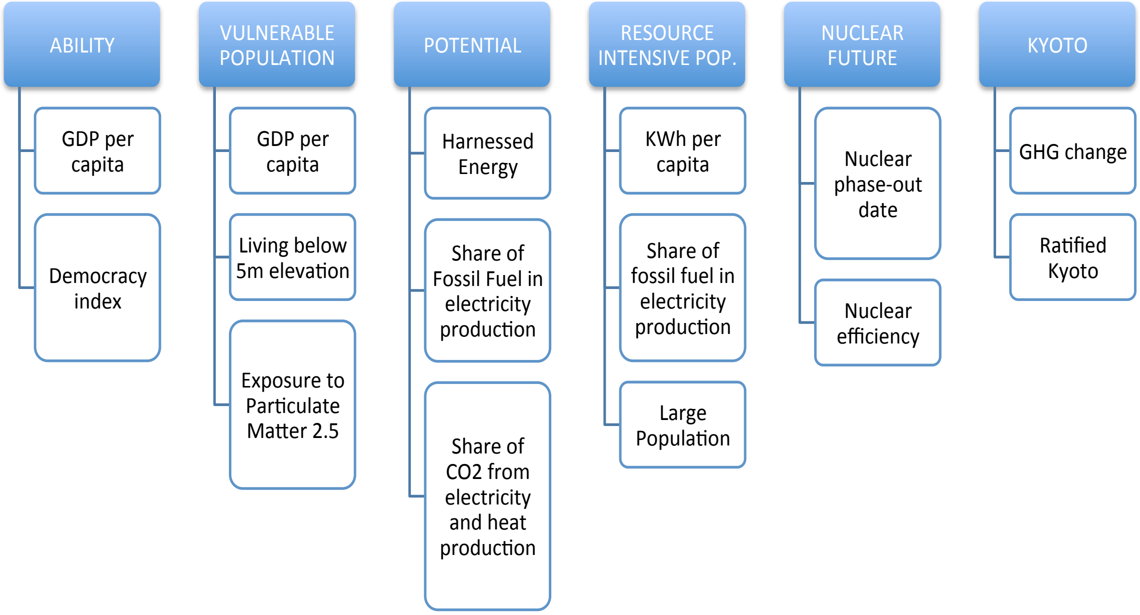


Figure 12: Combination of conditions that lead to the specific combined sets. Source: self-created

Figure 12, clearly exemplifies how the combined sets that are used in the following fsQCA analysis came into existence. It's clear that each combined set is a combination of individual conditions derived from the sustainable development framework and the three mutually reinforcing pillars. The independent variables (conditions) can originate from a wide array of backgrounds, as is evident when considering that a combined set can be a compilation of conditions that come from different pillars and don't necessarily have to come from the same school of thought or discipline. The combined sets were indeed created to ensure that the maximum number of conditions were taken into consideration for the following analysis. For this study had a relatively small number of cases (n=16), the combined sets were deemed necessary and useful, for a maximum of 6 conditions could be tested on the outcomes under investigation; otherwise the possible number of combinations would become excessive. Therefore, these 6 combined sets were created to capture the maximum amount of variance in terms of socioeconomic, policy or physical characteristics of specific countries under investigation.

ABILITY: wealthy democracy

Combined set, *logical and* (minimization)

ABIL = High GDP/capita *and* high democracy rating

Highest ABIL: Switzerland (0.958), Netherlands (0.884), Germany (0.865)

Lowest ABIL: India (0.003), China (0.015), Thailand (0.024)

Logical thought being that if a nations population is wealthy and live in a direct democracy then the nation would have the necessary resources at their disposal and therefore the ability to bring about change that the majority of the people desire.

Case	Democracy Rating	Fuzzy set score	GDP/Capita	Fuzzy set score	ABIL Score *logical and*
China	3.14	0.055	14,239	0.015	0.015
Germany	8.64	0.904	47,268	0.865	0.865
Japan	7.96	0.712	37,322	0.614	0.614
U.S.	8.05	0.746	55,837	0.955	0.746
Italy	7.98	0.720	35,896	0.566	0.566
UK	8.31	0.831	41,325	0.736	0.736
France	7.92	0.695	39,678	0.689	0.689
Spain	8.3	0.828	34,527	0.518	0.518
Australia	9.01	0.951	45,514	0.834	0.834
India	7.74	0.616	6,089	0.003	0.003
Korea	7.97	0.716	34,549	0.519	0.519
Belgium	7.93	0.699	43,992	0.802	0.699
Canada	9.08	0.957	44,310	0.809	0.809
Netherlands	8.92	0.942	48,459	0.884	0.884
Thailand	5.09	0.171	16,305	0.024	0.024
Switzerland	9.09	0.958	60,535	0.976	0.958
Lower bound	3		20,000		
Crossover Point	7.5		34,000		
Upper bound	9		55,000		

Table 5: Compilation of individual conditions that create 'Ability': shown are the raw values and their corresponding calibration scores using the shown thresholds and crossover point. Table: own illustration.

NVP: Non-Vulnerable Population

Combined set, *logical and* (minimization)

NVP = High GDP/capita *and* Low percentage of the urban population living below 5-meter elevation *and* Low amount of Particulate Matter 2.5 present in the air

Highest NVP: United States (0.847), Canada (0.809) Germany (0.725)

Lowest NVP: Netherlands (0.000), India (0.003), China (0.015),

Logical thought being if a country has a vulnerable population, to the onset and effects associated with climate change than they would be more likely to take necessary steps to ensure that their own population isn't put at further risk and would therefore desire alternatives (fossil fuel free) to generate electricity bearing in mind that the country or its underlying population has the fiscal means necessary.

Case	GDP/ Capita $	Fuzzy Score	% of Population living below 5 meter elevation	1- Fuzzy Score	Particulate matter 2.5 (mg/m^3)	1- Fuzzy score	NVP score *logical and*
China	14,239	0.015	4.2 %	0.491	54.37	0.033	0.015
Germany	47,268	0.865	3.01	0.725	15.35	0.797	0.725
Japan	37,322	0.614	11.94	0.188	16.03	0.763	0.188
U.S.	55,837	0.955	2.26	0.847	10.76	0.938	0.847
Italy	35,896	0.566	4.16	0.493	18.34	0.620	0.493
UK	41,325	0.736	4.2	0.491	10.81	0.937	0.491
France	39,678	0.689	2.15	0.86	14.02	0.853	0.689
Spain	34,527	0.518	3.49	0.623	11.65	0.921	0.518
Australia	45,514	0.834	3.61	0.595	5.93	0.984	0.595
India	6,089	0.003	1.14	0.943	46.68	0.068	0.003
Korea	34,549	0.519	2.03	0.874	29.02	0.292	0.292
Belgium	43,992	0.802	9.95	0.251	18.53	0.607	0.251
Canada	44,310	0.809	1.85	0.892	12.14	0.910	0.809
Netherlands	48,459	0.884	48.46	0.00	16.84	0.717	0.000
Thailand	16,305	0.024	6.29	0.396	22.36	0.442	0.024
Switzerland	60,535	0.976	0	0.981	17.59	0.670	0.670
Lower bound	20,000		1		10		
Crossover Point	34,000		4		20		
Upper bound	55,000		20		50		

Table 6: Compilation of individual conditions that create 'Non-Vulnerable Population': shown are the raw values and their corresponding calibration scores using the shown thresholds. Table: own illustration

POT: Potential

Combined set, *logical or* (maximization)

POT = Low Harnessed Energy *and* High share of CO2 emissions from electricity and heat production *and* High share of oil, gas or coal to generate electricity

Highest POT: Canada (0.961), Australia (0.960), India (0.960)

Lowest POT: Belgium (0.124), Italy (0.519), Germany (0.711)

Logical thought that countries that aren't already harnessing 0.6% of the incoming radiation striking their territory combined with the fact that over 40% of their CO2 emissions are directly linked to electricity or heat production *and* fossil fuels power 2/3 of electricity production highlights the immense potential that these countries have to replace their existing pollution intensive sources of electricity and harness to a greater extent the incoming solar radiation within their territory.

Case	Harnessed Energy	1-Fuzzy Score	Share of CO2 EH*	Fuzzy Score	Oil, gas and coal	Fuzzy score	POT score *logical or*
China	0.0307 %	0.955	52.95	0.807	77.4 %	0.802	0.955
Germany	0.9799	0.058	48.18	0.711	56.3	0.349	0.711
Japan	0.5207	0.605	51.55	0.781	82.0	0.877	0.877
U.S.	0.0202	0.957	47.1	0.686	67.5	0.546	0.957
Italy	0.5855	0.519	36.24	0.365	56.3	0.349	0.519
UK	0.1728	0.908	43.99	0.608	60.7	0.415	0.908
France	0.0903	0.939	16.92	0.032	5.1	0.020	0.939
Spain	0.1062	0.934	36.72	0.382	38.7	0.149	0.934
Australia	0.0041	0.960	59.56	0.896	85.1	0.913	0.960
India	0.0078	0.960	52.86	0.805	80.2	0.851	0.960
Korea	0.2394	0.873	60.44	0.905	69.3	0.601	0.905
Belgium	0.9826	0.056	26.7	0.124	33.4	0.110	0.124
Canada	0.0022	0.961	36.58	0.377	21.4	0.054	0.961
Netherlands	0.2651	0.857	41.05	0.529	82.6	0.889	0.889
Thailand	0.0195	0.957	44.13	0.612	91.5	0.958	0.958
Switzerland	0.2317	0.878	8.79	0.010	1.2	0.016	0.878
Lower bound	0.05		20		20		
Crossover Point	0.6		40		66		
Upper bound	1.0		66.7		90		

Share of CO2 EH = share of carbon dioxide from electricity and heat production

Table 7: Compilation of individual conditions that create 'Potential': shown are the raw values and their corresponding calibration scores using the shown thresholds and crossover point. Table: own illustration

RIP: Resource Intensive Population

Combined set, *logical and* (minimization)

RIP: High population *and* High KWh/capita *and* High Share of oil, gas and coal for electricity production

Highest RIP: Japan (0.695), U.S (0.546), China (0.530)

Lowest RIP: India (0.038), Switzerland (0.016), France (0.020),

Logical thought, to create a condition which captures which countries have resource intensive populations. Countries, which not only have very high per capita electricity consumption rates but simultaneously 2/3 of that electricity is generated by fossil fuel resources such as coal, gas or oil. Countries that meet all these criteria are obviously indicative of nations where renewable energy can build on progress or create new end roads altogether.

Case	Population (millions)	Fuzzy Score	KWh/ capita	Fuzzy Score	Oil, gas Coal	Fuzzy score	RIP score *logical and*
China	1364	1.000	3,762	0.530	77.4 %	0.802	0.530
Germany	81	0.564	7,019	0.831	56.3	0.349	0.349
Japan	127	0.695	7,836	0.877	82.0	0.877	0.695
U.S.	319	0.960	12,988	0.987	67.5	0.546	0.546
Italy	61	0.503	5,159	0.680	56.3	0.349	0.349
UK	64	0.512	5,407	0.703	60.7	0.415	0.415
France	66	0.518	7,374	0.853	5.1	0.020	0.020
Spain	46	0.263	5,401	0.703	38.7	0.149	0.149
Australia	24	0.066	10,134	0.953	85.1	0.913	0.066
India	1252	1.000	765	0.038	80.2	0.851	0.038
Korea	50	0.324	10,428	0.958	69.3	0.601	0.324
Belgium	11	0.026	7,967	0.883	33.4	0.110	0.026
Canada	36	0.146	15,519	0.996	21.4	0.054	0.054
Netherlands	17	0.040	6,821	0.818	82.6	0.889	0.040
Thailand	67	0.521	2,471	0.229	91.5	0.958	0.229
Switzerland	8	0.021	7,807	0.876	1.2	0.016	0.016
Lower bound	20		1,000		50		
Crossover Point	60		3,500		66		
Upper bound	300		10,000		100		

Table 8: Compilation of individual conditions that create 'RIP': shown are the raw values and their corresponding calibration scores using the shown thresholds and crossover point. Table: own illustration

NUCF: Nuclear Future

Combined set, *logical and* (minimization)

NUCF = High nuclear efficiency *and* High nuclear phase-out date

Highest NUCF: (.751) all countries above 70% efficiency

Lowest NUCF: Thailand, Italy, Australia, Japan (0.00) and Belgium (0.165)

Logical thought being that if either number is low, then nuclear power production is currently not an option or is planned to be phased out from the electricity mix and would need to be supplanted by another technology, and create an avenue for PV to be further implemented.

