ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

DEVELOPMENT DYNAMICS OF SOLAR ENERGY: CASE OF TURKEY

Ph.D. THESIS

Alper ÇELEBİ

Department of Management Engineering

Management Engineering Programme

MAY 2012

ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

DEVELOPMENT DYNAMICS OF SOLAR ENERGY: CASE OF TURKEY

Ph.D. THESIS

Alper ÇELEBİ
(507062001)

Department of Management Engineering

Management Engineering Programme

Thesis Advisor: Prof. Dr. Burç Ülengin

MAY 2012

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

GÜNEŞ ENERJİSİ GELİŞİM DİNAMİKLERİ: TÜRKİYE VAKASI

DOKTORA TEZİ

Alper ÇELEBİ
(507062001)

İşletme Mühendisliği Anabilim Dalı

İşletme Mühendisliği Programı

Tez Danışmanı : Prof. Dr. Burç Ülengin

MAYIS 2012

Alper Çelebi, **a Ph.D.** student of **ITU Institute of Science and Technology** student ID **507062001**, successfully defended the **dissertation** entitled "**DEVELOPMENT DYNAMICS OF SOLAR ENERGY: CASE OF TURKEY**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. Burç Ülengin** İstanbul Technical University	....
Jury Members:	**Prof. Dr. Sermin Onaygil** İstanbul Technical University	....
	Prof. Dr. Sıtkı Gözlü İstanbul Technical University	....
	Doç. Dr. Yıldız Arıkan Bahçeşehir University	....
	Doç. Dr. M. Atilla Öner Yeditepe University	....

Date of Submission: 31 January 2012

Date of Defense: 25 May 2012

To Ilknur, my wife, and Alp Tuna, my son...

FOREWORD

I personally believe that the past 5 years involved in the Ph.D. program have enriched my intellectual development and contributed to the development of my professional life. Obviously, doing a Ph.D. alone is challenging work, however, doing it in parallel to my professional life abroad while married with a son was even more challenging. I believe that the immense support and encouragement of my family, colleagues, advisor and the thesis committee allowed me to flourish. Completing this Ph.D. thesis would not at all have been possible without them.

Much of the credit must go to Prof. Dr. Burç Ülengin, my advisor. His constant support and encouraging guidance has increased the quality of the thesis and contributed to my personal motivation. Appreciation also goes to Prof. Dr. Sermin Onaygil and Prof. Dr Sıtkı Gözlü, members of the committee of thesis progress and Assoc. Prof. Dr. Yıldız Arıkan and Assoc. Prof. Dr. M. Atilla Öner, members of the thesis defence. Their feedback was invaluable.

I am extremely grateful for Eren Ocakverdi's contributions to my research. The thesis is immeasurably better as a result of his dedicated support and time.

I was fortunate to have great friends like Sibel Hür, who read and critized every single line amongst hundreds of pages; Can Mutluer who gave me positive support throughout the Ph.D.; Keith Resnick who read and challenged the storyline; Serdar Çelik who shares the same fortune as me, I am looking forward to hearing of his graduation; and Jean-Christoph Heyne, who supported the thesis and showed flexibility at a challenging work environment.

I owe a tremendous debt of gratitude to my family and in-laws: Necla Çelebi and Tülay Yüksel, mothers; Ahmet Çelebi and Kenan Yüksel, fathers; Nur Yüksel and Ilker Yüksel, junior siblings; Fatmagül Çelebi and Safiye Yüksel, grandmothers; for their patience, encouragement, understanding and moral support.

Last but not least, I want to thank Ilknur, my wife, for all of her support throughout the thesis. She has lovingly put up with the long nights and weekends that I have spent on the Ph.D. with incredible good will and patience. I am eternally grateful to her. I can only hope to repay her in the coming years.

I hope that this achievement will be an inspiration for the succeeding generations of our family, to reach higher goals in the future.

January 2012 Alper ÇELEBİ

Management Engineer, M.Sc.

