Use the Hype to Innovate: Social Bubbles to Save the World from Climate Change

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1 Abstract

This paper analyses the development of the boom in the renewable energy sector globally from 2005 to 2008 using the “social bubble” hypothesis. Developed in the chair, the hypothesis proposes that a widespread endorsement and commitment beyond what would be rationalized by a standard cost-benefit analysis is observed due to strong social interactions and reinforcing feedback effects. The bubble was triggered by a few high impact factors including two massive natural disasters and a rise in the global oil price. The enthusiasm and investments that lead to the bubble can be monitored by the Renewable Energy Industrial Index (RENIXX). It shows a large boom occurred in renewable energy investments compared to the global market between 2005 and 2008. The renewable energy sector, particularly the solar photovoltaic and wind power sectors, crashed when investors left because the technology was not progressing fast enough to be profitable. The influence of the oil price during the crash was also huge as it pushed the RENIXX price down in a cointegrated manner.

Our analysis of the social bubble shows that cleantech failed to return to private investors. Nevertheless, the global renewable energy installed capacity increased massively following the burst of the bubble; the infrastructure and knowledge gained are the fruits of the bubble and are strong assets for the future. Lastly, we looked at the role of governments in the development of Silicon Valley, the origin of the information technology and Internet revolutions. From the history of Silicon Valley and our bubble analysis we conclude that a huge push from governments over the next decades could be the right way to tackle the climate change issue.

“Only when the tide goes out do you discover who’s been swimming naked.” Warren Buffet

Contents

2 Introduction

In economics and finance, "bubble" refers to a situation in which the price of an asset increases due to excessive expectations that are temporarily disconnected from the fundamental value. Bubbles are part of human history and they burst when the predictions and hopes about the future are proven to be wrong. Shiller [2000] proposed twelve factors that encourage market bubbles, among them culture, political change and the influence of news.
The term "bubble" in a financial context relates to a market failure. The popular belief is that bubbles are always bad, but financial bubbles can also have positive consequences and be productive when they happen in a new technological field. This is the heart of the "social bubble" hypothesis. When a new technology appears, investors make decisions based on hopes about the potential outcome of a new technology, leading to a collective over-enthusiasm and a reduction of risk aversion. Once the more realistic potential of a "hyped" technology is realized, the bubble usually bursts as investors become more realistic about the potential of the technology. After the crash, the infrastructure and the knowledge built during the bubble often serve as valuable assets that can be used in the future. Janeway [2012] also sees the bubbles as a tool for progress: "In all their wasteful excess, bubbles have been necessary drivers of economic progress". Carlota Perez writes that bubbles are part of human history and that crises along the successive technological revolutions are not "black swans" (Perez [2013]). She holds that financial bubbles facilitate unavoidable over investment in new infrastructure. These cycles are related to the Schumpeterian "creative destruction", which sees that when a new technology creates new opportunities, old ones become obsolete.
The hypothesis of the social bubble claims that strong social interaction between enthusiastic supporters gives birth to reinforcing feedback that leads to widespread endorsement and extraordinary commitment by those involved, and goes beyond what could be rationalized by a standard cost-benefit analysis in the presence of uncertainties and risks. A social bubble is a social phenomenon that develops during a technological development, in which the following symptoms are likely present: (Gisler et al. [2011], Gisler and Sornette [2010]):

- Strong support for a specific idea/invention by different actors, including the public;
- Credit creation via public and private investment;
- Proliferation of ventures of all kinds;
- Accelerated price growth of corresponding firms trading on organized stock markets;
- Saturation of the idea and abrupt program termination.

The chair has conducted many case studies of bubbles from the angle of the social bubble hypothesis: the Apollo Program (Gisler and Sornette [2009]), the Human Genome Project (Gisler et al. [2011]) or the FuturICT project (Gisler et al.). The

social bubble hypothesis is a great tool for analyzing and understanding bubbles happening in new technologies or in any sector experiencing a "hype moment".
Over the last 250 years, three major industrial revolutions (IR) have occurred and dramatically increased economic productivity and changed humans' lifestyles. The first IR took place between 1770 to 1820, introducing coal and steel, which gave birth to the steam engine that enable the introduction of railroads and steamships for example. The second IR took place from 1870 to 1930 with the introduction of electricity and the internal combustion engine that enabled, for instance, the development of air conditioning, cars and commercial air transport. The third IR has been taking place since 1960 with the introduction of electronics, computers, the internet and mobile phones, giving birth to information and communication technology Gordon [2016]. It is controversially argued that a fourth IR has been occurring since the year 2000. This includes new technologies like cloud computing, the internet of things, blockchain technology, artificial intelligence, self-driving cars, genomics and neurotechnological developments. Today, one of the biggest challenges is that the climate on planet Earth is changing and threatening humanity. Today's way of life and consumption habits are far from sustainable and will inevitably lead to a massive change in the relationship between humans and the planet. What about developing new technologies that are able to provide clean energy and therefore protect the environment? Will a new IR happen and bring renewable energy to humanity?
In this paper we analyze a social and financial bubble that occurred between 2005 and 2008 in the renewable energy sector, using the angle of the social bubble hypothesis. The bubble mainly occurred in the solar photovoltaic (PV) and wind electricity production sector. Our analysis is developed from many angles (social, historical, technological, financial, etc.) in order to paint a precise picture of the bubble. Section 3 presents the main rational reasons for the fast emergence of renewable energies. In section 4, the exuberance of the bubble is shown, confirmed by the crash of the bubble. In section 5, a post-mortem analysis of the bubble is performed. It looks at some key measures to learn more about the bubble almost 10 years after the crash and to assess the current situation. Finally, section 6 describes the role of the American Government in the creation of Silicon Valley. This historical example crossed with the analysis of the bubble allows us to draw a few lessons for the next innovation cycle in renewable energy.

3 Rational reasons empowering renewable energy

A social bubble usually emerges through a series of events or discoveries that have a great impact on its development as they influence the behavior of the main actors, the technological developments and more generally the visibility of the themes subject to the social bubble. These events act as catalysts for the bubble as they increase the quantity of social interactions and investments in a certain technological field. The rational catalysts for the bubble in the renewable energy sector in the years 2000s are detailed in this section.

3.1 Natural catastrophes made global warming dangerous and real

In August 2003 a heat wave over Europe lead to the hottest summer since 1540. The combination of high temperature and the associated drought had a number of societal, economic and environmental impacts. The most important societal consequence was the increase in elderly mortality rates recorded in several European countries with a total of 30,000 to 40,000 estimated excess fatalities (García-Herrera et al. [2010], De Bono et al. [2004]). The economic losses caused by the heat wave have been estimated as exceeding €13 billion (Re [2004]) taking into account costs in hospital stays, ambulance trips, livestock and crop damage, property damage, timber losses, etc. The main environmental impacts were forest fires due to water stress and the massive melting of the Alpine glacier. The link between global warming and the heat wave has been studied and Stott et al. [2004] concludes that human influence has at least doubled the risk of a heat wave with a confidence level over 90%. Whether the heat wave was directly caused by humans or not, the fact is that a particularly hot summer has an influence on the way people think about global warming because both phenomena are related to a massive increase in temperature. Any event with bad consequences that can be rationally linked to global warming increases the awareness about climate change and therefore influences the social bubble surrounding renewable energy.

At the end of August 2005 Hurricane Katrina hit the coast of the Gulf of Mexico in the United States (US), it was one of the biggest hurricanes ever recorded in the US. Katrina had a massive physical impact on the land, affecting more than 20 million hectares (an area approximately the size of Great Britain). The town of New Orleans was the most affected with over 80% of the city being flooded. Katrina directly affected about 1.5 million people and more than 800,000 citizens were forced to live away from their homes (of State [2006]). The huge damages prompted the American Government to allocate more than $110 billion in federal aid. The offshore oil industry was also devastated by Katrina. 115 platforms were totally destroyed and sunk, 52 platforms were significantly damaged and 19 were set adrift. The reduced oil supply due to the non-operational platforms contributed to a rise in the oil price. The particularly intense and devastating hurricane season continued in the following months as Hurricanes Rita and Wilma kept a high level of tension in the US and on the oil price. Emanuel [2005] and Webster et al. [2005]) found a correlation between the sea temperature and hurricane intensity. These scientific studies were broadly relayed by all types of media, which helped people to see causality between global warming and the catastrophe caused by Katrina. This rational thought strengthened the social bubble in renewable energy as people felt that the consequences of global warming were directly impacting their lives in negative and dangerous ways.

To summarize, two major natural catastrophes directly touched two of the richest regions in the world with dramatic consequences, the heat wave in 2003 in Europe and the hurricanes in 2005 in the US. These events were rationally associated to global warming and therefore triggered the social bubble dynamic.

3.2 Scientific knowledge on climate change widely spread

In 2006, the documentary “An inconvenient truth” produced by Davis Guggenheim and featuring Albert Arnold Gore Jr. was presented to the world. The popularity of the former United States Vice President and 2000 presidential candidate combined with successful communication meant the film achieved massive popular success. The documentary’s message is simple: global warming is caused by humans and the consequences are and will be devastating. The arguments to support this message are based on scientific studies and presented by Al Gore. The documentary won many awards including the Oscar for best documentary in 2007 (of Motion Picture Arts and Sciences [2007]). Al Gore gave a brief speech on stage after receiving the Oscar where he urged people from all over the world to solve the climate crisis, which he described as a moral rather than political issue. The impact of this documentary was huge for the social bubble as it successfully popularized the climate change issue and reached a broad audience worldwide.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that climate change is happening and human caused. The communication around this scientific result rose the worldwide awareness and understanding of the climate change problem. In 2007 the Nobel Peace Prize was awarded jointly to the IPCC and to Albert Arnold Gore Jr. “for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change” (Nobel Foundation [2007]).