Case	Nuclear Efficiency	Fuzzy set score	Nuclear Phase-out date	Fuzzy set score	NUCF Score *logical and*
China	63.9	0.763	50 years	0.751	0.751
Germany	91.8	0.971	6 years	0.113	0.113
Japan	1.2	0.054	-2 years	0.038	0.038
U.S.	91.8	0.971	50 years	0.751	0.751
Italy	0	0.050	-29 years	0.050	0.050
UK	81.8	0.936	50 years	0.751	0.751
France	75.8	0.897	50 years	0.751	0.751
Spain	87.9	0.960	50 years	0.751	0.751
Australia	0	0.050	N/A (0)	0.050	0.050
India	74.4	0.886	50 years	0.751	0.751
Korea	77.8	0.910	50 years	0.751	0.751
Belgium	47.9	0.469	9 years	0.165	0.165
Canada	80.7	0.930	50 years	0.751	0.751
Netherlands	92.4	0.972	50 years	0.751	0.751
Thailand	0	0.050	N/A (0)	0.050	0.050
Switzerland	76.0	0.899	18 years	0.427	0.427
Lower bound	0		0		
Crossover Point	50		20		
Upper bound	85		100		

Table 9: Compilation of individual conditions that create 'Nuclear Future': shown are the raw values and their corresponding calibration scores using the shown thresholds and crossover point. Table: own illustration

KYOTO: Ratified Kyoto Protocol and had greenhouse gas reductions since 1990

Combined set, logical and (minimization)

KYOTO = High amount of GHG reductions since 1990 *and* ratified Kyoto Protocol

Highest KYT: UK (0.948), Germany (0.946), Netherlands (0.816)

Lowest KYT: China (0.002), Korea (0.026), India (0.031)

Logical thought being that there must be a combination of conditions that considers the fact that certain industrialized nations have made serious pledges to curb carbon dioxide and other GHG emissions. There were certain, Annex 1 countries, such as Japan, Australia and Canada that all initially ratified the Protocol, yet their total GHG emissions were greater in 2012 than in 1990. In addition the U.S. was one of only three countries worldwide to never ratify the Kyoto Protocol albeit being one of the worlds largest GHG emitters. Lastly the European Union used a ‘burden sharing’ agreement and the targets were tailored to the relative wealth of each country at the time, therefore Spain’s carbon-dioxide levels continued to grow in comparison with the 1990 base year, but was still in accordance with the protocol because other EU-15 member nations took on a greater burden to reduce domestic emissions

Case	GHG percent change 1990-2014	Fuzzy set score	Annex I: Ratified Kyoto Protocol	Fuzzy set score	KYOTO Score *logical and*
China	219.95	0.002	0	0.028	0.002
Germany	-24.23	0.946	1	0.981	0.946
Japan	13.35	0.403	1	0.981	0.403
U.S.	3.39	0.475	.01	0.050	0.050
Italy	-5.14	0.647	1	0.981	0.647
UK	-24.63	0.948	1	0.981	0.948
France	-10.01	0.765	1	0.981	0.765
Spain	18.72	0.366	1	0.981	0.366
Australia	57.93	0.154	1	0.981	0.154
India	116.44	0.031	0	0.028	0.028
Korea	122.62	0.026	0	0.028	0.026
Belgium	-3.26	0.595	1	0.981	0.595
Canada	68.73	0.117	.5	0.357	0.117
Netherlands	-12.64	0.816	1	0.981	0.816
Thailand	111.67	0.036	0	0.028	0.028
Switzerland	-4.05	0.617	1	0.981	0.617
Lower bound	-25		0.1		
Crossover Point	0		0.6		
Upper bound	100		0.9		

Table 10: Compilation of individual conditions that create 'Kyoto': shown are the raw values and their corresponding calibration scores using the shown thresholds and crossover point. Table: own illustration

5.4 Reasoning for setting of each crossover point for calibration

ABILITY*: ABIL*

GDP/Capita: The crossover point of $34,000 per capita was chosen because there was a significant drop to the next highest case, which was Thailand ($16,305) and is indeed not representative of a industrialized economy. Setting the crossover point at $34,000 ensured that the more developed economies would be separated from the three developing economies.

Democracy index: Crossover point of 7.5 was selected to ensure that all cases that displayed democratic tendencies would be accurately labeled. At this point, there were only two cases, China and Thailand that didn't meet the democratic requirement in the fuzzy set score.

NON-VULNERABLE POPULATION: *NVP*

GDP/Capita: The crossover point of $34,000 per capita was chosen because there was a significant drop to the next highest case, which was Thailand ($16,305) and is indeed not representative of a industrialized economy. Setting the crossover point at $34,000 ensured that the more developed economies would be separated from the three developing economies.

Percent of urban population living below 5m elevation: The crossover point of 4% was selected because this point was sure to capture cases that physically lie on the ocean and have port cities were significant amount of the population would be exposed to future calamities associated with climate change, such as global sea level rise and therefore have incentive to mitigate now and in the process protect their at risk population.

Particulate Matter 2.5: The crossover point of 20 mg/m^3 was selected, because according the World Health Organization that is the level at which each country should strive not to exceed in order to protect the local population (WHO, 2016).

POTENTIAL: *POT*

Harnessed Energy: The crossover point of 0.6% was selected because any cases that were harnessing at least half of 1 percent of the available solar resource striking their territory, would be representative of smaller countries that already have quite a large PV capacity with regard to the size of their country, and therefore are not representative of countries with definite potential for future photovoltaic capacity additions. While on the other hand, countries with very low values, typically representative of cases with large swaths of territory, were the solar resource is still largely untapped and therefore is representative of ample potential to fuel growing energy needs of the future.

Share of carbon dioxide from electricity and heat production: The crossover point of 40% was chosen because this would be representative of countries that have a big opportunity to reduce their emissions by switching to alternative forms of energy to generate electricity and heat. This set would be representative of cases where nearly half of all their carbon dioxide emissions are sourced from either the production of electricity or heat and therefore would be sectors where there exists potential to reduce emissions and corresponding carbon footprint.

Share of oil, gas and coal in electricity production: The crossover point of 66.7% was chosen because this would be representative of countries that have a big opportunity to reduce their emissions by phasing out fossil fuels from the electricity mix. This set would be representative of cases where at least 2/3 of their electricity is being generated by pollution intensive fossil fuel sources and therefore there exists obvious potential for PV and other alternative forms of energy to further decarbonize the electricity production sector, while countries that are below this value may have already installed significant amounts of renewables or have other mediums, such as nuclear power production or hydro to power their societies.

RESOURCE INTENSE POPULATION*: RIP*

Population: The crossover point of 60 was selected because there were a number of cases under investigation that were just slightly above 60 million inhabitants, and then there was a greater than 10 million-person drop-off to the next highest population. This threshold also represented a value, which almost evenly split the set into two equal parts, with 9 cases having more than 60 million inhabitants and 7 cases with less than that specific amount.

KWh/Capita: The value of 3,500 KWh/capita was selected as the crossover point for the per capita energy consumption for this ensured that all industrialized countries, as well as China (which uses more energy than any other country but still has a rather low per capita value because it also has the worlds largest population) would be grouped together within the set.

Share of oil, gas and coal in electricity production: The crossover point of 66.7% was chosen for this would imply that 2/3 of their electricity is sourced from pollution intensive fossil fuel sources and therefore are representative of cases with the dirtiest sourced electricity. The cases that have very low values in this respect, typically source their electricity from other, alternative sources such as nuclear, hydropower or more recently variable renewable energy.

NUCLEAR FUTURE: *NUCF*

Nuclear Efficiency: The crossover point of 50% and an upper bound of 85% efficiency was selected, for this ensured that all cases, that were indeed above 50% efficient would receive a set score greater than 0.751. This value is of importance, when the nuclear phase-out dates, the other condition, which makes up this combined set is taken into consideration. Because this a combined set formed through logical minimization, the lower value will always be selected, and therefore wanted to ensure that no nuclear capable countries nuclear efficiency set score dipped below 0.751 to ensure when the combined set was created that all countries with no immediate plans to phase-out nuclear power production would receive the same score, regardless of their nuclear efficiency. (So in a sense this condition became rather obsolete?)

Nuclear Phase-out date: The value of 20 years was selected as the crossover point for the nuclear phase-out date, for every case under investigation that had current plans to phase out their nuclear power programs, had envisioned doing so within a 6-18 year window. Reason being, that when the nuclear-phase out date was calibrated, all those cases with no current plans to phase-out received a period of 50 years and through the calibration all those values received a set score of 0.751.

<u>KYOTO</u>: *KYT*

Annex I Parties that ratified the Kyoto Protocol: the value of 0.6 was selected as the crossover point, because I had designated Canada a value of 0.5 in terms of their Kyoto commitment, for they notoriously removed themselves from the protocol although they had originally ratified the agreement. For this reason the Canada would receive a fuzzy-set score of 0.357, which is 'more out than in' and correctly classifies their half hearted commitment to the protocol and groups them with other Annex I members that never ratified such as the U.S. and developing economics which had no such emission reduction requirements.

Percent change in GHG emissions from 1990-2014: The value of 0 was selected as the crossover point, for this separated the countries that actually had made GHG emission reductions from the ones that had seen their emissions rise over the past two and half decades.

Together: combining these two conditions with a logical and (minimization) technique then it was possible to capture not only the ratifying annex I parties to the Kyoto Protocol but additionally get insights into which EU-15 countries had the most stringent reduction targets under the protocols burden sharing program; more specifically, captured the countries that were Annex I Parties and indeed saw their economies reduce their output of GHG emissions from 1990 to 2014.

5.5. Fuzzy set scores of combined sets and outcomes under investigation

OUTCOME 1: At least 10GW of installed photovoltaic capacity at the end of 2015.

Table 11: Fuzzy set scores and the raw data for the total installed capacity (GW) (OUTCOME 1) as well as the fuzzy-set scores of the combined sets that were previously constructed and interpreted.

Case	OUTCOME 1: *raw values*; thresholds: 1, 10, 30 Gw	OUTCOME 1: Over 10Gw PV capacity	ABIL	POT	RIP	NVP	NUCF	KYT
China	*43.54*	0.993	0.015	0.955	0.530	0.015	0.751	0.002
Germany	*39.7*	0.988	0.865	0.711	0.349	0.725	0.113	0.946
Japan	*34.41*	0.973	0.614	0.877	0.695	0.188	0.038	0.403
U.S	*25.62*	0.909	0.746	0.957	0.546	0.847	0.751	0.475
Italy	*18.91*	0.788	0.566	0.519	0.349	0.493	0.050	0.647
UK	*8.78*	0.402	0.736	0.908	0.415	0.491	0.751	0.948
France	*6.58*	0.246	0.689	0.939	0.020	0.689	0.751	0.765
Spain	*5.44*	0.184	0.518	0.934	0.149	0.518	0.751	0.366
Australia	*5.1*	0.166	0.834	0.960	0.066	0.595	0.050	0.154
India	*5.05*	0.165	0.003	0.960	0.038	0.003	0.751	0.031
Korea	*3.43*	0.104	0.519	0.905	0.324	0.292	0.751	0.026
Belgium	*3.25*	0.099	0.699	0.124	0.026	0.251	0.165	0.595
Canada	*2.50*	0.079	0.809	0.961	0.054	0.809	0.751	0.117
Netherlands	*1.57*	0.060	0.884	0.889	0.040	0.000	0.751	0.816
Thailand	*1.43*	0.057	0.024	0.958	0.229	0.024	0.050	0.036
Switzerland	*1.36*	0.056	0.958	0.878	0.016	0.670	0.427	0.617

OUTCOME 1: takes into account the total installed photovoltaic capacity of each country at the end of the year 2015. This outcome, is geared towards the large, industrialized economies which generally use lots of electricity, either because of high per capita consumption habits or because large populations correspondingly needs lots of electricity to meet their everyday needs. Obviously this outcome does not take into consideration that there exist a number of territorially smaller countries, typically with correspondingly smaller populations that require a smaller amount of installed PV capacity in absolute terms to reach a higher penetration rate in their electricity markets than their larger counterparts. For this reason another outcome, in addition to the installed capacity, was put under investigation, to be able to determine which countries were using their available solar resource to the best of their abilities. Trying to shine light on smaller countries that require smaller amounts of installed capacity in absolute terms, OUTCOME 2 was created. OUTCOME 2 very much takes into account the size of the country and how well the

respective countries are at harnessing the available variable source of solar energy to produce electricity and in turn power their societies and future development.

OUTCOME 2: At least 0.2% of incoming solar radiation harnessed to create electricity

Table 12: Fuzzy set scores, as well as the raw data for the share of total incoming solar radiation that is harnessed (OUTCOME 2) to generate electricity as well as the fuzzy set scores of the combined sets of the previously described conditions.

Case	*OUTCOME 2: Raw values;* thresholds: .05, 0.2, 1.0	OUTCOME 2: fuzzy-set scores	ABIL	RIP	NVP	NUCF	KYOTO
China	*0.0307%*	0.035	0.015	0.530	0.015	0.751	0.002
Germany	*0.9799*	0.946	0.865	0.349	0.725	0.113	0.946
Japan	*0.5207*	0.765	0.614	0.695	0.188	0.038	0.403
U.S	*0.0202*	0.028	0.746	0.546	0.847	0.751	0.475
Italy	*0.5855*	0.805	0.566	0.349	0.493	0.050	0.647
UK	*0.1728*	0.370	0.736	0.415	0.491	0.751	0.948
France	*0.0903*	0.104	0.689	0.020	0.689	0.751	0.765
Spain	*0.1062*	0.137	0.518	0.149	0.518	0.751	0.366
Australia	*0.0041*	0.021	0.834	0.066	0.595	0.050	0.154
India	*0.0078*	0.022	0.003	0.038	0.003	0.751	0.031
Korea	*0.2394*	0.536	0.519	0.324	0.292	0.751	0.026
Belgium	*0.9826*	0.947	0.699	0.026	0.251	0.165	0.595
Canada	*0.0022*	0.020	0.809	0.054	0.809	0.751	0.117
Netherlands	*0.2651*	0.560	0.884	0.040	0.000	0.751	0.816
Thailand	*0.0195*	0.028	0.024	0.229	0.024	0.050	0.036
Switzerland	*0.2317*	0.529	0.958	0.016	0.670	0.427	0.617

Chapter VI. Results for OUTCOME 1: Total installed capacity greater than 10 Gigawatts

6.1. Analysis of necessary conditions

Table 13: Analysis of necessary conditions, their negation for both positive and negative evaluation of the outcome under investigation -- more than 10GW photovoltaic capacity at the end of 2015.

	Positive outcome (OUTCOME)			*Negative outcome (outcome)*		
Condition	*Consistency*	*Coverage*	*RoN*	*Consistency*	*Coverage*	*RoN*
ABILITY	0.675	0.446	0.554	0.706	0.725	0.714
POTENTIAL	0.892	0.416	0.246	0.908	0.658	0.358
RESOURCE INTENSE POP.	0.549	0.895	0.968	0.177	0.449	0.851
NUCLEAR FUTURE	0.510	0.418	0.652	0.615	0.782	0.833
NON-VULNERABLE POP.	0.579	0.549	0.759	0.482	0.710	0.830
KYOTO COMMITMENTS	0.613	0.554	0.745	0.458	0.641	0.784
Negated conditions						
ability (~ABIL)	0.584	0.561	0.768	0.460	0.687	0.823
potential (~POT)	0.267	0.651	0.938	0.194	0.735	0.952
resource intense pop (~RIP)	0.662	0.341	0.325	0.958	0.767	0.576
nuclear future (~NUCF)	0.734	0.551	0.671	0.542	0.632	0.714
non vulnerable pop (~NVP)	0.694	0.463	0.567	0.694	0.719	0.715
kyoto (~KYT)	0.603	0.417	0.568	0.682	0.732	0.741

A necessary condition for the outcome is one that eclipses the 0.9 thresholds in terms of consistency. As is clear from table 13, there are two conditions that would qualify as being necessary for the outcome. The first necessary condition is in relation to the negative evaluation of the outcome, the condition, 'Potential' that the cases exhibit to further implement solar photovoltaic harnessing technology and decarbonize the existing electricity sector. In layman's terms this means that according to this analysis cases that do not have more than 10 Gigawatts of PV capacity at the end of 2015, must indeed always have the condition of 'Potential' present when the outcome is present. In addition, when the negated conditions are taken into consideration, then the negated condition of ‘RIP’, hence a non resource intensive population is also a necessary condition for a negative evaluation of the outcome— the cases with less than 10GW photovoltaic capacity.