TABLE OF CONTENTS

Page

ABBREVIATIONS

BIPV : Building integrated PV systems
BMU : The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CEC : Commission of the European Communities
CSP : Concentrated Solar Power
EC : European Commission
EEG : Renewable Energy Sources Act
EIE : General directorate of electrical power resources survey and development administration
EP : European Parliament
EPIA : European Photovoltaic Industry Association
ERU : Energy Regulatory Office
EU : European Union
FIT : Feed-in Tariff
GDP : Gross Domestic Product
ICAT : International Centre For Applied Thermodynamics
IPCC : Intergovernmental Panel on Climate Change
IEA : International Energy Agency
IEA PVPS : International Energy Agency Photovoltaic Power Systems Programme
IRR : Internal rate of return
Gov't : Government
GW : Gigawatt
kWh : Kilowatt hour
LCOE : Levelized cost of electricity
MW : Megawatt
NIPV : Not integrated PV systems
NPV : Net Present Value
NREAP : National Renewable Energy Action Plans
PV : Photovoltaic Power
REN21 : The Renewable Energy Policy Network for the 21st Century
RES : Renewable Energy Sources
TWh : Terawatt hour
UFTP : The National PV Technology Platform
VAT : Value added tax
WBGU : German Advisory Council on Global Change
Wp : Watt peak

LIST OF TABLES

Page

LIST OF FIGURES

Page

DEVELOPMENT DYNAMICS OF SOLAR ENERGY: CASE OF TURKEY

SUMMARY

The use of electricity is an unavoidable part of almost all daily activities. Currently, electricity supply heavily relies on fossil fuels. They are relatively cheap but using them creates a problem of long-term energy security and global warming. On the other hand, although solar energy is relatively expensive now, the diffusion of solar energy gains speed and attract investors due to its untapped potential and its steep cost reduction in the prior decades.

In this study, photovoltaic (PV) is the only focus. After analysis of PV diffusion in seven focused countries, four diffusion patterns (sustainable, fact catchers, unguided missiles and lacking trigger) have been identified according to the variables of market pick-up and diffusion speed characteristics.

Under the light of four diffusion patterns, three dimensions (trigger conditions, diffusion speed and upper limit) that differentiate the patterns from each other are identified. Determined trigger conditions are profitability (i.e. internal rate of return), IRR of a PV investment that meets minimum market expectations, availability of clear government commitment, lean administrative process in place and solar resources are higher than >800kWh/m^2. If all of the aforementioned trigger conditions are not met, then market pick-up is not expected. Diffusion speed is affected by IRR level, capita and political stability. The diffusion reaches an upper limit influenced by a country's PV installation target, solar potential, grid allowance, GDP growth per capita and the weight of FIT liability on GDP.

Due to limited historical data, Generalized Bass Model (GBM) and logistical model are used because both enable us to add exogenous variables in equations. Other growth curves i.e. Bass model, Gompertz are investigated but decided not to use due to limitation on adding exogenous variables.

Developed "improved logistic" model reached 0.972 value of R^2. Variables of triggered IRR and knowledge base are found to be statistically significant for determining diffusion speed considering any acceptance level, 0.01 or 0.05. Variables of Z6 (PV target 2020) and Z4 (GDP per capita) are statistically significant for determining upper limit considering an acceptance level of 0.1. "Improved GBM" model reached 0.997 value of R^2. Variables of X12 (triggered IRR) and X3 (knowledge base) are statistically significant for determining diffusion speed at any acceptance level, 0.01 or 0.05. "Improved logistic" has been selected as the reference model because "improved GBM" didn't generate reasonable forecasts for Turkey despite the fact that it generates higher R^2 validation.

The Turkish government introduced a new FIT for PV in 2011; however it is not expected to trigger the market according to identified four trigger conditions. The reason is related to two trigger points i.e. economic feasibility of an investment and government commitment.

Based on “improved logistic” forecasts a “sustainable” scenario starts with 240MW PV installations in 2014; reaches 1.4GW annual PV installations by 2020; 5.2GW cumulatively by 2020; this scenario might bring USD 2 billion in yearly investment and cause FIT liabilities of USD 1.4 billion (0.12% of GDP in 2010) to the Turkish government in 2020. “Fast catcher” scenario starts with 493MW and reaches 2.9MW annual PV installations and 10.6GW cumulatively by 2020; this scenario might bring USD 4 billion yearly investment and cause FIT liabilities of USD 3 billion (0.27% of GDP in 2010) to the Turkish government by 2020. The forecasts are cross-checked with local and international forecasts, other countries’ 2020 installation targets and installed base development of Turkey. All cross-checks provide satisfactory results.