Scientific knowledge about global warming, its human causes and its consequences were relayed to a very broad population in a very rational way by the documentary film “An inconvenient truth” and the IPCC. This work was broadly recognized and relayed, including by the world famous awards: the Oscars and the Nobel Prize. All this combined was a really strong catalyst for the growth of the social bubble.

3.3 The oil price drives the renewable energy up and down

The influence of the oil price on renewable energy is rational because both compete on the energy market. Renewable energy is an alternative if the oil price shoots up or if oil reserves are exhausted. What was the influence of the oil price on renewable energy prices during the bubble?

Before and during the renewable energy bubble the oil price increased tremendously before crashing. From 2004 to 2006, the oil price increased to exceed \$75 a barrel in mid 2006 and then dropped back to \$60 a barrel by early 2007. The price then rose steeply to \$92 a barrel in October 2007 and continued to rise to the record high of \$147.02 a barrel on 11 July 2008 before dropping very quickly. By October 2008, only three months after the historical peak, the oil price had fallen below \$70 a barrel. This decline in oil price is attributed to slowing demand due to economic decline caused by the global crisis.

The Renewable Energy Industrial Index (RENIXX) tracks the largest companies by market capitalization of freely tradable stocks worldwide in the renewable energy sector and is run by the International Economic Platform for Renewable Energies (IWR). We used the RENIXX to measure the renewable energy sector in order to monitor the bubble. Companies are eligible for the RENIXX if they produce more than 50% of their revenue from wind energy, solar power, bioenergy, geothermal energy, hydropower or the fuel cell sector. The weightings in the companies' indexes are based on their market capitalization. There are two main restrictions on the index composition: no more than 50% of the companies can come from one sector and the maximum weighting of an individual security is 15%. The companies that compose the RENIXX are updated twice a year, taking on board the biggest capitalizations and dropping the companies with the lowest capitalizations.

Figure 1 – The oil price per barrel, on the left scale, and Renewable Energy Industrial Index (RENIXX), on the right scale, (both daily close prices) as a function of time from January 2003 to December 2016

As shown in figure 1, the RENIXX went through two main peaks, one on its own in December 2007 and one simultaneously with the peak of the oil price in June 2008. We suggest that the RENIXX crashed on December 28 2007 when investors realized that renewable energies were much more complicated and expensive to develop than initially thought. But as the oil price was still increasing very quickly and renowned analysts announced that the oil price could reach $200 within the next two years (Menon [2008]), investors readjusted their valuation of the RENIXX companies and pushed the price of the RENIXX back up. This complex dynamic shows that the oil price influences the renewable energy sector, even though they are not directly related. It is also clear that they both have some intrinsic dynamics that do not depend on each other. We conclude that the first peak (December 2007) of the RENIXX bubble was endogenous to the renewable energy sector, whereas the second peak (June 2008) was exogenous and caused by the oil price.
The relation between the two time series during the crash following the second peak is very informative about the influence of the oil price on the RENIXX. The period of the crash is magnified in Figure 2, which shows that both time series followed a very similar tendency.

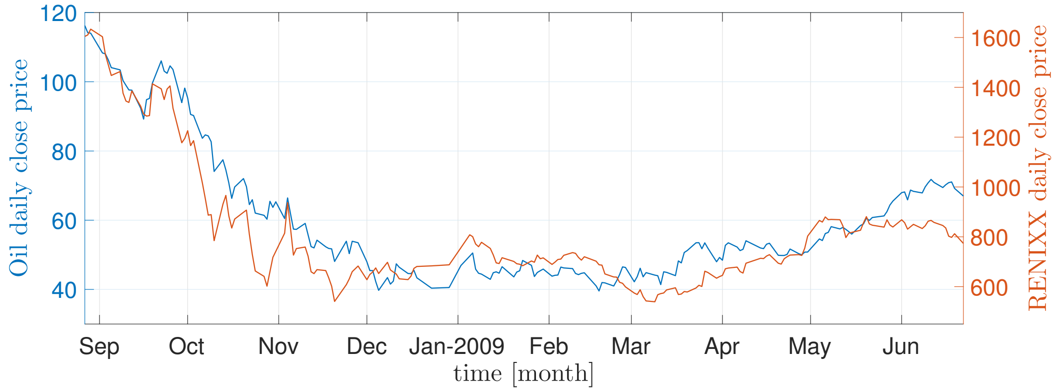


Figure 2 – The oil price per barrel on the left scale, and Renewable Energy Industrial Index (RENIXX) on the right scale, (both daily close prices) as a function of time from 27.08.2008 to 22.06.2009.

The Johansen test for cointegration (Johansen [1995]) was performed on the RENIXX and the oil price with the cointegrated VAR model detailed in equation 1. This test is typically performed when there are intercepts in the cointegration relation and linear trends in the data.

$$\Delta y_t = A(B' y_{t-1} + c_0) + c_1 + \epsilon(t) \tag{1}$$

With y_t being the matrix composed by the two variables (RENIXX, oil price) at time t, A the adjustment speed, B' the cointegrating vector, c_0 and c_1 two constants and $\epsilon(t)$ being the noise residual. The result of the test is clear. It shows that the two time series are clearly cointegrated on a sample of 195 daily prices from 27.08.2008 to 22.06.2009. The null hypothesis is rejected with a p-value of 1%, as the significance level was fixed at 5%. The clear cointegration of the crash supports the analysis that the second peak in the RENIXX was caused by the very high oil price.
Another way to analyse the influence of the oil price on the RENIXX is to express the RENIXX "in currency units" of the oil price, as showed in equation 2, which basically disentangles the RENIXX from the oil price.

$$\text{RENIXX-in-oil(t)} = \frac{\text{RENIXX(t)}}{\text{oil price(t)}} \tag{2}$$

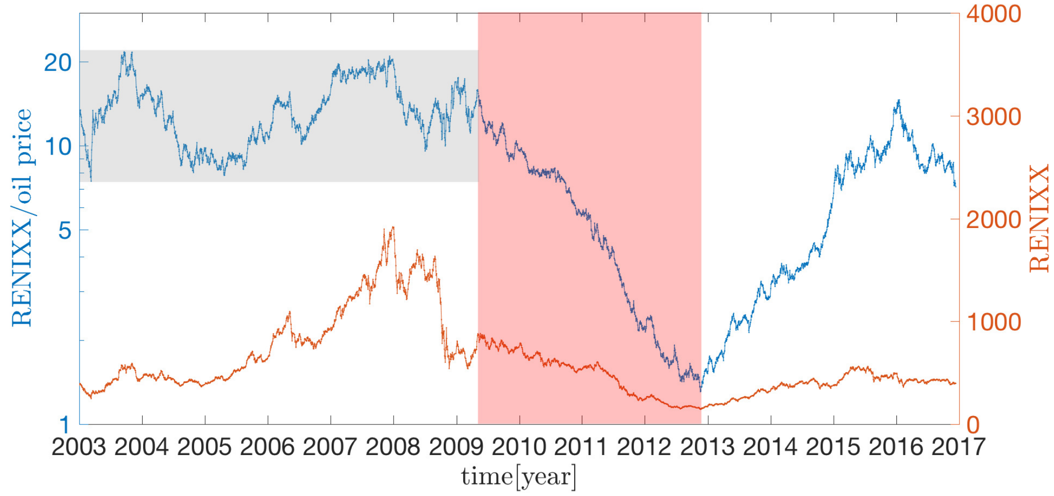


Figure 3 – RENIXX-in-oil(t) defined by equation 2 (in logarithmic scale), on the left scale, and Renewable Energy Industrial Index (RENIXX), on the right scale, (both daily close prices) as a function of time from January 2003 to December 2016. The grey rectangle highlights the period from 2003 to 2009 when the RENIXX was linked to the oil price. The red zone highlights the period from 2009 to 2012 when the RENIXX was decoupled with the oil price and the ratio RENIXX/oil price declined nearly constantly.

The grey rectangle on figure 3 shows that the ratio (RENIXX/oil price) stayed between 8 and 20 from 2003 to 2009, including the entire RENIXX bubble. During this period the market valued both oil and renewable energy in a similar manner with the rational argument that the oil price had a huge influence on the economic viability of substitute energy sources. In 2009 the RENIXX decoupled from the oil price (Alsayegh [2016]) and gained a life on its own when the oil price per barrel was over $100 and the RENIXX was in nearly constant decline. This period is magnified in red in Figure 3 with a nearly constant decline of the ratio (RENIXX/oil price), which went from a value of 20 in December 2007 to 1 by the end of 2012. This decoupling between renewable energy and the oil price was probably a result of investor disappointment towards renewable energy following the burst of the bubble.

4 Irrational exuberance in the bubble

Humans often invest their money based on very complex thoughts and psychological factors. These complex dynamics sometimes give rise to bubbles as the price of the asset does not match with its fundamental value. We study the irrational exuberance surrounding the bubble through an analysis of the RENIXX, which mirrors the investors' beliefs and their valuation of renewable energy technologies.

4.1 The renewable energy sector compared to the global market

The RENIXX, as shown in Figure 4, went through a bubble from 2005 to 2008. The index rose tremendously in 2005 (+62%), 2006 (+45%) and 2007 (+107%), passing from 395 points at the beginning of 2005 to 1918 points at the end of 2007. The index crashed in 2008 (-64%), stabilized in 2009 (+7%) and then decreased in 2010 (-29%), 2011 (-54%) and 2012 (-30%) to attain its lowest level of 145 points on 21.11.2012.