6.2. Analysis of sufficiency.

Table 14: Analysis of sufficiency which combinations of conditions can potentially lead to satisfying the OUTCOME (10+GW photovoltaic capacity)

Solution →	**ABIL*POT*RIP*nvp*nucf*kyt + abil*POT*RIP*nvp*NUCF*kyt + ABIL*POT*RIP*NVP*NUCF*kyt** *Greater than 10GW Photovoltaic capacity*		
Single case coverage	Japan	China	U.S.
Consistency	0.922	0.866	0.863
Raw coverage	0.275	0.227	0.188
Unique coverage	0.047	0.092	0.044
Solution →	**+ ABIL*POT*rip*NVP*nucf*KYT + abil*pot*rip*nvp*nucf*kyt** *Greater than 10GW Photovoltaic capacity*		
Single case coverage	Germany, **Switzerland**	Italy	
Consistency	0.807	0.803	
Raw coverage	0.431	0.386	
Unique coverage	*0.235*	*0.235*	
	Consistency Sufficient Condition: 0.796 *Coverage Sufficient coverage:* 0.695		

Table 14 shows which combination of conditions can lead to a positive evaluation with regard to having greater than 10 GW of installed PV capacity at the end of 2015. The consistency score measures the degree to which a relation of sufficiency between that combination of conditions and the outcome is met in the data set (Ragin, 2008). While coverage scores are computed by gauging the size of the overlap of two sets, relative to the size of the larger set (Ragin, 2008). The sufficient paths are shown in table 15, highlighting the various paths, which could possibly be taken to reach a minimum PV capacity of 10 Gigawatts. In addition to the intermediate solution, which is the combination of large and small circles, the parsimonious, or simplified solution is also presented, evident when only the large circles in table 16 are taken into consideration. The presence of a condition is shown with solid, black circles, while the absence of a condition is marked with a hollow circle. Every positively evaluated case received a consistency score that was above the required threshold; however, one contradictory case was conjoined through the analysis of the truth table with a positively evaluated case— Switzerland had the same truth table configuration as— Germany, which was correctly positively identified by the analysis as being sufficient for the outcome. In reality Switzerland has a fraction of the installed photovoltaic capacity of Germany (1.36 vs. 39.7 GW respectively) because of their similar socioeconomic structure their conditions mirrored one another in the truth table, table 12 above.

Table 15: Sufficient paths that can lead to positive evaluation (more than 10GW PV capacity)

OUTCOME: Over 10GW Photovoltaic capacity	*Intermediate solution*		
	Path 1	Path 2	Path 3
Wealthy Democracy – ABIL (Democracy and high GDP/capita)	●		●
Potential – POT (Low harnessed energy and high CO2 electricity/heat)	●	●	⬤
Resource Intensive Population – RIP (High KWh/cap, Oil gas coal electricity, Population)	⬤	⬤	
Non-Vulnerable Population – NVP (high GDP/capita and low population exposure)		○	
Nuclear Future – NUCF (high nuclear efficiency and phase out date)			◯
Kyoto Commitment – KYT (High GHG reductions since 1990)			⬤
Cases Covered	Japan; U.S.	China; Japan	Italy; Germany, **Switzerland**
Consistency	0.923	0.880	0.785
Raw coverage	0.443	0.474	0.489
Unique coverage	0.047	0.106	0.166

Solution consistency: 0.783
Solution coverage: 0.715

Bold: deviant case consistency in kind.
Black circles indicate the presence of a condition, and white circles its absence. Blank spaces indicate the irrelevance of a condition. Large circles: parsimonious solution enhanced causal interpretability. Small circles: factors that only appear as causally relevant in the intermediate solution.

As is evident from table 15, there are 3 separate paths that all lead to the same *OUTCOME*—at least 10GW of installed photovoltaic capacity within the country at the end of 2015. Two of the paths share a dominant, or parsimonious condition, which can be viewed as the principle component for the OUTCOME, with regard to 3 of the cases under investigation. The three separate paths will be further analyzed and discussed here to show were similarities but just as importantly, discrepancies arise along the various paths which all lead to the same OUTCOME.

- *Path 1: Resource Intensive Developed Countries*: Japan and the United States are indicative of two countries that have developed into wealthy, resource intensive, democratic societies which still have a massive 'Potential' to decarbonize their electricity markets. Developed countries, with large populations typically have large energy requirements to feed their consumption habits, which typically deplete natural resources but can also lead to having at least 10 Gigawatts of photovoltaic capacity.
  - *Wealthy democratic society (ABILITY) (and*)* that is home to a *Resource Intensive Population (RIP) (and*)* that has the *Potential to decarbonize electricity sector (POT) → over 10 GW PV capacity.*
- *Path 2: Asian countries with large vulnerable populations*: The second path is best exemplified by the two Asian cases that were correctly positively evaluated, both Japan and China boost a photovoltaic capacity well over the 10 GW threshold. There are similarities to the first path, for they share a common parsimonious solution, the 'Resource Intense Population' is the sole condition that remains. However, the two paths differ in the intermediate solution, for China is not home to a wealthy democratic society, but rather to a vulnerable population for a plethora of reasons which will be discussed in detail in the discussion
  - *Resource intensive population (RIP) (and*)* which has the *Potential to decarbonize electricity sectors (POT) (and*)* simultaneously reduce *vulnerabilities that their already exposed local populations experience (~NVP) → over 10 GW PV capacity.*
- *Path 3*: *Sustainable, European way:* This path is very different from the previous two paths, for the lone parsimonious condition from both *Path 1* and *Path 2*, the presence of a 'RIP' is perceived to be irrelevant in this path. This implies that there exist drastically different routes to ultimately end up at the same result. This path is composed of four conditions, three of which remain part of the parsimonious solution. Italy, Germany and the contradictory case of Switzerland are all representative of developed, wealthy democratic societies which were all Annex I parties to the Kyoto Protocol and actively worked to reduce their domestic greenhouse gas emissions. This coupled with that none of the cases can rely on nuclear power facilities to supply future fossil free sources of energy, highlights the importance and

potential that photovoltaic power production can have in meeting the demands of a society while simultaneously keeping international commitments.

- *Wealthy democratic society (ABIL) (and**) that had committed to the *first international climate agreement (KYOTO) (and**) and have plans to *phase out their nuclear power facilities (~NUCF) (and*)* still have an opportunity to further *decarbonize their electricity and/or heat production sectors* or harvest a grater fraction of the *available incoming solar radiation (POT) → over 10 GW PV capacity*

The consistency values of all three paths can be judged as sufficiently high enough to lead to the outcome. With regard to the empirical evidence of the paths, all three paths positively identify three cases, although Japan is present in both the *1st and 2nd path* while the 3rd path includes the contradictory case of Switzerland. The *1st path* is the most robust considering its high consistency score (0.923) as well as high raw cover value (0.443). The raw cover value indicates how well the path alone can explain the outcome under investigation. It must be noted, that although the *1st path* had the highest consistency score the other two paths had higher raw coverage scores, 0. 474 and 0.489 respectively. The individual paths will be further explored, discussed and analyzed in the following discussion section.

The parsimonious solution does cover all cases with a positive outcome. Due to the subdued complexity of the paths it allows for easier interpretability. Strong performance in the photovoltaic sector of a country, ensuring over 10 Gigawatts of photovoltaic power installed by the end of 2015 seems possible both in the context of developed nations of the European union which were driven by international commitments such as the Kyoto Protocol combined with the fact that they could no longer rely on nuclear power to supply carbon free electricity in the near future, coupled with the fact that their electricity and/or heat production sectors still present opportunities to decarbonize. The first two paths are representative of cases that have taken a different approach to the same outcome, mainly driven by the fact that they have very large, energy intensive populations that are still predominately fueled by fossil fuels. These large, energy intensive economies have began to transition to alternative forms of energy, such as photovoltaic power production, however in these cases the share still only represents a minute fraction of the total electricity requirements and therefore, although the recent renewable push, the electricity sectors of these countries will take time to decarbonize, representing further opportunities for solar photovoltaic to penetrate further into the respective electricity markets.

These findings of adequate pathways that lead to the positive outcome should be validated in the next section by identifying and highlighting the appropriate paths for a negated outcome—less than 10GW photovoltaic capacity at then end of 2015—if pathways prove to be sufficient for both the positive and negative outcome than the findings are not conclusive and uninterruptable.

6.3 Analysis of sufficient conditions for negated outcome.

The following table, table 16, shows the adequate paths for the negated solution, specifically the cases that have less than 10 GW of installed photovoltaic power at then end of 2015 (for the associated truth table see table 26 on page 90). In addition to the intermediate solution term, when both the large and small circles are taken into consideration the parsimonious, or simplified solution is evident when the small circles are disregarded and focus only on the large circles in the respective paths.

Table 16: Sufficient paths that can lead to negative evaluation (less than 10GW PV capacity)

outcome: less than 10GW Photovoltaic capacity	*Intermediate solution*	
	Path 1	Path 2
Wealthy Democracy – ABIL (Democracy and high GDP/capita)		●
Potential – POT (Low harnessed energy and high CO2 electricity/heat)	•	•
Resource Intensive Population – RIP (High KWh/cap, Oil gas coal electricity, Population)	○	○
Non-Vulnerable Population – NVP (high GDP/capita and low population exposure)		•
Nuclear Future – NUCF (high nuclear efficiency and phase out date)	●	
Kyoto Commitment – KYT (High GHG reductions since 1990)		○
Cases Covered	India; Korea; UK, Netherlands; Spain, Canada; France	Australia; Spain, Canada
Consistency	0.862	0.826
Raw coverage	0.602	0.348
Unique coverage	0.332	0.079
Solution consistency: 0.843 *Solution coverage:* 0.680		

Bold: deviant case consistency in kind.
Black circles indicate the presence of a condition, and white circles its absence. Blank spaces indicate the irrelevance of a condition. Large circles: parsimonious solution, enhanced causal interpretability. Small circles: factors that only appear as causally relevant in the intermediate solution.

In addition to the necessary conditions for the negated outcome, obtained from table 12, there are additional conditions that in combination with others are sufficient for the outcome. As is evident from table 16, there are two adequately sufficient paths that can lead to the negative evaluation—not having at least at 10 GW of installed photovoltaic capacity at the end of 2015.

- *Path 1: Countries with a nuclear future:* It is evident from the analysis of this first sufficient path that the dominant conditions for a negative evaluation are the fact that all these cases have no plans to end their nuclear power production programs combined with the fact that while their populations vary in size and socioeconomic standing they are not particularly 'Resource intensive' (~RIP) although each country has potential to decarbonize respective sectors and/or use a greater share of available solar resource.
    - *Non resource intensive population (~RIP) (and*)* with no plans to phase out *nuclear power production (NUCF) (and*)* potential to decarbonize electricity and/or heat production sectors or harness greater fraction of available solar radiation *(POT)* → negative evaluation: *less than 10 GW PV capacity.*
- *Path 2: Non Committed Annex I parties to the Kyoto Protocol:* This second path is home to the cases that were all Annex I parties to the convention of the Kyoto Protocol however none actually reduced their domestic greenhouse gas emissions from their 1990 levels. However, this is just one of many conditions that makes up this pathway. In addition to their lack of emission reductions, all three cases are also representative of relatively wealthy democratic societies which in and of itself helps to reduce the populations overall vulnerability, evident by the presence of the condition, 'Non-vulnerable population' in the intermediate solution. These three conditions in conjunction with the fact that all three populations are not necessarily large enough to be deemed resource intensive and the fact that there is ample opportunity to decarbonize their electricity sectors combine for a weak evaluation.
    - *Wealthy democratic societies (ABIL) (and*)* that are home to a *non-vulnerable (NVP) (and*) Non resource intensive population (~RIP) (and*)* which *did not* undertake *stringent Kyoto commitments (~KYOTO) (and*)* have plenty of *potential to decarbonize* existing electricity infrastructure and/or harness more of the available solar resource *(POT)* → *negative evaluation: less than 10 GW PV capacity.*

It is evident from the analysis of sufficiency that there are two acceptable, albeit different paths that are adequate for a negative evaluation of the outcome, specifically having less 10 GW of installed photovoltaic capacity at the end of 2015. Although the first path is much more inclusive in terms of cases that fall under its classification, the 2^{nd} *path* illuminates a very different set of conditions that in combination would also be sufficient for the presence of the negated outcome. When the results of the positive and negative evaluation are compared it can be concluded that there exits no path that is sufficient for both outcomes.

Table 17: Intermediate solution terms for both the negative and positive evaluation regarding if specific countries have greater than a10 Gigawatt photovoltaic capacity. Table: own illustration

Negative Evaluation (intermediate solution)*: outcome 1: less than 10 GW PV capacity*	
~RIP*NUCF*POT + ~RIP*~KYOTO*ABIL*NVP*POT → negative	
Path 1: ~RIP*NUCF*POT, or	*(India, Korea, Canada, Spain, UK, Netherlands, France)*
Path 2: ~RIP*~KYOTO*ABIL*NVP*POT	*(Australia, Canada, Spain)*
Positive Evaluation (intermediate solution)*: OUTCOME 1: over 10 GW PV capacity*	
RIP*POT*ABIL + RIP*POT*~NVP + KYOTO*~NUCF*POT*ABIL → positive	
Path 1: RIP*POT*ABIL, *or*	*(United States, Japan)*
Path 2: RIP*POT*~NVP, *or*	*(China, Japan)*
Path 3: ~NUCF*KYOTO*POT*ABIL	*(Germany, Italy, Switzerland.)*

As is evident from table 17, none of the paths are sufficient for both the positive and negative evaluation. In fact, a number of the conditions indeed offset one another, for example 'RIP' is present in the parsimonious solution in two paths for a positive evaluation, while the absence of the condition (~RIP) is present in the parsimonious solution of both sufficient paths for a negative evaluation. Considering none of the paths are contradictory the results will be further interpreted in the discussion.