In order to trigger the PV market, Turkey should address the topic of economic attractiveness and government commitment. Turkey should pay attention to the following topics when designing a policy; FIT should provide adequate financial incentives (not more not less than expected); clear government commitment should be shown by communicating short, mid and long-term installation targets as done in wind case or, as was done in the case of Wind Power installation; transparent and lean regulatory procedures should be in place to avoid over-bureaucracy; grid capacity for PV should be followed carefully and lastly, promotion of PV should be done to build up public awareness.

GÜNEŞ ENERJİSİ GELİŞİM DİNAMİKLERİ: TÜRKİYE VAKASI

ÖZET

Enerji kullanımı günlük hayatın vazgeçilmezlerindendir. Günümüzde enerji arzı ağırlıklı olarak fosil yakıtlı enerji kaynaklarına dayanmaktadır. Fosil kaynaklarının kısıtlı olması ve küresel ısınma yeni enerji kaynağı arayışlarını hızlandırmaktadır. Yenilenebilir enerji kaynaklarına artan ilginin temel nedeni budur. Yenilenebilir enerji kaynakları 2010 yılı itibariyle küresel enerji arzında %20 pay almasına rağmen hidroelektrik santralleri dışındaki yenilenebilir kaynaklarının payı toplamın sadece %3'unu oluşturmaktadır. Güneş enerjisi işlenmemiş potansiyelinin büyüklüğünden ve maliyetindeki son 10 yıldaki hızlı düşüşten dolayı araştırmacıların, şirketlerin ve yatırımcıların odağındadır.

PV son 5 yılda en hızlı büyüyen endüstrilerden bir tanesidir. PV'nin küresel kurulu gücü 2005'teki 5GW seviyesinden 2010'da 40GW seviyesine yükselmiştir, bu 2005 yılından bu yana yıllık ~50 büyüme anlamına gelmektedir (EPIA, 2011). Büyüklüğün daha net anlaşılması için; kabaca dünya'daki PV kurulu gücünün hemen hemen Türkiye'nin elektrik üretim santrallerinin toplam kapasitesi (50GW) kadar olduğunu söyleyebiliriz. Türkiye, Portekiz'den ve İspanya'dan sonra Avrupa'da en yüksek üçüncü güneş potansiyeline sahip olmasına rağmen birkaç deneysel amaçlı kurulmuş istasyon dışında maalesef PV kurulu gücü yoktur.

Literatür araştırmasında güneş enerjisi endüstrisi için teknoloji yayılım şekillerinin ortaya çıkarılması ve teknoloji yayılım tahmini konusunda bir açık tespit edilmiştir. Literatürde bulunan çalışmaların ağırlıklı kısmı yayılımı olumlu ve/ya olumsuz etkileyen değişkenleri anlamaya yönelik olduğu gözlemlenmiştir. Bulunan birkaç PV yayılım modelinde tahmin değerleri ile gerçekleşmiş veriler arasında yüksek ölçüde farklılaşma mevcuttur. Türkiye'de yapılan çalışmalar belli bir bölgenin güneş enerjisi potansiyelinin farklı yöntemlerle hesaplamasından ve özel uygulama alanlarının araştırılmasından öteye gitmemiştir.

Türkiye'nin geçmiş verisinin olmamasından dolayı küresel seviyede elde edilen sonuçlar aşağıda bahsedilen dört aşamalı bir yöntemle Türkiye'ye uyarlandı. Ülkelerdeki PV yayılımları incelerek ortak yayılım şekilleri oluşturuldu. Yayılım için yeni ürün tahminlerinde kullanılan istatistiki yöntemlerle bir model geliştirildi. Türkiye için oluşturulan PV yayılım senaryolarına göre modeller çalıştırılarak 2020 yılına kadar kurulu güç tahmini yapıldı. Bunlara ek olarak diğer ülkelerden öğrenilenler çerçevesinde öneri paketi oluşturuldu.