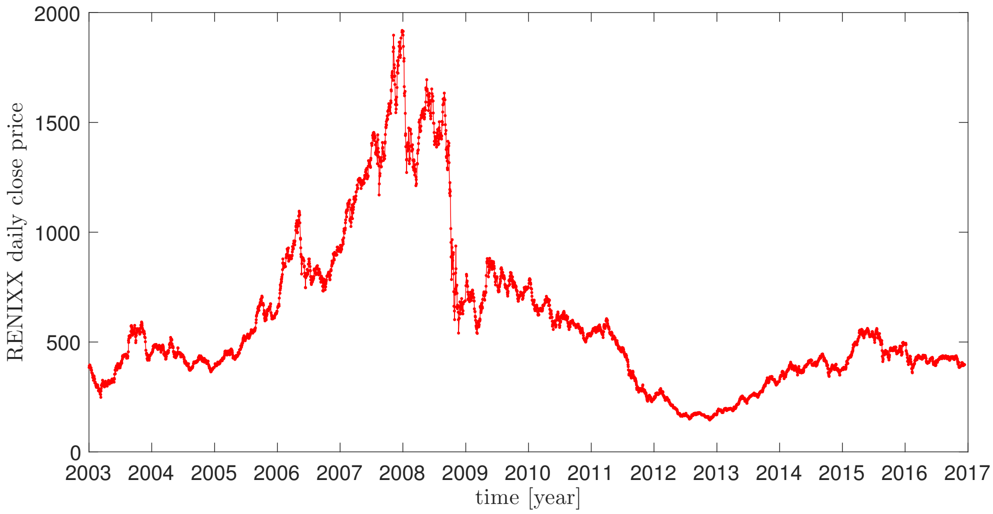


Figure 4 – Renewable Energy Industrial Index (RENIXX) (daily close prices) as a function of time from January 2003 to December 2016

2007 was an extraordinary year for the RENIXX as its price almost continuously increased. It rose by 107.3%, reaching a top high of 1918 points on December 28 2007. Optimism surrounding investments in renewable energy was huge during this period, for example IWR Director Norbert Allnoch said on 5 June 2007: "The industry is enjoying a strong tailwind thanks to the ongoing climate debate. The overall favorable environment for investments in renewable energy technologies continues to improve, especially internationally" IWR [2007b].
The prospects for 2008 were really optimistic according to Allnoch. He predicted that: "Oil and gas prices and climate concerns should continue to drive market trends in 2008" IWR [2008]. But then the RENIXX price crashed for the first time reaching a low of 1221 on 20.3.2008 (-35% since the 28.12.2007) before rising again to reach a second peak on 17.06.2008 of 1652 (+35% since the 20.03.2008). The RENIXX crashed very quickly in the second half of 2008 to finish at 699 points on 30.12.2008 (-58% since the 17.06.2008). Analyzing the situation after 2008, the IWR wrote: "Following the high RENIXX profits in 2006 (+42%) and 2007 (+107%), stock prices collapsed due to the global financial crisis and the price of oil that has plummeted from its all-time high recorded at midyear". The cause of the crash, according to the IWR, was the global financial crisis and the crash of the oil price.

Optimism about the future was still present in January 2009, with Allnoch stating: "2008 was a very difficult year for the international renewable energy industry. However, the current turbulences in the financial and energy markets along with the short-term impact on companies cannot hide the fact that the long-term growth path for renewables remains intact." IWR [2009].
As shown in section 3.3, the oil price had a big influence on the crash of the RENIXX. In 2008, the global market revealed a bubble and a global crash triggered by the real estate bubble in the USA. Was the RENIXX bubble illustrated in Figure 4 fueled by hope and high expectations in the cleantech sector? Or could it be that the RENIXX was actually only driven by the global market?
To disentangle the RENIXX from the global market, the RENIXX is expressed "in currency units" of the Standard & Poor's 500 (S&P500), a stock market index based on the market capitalizations of 500 large companies listed on the NYSE or NASDAQ and used as a global market indicator.

$$\text{RENIXX-in-S\&P500(t)} = \frac{\text{RENIXX(t)}}{\text{S\&P500(t)}} \tag{3}$$

Figure 5 – RENIXX-in-S&P500(t)=RENIXX(t)/S&P500(t) daily close prices (in logarithmic scale) as a function of time from January 2003 to December 2016

Figure 5 shows the ratio from equation 3 in a logarithmic scale in function of time. This ratio increased by a factor of 4.3 (from 0.3 in December 2004 to 1.3 in January 2008) during the rise of the bubble. With the crash of the bubble, the ratio went down to 0.1 in November 2012, which is more than 12 times smaller than at the height of the bubble. The RENIXX over performed the global market for more than three years before underperforming it for four years. This evolution of the "RENIXX in S&P500" confirms that the RENIXX went through a bubble and that it did not follow the global market. The diagnosis of an intrinsic bubble in the renewable energy sector is clear, which confirms the exuberance in this sector during the bubble.

4.2 LPPLS analysis of the RENIXX

Our group defines a bubble as a phenomenon of super-exponential growth. This understanding has been built on in many papers (Johansen et al. [1999], Johansen and Sornette [2010], Sornette [2009], Sornette et al. [2001], Sornette and Zhou [2006], Jiang et al. [2010]). The methodology is based on the hypothesis that positive feedback on the growth rate of a price leads to faster than exponential price growth. The mathematical embodiment is obtained as the expansion of the Log-Periodic Power-Law Singularity (LPPLS) model Filimonov and Sornette [2013]:

$$lnP(t) = A+B(t_c-t)^m+C_1(t_c-t)^m cos(\omega\, ln(t_c-t))+C_2(t_c-t)^m sin(\omega\, ln(t_c-t))+\epsilon(t) \quad (4)$$

Where $P(t)$ is the price of the asset, t is the time, t_c corresponds to the bubble end and $\epsilon(t)$ is a noise residual. $A, B, C_1, C_2, m, \omega$ are all parameters defining this nonlinear equation.

Figure 6 shows clear evidence of a super-exponential growth in the RENIXX from August 2004 to December 2007.

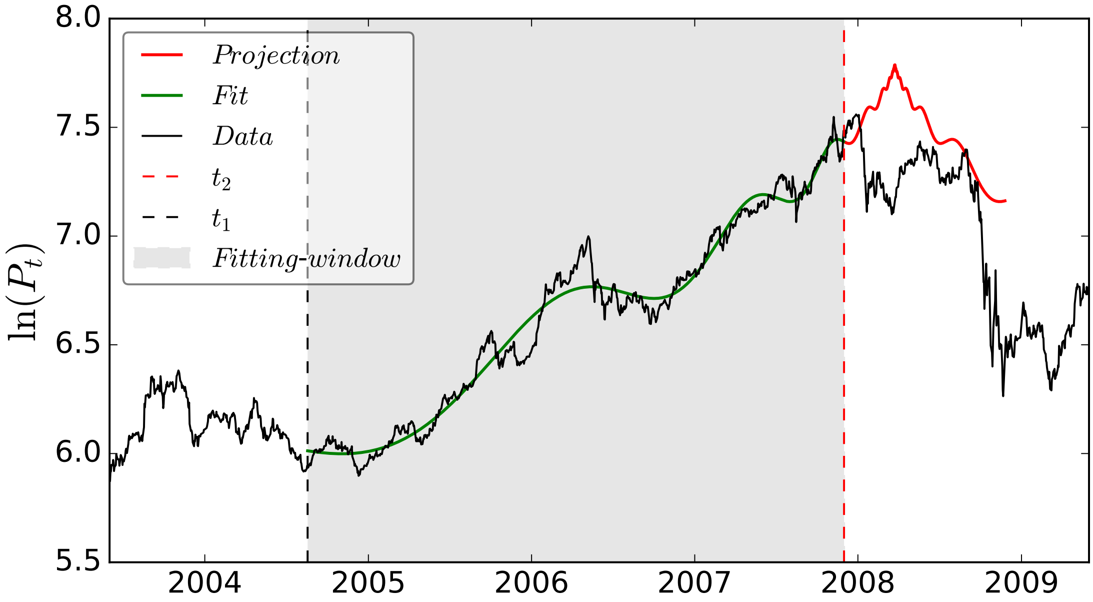
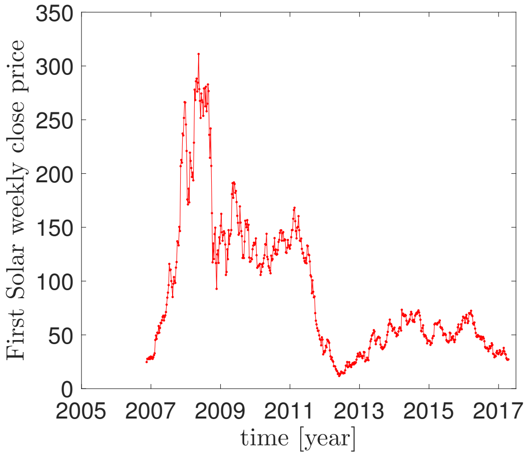


Figure 6 – RENIXX daily prices in logarithmic scale from 2003 to 2009. The oscillating continuous line corresponds to the calibration of equation 4 to the RENIXX with the parameters: $t_c = 113.5$, $A = 2.054$, $B = -0.002$, $C_1 = 0.0003$, $C_2 = -0.0001$, $m = 0.67$, $\omega = 7.56$. The fitting window is given by the two vertical lines from August 2004 to December 2007, over 1200 days. The upward curvature in this log (price) versus time means the price super-exponentially accelerated, matching our definition of a bubble (Sornette [2009]).