Chapter VII. Results for OUTCOME 2: Percent of solar resource harnessed.

7.1 Analysis of necessary conditions.

Table 18: Analysis of necessary conditions, their negation for both positive and negative evaluation for the outcome under investigation – at least 0.2% of incoming solar energy harnessed and used to generate electricity at the end of 2015.

	Positive outcome (OUTCOME)			*Negative outcome (outcome)*		
Condition	*Consistency*	*Coverage*	*RoN*	*Consistency*	*Coverage*	*RoN*
ABILITY	0.867	0.535	0.597	0.609	0.652	0.664
RESOURCE INTENSE POP.	0.424	0.645	0.899	0.289	0.764	0.930
NUCLEAR FUTURE	0.453	0.347	0.626	0.666	0.884	0.904
NON-VULNERABLE POP.	0.547	0.484	0.734	0.517	0.793	0.873
KYOTO	0.758	0.639	0.783	0.399	0.583	0.758
Negated conditions						
ability (~ABIL)	0.436	0.392	0.705	0.566	0.881	0.924
resource intense pop (~RIP)	0.845	0.407	0.348	0.865	0.722	0.533
nuclear future (~NUCF)	0.848	0.595	0.693	0.507	0.617	0.705
non-vulnerable pop (~NVP)	0.767	0.478	0.574	0.664	0.717	0.714
kyoto (~KYTOTO)	0.506	0.327	0.532	0.753	0.844	0.831

As previously mentioned a necessary condition constitutes that the consistency threshold of the condition under investigation must eclipse a level of 0.9 for it to be deemed necessary for the outcome under investigation. Given this criteria it is evident from table 20 that there are zero conditions that individually meet this threshold and therefore no condition, nor its negation is deemed necessary by itself for either a positive or negative evaluation of the outcome under investigation.

7.2 Analysis of Sufficiency for positive evaluation of OUTCOME 2.

Table 19: Analysis of sufficiency: which conditions and in which combination are sufficient for positive evaluation of OUTCOME 2 (At least 0.2% of solar radiation harnessed)

Solution	**ABIL*RIP*nvp*nucf*kyt** +	**ABIL*rip*nvp*nucf*KYT** +	**ABIL*rip*NVP*nucf*KYT**
→	*At least 0.2% of incoming solar radiation harnessed for electricity generation*		
Single case coverage	Japan	Italy, Belgium	Germany, Switzerland
Consistency	0.884	0.824	0.784
Raw coverage	0.282	0.491	0.466
Unique coverage	0.090	*0.408*	*0.408*
Consistency Sufficient Condition: 0.841			
Coverage Sufficient Condition: 0.680			

The raw consistency threshold was set at 0.78. The next highest consistency score is 0.685 (Korea)

The analysis of sufficiency for a positive evaluation for *OUTCOME 2*, is displayed in table 19, and highlights that there are three various combination of conditions or their negation that could be sufficient for the outcome, harnessing at least 0.2% of the solar resource that is available within a cases territorial grounds and converting it to electricity. All 5 cases, shown in table 19, are positively identified, as previously mentioned this model failed to identify 2 cases whose fuzzy outcome scores were greater than 0.5. As previously stated these two cases were rather ambiguous for they were very close to the crossover point between a positive and negative evaluation of the outcome. The following table, table 20, highlights the adequate paths that could lead to a positive evaluation for the outcome under investigation. As with previous solution terms the paths show both the intermediate solution (considering all circles present in the path) and the simplified, parsimonious solution, when only the large circles are taken into consideration.

Table 20: Sufficient paths that can lead to a positive evaluation of OUTCOME 2 (greater than 0.2% of available incoming solar radiation harnessed and used to generate electricity).

OUTCOME: > 0.2% solar radiation harnessed	*Intermediate solution*	
	Path 1	Path 2
Wealthy Democracy – ABIL (Democracy and high GDP/capita)	●	•
Resource Intensive Population – RIP (High KWh/cap, Oil gas coal electricity, Population)	•	◦
Non-Vulnerable Population – NVP (high GDP/capita and low population exposure)	○	
Nuclear Future – NUCF (high nuclear efficiency and no phase out date)	○	○
Kyoto Commitment – KYT (High GHG reductions since 1990)		●
Cases Covered	Japan	Italy, Belgium; Germany, Switzerland
Consistency	0.906	0.824
Raw coverage	0.356	0.600
Unique coverage	0.093	0.366

Solution consistency: 0.844

Solution coverage: 0.693

As is evident from table 20, there are 2 different paths that can be taken by the cases under investigation, which can ultimately lead to a positive evaluation for OUTCOME 2— At least 0.2% of the incoming solar radiation being converted to electricity. The two paths share two communal conditions, but also vary across multiple facets. However, the paths should be analyzed as a whole, opposed to a breakdown of individual conditions. The major similarity that both cases share is the fact that both paths include the condition '~NUCF' in their parsimonious solutions, highlighting the importance of the nuclear industry, or future lack thereof in ensuring fossil free sources of electricity, such as photovoltaics enter the markets and actively work to offset and replace the fossil free sourced electricity in the cases that plan to phase out the nuclear power production in the near future. The two sufficient paths for a positive evaluation of outcome 2 are detailed in the following paragraphs.

- *Path 1: Vulnerable population with no nuclear future:* Japan is the case that best exemplifies this path for they are a developed, democratic society (ABIL) which has a rather vulnerable population (~NVP) in conjunction with the fact that there was a serious nuclear accident in 2011, which only exacerbated the underlying vulnerability of the population. The accident also contributed, to greater natural resource consumption for the nuclear power plants went offline, yet the demand for electricity by the 'Resource intensive population' did not correspondingly dwindle, but rather opened the door for alternative renewable energy such as solar photovoltaic to earnestly enter the market, visible by the fact that Japan had nearly 35 GW of PV capacity at the end of 2015.
    - *Wealthy democratic society (ABIL) (and*)* home to *vulnerable (~NVP) (and*) resource intensive population (RIP) (and*) that since 2011 can no longer rely on nuclear* power to produce fossil free electricity *(~NUCF)* → *positive evaluation: at least 0.2% solar radiation harnessed.*
- *Path 2: European Annex I members to the Kyoto Protocol:* The distinctive trait of this adequate path is that each case is a European, Annex I party to the Protocol. All four cases undertook emission reductions under the initial international climate agreement (KYOTO), in addition to the fact that three of the cases (Germany, Belgium and Switzerland) are actively planning to phase out nuclear power while Italy phased out the technology in 1987 following the Chernobyl disaster, hence none of the cases have a nuclear future (~NUCF). These parsimonious conditions combine with the fact that each case is further represented by the fact that they are all well off European, democratic societies (ABILITY) whose populations are not very resource intensive (~RIP)
    - *Wealthy European societies (ABIL)(and*)* that had commitments under *the Kyoto Protocol (KYOTO)(and*) can not rely on nuclear power to continue providing fossil free electricity in the future (~NUCF)* and do not have overly large, *resource intensive populations (~RIP)* → *positive evaluation: more than 0.2% of incoming solar radiation harnessed.*

It is clear from table 20 that there are two distinct paths, which have similarities in the form of the presence, or absence of specific conditions. The two conditions that arise in both sufficient paths are the lack of nuclear future (~NUCF) in the parsimonious solution and therefore the absence of a nuclear future in reality. The second robust condition that is found in both paths is the presence of 'ABIL', signifying that every single case that was positively evaluated by the model is a wealthy, democratic society. The consistency values of both paths can be judged as sufficiently high enough to lead to the outcome. With regard to the empirical evidence of the paths, the 2nd path is much more inclusive considering that four cases fall within this solution, while the first path is empirically representative of only one case under investigation, Japan. These findings of the two adequate paths that lead to the positive evaluation of *OUTCOME 2* should be validated in the next section by identifying and highlighting the appropriate paths that can lead to a negative evaluation of *OUTCOME 2*—harnessing less than 0.2% of the available incoming solar radiation within a cases territory—if there exist sufficient pathways for both, positive and negative evaluation of the outcome under investigation than the findings are not conclusive and uninterruptable.

7.3 Analysis of sufficient conditions for negative evaluation of outcome 2.

The following section focuses on which combination of conditions would be sufficient to suffice a negative evaluation of outcome 2, which cases do not harness at least 0.2% of the incoming solar radiation that is available within their territorial grounds.

Table 21: Analysis of sufficiency: which conditions and in which combination are sufficient for a negative evaluation of outcome 2 (less than 0.2% of solar radiation harnessed)

Solution →	abil*RIP*nvp*NUCF*kyt +	ABIL*RIP*NVP*NUCF*kyt +	ABIL*rip*NVP*NUCF*kyt
	Less than 0.2% of incoming solar radiation harnessed for electricity generation		
Single case coverage	China	United States	Spain, Canada
Consistency	1.000	1.000	0.964
Raw coverage	0.162	0.135	0.293
Unique coverage	0.090		
Solution →	abil*rip*nvp*NUCF*kyt +	ABIL*rip*NVP*NUCF*KYT +	ABIL*rip*nvp*NUCF*kyt
	Less than 0.2% of incoming solar radiation harnessed for electricity generation		
Single case coverage	India	France	**Korea**
Consistency	0.962	0.943	0.934
Raw coverage	0.320	0.280	0.234
Unique coverage	0.090		
	Solution consistency: 0.961		
	Solution coverage: 0.554		

The raw consistency threshold was set at 0.90. The next highest consistency score is 0.877 (Australia)

Table 21 shows that there are five various combinations of conditions, or their negation that would be sufficient for a negative evaluation of outcome 2. In addition table 21 highlights that there exists one contradictory case within this model, case being the Republic of Korea, whose fuzzy score for *OUTCOME 2* was greater than 0.5, however it has incorrectly been labeled as a member of the negatively evaluated cases. However, Korea does indeed harness more than 0.2% of available solar radiation, although the fuzzy value is very close to the value of 0.5, better known as the crossover point and therefore the case itself is rather ambiguous. The truth table for the underlying analysis of sufficiency can be found in the appendix section, table 29 on page 93. The following table, table 22, highlights all the adequate pathways that can be taken to ensure the pathway is sufficient for the negative evaluation of outcome 2. Like in all previous presented solution pathways the intermediate solution is recognizable by taking all circles into consideration, while the parsimonious, or simplified solution is evident when only the larger circles are taken into account.

Table 22: Sufficient paths that can lead to a negative evaluation of outcome 2 (less than 0.2% of available incoming solar radiation used to generate electricity)

outcome: < 0.2% of incoming radiation harnessed	*Intermediate solution*			
	Path 1	Path 2	Path 3	Path 4
Wealthy Democracy – ABIL (Democracy and high GDP/capita)	◦			
Resource Intensive Population – RIP (High KWh/cap, Oil gas coal electricity, Population)			◦	◦
Non-Vulnerable Population – NVP (high GDP/capita and low population exposure)		●	●	
Nuclear Future – NUCF (high nuclear efficiency and phase out date)	●	●	●	●
Kyoto Commitment – KYT (High GHG reductions since 1990)	○	◦		○
Cases Covered	India; China	Spain, Canada; U.S.	Spain, Canada; France	India; **Korea**; Spain, Canada
Consistency	0.966	0.965	0.958	0.935
Raw coverage	0.358	0.300	0.385	0.461
Unique coverage	0.028	0.007	0.092	0.018
Solution consistency: 0.940 *Solution coverage:* 0.588				

Bold: deviant case consistency in kind.
Black circles indicate the presence of a condition, and white circles its absence. Blank spaces indicate the irrelevance of a condition. Large circles: represents parsimonious solution for enhanced causal interpretability. Small circles: factors that only appear as causally relevant in the intermediate solution.

According to the analysis of sufficiency for a negative evaluation of outcome 2 which is under investigation there exist 4 different paths, see table 22, of various different combination of conditions that would be sufficient for a negative evaluation of the outcome—hence those cases that harness less than 0.2% of the incoming solar radiation available within their territorial grounds. There is one dominant condition that is present in the parsimonious solution of each potential path, the fact that all these countries have no intentions to phase out their nuclear power production programs is a constant condition across all pathways; this condition then works in combination with other conditions across the 4 different pathways to ultimately pass the analysis of sufficiency for a negative evaluation of the outcome under investigation.

- *Path 1: Large Developing Countries:* Both China and India have been at the forefront of recent development, boosting rapidly growing economies. However neither would be considered a wealthy democratic society (~ABIL) for this reason both were Annex 2 Parties to the Kyoto Protocol and therefore not required to reduce their domestic emissions (~KYOTO). This combined with the fact that there are no plans to phase out nuclear power facilities (NUCF) in the near future ensures the fact that these cases will not be harnessing 0.2% of the available incoming solar radiation.
    - *Developing countries (~ABIL)(and*)* that had zero commitments under *the Kyoto Protocol (~KYOTO)(and*)* and can rely on *nuclear power facilities in the future (NUCF)* → *negative evaluation: less than 0.2% of incoming solar radiation harnessed to generate electricity*
- *Path 2: Countries with non-vulnerable populations:* As previously mentioned, all sufficient pathways for a negative evaluation share the parsimonious condition (NUCF). Although, the U.S., Canada and Spain were Annex I parties to the Kyoto Protocol, all three emitted more greenhouse gases in 2012 than in the 1990 base year. What differentiates this pathway from the first sufficient path is the fact that none of these cases are home to vulnerable population. The combination of these conditions are sufficient to ensure that a country will not harness 0.2% of the solar radiation available within their territory.
    - Countries with *non-vulnerable populations (NVP)(and*)* that did not experience *greenhouse gas reductions between 1990 and 2012 (~KYOTO)(and*)* have no plans to phase out *nuclear power facilities (NUCF)* → *negative evaluation*
- *Path 3: Non-resource intensive, non-vulnerable populations*: This path is very similar to the 2nd *path,* for they share the same parsimonious solution. The only discrepancy is that, in the 3rd *path,* the Kyoto condition becomes irrelevant, while the absence of the 'RIP'

condition (~RIP) is present in the intermediate solution. This shows that having a non vulnerable, non-resource intensive population, which can rely on nuclear power production to supply fossil free electricity in the future is sufficient to ensure that countries are not harnessing 0.2% of available incoming solar radiation.