Yeni ürün yayılımının tahminlerinde en sık kullanılan büyüme eğrileri Bass model, genelleştirilmiş bass model (GBM), lojistik, Gompertz olarak listelenebilir. Dışarıdan değişken eklenmesine izin verdiğinden dolayı GBM ve lojistik'in en uygun modelleme yöntemleri olduğu tespit edildi.

Çalışmada kurulu gücün 1GW'a ulaşması, satın alma garantisi tipi teşviklerin mevcudiyeti ölçütlerine göre değerlendirilme yapılarak Almanya, İspanya, Çek

Cumhuriyeti, Fransa, İtalya odak ülke olarak seçilmiştir. Bunlara ek olarak komşu ülkelerden Bulgaristan ve Yunanistan da cömert FIT sağlanmasına rağmen tetiklenmeyen PV pazarları olmasının Türkiye için örnek olacağı düşünülerek bu iki ülke de odak ülke listesine eklenmiştir.

Yedi ülkedeki PV yayılımın başladığı yıl "yıl 1" olacak şekilde normalize edilip benzer yayılım şekilleri tespit edilerek aşağıdaki dört tip belirlenmiştir:

Sürdürülebilirler (Sustainable): Sadece Almanya'nın dahil olduğu gruptur. Verdiği satın alma garantilerinde yatırımcılara makul ölçülerde iç karlılık oranı (IRR, ortalama ~%8) sağlar. Şeffaf ve yapısal yönetimsel süreçleri mevcuttur. PV endüstrisinin gelişimi için hükümetin kısa – orta – uzun vadeli taahhütleri mevcuttur.

Hızlı koşucular (Fast catchers): İtalya ve Fransa'daki yayılma şeklidir. Yatırımcılarına göreceli olarak daha yüksek IRR (ortalama ~12%) sağlayarak daha hızlı bir büyüme gerçekleştirmektedir. Her iki ülkede de yayılımın başlangıcında bazı yönetimsel engellerle karşılaşılmıştır ancak sonrasında bunlar yeni çıkarılan yönetmeliklerle ortadan kaldırılarak yayılım tetiklenmiştir. Satın alım garantilerin devletin bütçesinde oluşturacağı yük uzun vadedeki sürdürülebilirligi belirsizdir.

Rotasızlar (Unguided missiles): İspanya ve Çek Cumhuriyeti bu gruba dahildir. Bu yayılım seklinde IRR seviyesi %12'yi aşmakta, bazı yıllarda %16 mertebesine varmaktadır. Çekici yatırım koşulları ve uyguladıkları yalın yönetsel süreçlerle büyük ölçüde yatırımcıların ilgisini çekmişlerdir. Ülkeler PV yatırımının gelişimini sıkı kontrol altında tutmamışlardır. Hızlı yayılım başlangıçta bir başarı öyküsü olarak gözükse de sonrasında 20 yıl için yüksek teşvik taahhütlerinden dolayı devlet için kâbus haline dönüşmüştür. Her iki ülke de benzer zorluklarla karşılaşarak geriye yönelik teşviklerde değişiklik yapma veya yatırımcılara ek vergi getirme yoluna gitmiştir. Bu tur sürprizler sadece o ülkelere yatırım yapanların değil küresel boyutta PV endüstrisindeki yatırımcıların güvenini önemli ölçüde kırmıştır.

Tetiklenmemişler (Lacking trigger): Yunanistan ve Bulgaristan bu gruba dahildir. Her iki ülkede de yatırımcılar için oldukça çekici IRR seviyeleri taahhüt edilmesine rağmen bürokratik engeller, belirsiz / uzun yönetimsel süreçler ve/ya kötüleşen ekonomik koşullardan dolayı pazarın tetiklenmesi beklendiği gibi gerçekleşmemiştir.