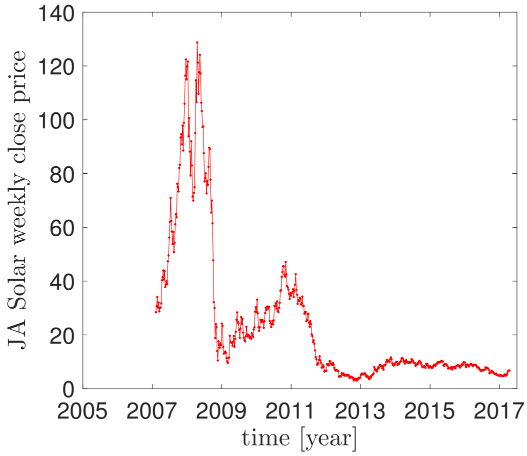
4.3 A look at some individual stock prices

An analysis of individual stock prices gives a more precise and detailed view of the bubble's dynamic. The detailed composition of the index at different times is

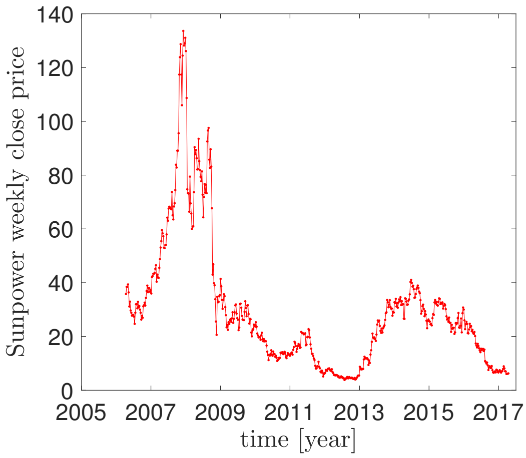
shown in section 8.1. On 1 April 2007, 49.5% of the RENIXX was composed of companies active in the solar PV sector and 35.5% of companies active in wind power. During the bubble, the RENIXX was mainly tracking these two technologies as they represented more than 85% of the index.
Many companies in the solar sector rose tremendously during 2007. The American company First Solar LLC saw the greatest annual progression (+714%), followed by the Chinese JA Solar Co. (+274%), the American Sunpower Co. (251%), the Chinese Yingli Green Energy (+235%), the German companies Solon SE (+204%) and Q-Cells AG (+187%).



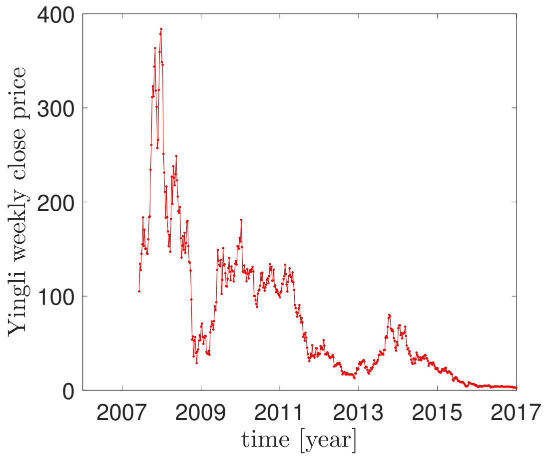
(a) First Solar LLC



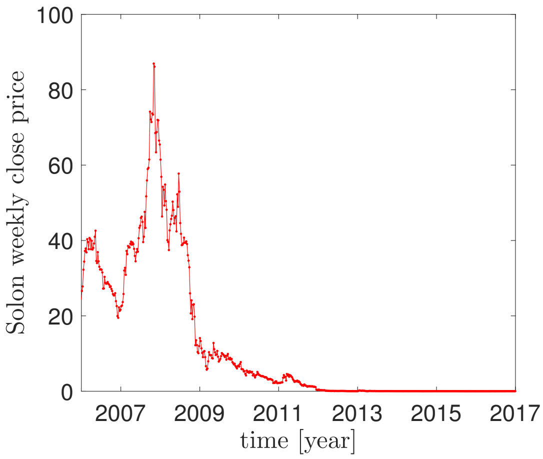
(b) JA Solar Co.



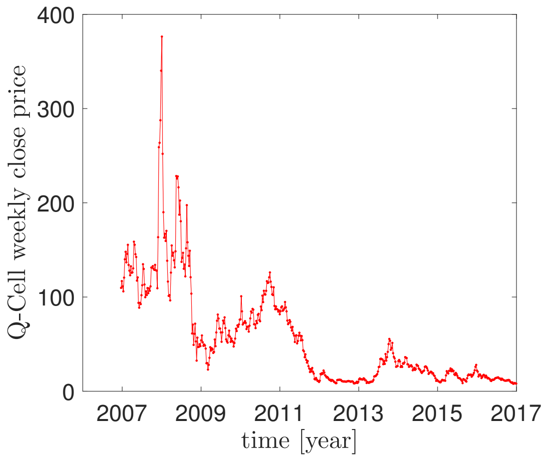
(c) Sunpower Co.



(d) Yingli Green Energy



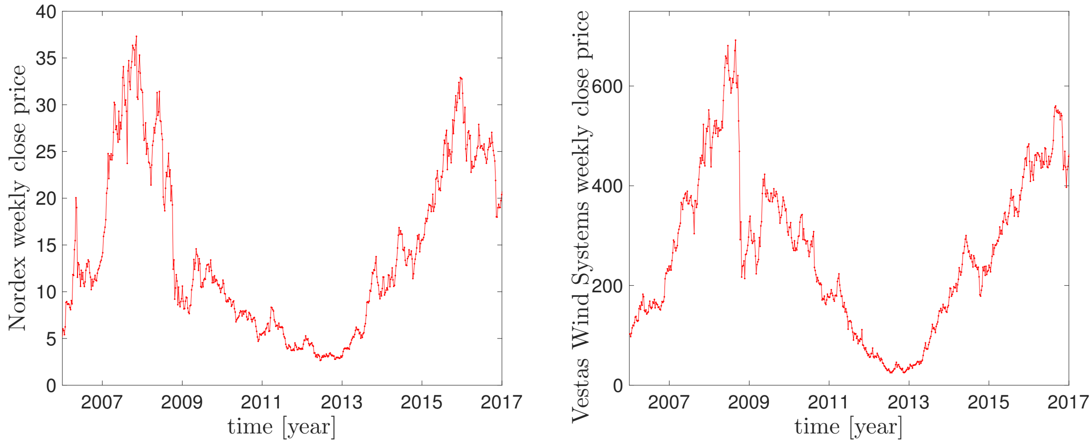
(e) Solon SE



(f) Q-Cells AG

Figure 7 – Weekly prices as a function of time from the six best performing companies working in the solar sector during 2007

The evolution of the price for the six best performing solar companies in 2007, shown in Figure 7, appear to be very similar to each other as the price increased tremendously, peaked by the end of 2007 and then decreased strongly. The long-term trend has also been similar for the six companies since 2012. None of the six companies' stock prices have recovered to a level near to where they were at the peak of the bubble.



(a) Nordex AG

(b) Vestas

Figure 8 – Weekly prices as a function of time from the two best performing companies working in the wind sector in 2007

Among the companies active in wind power, Nordex AG progressed the most (+130%) in 2007, followed by the Danish manufacturer Vestas (+124%) IWR [2008]. The dynamics of their prices was very similar to the solar PV sector until 2012 when they went through the bubble. But as of 2013 the wind power sector took a completely different direction than the solar PV sector. By 2015 the prices from the two companies in the wind power sector began to grow again, reaching a similar level as during the bubble. There are two main hypotheses to explain this rebound in the wind power sector: either wind power technology had matured enough to be marketable and profitable or it entered a new bubble phase peaking in 2015-2016. Section 4, with the support of different time series analyses and the LPPLS model, allows us to conclude that the bubble was clear in the renewable energy sector. External influences exist but the main engine of the bubble was the exuberant hope compared to the fundamental value of these new technologies, especially in the solar PV and wind sectors. This irrational exuberance is typical of all social and financial bubbles.

5 Post-Mortem Analysis

This section provides more detail of the bubble using the data gathered up until today. We look at a few precise measures like the return for private investors, the global installed capacity and the costs or efficiency of renewable energy. These different angles provide key insights to help understand the dynamics both during and after the bubble.

5.1 Clean technologies failed to deliver to private investors

In general, innovators face financial problems between government-supported research and commercialization. Venture capital (VC) investors support risky new businesses by investing in early-stage companies in exchange for an ownership stake of the company. VC's role, in many sectors, is to select the most promising innovators and to finance them in order to bridge the gap between the innovation and commercialization of the product. Which role did VC played in the clean energy bubble? How profitable was the bubble for VC?
VC spent over $25 billion funding clean energy technology (cleantech) start-ups between 2006 and 2011 Gaddy et al. [2017]. The IPOs from Q-Cells AG, SunPower Co. and Suntech Power Holdings Co. Ltd. for more than $100 million each in 2005 attracted a lot of VC in the cleantech sector as they were looking for a new "boom" and new investment opportunities after the crash of the dotcom bubble.