  - *Countries that have non-resource intensive (~RIP)(and*) non-vulnerable populations (NVP)(and*)* that can rely on *nuclear power* to provide fossil free electricity *in the future (NUCF) → negative evaluation*

- *Path 4: No Kyoto Reductions and a nuclear future:* This path takes up similar characteristics as the *1st path,* and they share a parsimonious solution; evident by the fact that each country has a nuclear future and failed to reduce their domestic greenhouse gas emissions from 1990 to 2012. As we have seen the combination of these two conditions alone is sufficient for harnessing less than 0.2% of incoming solar radiation according to the parsimonious solution. However, the intermediate solution, in this 4th path, highlights the fact that a non-resource intensive population also plays a role in conjunction with the parsimonious conditions to lead to a negative evaluation.
  - Countries with *non-resource intensive populations (~RIP)(and*)* no *reduction in greenhouse gas emissions* between 2012 and 1990 *(~KYOTO)(and*)* no plans to phase out *nuclear power production in the future (NUCF) → negative evaluation.*

Now that the sufficient pathways for both positive and negative evaluations have been determined, it is possible to compare and ensure that none of the pathways are valid for both a positive and negative evaluation. The two solutions actually complement one another very nicely, for the condition, which is consistently present for a positive evaluation, '~NUCF', is the same condition which is consistently present in the parsimonious solution for the negative evaluation. This notion of a future with, or without nuclear power production is a key determinant in whether the cases under investigation have harnessed at least 0.2% of the incoming solar radiation striking their territory.

Table 23: Intermediate solution terms for both the negative and positive evaluation regarding if countries harness at least 0.2% of the available incoming solar radiation. Table: own illustration

Negative Evaluation (intermediate solution)*: outcome 2: less than 0.2% harnessed*	
NUCF*~KYT*~ABIL + NUCF*~KYT*NVP + NUCF*~RIP*NVP + NUCF*~KYT*~RIP → Negative	
Path 1: NUCF*~KYT*~ABIL, or	*(China, India)*
Path 2: NUCF*~KYT*NVP, or	*(Spain, Canada, U.S)*
Path 3: NUCF*~RIP*NVP, or	(*Spain, Canada, France)*
Path 4: NUCF*~KYT*~RIP	*(India, Korea, Spain, Canada)*
Positive Evaluation (intermediate solution)*: OUTCOME 2: more than 0.2% harnessed*	
~NUCF*~NVP*RIP*ABIL + ~NUCF*KYOTO*~RIP*ABIL→ positive	
Path 1: ~NUCF*~NVP*RIP*ABIL, *or*	*(Japan)*
Path 2: ~NUCF*KYOTO*~RIP*ABIL	*(Italy, Belgium, Germany, Switzerland)*

Table 23, makes it clear that none of the sufficient pathways for a positive or negative evaluation are composed of the same conditions, and for this reason the results are deemed acceptable. The various paths will be further interpreted, compared and contrasted in the following discussion section.

Chapter VIII: Discussion of OUTCOME 1: Total installed photovoltaic capacity.

The investigation of the total installed photovoltaic capacity of each case under investigation was of interest for it allowed for an analysis of the world's most solar friendly countries in terms of total capacity. More specifically, which combination of various socioeconomic and ecological conditions would work together within these cases to foster the friendliest environment for cumulative solar photovoltaic capacity. In the following sections the various pathways that were deemed sufficient in the previous sections will be further examined and interpreted with an eye towards the socioeconomic makeup and the underlying implications of the results for the cases and their underlying populations.

8.1 Discussion regarding positively evaluated sufficient pathways

The results in chapter 6 revealed that there were 3 different pathways that were deemed sufficient for a positive evaluation during the analysis of outcome 1.

- ***Path 1: Resource Intensive Developed Countries**: (Japan and United States)*
    - *Wealthy democratic society (ABILITY) (and*)* that is home to a *Resource Intensive Population (RIP) (and*)* that has the *Potential to decarbonize electricity sector (POT) → over 10 GW PV capacity.*

The cases captured by this path are representative of democratic, developed and industrialized countries that are concurrently home to over 100 million people. Although these countries (United States, and Japan) can be classified as wealthy democracies, they also have serious opportunities to further decarbonize their fossil fuel intensive electricity sectors, the dominating condition in this path is the fact that these countries support large population whom live resource intensive lifestyles, continuously fueled by a dominant mix of fossil fuel, evident by the fact that over 66.7% of the electricity in both Japan and the United States continued to be sourced by oil, gas or coal at the end 2014 (Worldbank, 2016). Therefore it is obvious that although that both cases rank in the top 4 in terms of installed photovoltaic capacity, the electrical output from their installed photovoltaic capacity still only represents a small fraction of the overall electrical generation, which is ultimately a signal from its resource intensive populations. These developed societies have support consumer societies, which are resource intensive especially considering Japan has a population of 127 million and the United States nearly 350 million inhabitants. Solar photovoltaic has assisted Japan offset its last nuclear capabilities following the 2011 Fukushima accident, which will be discussed in detail in the following discussion with regard to the first sufficient path for a positive evaluation in relation to outcome 2. However, what is clear is that solar photovoltaic can meet the growing energy requirements of developed countries if they attribute the appropriate policies that begin the transition to a sustainable, low carbon society. This highlights that other wealth democratic societies with large populations can follow the same path to decarbonize their electricity sectors for the majority of countries are still dependent on the traditional fuel sources to power their development

- ***Path 2: Asian countries with large vulnerable populations:*** *(Japan and China)*
  - *Resource intensive population (RIP) (and*)* which has the *Potential to decarbonize electricity sectors (POT) (and*)* simultaneously reduce *vulnerabilities that their already exposed local populations experience (~NVP) → over 10 GW PV capacity.*

The makeup of this sufficient path was similar to the 1st pathway considering that the only condition that remains for the simplified, parsimonious solution is once again the ‘Resource Intensive Population’. The fact that this condition in and of itself is sufficient in regards to the parsimonious solution speaks to the fact how big of an influence a resource intensive population can have on a countries overall solar photovoltaic capacity. What constitutes having the presence of such a ‘Resource Intensive Population? The exact construction of the condition can been seen in table 8, on page 40, and the logical thought concerning the thresholds for the calibration of the individual conditions that make up the combined set on page 44. However, a ‘Resource Intensive Population’ is on that eclipsed the 100 million person threshold and whose socioeconomic development is still strongly tied to fossil fuel sources (over 66.7% of electricity production). If the intermediate solution of this second path is analyzed there is another shared condition with the 1st path. The presence of the ‘Potential’ condition is also part of the intermediate solution as was the case in the previous path. What ultimately differentiates these paths is the fact that in the 2nd path the absence of the condition, ‘non-vulnerable population’ (~NVP), is present in the intermediate solution. What this specifically means is that the two cases that are appropriated with this 2nd path (Japan and China) have vulnerable populations. This fact is evident through the absence of the condition ‘NVP’, indicating that the cases underlying population is vulnerable. This condition encapsulates a number of various conditions that can mark a population’s susceptibility to continued fossil fuel combustion (the logic behind the combined set can be found on page 38 and 43). In this analysis a population can be vulnerable to local air pollution, attributed by the particulate matter 2.5 present in the local air. If the amount of particulate matter 2.5 exceeded 20 micrograms per cubic meter, double the WHO’s recommended levels than a cases population would be considered vulnerable. Additionally, if a 4% of cases urban population lives below 5 meters elevation, or the per capita GDP was below $34,000 it was also rated vulnerable to a continuation of fossil fuel combustion, no only directly but in the future through sea level rise which will require financial resources to adequately build infrastructure which protects the underlying population. According to experts, under high mitigation scenarios (RCP 2.6) global sea level is expected to rise 0.4-0.6 meters by 2100 and 0.6-1.0 by 2300. However current INDC submitted under the Paris Agreement indicated that we are closer to the unmitigated warming scenario (RCP 8.5), which would translate to a global sea level rise of 0.7-1.2 meters by 2100, and 2-3 meters 2300 (Horton et al 2011). China's population would have qualified as 'vulnerable' under all three of these sub-conditions, while Japans population is primarily susceptible to sea level rise, considering that nearly 12% of the urban population lives below 5 meters elevation (see table 6 for the raw and calibrated values of individual conditions that make up 'non-vulnerable population' on page 38). Additionally the world health organization has stressed the importance of clean air and the serious impact that deteriorated air quality can have on the population for the its serious adverse health effects related to poor air quality. Often this air pollution is sourced from the combustion of fossil fuel. For example the pollution used to quantify air pollution in this analysis, particulate matter 2.5 can adverse impacts on human health even at low concentrations, in fact no threshold has been identified where no damage occurs to human health. Therefore the 2005 WHO guideline limits aimed to achieve the lowest concentrations of PM possible (WHO, 2016)

- ***Path 3*: *Sustainable, European way***: *(Italy, Germany, Switzerland)*
    - *Wealthy democratic society (ABIL) (and**) that had committed to the *first international climate agreement (KYOTO) (and**) and have plans to *phase out their nuclear power facilities (~NUCF) (and*)* still have an opportunity to further *decarbonize their electricity and/or heat production sectors* or harvest a grater fraction of the *available incoming solar radiation (POT) → over 10 GW PV capacity*

This 3rd path highlights a very different route that can be taken to ensure photovoltaic technology is being integrated into the existing electricity mix. The key components of this path resonate to the fact each case undertook carbon dioxide emissions reduction pledges as Annex I parties to the Kyoto Protocol. Germany and Italy undertook major reductions. This fact, was captured and illuminated by the creation of the 'Kyoto' condition, which took into account all countries that ratified the Kyoto Protocol *and* simultaneously reduced their emissions of greenhouse gases in 2013 when compared with their 1990 outputs. In fact the two positively evaluated cases captured by this path, Germany and Italy had had the greatest carbon dioxide reductions of any EU 15 country 1990 and 2013. All of the pledges made under the Kyoto Protocol as well as the actual percentage change in carbon dioxide emissions by cases under investigation in this analysis between 2013 and the 1990 base year can be seen in table 1, on page 9. This sufficient pathway also incorrectly gave Switzerland a positive evaluation although its 1.34 GW photovoltaic capacity falls far short of the 10 GW capacity that is required for a positive evaluation of outcome 1. Switzerland was incorrectly associated with this sufficient pathway because its truth table configuration in the analysis of sufficiency mirrored that of Germany. The reason that Switzerland doesn't posses even 2% of Germany's installed photovoltaic capacity can be attributed to the fact that Switzerland has a population that is roughly one-tenth the size of Germany's. Additionally Switzerland's electricity sector had already rid itself of fossil fuel sources, evident by the fact that only 1% of their electricity is sourced from the pollution intensive, traditional three—oil, gas and coal. However it must be noted that although Switzerland has a very carbon friendly electricity sector, there have been discussions to phase out the existing nuclear power facilities. The nuclear power sector currently attributes roughly 40% of Switzerland's electricity, and therefore represents a significant portion of supply that could potentially need to be replaced in the near future. If Switzerland proceeds with phasing out their nuclear facilities by 2034, which has been discussed than solar photovoltaics and other renewable energy sources will have a serious opportunity to replace one significant fossil free source of electricity with another sustainable, renewable, source. If the phase out happens than the solar photovoltaic capacity of Switzerland could balloon to meet the demand shortcomings created by the phase out of nuclear power facilities. This could be the case because Switzerland is a very wealthy, democratic society that would not stand for replacing one fossil free source of electricity with a pollution intensive source, at which time their solar photovoltaic capacities could be more in line with top European promoters although they have small, non resource intensive populations they are at a level of development that anything contrary to this notion would be surprising.

8.2 Discussion regarding sufficient pathways for a negative evaluation

- *Path 1: Countries with a nuclear future: (India, Korea, UK, Netherlands, Spain, Canada, and France)*
  - *Non resource intensive population (~RIP) (and*)* with no plans to phase out *nuclear power production (NUCF) (and*)* potential to decarbonize electricity and/or heat production sectors or harness greater fraction of available solar radiation *(POT)* → negative evaluation: *less than 10 GW PV capacity*.

The analysis brought to light the fact that countries that can rely on their existing nuclear power programs to supply a fossil free source of electricity in the future are more likely to have a negative evaluation as is the case for all seven of the cases that were evaluated under this sufficient pathway.

- *Path 2: Non Committed Annex I parties to the Kyoto Protocol: (Australia, Spain and Canada)*
    - *Wealthy democratic societies (ABIL) (and*)* that are home to a *non-vulnerable (NVP) (and*) Non resource intensive population (~RIP) (and*)* which *did not* undertake *stringent Kyoto commitments (~KYOTO) (and*)* have plenty of *potential to decarbonize* existing electricity infrastructure and/or harness more of the available solar resource *(POT)* → *negative evaluation: less than 10 GW PV capacity*

The second path, highlights an interesting finding, the fact that all three cases were indeed Annex I parties to the Kyoto Protocol, however, none of them actually reduced their greenhouse gas outputs between 1990 and 2013. In fact, two of the cases, Canada and Australia saw their carbon dioxide outputs increase by over 20% between 2013 and the 1990 base year (see table 1 on page 17). Spain was assisted under the burden-sharing program of the Kyoto Protocol and was therefore permitted to increase their carbon dioxide output by up to 15% while other, more capable European countries took on a greater burden under the 8% communal reduction target enforced under the Kyoto Protocol. Furthermore, at this point in time each case had the 'Ability' to undertake agendas that are high on societies to do list, for each case was representative of a wealthy democracy with a minimum $34,000 GDP per capita. In relation to this condition, the counterargument could also be made that democratic societies are often influenced by the preferences and agendas of wealthy individuals or companies, which then influence policy through lobbying. This could almost certainty be the case in both Australia and Canada, where the oil and gas companies represent a large vesting interest in polices that are favorable to their fossil fuel intensive reserves of natural resources. The left leaning Polaris institute reports that more than 2,700 meetings between oil and gas lobbyists and federal office holders since 2008 have unfortunately helped turn Canada into a 'Petrol-State' (Huffingtonpost, 2012). Likewise, in the worlds southern hemisphere, the Australian Petroleum Production and Exploration Association (APPEA) spent nearly $4 million in 2015 to 'obstruct' more ambitious climate policy (The Sydney Morning Herald, 2016). These revelations highlight that there are serious efforts within both countries by oil and gas companies to protect their interests by lobbying the governments to undermine the efforts to decarbonize. The lobbying power of these oil and gas companies are exacerbated by the fact that none of these cases are home to vulnerable populations. More specifically the populations were adequately wealthy, with a per capita GDP exceeding $34,000, and their populations exposure to future sea level rise and current levels of particulate matter 2.5, are neither pressing in the sense that it would entice the countries to currently invest more in fossil free source of electricity.