Yayılım şekillerini farklılaştıran üç boyut ve onları etkileyen değişkenler aşağıdaki gibi belirlenmiştir. Yayılım başlaması için *tetikleyici koşullar (trigger conditions)* olarak isimlendirilen unsurların oluşması gerekmektedir. Belirlenen 4 tetikleyici unsur şu şekildedir: PV elektriğinin satın alma garantisi pazarın beklediği asgari IRR seviyesini sağlaması (küresel asgari oran %6'dir ancak ülkelerin yatırımcı iştahı farklılık gösterebilmektedir), PV'ye yönelik net kısa – orta – uzun vadeli hükümet taahhüdü, ağır bürokrasiden arındırılmış yalın yönetimsel süreç, asgari güneş enerjisi potansiyelinin >800kWh/m^2'dan fazla olması. Pazarın gelişmesi için belirlenen bu dört koşulun da aynı zamanda oluşması gerekmektedir. Aksi takdirde Bulgaristan ve Yunanistan'da olduğu gibi yayılım şekli "tetiklenmeyenler" olmaktadır. Diğer boyut *yayılım hızı (diffusion speed)* olarak isimlendirilmiştir. Yatırımcılara sağlanan IRR seviyesi, ülkede oluşan bilgi birikimi, FIT seviyesi, PV kurulum başvurusunun sonuçlanması için geçen süre, GSMH (büyüme ve kişi başına), politik istikrar yayılım hızını belirleyen değişkenler olarak tanımlanmıştır. Son boyut *üst limit (upper limit)* olarak isimlendirilmiştir. Ülkenin PV kurulu güç hedefi, güneş enerjisi potansiyeli, elektrik dağıtım ağının PV kurulu gücünü kaldırabilme potansiyeli, GSMH (büyüme ve kişi başına) ve devletin PV elektriğini satın alma garantisinin GSMH'daki payı üst limiti belirleyen değişkenler olarak tanımlanmıştır.

İstatistiki modelleme amacıyla GBM ve lojistik yöntemlerinin seçilmiştir. Ancak her iki yöntemdeki özgün denklemlerde üst limiti sabit bir sayıdır, modelleme için özgün denklemlerde iyileştirmeler yapılarak üst limit dışarıdan değişken eklenebilir bir fonksiyonu haline getirilmiştir. Yeni modeller "geliştirilmiş GBM" ve "geliştirilmiş lojistik" olarak isimlendirilmiştir. GBM için EViews yazılımında bir eklenti geliştirilmiştir ve geliştirilen eklenti EViews tarafından ana sayfalarında duyurularak diğer kullanıcıların da hizmetine açılmıştır.

"Geliştirilmiş GBM" doğrulama sonuçlarında "geliştirilmiş lojistik"e göre genel anlamda daha iyi sonuç üretmesine rağmen "geliştirilmiş GBM'in Türkiye için yaptığı tahminler rasyonel değildir. İlk yıl tahmin edilen kurulu güç bir zirve yapıp sonraki yıllarda azalmaktadır. Bu özette sadece "geliştirilmiş lojistik" sonuçları referans sonuç olarak incelenecektir. Meraklısı için GBM'le ilgili tüm denemeler, sonuçlar, nedenler doktora tezinde tartışılmıştır.

0.972 R^2 değeri gözlenen veri ile tahmin edilen verinin birbirine yüksek seviyede uyumlu olduğunu göstermektedir. Bunun dışında hem 0.1 hem de 0.05 kabul seviyesinde "tetiklenmiş IRR" (X12) ve "oluşmuş bilgi" (X3) istatistiki açıdan yayılımın hızını etkilemesi anlamlı bulunmuştur. "2020 yılı PV hedefi" (Z6) ve "kişi başına GSMH" (Z4) 0.1 kabul seviyesinde istatistiki açıdan anlamlı çıkmıştır.

Bu sonuçlar ışığında seçilen yedi ülke için gözlenen ve tahmin edilen veriler (alt ve üst limitler %95 güven aralığında belirlenmiştir) için doğrulama (validation) yapılmıştır. Aşağıda bu doğrulamalardan Almanya için yapılan bir örnek bulunmaktadır. Sonuçlar tatmin edicidir.