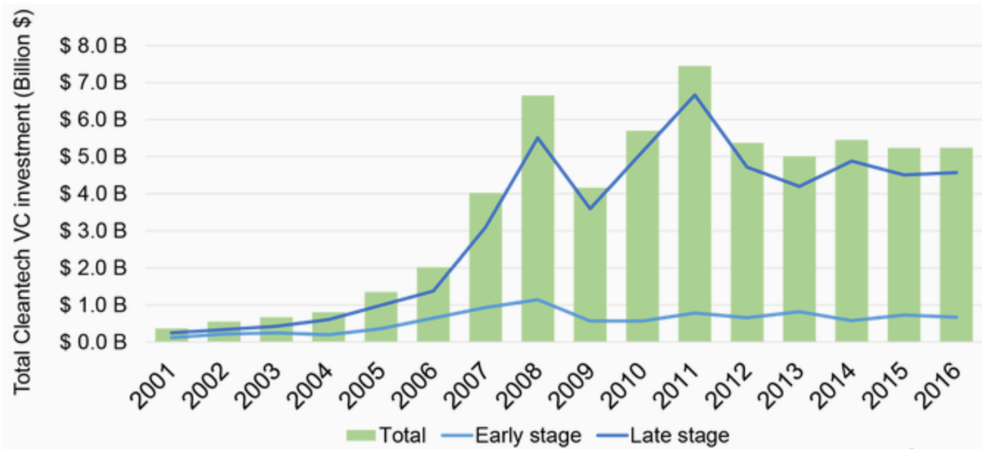


Figure 9 – Figure from Saha and Muro [2017] showing the evolution of VC investment in cleantech companies. The total amount is split into two categories: early stage comprising seed and series A rounds of financing and late stage comprising series B and growth equity rounds.

Figure 9 shows that the VCs only invested in cleantech in a limited manner until 2004. The investments then rose strongly between 2005 and 2008. After the 2008 crisis it took three years to recover, with investments reaching their peak in 2011. Since 2012 investments have remained somewhat constant at around 5 billion per year. After the decrease due to the 2008 crisis, the early stage investments have never recovered their pre-crisis level. In contrast the late stage (series B and growth equity) investments recovered quickly. Since 2008 more than 80% of total VC investments in cleantech were made in mature companies that were near or at profitability (Saha and Muro [2017]).

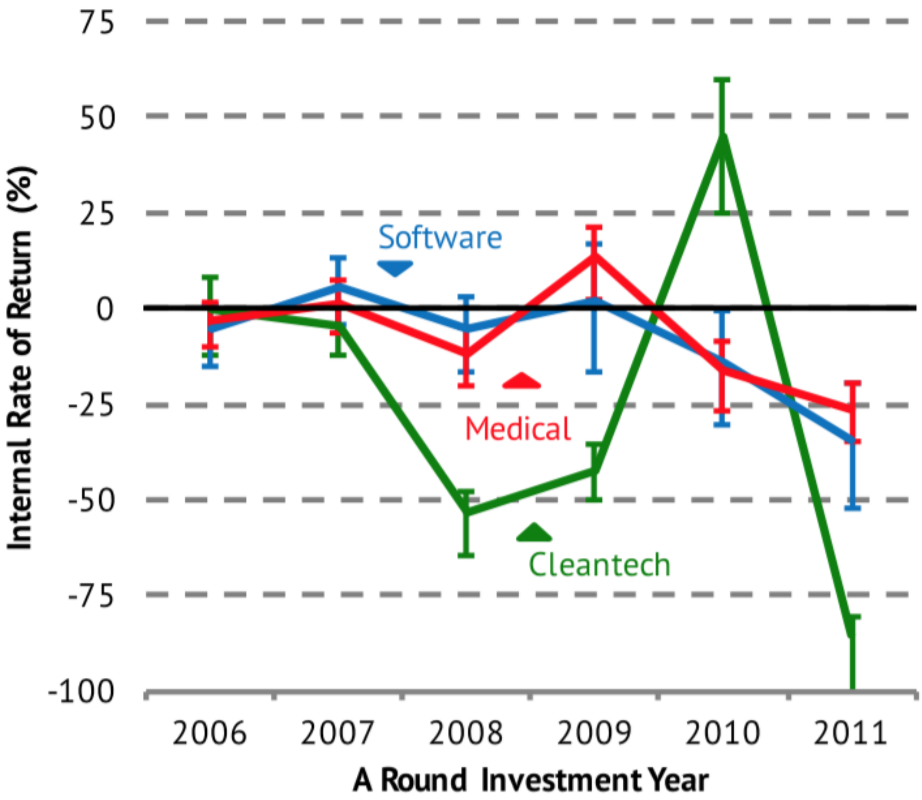


Figure 10 – Figure from Gaddy et al. [2017] showing the evolution of the Internal Rate of Return (IRR) by industry sector in A-round investments from 2006 to 2011. The IRR calculation is made on all investments and evaluates successes and failures. Cleantech yielded negative returns and performed poorly compared to the other sectors in all years except 2010, which was dominated by one deal: Nest.

Between 2006 and 2011 cleantech investment was poorly suited to VC investors as they failed to deliver profit. This can be explained by a combination of many factors. First, the time until commercialization is often too long, VC typically works on a time scale from three to five years, which is too short to bring a product to the market in the renewable energy sector. Second, the capital required to build and scale large factories is huge, it is, for example, significantly higher than in the software industry. Third, the commodity market typically shows thin margins which force companies to scale up massively to make profit. Finally, the large industrial corporations in the commodity industry appear to be much more reluctant to buy small cleantech companies than big corporations in IT or the medical industry, which clearly limits exit possibilities for VC investors. All these reasons help to explain why cleantech failed to yield positive returns to investors, as shown in Figure 10.
VC has continued to invest in cleantech since 2011, but mainly in companies that are less capital intensive and are near to commercialization. This strategy makes sense as it helps avoid the "Valley of Death", which refers to companies needing high capital intensity with a high technological risk (Gosh and Nanda [2010]). Saha and Muro [2017] studied the distribution of investments in the different clean technology sectors from 2011 to 2016 and concluded that VC investments had been concen-

trated in a few technology areas. The biggest one being energy efficiency (20.8%) followed by transportation (20.6%). The most successful example was Nest, which was founded in 2010 and acquired by google in 2014 for $3.2 billion Tilley [2014]. Nest first developed and sold a learning thermostat that optimizes heating and cooling in homes. It is often seen as a cleantech company as it helps to save energy, however it is mainly a company that develops and applies the latest IT and engineering technologies to heat and cool houses. Clean technologies like hardware, materials, chemical or manufacturing processes, like solar panels or wind electricity production, tend to have much more complicated and expensive development phases than software, meaning they generally need more time and investment before they create value for investors.

Following this analysis, it seems clear that up to 2011 VC made some mistakes in the way it invested in clean technologies with regards to investments structures. There was significant hype surrounding cleantech investments in the VC industry from 2003 to 2008. After the burst of the dotcom bubble in 2000 cleantechs were seen as one of the growing sectors that would change the world and bring huge profit. After the burst of the cleantech bubble, VC adapted its strategy towards shorter term investments in the cleantech sector and has kept to this strategy since 2011.

5.2 Clean technologies are too expensive compared to traditional ones

The cost for the end customer is a key parameter for governments in making decisions about their nations' energy portfolios. Logically, the cheaper the energy delivered by a technology is, the more chance it has of being implemented. There are often forecasts from experts about the future price of a new energy source and the consequences for other energy sources (for example: Shankleman and Warren [2017]). Costs for any energy supply technology can be split into different phases like the development of the technology, the building, the running and decommission of the facility. For each particular phase, the price for the end customer can be reduced through state support (tax reduction, subsidies, etc.) or delayed using credit or other financial instruments like decommissioning funds paid in advanced.

A recent criticism of clean technology is that it is too expensive compared to traditional technologies, mainly fossil fuels, nuclear power plants and dams. It is true that clean technologies are more expensive. A report by the Council of European Energy Regulators shows that the weighted average subsidy paid to renewable energy in the EU 26 in 2015 was 110 €/MWh of European Energy Regulators [CEER]. The minimum was in Norway with 16 €/MWh and the maximum in the Czech Republic with 184€/MWh. These subsidies need to be compared to the wholesale price of electricity in Europe, which lies between 40€/MWh and 60€/MWh. It is interesting to note that the proportion of gross electricity produced by renewable energy sources ranged from 1% in Norway to 62% in Denmark with an average in the EU26 of 16% in 2014.

The cost of clean technologies needs to be competitive with traditional energy sources so that they can be broadly implemented. One way to achieve price competitiveness between clean technologies and traditional energy sources would be to invest massively in research and development in order to improve the cost efficiency of clean technologies. An alternative way to achieve price competitiveness would be to wait until traditional sources become rare enough so that their prices increase due to limited supply compared to the demand.

5.3 Clean technologies are less efficient compared to traditional ones

A possibility for analyzing the efficiency of an energy production technology is to look at the ratio of Energy Return over Energy Invested (ERoEI), which is a measure of the amount of energy a certain technology provides for a given amount of energy invested.

A challenge in interpreting the ERoEI measure is that there are two different types of studies, conceptual and experimental. The conceptual studies are conducted without measuring proper electricity or energy inputs and outputs, rather, for example, they take the radiation from the sun as a theoretical input to calculate the efficiency a solar panel. The experimental studies measure the energy inputs and outputs as precisely as possible. There are also many studies that combine both approaches. Another challenge in achieving consistency in ERoEI results is that the technologies and the locations of these studies vary considerably. Furthermore, some studies take the entire life cycle of the technology studied into account (mining, production, transport, exploitation, decommissioning, recycling, etc.) while others only consider a part of the life cycle. All these elements and the different methodologies used make it really difficult to compare studies. This is why we chose to use the results of many studies to compare to different technologies.