8.3 Conclusions regarding Outcome 1.

According to the analysis there were three sufficient paths that could lead to a positive evaluation. Path 1 and 2 are indicative of unsustainable resource intensive populations. Although the countries: China, Japan and the United States rank in the top-4 globally in terms of installed photovoltaic capacity at the end of 2015, the power generated from solar photovoltaic technology represents only a small fraction of the overall demand. The third path sufficient path highlights a markedly different, more sustainable route that European countries have taken in their pursuit to transition to low carbon societies. This notion becomes evident when considering that these countries were committed to the first international climate agreement, the Kyoto Protocol that called for the Annex I parties to reduce their dependence on fossil fuel sources.

Considering the solution formula for the first two sufficient paths, there are a number of other countries in the world that currently have similar characteristics and therefore could potentially be prime candidates to implement solar photovoltaic technology into their existing electricity mix. The countries that were positively evaluated by path 1 or 2; China, Japan and the United States are all home to 'Resource Intensive Populations'. The countries that currently have a similar make up in terms of being a 'Resource Intensive Population' are: Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russia and Mexico. More specifically these seven countries have a population greater than 100 million people and concurrently over two-thirds of their electricity is sourced by fossil fuel sources. However, only Russia currently has kwh/capita electricity consumption that would suffice it to be labeled a 'Resource Intensive Population' with regard to the set thresholds of the calibration. It must be noted, however, that as these seven countries continue to develop, their per capita electricity consumption will continue to increase at which time they all could meet the requirements of being a 'Resource Intensive Population'. For this reason these seven countries are ideal candidates to follow the sufficient pathway driven by 'Resource Intensive Population' and highlighted by the route taken by China, Japan and the United States to their current standing in the top-4 solar photovoltaic capable countries.

Chapter IX. Discussion of OUTCOME 2: Percentage of solar radiation harnessed.

The first outcome provided insights into which countries have the greatest installed photovoltaic capacity, yet failed to account for how well each case was at harnessing the available solar resource within their territory. It was determined that it was necessary to test a second outcome, which took into consideration how effectively each case under investigation was harnessing the available solar resource within their territory. This was deemed necessary for there were a number of cases that received a negative evaluation with regard to outcome 1, which harnessed a greater fraction of the available solar resource than their positively evaluated counterparts. The desire was to take into consideration, countries that harnessed a higher fraction of the available solar resource in their territory than some countries that were positively evaluated for having an installed photovoltaic capacity greater than 10 GW. These cases generally supported smaller and therefore less resource intensive populations, which typically require less total installed capacity to reach a higher market penetration in terms of photovoltaic power production within the electricity production sector. For this reason the second outcome was created, so that smaller, less resource intensive countries could also be extended an opportunity to present sufficient pathways that take into account the percentage of available solar resource harnessed by solar photovoltaic technology opposed to total installed capacity; which is more so geared to the worlds largest, more resource intensive economies. Albeit this 2nd outcome attempts to highlight which countries from the investigation of outcome 1 (The top 16 solar PV capacity countries in the world) do the most with their available solar resource, and harness at least 0.2% of the solar resource within their country to generate electricity via photovoltaic technologies.

9.1 Discussion regarding sufficient pathways for positive evaluation

- **Path 1:** ***Vulnerable population with no nuclear future:*** *(Japan)*
    - *Wealthy democratic society (ABIL) (and*)* home to *vulnerable (~NVP) (and*) resource intensive population (RIP) (and*) that since 2011 can no longer rely on nuclear* power to produce fossil free electricity *(~NUCF)* → *positive evaluation: at least 0.2% solar radiation harnessed.*

This path is indicative of countries that can no longer rely on nuclear power production to supply a fossil free source of electricity to a population that is already susceptible to the externalities associated with fossil fuel combustion. This fact is evident through the absence of the condition 'NVP', indicating that the cases underlying population is vulnerable. This condition encapsulates a number of various conditions that can mark a population's susceptibility to continued fossil fuel combustion. In this analysis a population can be vulnerable to local air pollution, attributed by the particulate matter 2.5 present in the local air. If the amount of particulate matter 2.5 exceeded 20 micrograms per cubic meter, double the WHO's recommended levels than a cases population would be considered vulnerable. Additionally, if a 4% of cases urban population lives below 5 meters elevation, or the per capita GDP was below $34,000 it was also rated vulnerable to a continuation of fossil fuel combustion, no only directly but in the future through sea level rise which will require financial resources to adequately build infrastructure which protects the underlying population. According to experts, under high mitigation scenarios (RCP 2.6) global sea level is expected to rise 0.4-0.6 meters by 2100 and 0.6-1.0 by 2300. However current INDC submitted under the Paris Agreement indicated that we are closer to the unmitigated warming scenario (RCP 8.5), which would translate to a global sea level rise of 0.7-1.2 meters by 2100, and 2-3 meters 2300 (Horton et al 2011). It is estimated that 3 billion people live within 200km of a coastline, and is expected to double by 2025 (Creel, 2003). This speaks to the continued migration of the human population from rural areas and into cities that dot the low-lying coastline, which are attractive for their perceived economic benefits. However the booming urban populations in coastal areas are threatening the ecosystem, which provides many of the economic benefits. Therefore if a country already has 4% of its urban population living below 5-meter elevation the population and supporting ecosystem alike will only be put under greater stress in the future if fossil fuel combustion, and resulting sea level rise is not curbed. The ideal case example in reality and captured by path 1 is the country of Japan, where nearly 12% of the urban population lives below 5 meters elevation. And in part to the susceptibility of their coastlines the aftermath of an earthquake and resulting tsunami in 2011 lead to a meltdown of the nuclear reactor in Fukushima, resulting in one of the worst nuclear accidents to date. The accident lead many countries to review their exiting nuclear programs and asses the risk/reward aspects, with some deciding to begin to phase out their aging nuclear power production programs, opening the door for photovoltaics and other renewable to enter the markets—similar to what has happened in Japan following the Fukushima fallout. The Japanese government presented three strategies of nuclear power reduction and had mentioned that they would prefer the zero nuclear energy scenario in the future (McLellan, 2013). The Fukushima accident brought the urgency of energy policy consideration back to the forefront of public and academic discussion, and there have been a number of reports published pertaining to Japans energy policy and supply options moving forward (Vivoda, 2012)(Huang and Nagasaka, 2012). In addition there are two more conditions that were a part of the intermediate solution associated with Japan through this 1st path. The presence of both 'Ability' and 'Resource Intense Population' goes to highlight that Japan is an advanced, wealthy and democratic society that has a rather large appetite for natural resources. It may seem like a contraction that a resource intensive population would receive a positive evaluation for harnessing its available solar radiation. However, this contraction is explained when you consider that the Fukushima accident and following shut down of other nuclear reactors, which represented 25% of the electrical supply in 2011 was immediately removed and needed to be replaced within the energy equation (WorldBank, 2016). This void had to be filled with what was immediately accessible and for that reason Japan saw its share of fossil fuels in electricity production climb from 60.5% in 2010 to 82% in 2014, nearly a 5% higher clip than China (WorldBank, 2016). For this reason, although Japan is a positively evaluated case when it comes to harnessing available solar resource it has revoked to a fossil fueled society after the sudden fallout of their nuclear power facilities and therefore their population has been deemed resource intensive within the analysis and in reality. The fact is they currently have a large, energy intensive population for they rank 3rd in terms of total installed capacity with 34.41 GW (outcome 1) and 4th in terms of percentage of available solar energy harnessed at 0.52% among all 16 cases (outcome 2) yet their current share of fossil fuels in the electricity mix is once again dominant. This does however open the obvious door for PV and other renewable options to aggressively enter the market, something that has been mentioned by several researchers in the wake of the Fukushima accident. One study suggested that a 75% soar and 25% wind would minimize the needs for storage, while the optimal balance would be 50% solar, 20% wind 30% other renewables and backup power (Tsuchiya, 2012). These figures support other studies that have shown solar-wind power systems with appropriate storage and back-up systems can provide a significant level of reliability (Esteban, 2012). This speaks to the real opportunity PV and other renewables have in Japan and other countries that cannot rely on their nuclear power programs to continue to provide a fossil free source of energy, a stepping-stone to sustainability, to power their socioeconomic development.

- ***Path 2: Annex I members of the Kyoto Protocol:*** *(Italy, Belgium, Germany and Switzerland)*
  - *Wealthy European societies (ABIL)(and*)* that had commitments under *the Kyoto Protocol (KYOTO)(and*) can not rely on nuclear power to continue providing fossil free electricity in the future (~NUCF)* and do not have overly large, *resource intensive populations (~RIP) → positive evaluation: more than 0.2% of incoming solar radiation harnessed*

This second path encompasses all other cases that were positively evaluated and would be sufficient for the outcome to be present. This second path is markedly different from the *1st path* for each case is representative of a European country that was an Annex I member to the Kyoto

Protocol and reduced their carbon dioxide emission between the 1990 base year and 2013. In fact Germany, Italy and Belgium all experienced reductions greater than 15%, while Switzerland almost made good on their 8% reduction pledge (all cases pledges and recorded reductions can be seen in table 1, on page 9). It was mentioned during the discussion of the previous path that it seemed peculiar to see a 'Resource Intensive Population' present in the solution term for a positive evaluation of outcome 2. However, in this 2nd path all cases are indicative of a 'non resource intensive population' (~RIP).

However what all 5 cases have in common, with regard to both sufficient pathways is that that they all share the conditions '~NUCF' and 'Ability'. While 'Ability' was present in the parsimonious solution of the 1st path, it only appears to be significant in the intermediate solution of the 2nd path but still speaks to the importance that a wealthy democratic society has in terms of pushing policy agendas that take advantage of the available renewable resources that are available within their territorial bounds. The only condition that appears in the simplified, parsimonious solution of both sufficient paths is the fact that none of the positively evaluated cases have a future with regards to a nuclear power program. This fact speaks to the importance of this condition, for it's this condition, '~NUCF' in combination with others that allows for a positive evaluation of outcome 2. So to say countries that cannot rely on this fossil free source of electricity in the future must integrate other fossil free technologies, such as solar photovoltaic, to ensure that they make good on their emission reduction commitments laid forth under international climate agreements; or to ensure that the resilience of an already vulnerable population is not further exacerbated by continued high rates of fossil fuel consumption, as is the case in Japan.

9.2 Discussion regarding sufficient pathways for negative evaluation.

- *Path 1: Large Developing Countries: (India and China)*
    - *Developing countries (~ABIL)(and*)* that had zero commitments under *the Kyoto Protocol (~KYOTO)(and*)* and can rely on *nuclear power facilities in the future (NUCF)* → *negative evaluation: less than 0.2% of incoming solar radiation harnessed to generate electricity*

Although both China and India have been at the forefront of recent development they are symbolic of countries that had zero obligations under the Kyoto Protocol to reduce their emissions due to *common but differentiated responsibilities* which put the impetus on developed Annex 1 countries. This combined with the fact that they have no plans to phase out their nuclear power production facilities are the two primary conditions, and prevalent by the fact that this combination is the parsimonious solution. From the previous section it is clear that loosing the ability to produce nuclear sourced power has serious advantages in terms of harnessing the solar resource available within a cases territory, but in both positively evaluated pathways that was the case in conjunction with rather wealthy, developed and democratic societies. When those two facts are taken into consideration than this sufficient pathway for a negative evaluation is the antithesis of the paths that can lead a positive evaluation, evident from the previous discussion of positively evaluated cases. In the case of this negatively evaluated path, both India and Chin have rapidly developing economies, yet neither is currently representative of a case with ‘Ability’. For ‘Ability’ to be present, cases must have at least a per capita GDP of $34,000. This is certainly not the case in China ($14,239) and even less so in India which was the poorest country under investigation in per capita terms with a value of $6,089. This speaks to the fact that their society has yet to reach the developmental standing of other cases under investigation and highlights the importance of having a wealthy, democratic society to advocate for the advancement of renewable energy policies and higher integration into existing electricity schemes to harness a greater fraction of the available resource.

- *Path 2: Countries with non-vulnerable populations: (Spain, Canada, United States)*
    - Countries with *non-vulnerable populations (NVP)(and*)* that did not experience *greenhouse gas reductions between 1990 and 2013 (~KYOTO)(and*)* have no plans to phase out *nuclear power facilities (NUCF)* → *negative evaluation*

The constant condition, having a nuclear future, works in combination with the fact that all three of these cases are home to non-vulnerable populations. More specifically this means that their citizens are not breathing particularly contaminated air, at least in terms of particulate matter 2.5. In addition they are not very susceptible to future sea level rise and are sufficiently wealthy. But this can have adverse consequences as well, for the urgency of the problem for the underlying population of each country is not necessarily imminently at risk or overly exposed to externalities, such as local air pollution, associated with fossil fuel combustion and can therefore act as a deterrent for countries to harness a greater fraction of their available renewable energy resources. In addition to these two conditions, the intermediate solution also indicates that absence of ‘Kyoto’ condition, which speaks to their lack of commitment as Annex I parties to the Kyoto Protocol, albeit Spain was pardoned from carbon dioxide reductions under Kyoto’s burden sharing agreement. Canada originally ratified the agreement, yet pulled out when they realized they wouldn’t be able to honor their pledge. In fact Canada saw their carbon dioxide emissions rise 23% between the 1990 base year and 2013 (table 1 page 9). The U.S. notoriously refused to ever ratify the protocol after a change in administration, although under the direction of former Vice President, Al Gore, the United States was an advocate of emission reductions and key contributor in talks leading up to the Kyoto Protocol. However, with the change in administration and the rise of the Republican president George W. Bush to the top position in the U.S. government signaled a shift to stay the unsustainable course.