Türk hükümeti yeni tevsik yasasını 2011 yılında yürürlüğü koydu. Pazarın başlaması için belirlenen tetikleyici unsurlar incelendiğinde yeni teşvik yasasının koşulları sağlamadığı görülmektedir. Taahhüt edilen satın alma garantisi ve bugünkü PV yatırım maliyetleri düşünüldüğünde asgari gerekli olan IRR koşulu (>%6) sağlamamaktadır. Buna ek olarak Türk hükümetinin PV yatırımlarına yönelik net bir hedefi ve/ya mesajı bulunmamaktır. Belirlenen dört tetikleyici koşuldan yukarıdaki iki koşul oluşmadığı için 2013 yılı sonuna kadar yürürlükte kalması planlanan yasanın PV pazarının tetiklenmesi beklenmemektedir. Bu durum "tetiklenemeyenler" olarak tanımlanan yayılım sekline denk düşmektedir.

Modellemedeki gelecek senaryoları sadece 2014 yılından itibaren başlamıştır. Oluşturulan dört küresel yayılım şekillerinden "rotasızlar" ve "tetiklenemeyenler" hiç bir zaman hükümetlerin özellikle planladığı yayılım şekilleri değildir. Dolayısıyla Türkiye'de 2013 yılı sonrasındaki yayılım şekil senaryoları için "sürdürülebilirler" ve "hızlı koşucular" tipleri referans alınacaktır. Yayılım senaryoları arasındaki temel fark IRR seviyeleridir. "Sürdürülebilirler" yayılım senaryosu için IRR seviyesi %8, "hızlı koşucular" için %12 kullanıldı.

"Sürdürülebilirler" yayılım senaryosunda 2014 yılında 240MW kurulu güç ile yayılımın başlaması öngörülmüş olup yıllar boyunca kurulu güç tahminleri artarak 2020 yılında 1.4GW'a erişmektedir. Bu sonuçlarla birikimli kurulu gücü 2020 yılında 5.2GW'a ulaşmaktadır.

"Hızlı koşucular" yayılım senaryosunda ise 2014 yılında 493MW kurulu güç ile yayılımın başlaması öngörülmüş olup yıllar boyunca kurulu güç tahminleri artarak 2020 yılında 2.9GW'a erişmektedir. Bu sonuçlar birikimli kurulu gücü 2020 yılında 10.6GW ulaşmaktadır.

PV endüstrisi hükümetin seçeceği yayılım şekillerine göre önemli miktarda yatırım imkanı sağlayacaktır. Sistem kurulum maliyetlerini ile “sürdürülebilirler” ve “hızlı koşucular” senaryolarında tahmin edilen kurulu güç gelişimi düşünüldüğünde 2014 yılında yıllık yatırım maliyeti sırasıyla 500 milyon USD ve 1 milyar USD; 2020 yılı için yatırım tutarı sırasıyla 2 milyar USD ve 4 milyar USD olacağı hesaplanmıştır.

Bununla birlikte benzer bir hesaplama satın alma garantilerinin kamuya getireceği taahhüt büyüklüğü için yapılmıştır. 2014 yılındaki ödeme her iki senaryo için 100 milyon USD mertebesindeyken 2020 yılında “sürdürülebilirler” senaryo için toplam kurulu güç için ödenecek miktar 1.4 milyar USD’a, “hızlı koşucular” senaryosunda için ise 3 milyar USD’a ulaşmaktadır. Ödenecek tutarların tahmin edilen GSMH’laki payı “hızlı koşucular” senaryosunda dahi sadece %0.27 ile sınırlı kalacaktır. Bu oran bugün Çek Cumhuriyeti’nde %0.5, Almanya’da ise %0.2 olduğu düşünülürse göreceli olarak ekonominin kaldırabileceği bir yükümlülük olarak değerlendirilebilir. Yapılacak yatırımların, yerel ve/ya ihracat için yapılacak bileşen üretiminin sağlayacağı istihdam ve katma değerin ekonomik değeri ayrıca hesaplan-malıdır.