Murphy and Hall [2010] give a broad review of the foremost empirical efforts regarding ERoEi. They also give a detailed list of ERoEI for various energy resources for the United States and perform a comparison of the most common resources. The evolution of the ERoEI of oil is very interesting as the ratio has been diminishing over time as oil reserves are becoming increasingly difficult to exploit. For example, the first oil wells were just under the Earth's surface in accessible areas whereas newer wells are mostly oil sands or offshore platforms that dril deep under the sea. In the US, the ERoEI for oil evolved from over 100 in the 1930s to 28 in the 1970s and to around 9 today.

The ERoEI for solar PV is believed to be around 7 (Raugei et al. [2017]). Nevertheless, in 2016 Ferroni and Hopkirk [2016] calculated a controverted ERoEI for solar PV in Germany and Switzerland. They took the entire life cycle of a photovoltaic solar panel into account. The result obtained was a ratio of 0.82 with an error of $\pm 15\%$, which would mean that PV technologies are not a source of net energy in continental Europe, but rather a source of net energy loss. This result was strongly criticized by Raugei et al. [2017], who argues that many fundamental mistakes were made, including the use of outdated information, invalid assumptions on PV specifications and the choice of boundaries. Raugei et al. [2017] conclude with an ERoEI of 7-8 for solar PV.

More studies have been conducted for the wind industry than for solar. Kubiszewski et al. [2010] performed a meta-analysis taking into account 119 wind turbines, sub-

ject of 50 different analyses from 1977 to 2007. There are still big differences between the analyses, mainly due to assumptions regarding the operating characteristics of wind turbines, for example their assumed lifetime. The average ERoEI for all studies (operational and conceptual) is 25.2 with a standard deviation of 22.3. This analysis really shows that the ERoEI depends on the exact condition in which a wind turbine is installed, which explains the huge standard deviation.
After comparing the ERoEI, it seems clear that wind power is generally more efficient than solar PV. However, if there is too little wind or space to install windmills, solar PV can be more efficient in some places. To date, renewable energy has not been widely adopted and one of the key factors to improve is its efficiency. Ideally the ERoEI of cleantech should be bigger than the ERoEI of other technologies. Efficiency is key in the adoption of a technology but other factors like the price, production capacity, transportability, storage and the convenience of use are also key determiners. For example, an ERoEi below 1 can clearly make sense for use in a difficult environment like in space, remote mountains or cities full of smog.

5.4 The worldwide installed clean power capacity boomed over 10 years

The technological progress and increased awareness about global warming that developed during the bubble are now potentially fostering the installation of new renewable energy sources. In the past costly infrastructure has been developed during bubbles. One of the most famous examples is the railway infrastructure in Britain that was developed around 1830 with the support of the "Railway mania" bubble. How did the global installed capacity of renewable electricity evolve both during and after the bubble?

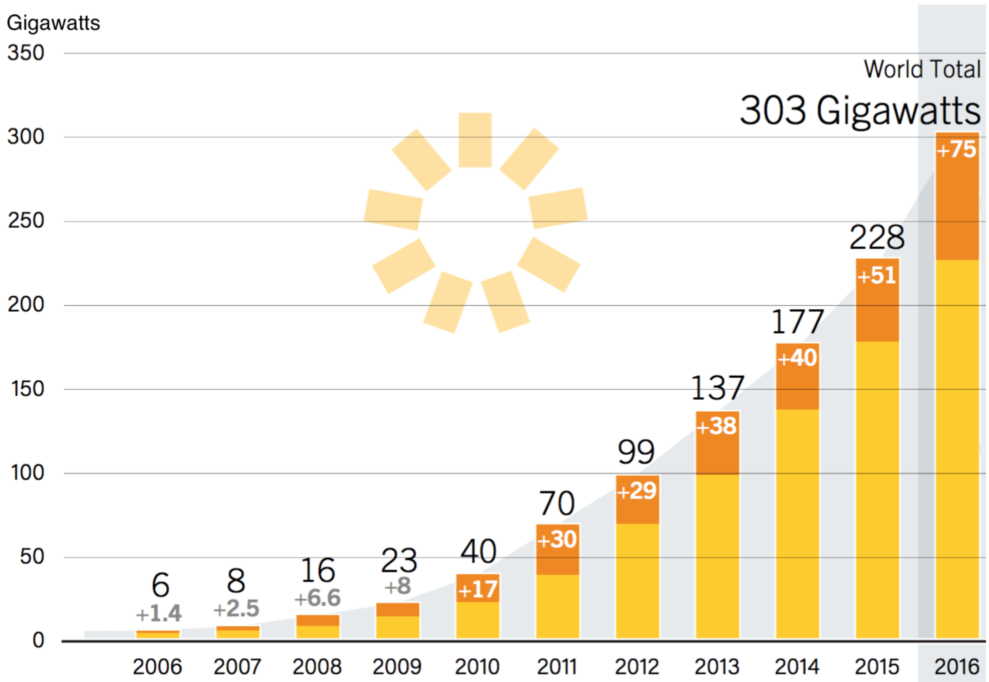


Figure 11 – Figure from Sawin et al. [2017] showing the solar PV global capacity and annual additions from 2006 to 2016. The global capacity is the theoretical total power produced with ideal conditions. The power produced is therefore lower than the global capacity. The annual additions are gross additions, as the decommissionings are taken into account.

The solar PV went from a global capacity of 6 installed gigawatts in 2006 to 303 installed gigawatts in 2016 globally, the increase of a factor 50 over 10 years is significant. Furthermore, the additional installed capacity has been increasing every year since 2006, excepting in 2012 where it stayed nearly constant compared to 2011. In 2016, at least 17 countries had enough solar PV capacity to meet 2% or more of their electricity demand, the leading countries being Honduras (9.8%), Italy (7.3%), Greece (7.2%) and Germany (6.4%) (Sawin et al. [2017]).

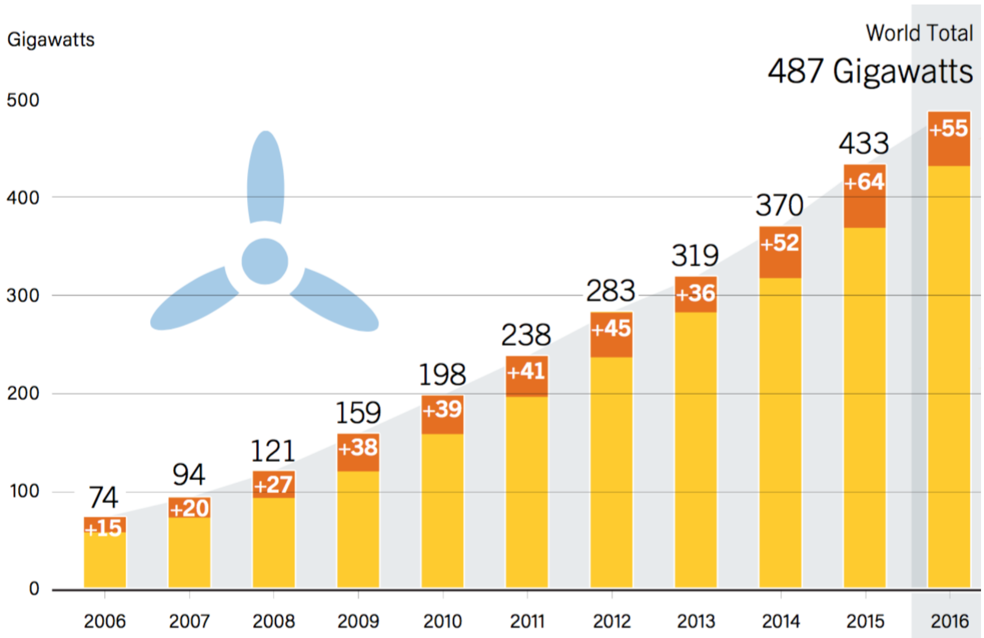


Figure 12 – Figure from Sawin et al. [2017] showing the global wind power capacity and annual additions from 2006 to 2016. The global capacity is the theoretical total power produced with ideal conditions. The power produced is therefore lower than the global capacity. The annual additions are gross additions, as the decommissionings are taken into account.

Global wind power capacity has progressed by a factor 6.5 from 2006 to 2016 going from 74 to 487 installed gigawatts. The increase of the global installed capacity is slower than in the solar PV sector but is also significant. By the end of 2016 more than 90 countries had seen commercial activity surrounding wind power and at least 24 countries met 5% or more of their annual electricity demand with it. Moreover, the wind sector is now developing strongly towards offshore wind power with a global installed capacity of 14 gigawatts in 2016 (Sawin et al. [2017]).
The global capacity from combined solar PV and wind power increased by a factor of 10 between 2006 and 2016. The bubble certainly played a huge role in this massive development by attracting huge investments, encouraging technological progress and increasing awareness about global warming. However, the share of electricity produced by solar PV and wind power remains small compared to other electricity sources: around 4% of the global electricity production. Concretely, solar PV or wind power produced around 1,000 terawatt hours (TWh) in 2015 compared to a global electricity production of about 24,000 TWh (Petroleum [2017], Administration [2017]).