- *Path 3: Non-resource intensive, non-vulnerable populations*: *(Spain, Canada, France)*
    - *Countries that have non-resource intensive (~RIP)(and*) non-vulnerable populations (NVP)(and*)* that can rely on *nuclear power* to provide fossil free electricity *in the future (NUCF)* → *negative evaluation*

This path is very similar to the *2nd path,* for they share the same parsimonious solution, and the only discrepancy is that in this third path the Kyoto condition becomes irrelevant while the '~RIP' condition, is present in the intermediate solution. This goes to say that while in the *2nd path* the absence of Kyoto commitments in combination with the parsimonious conditions were sufficient to lead to a negative evaluation, in this path all three cases that are identified by this path are home to 'non resource intensive populations'; although their per capita consumption rates are rather high, each country is home to less than 100 million people (in the case of Canada and Spain less than 50 million) and in each case less than 40% of their electricity is sourced by oil, gas or coal sources, to see a complete breakdown of the 'RIP' condition see table 9 on page 56.

- *Path 4: Nuclear Future with Non Stringent Kyoto Commitments:*
    - Countries with *non-resource intensive populations (~RIP)(and*)* no *reduction in greenhouse gas emissions* between 2012 and 1990 *(~KYOTO)(and*)* no plans to phase out *nuclear power production in the future (NUCF)* → *negative evaluation.*

This path takes up similar characteristics as the *1st path,* and they share a parsimonious solution; evident by the fact that each case has a nuclear future combined with the fact that none of the cases saw their 2012 greenhouse gas emissions reduced compared to their 1990 levels, these two conditions was once again enough to ensure from a simplified view that these cases would not be harnessing at least 0.2% of the incoming solar radiation available in their territory. Similar to the 3rd path this pathway also included '~RIP' as part of the intermediate solution. This suggests that although none of the cases were committed to reducing emissions under the Kyoto Protocol they were also not home to large populations, which simultaneously have a high share of oil, gas or coal in their electricity sector coupled with high per capita electricity consumption patterns.

9.3 Conclusions regarding Outcome 2.

What all 5 positively evaluated cases have in common, with regard to both sufficient pathways is that that they all share the conditions '~NUCF' and 'Ability'. While 'Ability' was present in the parsimonious solution of the 1st path, it only appears to be significant in the intermediate solution of the 2nd path but still speaks to the importance that a wealthy democratic society has in terms of pushing policy agendas that take advantage of the available renewable resources that are available within their territorial bounds. The only condition that appears in the simplified, parsimonious solution of both sufficient paths is the fact that none of the positively evaluated cases have a future with regards to a nuclear power program. This fact speaks to the importance of this condition, for it's this condition, '~NUCF' in combination with others that allows for a positive evaluation of outcome 2. So to say countries that cannot rely on this fossil free source of electricity in the future must integrate other fossil free technologies, such as solar photovoltaic, to ensure that they make good on their emission reduction commitments laid forth under international climate agreements; or to ensure that the resilience of an already vulnerable population is not further exacerbated by continued high rates of fossil fuel consumption, as is the case in Japan.

Considering the solution formula, there are a number of other countries in the world that have similar criteria and therefore could potentially take the same path to integrate more solar photovoltaic into their existing electricity mix. The countries that have similar make up as the positively evaluated cases are: Denmark, Sweden, Austria, Ireland, Lichtenstein and New Zealand. These six countries all have a GDP/capita above $34,000 and can not rely on nuclear power to supply a fossil free source of electricity in the future. Obviously some of these countries may be more ideally situated from a geographical standpoint to integrate solar photovoltaic technology than others, but the macro makeup of these countries could facilitate a greater solar photovoltaic capacity.

9.4 Study Limitations.

Qualitative Comparative Analysis has been widely applied within the field of social sciences; however, its association with natural resource management has been brief. Given that the amount of renewable energy that is deployed is often characteristic of casual complexity, QCA offers a promising method to untangle the possible configurations. One major critique of this study could be that all these cases are already representative of the worlds top solar photovoltaic promoting countries, opposed to broader investigation of cases that have yet to implement solar photovoltaic technology to as great a degree. Secondly, this study does not take into account any of the various government support policies that have been paramount in their importance to support this young, booming solar photovoltaic market. Government support policies, such as feed-in tariffs, subsidies or renewable energy portfolios to name a few have been absolutely essential in allowing solar photovoltaic and other renewable energy options compete with the cheapest sources of energy, namely coal. However, as the solar photovoltaic market continues to develop and mature it will no longer be required to be propped up and supported by government support—'carrot policies'.

Another limitation could be a critique of the selected conditions used for the QCA analysis. For example, of the six conditions that were used in the analysis: 'Ability', 'Potential', 'Resource Intensive Population', 'Non-Vulnerable Population', 'Nuclear Future' and 'Kyoto', it could be argues that some have a casual influence on the outcome under investigation, while others are rather co-occurrences and therefore have no clear casual direction. The conditions, 'Nuclear Future' and 'Kyoto' I would argue have a direct casual relationship with both outcomes under investigation. Both of these conditions should have a direct impact on solar photovoltaic capacity, for the Kyoto Protocol laid out emission reduction targets and countries typically don't replace a fossil free source of electricity with a more pollution intensive source. However there are other conditions, for example, 'Resource Intensive Population' and 'Potential' that most likely do not have a direct casual influence with regard to the installed solar photovoltaic capacity of a country. A 'Resource Intense Population' requires large sums of energy to power their current and future development. Typically solar photovoltaic power generated electricity still only represents a small fraction of the total required and therefore solar photovoltaic is just one of many available options to address the growing energy needs of these economies. However, if the cost of solar photovoltaic energy production continues to decrease than the technology could soon be the cheapest and most attractive electricity generation option—fossil fueled, or renewable.

Chapter X. Conclusion pertaining to photovoltaic energy production

As the global society continues down this developmental path and sees both its population and energy use per capita increase, the physical limits to its continued fossil fuel consumption are fast approaching. The availability of resources is not the limiting agent, but rather the planets ability to adapt to a changing atmospheric chemical composition that has seen all greenhouse gasses related to fossil fuel combustion rise significantly since the industrial revolution. In order for a future society to be sustainable while operating at or above our current standard of living a shift away from carbon based energy sources must occur, and solar photovoltaic can play an integral role in this transition to low carbon societies. Predicting the future development of any technology is by nature fraught with uncertainty. Furthermore, global installed PV capacity today is a minor fraction of expected future deployment. But it is therefore imperative to highlight the different paths that the world's current top photovoltaic countries have taken to integrate the technology into their existing electricity sector. This decade few industries have experienced a boom as fast or as unpredictable as the solar photovoltaic industry. This analysis has yielded numerous different sufficient pathways that can lead to a positive evaluation for the investigation related to either the total installed capacity or the percentage of available solar resource harnessed to produce to electricity. As expected the pathways for a positive evaluation differ depending on the outcome under investigation. Therefore each outcome will be focused on individually at first to highlight the paths that countries have taken to implement solar photovoltaic technology into their electricity mix as to reduce their dependence on fossil fuels, replace an existing technology or assist fueling a growing energy and socioeconomic sector. Regardless the reason for the integration of solar photovoltaic technology it is representative of an important starting point in the transition to sustainability and a low carbon society in the future.

With regard to total installed photovoltaic capacity, the analysis provided two sufficient paths that could lead a country to having at least a 10 Gigawatt photovoltaic capacity at the end of 2015. Of the 16 cases under investigation, 5 met this threshold: China, Germany, Japan, United States and Italy. These 5 cases highlighted that there were three sufficient paths that could lead to a positive evaluation. The worlds three largest economies, the United States, China and Japan all call attention to the fact that their large resource intensive populations are a major driving force behind their countries PV capacity. The United States is representative of countries that are consumer intensive wealthy democratic societies that are still heavily dependent on fossil fuels to power their socioeconomic development. China on the other hand took a pathway, which is also dominated by its resource intensive population, however, they are still rapidly developing and have a population that is seriously at risk to high levels of air pollution produced by the combustion of fossil fuels. Japan is indicative of a mix of the two previous paths, and was actually sufficient under either. Not only do they support a resource intensive population heavily dependent on fossil fuels, particularly following the Fukushima accident. Japan is also home to a wealthy democratic society, however the population is vulnerable to continued fossil fuel combustion, for 12% of their urban population lives below 5-meter elevation. This highlights the population's susceptibility to future sea level rise, a negative externality associated with the burning of fossil fuels, which increases the atmospheric temperature via the greenhouse effect. Additionally it reinforces the solution term that indicates the presence of a vulnerable population can having on integrating solar photovoltaic technology into the existing electricity mix as countries work to lessen their dependence on fossil fuel combustion as they try to circumvent the negative externalities associated with their continued prevalence. All three of these cases are representative of countries were solar PV only makes up a small portion of their overall electrical requirements. Therefore these three countries are still largely unsustainable, although they all rank in the top 4 in terms of installed photovoltaic capacity. The other two positively identified cases related to this outcome, Germany and Italy, took a much more sustainable path which was highlighted by their commitments under international climate protocols such as Kyoto which focused on reducing emissions in the name of common but differentiated responsibilities. This third pathway highlights the importance of international climate agreements with a focus on the reduction of carbon intensive sources in exchange for renewables. Albeit each one of these countries is also representative of a developed (hence their commitments as Annex I parties to the Kyoto Protocol), democratic society that still have potential to decarbonize their electricity or heat production sectors; on top of that they will not be able to rely on nuclear power production facilities to supply a steady fossil free source of electricity in the future.

With regard to the second outcome put under investigation, which took our top-16 cases from the previous analysis and tested as to which were harnessing the greatest fraction of the available solar radiation within their territory—all positively evaluated cases had to harness at least 0.2% of the solar radiation available to them. Once again this analysis yielded the presence of 5 positively identified cases that all harnessed more than this 0.2% of the available solar radiation via solar photovoltaic technology. Three of the cases are the same as the ones positively identified under outcome 1. Germany, Italy and Japan were all positively evaluated under both outcomes meaning they all three harnessed at least 0.2% of the available solar radiation and had a photovoltaic capacity of at least 10 gigawatts. However, this second outcome did identify two new cases that did not meet the requirements for a positive evaluation under outcome 1. These two positively identified cases under outcome 2 were Belgium and Switzerland. There were two sufficient pathways associated with this 2nd outcome that could lead to a positive evaluation. The first sufficient path was once again representative of the country of Japan, a wealthy yet vulnerable population that could no longer rely on nuclear power to supply a fossil free source of electricity. The second sufficient path under this outcome had some shared characteristics with the first, specifically the status of wealthy, developed countries. What differentiated the two paths is the fact that both Germany and Italy took pledges under they Kyoto Protocol and coincidently saw their carbon dioxide emissions fall by at least 15% between 2013 and the 1990 base year. However, both paths shared a dominant, parsimonious condition—fact that none of these positively evaluated cases can rely on nuclear power production in the future—which speaks to the opportunity that PV has had, and will continue to have, assisting to help meet the supply gaps created by the phasing out of nuclear power facilities, replacing one fossil free source with another, imperative in the ongoing effort to transition to low carbon societies.

The lack of being able to rely on nuclear power production to supply a fossil free source of electricity in the future is one parsimonious condition that is prevalent across 3/5 of the of the positively evaluated cases. In addition, this condition is part of the solution term for all three cases that are positively evaluated with regard to both outcomes. This leads me to conclude that not being able to rely on nuclear power production in the future is beneficial with regard to a countries solar photovoltaic capacity. This is highlighted by the fact that both Germany and Japan ranked first and second in the world in terms of installed photovoltaic capacity prior to the 2014 boom within the Chinese domestic market. The third positively evaluated case under both outcomes, Italy, had decided decades ago that nuclear power production would be unsuitable for threats created by the seismic active zone in which they reside.

However as previously stated there are two positively identified cases from outcome 1 that reached their current standing within the photovoltaic landscape despite the fact that they have no plans to phase out their nuclear power facilities. This speaks to the underlying notion associated with QCA of casual complexity, specifically that there are a number of different pathways that can lead to the same outcome(s). Considering both outcomes, there are 5 sufficient pathways that can lead to a positive evaluation with regard to either outcome. Each pathway seems to have one of two reoccurring conditions in their parsimonious solution, either the inability to rely on nuclear power facilities in the future, or the fact that the underlying population is resource intensive such as in the case of the United States and China. This is highlighted by the fact that there remains only one condition in the parsimonious solution for both of these cases— a resource intensive population. These two cases are representative of the two biggest energy consumers in the world and although the recent boom in both domestic photovoltaic markets, the total installed capacity still represents a small fraction of the overall requirements needed to meet the societal demand. Although this pathway is currently unsustainable it highlights the interesting conundrum that having a resource intensive population can have in terms of a countries total installed photovoltaic capacity. As these two cases indicate, having a resource intensive population has a positive effect on countries installed photovoltaic capacity, although the technology currently represents only a small fraction of overall electrical output. Therefore, the presence of a resource intensive population in combination with either a wealthy democratic society, or a vulnerable population and the potential to decarbonize their electricity sectors is sufficient to ensure that both cases had an installed photovoltaic capacity of at least 10 GW at the end of 2015. In essence the foundation has just now been laid for solar photovoltaic integration into the existing electricity mix of these large, resource intensive economies which is crucial to ensuring a sustainable future—for without the efforts of the worlds largest emitters—every other countries efforts to decarbonize would be compromised.

The notion of sustainable development has been a primary driver of the worlds leading solar photovoltaic promoters, although no variable from the sustainable development framework is solely responsible for driving this decades solar photovoltaic boom, it has enabled avenues for countries to begin aggressively integrating solar photovoltaic technology as the clean, safe, renewable and truly limitless option that it represents. The insights gained through this analysis can highlight and bring to attention the various possible pathways countries with similar socioeconomic and geographical characteristics could take in their transition to a more sustainable society. The combustion of fossil fuel has far reaching consequences and the situation will only be further exacerbated if the necessary steps are not taken now to transition our societies with the available technology, such as solar photovoltaic to ensure our already fragile climate has an opportunity to once again find its state of equilibrium.

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Appendix:

Table 24: Raw data matrix

Case	Outcome 10+GW installed PV capacity	Population (millions)	GDP per capita	KWh per capita	% of Population living below 5 meter elevation	Share of Oil, gas, coal in electricity mix	Share of CO2 from electricity and heat prod.	Share of incoming solar energy captured
China	43.54	1364	14,239	3,762	4.2 %	77.4 %	52.95 %	0.0307
Germany	39.7	81	47,268	7,019	3.01	56.3	48.18	0.9799
Japan	34.41	127	37,322	7,836	11.94	82.0	51.55	0.5207
U.S	25.62	319	55,837	12,988	2.26	67.5	47.1	0.0202
Italy	18.91	61	35,896	5,159	4.16	56.3	36.24	0.5855
UK	8.78	64	41,325	5,407	4.2	60.7	43.99	0.1728
France	6.58	66	39,678	7,374	2.15	5.1	16.92	0.0903
Spain	5.44	46	34,527	5,401	3.49	38.7	36.72	0.1062
Australia	5.1	24	45,514	10,134	3.61	85.1	59.56	0.0041
India	5.05	1252	6,089	765	1.14	80.2	52.86	0.0078
Korea	3.43	50	34,549	10,428	2.03	69.3	60.44	0.2394
Belgium	3.25	11	43,992	7,967	9.95	33.4	26.7	0.9826
Canada	2.50	36	44,310	15,519	1.85	21.4	36.58	0.0022
Netherlands	1.57	17	48,459	6,821	48.46	82.6	41.05	0.2651
Thailand	1.43	67	16,305	2,471	6.29	91.5	44.13	0.0195
Switzerland	1.36	8	60,535	7,807	0	1.2	8.79	0.2317
Lower threshold	1	20	20,000	1,000	1	50	20	0.05
Crossover point	10	60	34,000	3,500	4	66	40	0.6
Upper threshold	30	300	55,000	10,000	20	100	60	1.0

China	0.993	1.000	0.015	0.530	0.509	0.802	0.807	0.045
Germany	0.988	0.564	0.865	0.831	0.275	0.349	0.711	0.942
Japan	0.973	0.695	0.614	0.877	0.812	0.877	0.781	0.395
U.S	0.909	0.960	0.955	0.987	0.153	0.546	0.686	0.043
Italy	0.788	0.503	0.566	0.680	0.507	0.349	0.365	0.481
UK	0.402	0.512	0.736	0.703	0.509	0.415	0.608	0.092
France	0.246	0.518	0.689	0.853	0.140	0.020	0.032	0.061
Spain	0.184	0.263	0.518	0.703	0.377	0.149	0.382	0.066
Australia	0.166	0.066	0.834	0.953	0.405	0.913	0.896	0.040
India	0.165	1.000	0.003	0.038	0.057	0.851	0.805	0.040
Korea	0.104	0.324	0.519	0.958	0.126	0.601	0.905	0.127
Belgium	0.099	0.026	0.802	0.883	0.749	0.110	0.124	0.944
Canada	0.079	0.146	0.809	0.996	0.108	0.054	0.377	0.039
Netherlands	0.060	0.040	0.884	0.818	1.000	0.889	0.529	0.143
Thailand	0.057	0.521	0.024	0.229	0.604	0.958	0.612	0.043
Switzerland	0.056	0.021	0.976	0.876	0.019	0.016	0.010	0.122

Case	Nuclear Efficiency	Nuclear Phase out date	Democracy Rating	% GHG change 1990 -2014	C02 emissions (kt)	Particulate matter 2.5 (mg/m^3)	Annex I: Ratified Kyoto
China	63.9	50 years	3.14	219.95	10,249,463	54.37	0
Germany	91.8	6 years	8.64	-24.23	757,313	15.35	1
Japan	1.2	-2 years	7.96	13.35	1,243,384	16.03	1
U.S	91.8	50 years	8.05	3.39	5,186,168	10.76	.01
Italy	0	-29 years	7.98	-5.14	344,786	18.34	1
UK	81.8	50 years	8.31	-24.63	457,473	10.81	1
France	75.8	50 years	7.92	-10.01	333,191	14.02	1
Spain	87.9	50 years	8.3	18.72	263,969	11.65	1
Australia	0	N/A (0)	9.01	57.93	377,906	5.93	1
India	74.4	50 years	7.74	116.44	2,034,752	46.68	0
Korea	77.8	50 years	7.97	122.62	592,499	29.02	0
Belgium	47.9	9 years	7.93	-3.26	93,619	18.53	1
Canada	80.7	50 years	9.08	68.73	475,735	12.14	.5
Netherlands	92.4	50 years	8.92	-12.64	169,973	16.84	1
Thailand	0	N/A (0)	5.09	111.67	303,118	22.36	0
Switzerland	76.0	18 years	9.09	-4.05	40,348	17.59	1
Lower threshold	0	0	3	-25	100,000	10	0.1
Crossover point	50	20	7.5	0	500,000	15	0.6
Upper threshold	85	100	9	100	1,000,000	50	0.9

Case	Nuclear Efficiency	Nuclear Phase out date	Democracy Rating	% GHG change 1990 -2014	C02 emissions (kt)	Particulate matter 2.5 (mg/m^3)	Annex I: Ratified Kyoto
China	0.763	0.751	0.055	0.002	0.998	0.967	0.028
Germany	0.971	0.113	0.904	0.946	0.542	0.203	0.981
Japan	0.054	0.038	0.712	0.403	0.619	0.237	0.981
U.S	0.971	0.751	0.746	0.475	0.955	0.062	0.050
Italy	0.050	0.050	0.720	0.647	0.242	0.380	0.981
UK	0.936	0.751	0.831	0.948	0.422	0.063	0.981
France	0.897	0.751	0.695	0.765	0.227	0.147	0.981
Spain	0.960	0.751	0.828	0.366	0.126	0.079	0.981
Australia	0.050	0.050	0.951	0.154	0.289	0.016	0.981
India	0.886	0.751	0.616	0.031	0.732	0.932	0.028
Korea	0.910	0.751	0.716	0.026	0.515	0.708	0.028
Belgium	0.469	0.165	0.699	0.595	0.048	0.393	0.981
Canada	0.930	0.751	0.957	0.117	0.455	0.090	0.357
Netherlands	0.972	0.751	0.942	0.816	0.081	0.283	0.981
Thailand	0.050	0.050	0.171	0.036	0.190	0.558	0.028
Switzerland	0.899	0.427	0.958	0.617	0.033	0.330	0.981

Table 25: Truth table, analysis of sufficiency for a positive evaluation of outcome 1.

ABIL	POT	RIP	NVP	NUCF	KYT	OUTCOME	#	Consistency	PRI
1	1	1	0	0	0	1 (Japan)	1	.922	.850
0	1	1	0	1	0	1 (China)	1	.866	.744
1	1	1	1	1	0	1 (United States)	1	.863	.725
1	1	0	1	0	1	1 (Germany, **Swtizerl.)**	2	.807	.657
1	1	0	0	0	1	1 (Italy)	1	.803	.602
1	0	0	0	0	1	0 (Belgium)	1	.709	.506
0	1	0	0	0	0	0 (Thailand)	1	.662	.389
1	1	0	1	0	0	0 (Australia)	1	.616	.305
1	1	0	1	1	1	0 (France)	1	.614	.293
0	1	0	0	1	0	0 (India)	1	.565	.284
1	1	0	0	1	1	0 (UK, Netherlands)	1	.534	.112
1	1	0	0	1	0	0 (Korea)	1	.502	.090
1	1	0	1	1	0	0 (Spain, Canada)	2	.492	.215

PRI = proportional reduction in inconsistency. Raw consistency threshold (0.80)

The truth table above shows the various combinations of conditions that were sufficient for a positive evaluation of the outcome given a threshold of 0.80.

Table 26: Truth table, analysis of sufficiency for negative evaluation of outcome 1

ABIL	POT	RIP	NVP	NUCF	KYT	OUTCOME	#	Consistency	PRI
1	1	0	0	1	0	1 (Korea)	1	.951	.910
1	1	0	0	1	1	1 (UK, Netherlands)	2	.941	.888
1	1	0	1	1	0	1 (Spain, Canada)	2	.861	.785
1	1	0	1	1	1	1 (France)	1	.840	.707
1	1	0	1	0	0	1 (Australia)	1	.831	.695
0	1	0	0	1	0	1 (India)	1	.827	.716
0	1	0	0	0	0	0 (Thailand)	1	.785	.611
1	1	0	0	0	1	0 (Italy)	1	.702	.398
0	0	0	0	0	1	0 (Belgium)	1	.701	.494
1	1	1	1	1	0	0 (United States)	1	.638	.275
1	1	0	1	0	1	0 (Germany, Switzerl.)	2	.630	.343
1	1	1	0	0	0	0 (Japan)	1	.612	.256
1	1	1	0	0	0	0 (Japan)	1	.561	.150

PRI = proportional reduction in inconsistency.

Table 27: Analysis of sufficiency: which conditions and in which combination are sufficient for the negated outcome (1) under investigation (less than 10GW photovoltaic capacity)

Solution	ABIL__*POT*rip*__nvp__*NUCF*__kyt + ABIL__*POT*rip*__nvp__*NUCF*__KYT + ABIL__*POT*rip*__NVP__*NUCF__*kyt → *Less than 10GW Photovoltaic capacity*		
Cases Covered	Korea	U.K, Netherlands	Spain, Canada
Consistency	0.951	0.941	0.861
Raw coverage	0.245	0.287	0.269
Unique coverage	*0.164, 0.096*	*0.164*	*0.164, 0.079*
Solution	ABIL__*POT*rip*__NVP__*NUCF__*KYT + __ABIL*POT*rip*NVP*nucf__*kyt + abil__*POT*rip*__nvp__*NUCF__*kyt → *Less than 10GW Photovoltaic capacity*		
Cases Covered	France	Australia	India
Consistency	0.840	0.831	0.827
Raw coverage	0.257	0.258	0.284
Unique coverage	*0.164*	*0.079*	*0.096*

Consistency Sufficient Condition: 0.831

Coverage Sufficient Condition: 0.620

Bold: deviant case consistency in kind (membership > 0.5 in path but not in outcome).
The raw consistency threshold was set at 0.75. The next highest consistency score is 0.702 (Italy)

Table 28: Truth table, analysis of sufficiency for positive evaluation of outcome 2.

ABIL	RIP	NVP	NUCF	KYT	OUTCOME	#	Consistency	PRI
1	1	0	0	0	1 (Japan)	1	.884	.705
1	0	0	0	1	1 (Italy, Belgium)	2	.824	.652
1	0	1	0	1	1 (Germany, Switzerl.)	2	.784	.605
1	0	0	1	0	0 (Korea)	1	.685	.173
1	0	0	1	1	0 (UK, Netherlands)	2	.662	.222
1	0	1	0	0	0 (Australia)	1	.598	.219
1	1	1	1	0	0 (United States)	1	.582	.000
0	1	0	1	0	0 (China)	1	.554	.000
1	0	1	1	1	0 (France)	1	.507	.103
0	0	0	0	0	0 (Thailand)	1	.500	.203
1	0	1	1	0	0 (Spain, Canada)	2	.449	.062
0	0	0	1	0	0 (India)	1	.412	.061

PRI = proportional reduction in inconsistency. Raw consistency threshold: 0.78.

The truth table above shows which combination of conditions could be sufficient for a positive evaluation given that the raw consistency threshold was set at 0.78. Any consistency score eclipsing this threshold would be considered sufficient for a positive evaluation. There are two cases whose fuzzy outcome scores are greater than 0.5, yet they fail to be captured by this model (Korea, Netherlands). However it must be noted that both cases fuzzy scores (.536 and .560 respectively, all values reviewable in table 11 on page 52) are close to the crossover point, making their scores rather ambiguous and the cases themselves poor options from which to draw conclusions as to which combination of conditions could be sufficient for a positive evaluation of the outcome.

Table 29: Truth table, analysis of sufficiency for negative evaluation of outcome 2.

ABIL	RIP	NVP	NUCF	KYT	OUTCOME	#	Consistency	PRI
0	1	0	1	0	1 (China)	1	1.000	1.000
1	1	1	1	0	1 (U.S.)	1	1.000	1.000
1	0	1	1	0	1 (Spain, Canada)	2	.964	.938
0	0	0	1	0	1 (India)	1	.962	.939
1	0	1	1	1	1 (France)	1	.943	.897
1	0	0	1	0	1 (Korea)	1	.934	.827
1	0	1	0	0	0 (Australia)	1	.887	.781
0	0	0	0	0	0 (Thailand)	1	.873	.797
1	0	0	1	1	0 (UK, Netherlands)	1	.840	.631
1	1	0	0	0	0 (Japan)	1	.724	.295
1	0	0	0	1	0 (Italy, Belgium.)	2	.672	.348
1	0	1	0	1	0 (Germany, Switzerl.)	2	.656	.372

PRI = proportional reduction in inconsistency. *Raw consistency threshold: 0.9*

Declaration

under Art. 28 Para. 2 RSL 05

Last, first name:	Simon Steffen
Matriculation number:	14-116-263
Programme:	Master in Climate Sciences
Thesis title:	This Decades Solar Photovoltaic Emergence; a cross-sectorial investigation of conditions that foster solar photovoltaic electricity production
Thesis supervisor:	Dr. Karin Ingold

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due acknowledgement has been made in the text. In accordance with academic rules and ethical conduct, I have fully cited and referenced all material and results that are not original to this work. I am well aware of the fact that, on the basis of Article 36 Paragraph 1 Letter o of the University Law of 5 September 1996, the Senate is entitled to deny the title awarded on the basis of this work if proven otherwise. I grant inspection of my thesis.

....	....
Place, date	Signature