6 The power of government funding

William Janeway describes innovation as the result of a complex "three-player game" between the state, financial capitalists and entrepreneurs Janeway [2012]. History has shown that strategic choices made by governments to invest heavily in a particular technological sector can be an extraordinary tool for spurring innovation and growth. For example, the US managed to take a man to the moon (Gisler and Sornette [2009]) and to read the human genome using this strategy (Gisler et al. [2011]). It not only set ambitious goals within one sector, but also created the Defense Advanced Research Projects Agency (DARPA) in 1957 with the mission of ensuring that the US avoided any technological surprise after the Soviets launched the first satellite (Sputnik 1). DARPA, with an annual budget of $3 billion, plays in key role in the defense sector, but it also makes technological inventions which the entire population benefit from.

As Mariana Mazzucato argues in Mazzucato [2013], the role of VC in innovation has been oversold while the crucial role played by governments has not been properly recognized. For example, many key technologies that enabled the iPhone to revolutionize communication are the result of research carried out in public research centers and labs including DARPA like liquid-crystal displays (LCD), global positioning systems (GPS), multi touch screens or artificial intelligence with a voice-user interface program. Apple has been extremely successful in integrating all of these newly developed technologies in well-designed and user-friendly products. The example of the iPhone clearly shows how the private and public sectors can work together in a complementary way to develop an innovative, technological and marketable product.

6.1 The high impact countries in the renewable energy sector

A few large and powerful countries had a huge influence on the bubble through their political decisions. Below is a short summary of the actions undertaken by four of the most influential countries in the renewable energy industry.

Germany has been a leader in the renewable energy sector for about 20 years. In 1999 a program to support PV solar panels was launched with the goal of installing PV on 100,000 roofs. Through government subsidies and massive orders, the German Government played a huge role in developing German and international companies in the wind and PV sectors. In 2010 the German Government set the goal of moving away from fossil fuels and abandoning nuclear power. The program to achieve this ambitious challenge is called "Energiewende" - energy transformation. The transition is based on implementing renewable energy supply, mainly wind power and solar PV, as the phase-out of the nuclear reactors should be completed by 2022. In 2016, 34% of the German electricity was produced by renewable sources Burger [2017]. Germany managed to reduce its GHG emissions by 27% from 1990 to 2011 and has the goal to reduce its GHG emissions by 55% by 2030 Buchan [2012]. The massive government support of renewable energy in Germany, enabled by the country's strong economy and the population's support for relatively progressive environmental policy, played a key role in the RENIXX bubble, with Germany providing not only subsidies but also huge orders to the wind and solar industry.

The US also played an important role on the renewable energy market. On the 8 August 2005, the then US President George W. Bush signed the Energy Policy Act (Congress [2005]). The first line of the document clearly states its goal: "To ensure jobs for our future with secure, affordable, and reliable energy". Major provisions including tax incentives to encourage domestic energy production were enforced. New efficiency standards were established in many fields including in residential and commercial products. Another major purpose was to increase the production and use of renewable energy. For example, new tax credit for residential investments in solar power and fuel cell systems or an increase in credit for commercial solar installations was offered. Moreover, the renewable electricity production credit and the requirement for the renewable energy purchase by the government were increased. This law was a big turn towards renewable energy in US Energy Policy. In 2007 the US Congress established the Advanced Research Projects-Energy (ARPA-E) modeled on the successful DARPA., ARPA-E funded at $400 million as part as the economic stimulus package has funded over 400 potentially transformational energy technology projects since 2009. (ARPA-E [2017]).

In 2007 China became the world's largest producer of solar PV. Many policy programs since the mid 1990s have supported the low-carbon transition within China, supporting the solar PV industry Zhang et al. [2014]. Armed with tens of billions in loans from the Chinese Government and the China Development Bank, Chinese companies deeply disrupted the global cleantech market by dropping prices Fehrenbacher [2015]. Recently China has started to tackle its massive air pollution crisis and its strategy is to close coal power plants and open huge solar PV facilities to produce electricity. Moreover, the Chinese Government wants to increase its electricity production to support its economic growth Lacey [2011].

Denmark is the leading producer of wind power (Mazzucato [2013]). Government policies have a huge influence on the development of clean technologies and it is often hard to convert government-funded R&D into commercial products. This was successfully done in Denmark when Vesta purchased patents generated by the Danish research program. Then Vesta developed large-scale wind power generators. To become marketable, these products were encouraged by tax credits that were then phased out over a decade. This helped to launch the domestic market for wind energy as the export market was also growing. This private-public collaboration allowed Vesta to become one of the leading companies in the wind power sector worldwide.

In short, these four countries played a huge role in the development of the social bubble by encouraging renewable energy production. The role of each country depends on many factors like the geographic environment, political choices and laws. The combination of these factors shapes actions which are enforced though many measures like subsidies, tax reduction, federal orders, research credit and construction authorization.

6.2 Learn from the past: the "true history" of Silicon Valley

There is a common belief that Silicon Valley started with the personal computer but the true origin of the most innovative place on earth is different and actually goes back to the Second World War (WW2) as explained in detail by Blank [2016]. The Allies planned to defeat the Germans by destroying their critical infrastructure with bombs dropped from planes. In contrast, the German Air defense system, the most sophisticated in the world at the time, aimed to destroy the Allies' planes flying from England towards Germany. From 1942, the German goal was to make the strategic bombing too painful for the Allies to continue. The brand-new radars and electronic systems were positioned on the ground (fixed and mobile) and in the German airplanes. The aim was to localize the Allies' planes before they were over German soil and destroy them before they managed to bomb their target. Using this system, the Germans managed to destroy between 4% and 20% of the Allies' planes per mission. The biggest loss for the Allies was actually the pilot who needed years of training, and not the plane, which could be produced relatively quickly in a factory.

The Harvard Radio Research Lab (HRRL), with 800 workers, was secretly founded in 1942 to understand and shut down the German's radar system. In 12 months, the lab invented planes which contained no bomb but equipment to analyze all German signals. Initially the Allies used very archaic methods like reflecting the radars' signal using aluminum foil, throwing 46,000 foil sheets toward German planes. This was carried out in July 1943 and the Allies destroyed Hamburg as the German radar system was not working because the waves were reflected by the aluminum foil. However this mechanical method only worked once as it used 3/4 of the US's aluminum foil reserves. The war was taking place in the air and on the ground but also in the laboratory, where scientists sought to develop the best electronic products. The developments made at HRRL were key for the Allies in winning the war.

WW2 initiated a big change in the relationship between militaries and universities as militaries began to directly fund some universities to complement their R&D programs. Frederik Terman, director of the HRRL and originally from California, set up his own lab in the Stanford School of Physical Sciences in 1945 to research microwaves with 11 key members of the HRRL. The US military approached Terman in 1949 and doubled the electronic lab at Stanford at the beginning of the Cold War. The goal was the same as during WW2, to understand the enemy's electronic system and beat it. The major challenge was that the US planes could not fly over the USSR, so they flew around the borders to gather some signals to then analyze. One of their challenges was to force the Soviet radars to be turned on without starting a hot war. The ultimate altitude to analyze the waves from was space, and the first satellite was launched in 1960. As the race for space played a key role in the Cold War, Silicon Valley was developing the systems for these satellites and acquired valuable expertise in this domain too.

Silicon Valley begun to change in 1955 as Terman encouraged his students to leave university and his lab to create their own companies. The valley became a "Microwave Valley" with the government, including CIA and NSA, being the biggest client of many private companies. The military was funding entrepreneurs to develop and produce technological systems and products for the Cold War. At that time, the main motivation was not profit but winning the technological battle against the USSR.

William Shockley, known as the other "founder" of Silicon Valley, invented the transistor and had a military background in weapon R&D. He founded Intel and 65 other chip companies, all involved in semiconductors, significantly helping to implement new technologies and an entrepreneurial spirit into the Valley.

Today the Valley is full of private capital and military financed companies are very few. How did the private investors arrive in Silicon Valley when they were mainly based on the East Coast of the US? In 1955, the first companies went public, which attracted the first VC to Silicon Valley. Before 1973 venture capitalism was very small as defense budgets had primarily supported all companies but everything changed in 1979 and VC exploded because the government decided two things:

- Taxes were reduced on capital gains (amount of tax on stock profit) from 50% to 28%;
- Pension funds were allowed to invest up to 10% in VC

In the following years, the amount of money coming from VC jumped by a factor of ten, which pushed the development of the Valley. As the Cold War ended, the main goal in Silicon Valley is to make profit.
This brief history of Silicon Valley, probably the most innovative place in the world, clearly shows the influence of the American Government in its development. The influence of wars is immense as they prompted the US to invest in new technologies in order to win. Also, the legal framework needed to be adapted to create the right context so that private capitalists could take on the role of providing funding.

6.3 Lessons for today

According to us governments should play a big role in choosing a clear direction for investments in order to help protect humanity against the threats from the changing environment. To do so, we believe that governments should have a better understanding of innovation and technological cycles, including social bubbles.
More precisely, insightful lessons can be taken from the study of the social and financial bubble in the renewable energy sector from 2005 to 2008. Understanding the role of each actor and the influence of the oil price and the global market on the bubble is a very good base from which to plan the next government actions to support clean technologies.
Governments could also learn important lessons from the “true history” of Silicon Valley. Surprisingly, Silicon Valley emerged from federal investments caused by wars and not in the garage of brilliant students. The creation of a “Green Valley” with a combination of a new social bubble in the renewable energy sector could potentially be an effective way to tackle the problem that humanity faces with global warming and climate change.

7 Synthesis

This analysis of the social bubble in the renewable energy sector from 2005 to 2008 allowed us to make many key findings. First the bubble in the renewable energy sector, mainly in the solar PV and the wind power sectors, was real. The beliefs towards these technologies went through a massive exuberance as the value given to them was far from their fundamental value. The signal is clear as the RENIXX over performed the global market for more than three years before underperforming it for four years. Second, the influence of the oil price on the renewable energy sector followed two different dynamics. From 2003 to 2009, the RENIXX was valued in a similar way to the oil price. From 2009 to 2012, the dynamic changed and the RENIXX gained a life on its own after the bubble burst. Third, the bubble was triggered by catalysts like natural disasters that made global warming become truly dangerous, even for the richest countries in the world. Fourth, the complex interaction between governments, private investors and entrepreneurs is better understood. For example, we learned that VC had been investing massively in cleantech since 2005, playing a large role in the creation and perpetuation of bubble. The return on investment was negative, which forced VC to adapt its investment structure and strategy to this new type of technology. Governments also played a huge role in the bubble by deciding to support these technologies through subsidies, tax exemptions and by placing huge orders. Fifth, renewable energy, if to achieve widespread adoption, needs to be more efficient and cheaper in order to become a real alternative to fossil fuels and traditional energy sources. Finally, the installed capacity in solar PV and wind power increased massively since the bubble began. Alongside the knowledge developed, this infrastructure is a strong asset for the future.

The parallel between the challenges caused by global warming and the creation of Silicon Valley also provides a number of insights. The last massive technological breakthrough happened after strategic and sustained government support due to massive threats caused by wars. Governments should, according to us, play a much bigger role than they do today in order to create a "Green Valley" that could develop the technological breakthrough needed to solve the threats caused by climate change.

To continue this work, and in order to better understand innovation in the renewable energy sector, we would place focus on two different approaches. The first approach would be to conduct a precise study to understand why solar PV and wind power followed different paths following the burst of the bubble. This study would be useful to understand in a more detailed manner what allowed one sector to recover successfully and not the other. The second approach would be to study the history of green innovation over the last century in order to have a deeper understanding of the links between technological breakthrough, governments' actions, natural catastrophes and popular opinion. This long-term understanding would help to better understand the next innovation cycle in the renewable energy sector in order to make it more successful than the previous ones.

8 Appendices

8.1 Detailed composition of the RENIXX

Company	Country	Sector	Rank
Vestas	Denmark	Wind power	1
Gamesa Group Tecnologica S.A.	Spain	Wind power	2
SolarWorld AG	Germany	Solar energy	3
Q-Cells AG	Germany	Solar energy	4
Suntech Power Holdings Co. Ltd.	China	Solar energy	5
VeraSun Energy Co.	USA	Biofuels	6
Renewable Energy Corporation	Norway	Solar energy	7
Conergy	Germany	Solar energy	8
Energy Conversion Devices Inc.	USA	Solar energy, Fuel cells	9
Evergreen Solar Inc.	USA	Solar energy	10
Pacific Ethanol Inc.	USA	Biofuels	11
Nordex AG	Germany	Wind energy	12
Canadian Hydro Developers Inc.	Canada	Hydropower	13
Ballard Power Systems Inc.	USA	Fuel cells	14
FuelCell Energy Inc.	USA	Fuel cells	15

Table 1 – Composition of the RENIXX from 03.07.2006 to 01.01.2007. Each company is listed with the country it is based in and its main sector of activity, the ranking is according to the weighting on the RENIXX on 03.07.2006 (IWR [2006]).

In the second half of 2006, from the table 1, two companies from the wind sector had the biggest weighting in the index and the solar sector had the largest number of companies (7 out of 15 companies).
On 2 January 2017 the number of companies increased from 15 to 20. “The companies’ increased stock exchange capitalization has made it possible to extend the basis of RENIXX World”, explained IWR Director Dr. Norbert Allnoch. (IWR [2007c])

Company	**Country**	**Sector**	**Weighting 01.04.2007**
Vestas	Denmark	Wind	15.00%
Gamesa Group Tecnologica S.A.	Spain	Wind	14.30%
Nordex AG	Germany	Wind	3.51%
*Repower Systems AG	Germany	Wind	2.67%
Q-Cells AG	Germany	Solar	11.56%
Suntech Power Holdings Co. Ltd.	China	Solar	8.82%
SolarWorld AG	Germany	Solar	7.71%
Renewable Energy Corporation	Norway	Solar	7.43%
*First Solar LLC	USA	Solar	4.72%
Conergy	Germany	Solar	4.48%
*SunPower Co.	USA	Solar	3.41%
Evergreen Solar Inc.	USA	Solar	1.43%
VeraSun Energy Co.	USA	Bioethanol	2.26%
Pacific Ethanol Inc.	USA	Bioethanol	1.85%
*Verbio Vereinigte BioEnergie AG	Germany	Bioethanol	0.59%
Ballard Power Systems Inc.	Canada	Fuel Cell	1.48%
FuelCell Energy Inc.	USA	Fuel Cell	1.28%
Canadian Hydro Developers Inc.	Canada	Hydropower	2.00%
Energy Conversion Devices Inc.	USA	Batteries	3.60%
*Ormat Technologies Inc.	USA	Geothermal	1.89%

Table 2 – Composition of the RENIXX from 02.01.2007 to 30.06.2017. Each company is listed with the country it is based in, its the main sector of activity and its weighting in % of the RENIXX index on 01.04.2007 (IWR [2007c]). The 5 newly added companies in the RENIXX are marked with a *.

On 1 July 2007 the RENIXX went from taking the 20 to the 30 biggest capitalizations of the renewable energy sector. 11 companies were added on that day including 6 companies active in the solar energy sector. Verbio Vereinigte BioEnergie (Bioethanol) was removed from the index as its market capitalization had become smaller than the companies added (IWR [2007a].)

Company	Country	Sector
Vestas	Denmark	Wind
Gamesa Group Tecnologica S.A.	Spain	Wind
Nordex AG	Germany	Wind
Repower Systems AG	Germany	Wind
Q-Cells AG	Germany	Solar
Suntech Power Holdings Co. Ltd.	China	Solar
SolarWorld AG	Germany	Solar
Renewable Energy Corporation	Norway	Solar
First Solar LLC	USA	Solar
Conergy	Germany	Solar
Sunpower Co.	USA	Solar
Evergreen Solar Inc.	USA	Solar
*Yingli Green Energy	China	Solar
*Solon SE	Germany	Solar
*ReneSola	China	Solar
*LDK Solar Co.	China	Solar
*JA Solar Co.	China	Solar
*Ersol	Germany	Solar
VeraSun Energy Co.	USA	Bioethanol
Pacific Ethanol Inc.	USA	Bioethanol
*Aventine	USA	Bioefuels
*Schmack	Germany	Biogas
Ballard Power Systems Inc.	Canada	Fuel Cell
FuelCell Energy Inc.	USA	Fuel Cell
*Plug Power	USA	Fuel Cell
Canadian Hydro Developers Inc.	Canada	Hydropower
Energy Conversion Devices Inc.	USA	Batteries
Ormat Technologies Inc.	USA	Geothermal
*Theolia	France	Renewable supplier
*EDF Energies nouvelles	France	Renewable supplier

Table 3 – Composition of the RENIXX from 01.07.2007 to 31.12.2007. Each company is listed with the country it is based in and its main sector of activity (IWR [2007a]). The 11 newly added companies in the RENIXX are marked with a *.

The RENIXX composition was modified at the end of 2007/beginning of 2008 as part of a regular review of market capitalization with six companies being replaced: Iberdrola Renovables (wind, Spain), Clipper (wind, Britian-USA), Motech (Solar, Taiwan), Solarfun Power (solar, China), Meyer Burger (solar, Switzerland), and Schmack Biogas (biogas, Germany) were added to the RENIXX while Conergy (solar, Germany), Ersol (solar, Germany), and Renesola (solar, USA), Aventine (bioethanol, USA), EnviTec Biogas (biogas, Germany) and Plug Power (Fuel cell, USA) were dropped.

8.2 New type of investors for clean technology

As of 2017 the combination of public and private investments has failed to bring renewable energy production technologies to a marketable level on a very large scale. As shown in section 5.1, VC did not profit from the bubble and consequently it adapted its investment strategy for the renewable energy sector. Below is a list of 3 innovative private investment structures that have been created recently, taking into account the difficulties of the private sector during the bubble.
The European Union and 22 countries engaged in Mission Innovation (MI) to dramatically accelerate global clean energy innovation (Innovation [2015]). Participating countries committed to double their governments' clean energy R&D investments over five years, while encouraging greater levels of private sector investment. MI was announced in Paris in November 2015 and is planned to be enforced by 2021, amounting to a combined $30 billion per year.
The Breakthrough Energy Coalition, a group of wealthy investors led by Bill Gates, announced $1 billion of patient investments in new energy innovations (Condliffe [2016]). The aim is to bring innovations, funded by governments, from start-up to bankability. The investment goals are set to 20 years, which is probably a realistic time frame to develop a marketable product in the clean energy technology sector. Five specific areas of investments have been defined by the coalition: electricity, transportation, agriculture, manufacturing and buildings.
In the technology sector SoftBank and Masayoshi Son announced the opening of a $100 billion fund to invest in new technologies like artificial intelligence, connected devices and satellites (Elstrom and Alpeyev [2017]). Son says: "We saw a big bang in PCs, we saw a big bang in the internet. I believe the next big bang is going to be even bigger. To be ready for that, we need to set the foundation and that foundation is SoftBank Vision Fund."
The future will tell if these investment structures were successfully able to support the development of clean technologies or not. In any case, it is important to find the right way of investing and supporting a new technology in a smart combination of private and public investment that suits the actual technology, the economic and cultural environment.

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