Almanya’da gözlemlendiği gibi düzgün bir yasal düzenleme ile PV endüstrisi bir başarı öyküsü olabileceği gibi Çek Cumhuriyeti ve İspanya örneklerinde olduğu rotasız yasal düzenlemelerin sonuçları kamunun kâbusu olabilmektedir. İncelenen ülkelerdeki PV yayılımının iyi, iyileştirmeye açık yönleri ve yapılan uluslararası çalışmalar ışığında Türkiye için aşağıdaki politika önerileri oluşturulmuştur.

Yeterli finansal destek: Uygulamaya koyulacak FIT yatırımcılara makul getiri sağlamalıdır. Cömert tasarlanan teşvikler spekülatif bir pazar oluşturabileceği gibi, tutucu tasarlanmış teşvikler pazarın tetiklememektedir. Bu yüzden teşvik seviyesi öyle bir tasarlanmalıdır ki yatırımcının sadece asgari ihtiyaç duyduğu IRR sağlamalıdır. Küresel örneklerde %8 IRR pazarın “sürdürülebilirler” seklinde yayılımını %12 IRR pazarın “hızlı koşucular” seklinde yayılımını sağlamaktadır. Ancak bu değerlerin Türkiye’deki yatırımcıların iştahlarıyla uyumlandırılması düşünülebilir. PV teknolojisi hızla ucuzladıkça ilk yatırım maliyetleri azalmaktadır. Bu yüzden teşvik büyüklüğü maliyetlerdeki düşmeye paralel yatırım gerçek değerini yansıtmalıdır. Bu kamunun pazarı yakın takibini gerektirir. Bunun dışında şu anki teşvik yasasında olduğu gibi yıllık kurulum büyüklüğünü sınırlamakta spekülatif pazarı önleyici bir tedbirdir.

Endüstri gelişimini yönelik kesin taahhüt: Türk hükümetinin Cumhuriyetin 100. kuruluş yılı için öngördüğü 100GW’lik kurulu güç içerisinde güneş enerjisi için özel bir hedef belirtilmemiştir. Ülkedeki toplam kurulu güç gelişimi, enerji üretim teknolojilerinin dağılımı, ithal edilen enerji kaynaklarına bağımlılık gibi kıstaslar düşünülerek kısa – orta – uzun vade için PV kurulu güç hedefleri belirlenmelidir. Uzun vadeli hedefe ek olarak kısa ve orta vadede kilometre taşları belirlenerek gelişimin takip edilmesi sağlanmalıdır.

Şeffaf ve yalın düzenleyici süreçler: Bulgaristan ve Yunanistan yatırımcılara yüksek getiriler taahhüt etmesine rağmen güneş enerjisi pazarı tetiklenememiştir. Bunun nedeni karmaşık süreçlerdir. PV diğer tüm enerji üretim teknolojilerinden farklı olarak dağınık bir yapıya sahiptir. Yani kamu kuruluşlarına başvuru yapacaklar 10MW – 100MW’lik üretim tesisi kurmak isteyenlere ek olarak evlerin çatısına kW büyüklüğünde PV kurulumu yapmak isteyen ancak enerji konusuna hakim olmayan binlerce vatandaşlar olabilir. Dolayısıyla sürecin şeffaf ve yalın olması kritik başarı unsurudur. Burada iki öneri öne çıkmaktadır. Birincisi belirli büyüklüğe kadar yapılan başvuruların tek yerden yapılarak zaman ve para tasarrufu sağlanmasıdır.

İkincisi ise "tip proje" denilen standart büyüklükte projeler oluşturularak vatandaşların proje tasarımına ayıracakları para ve teknik aksaklıklar asgariye indirilmesidir.

İletim / dağıtım hatlarının kapasiteleri takip edilmelidir: İletim ve dağıtım hatları PV gibi dalgalı enerji sağlayan elektrik üretim teknolojilerini belli bir kapasiteye kadar kaldıra-bilmektedir. Bu kapasite bazı kaynaklarda %10 olarak gösterilirken bazı kaynaklarda %30 olarak gösterilmektedir. Ancak ilgili kurumların yakın takibi ile Türkiye özelinde bir limit noktası belirlenmelidir.

PV farkındalığının yaratılması: Kamunun hem küçük hem de büyük yatırımcıları hedef alan bilgilendirmeler yapması gerekmektedir. Bilgilendirmeler konunun çevresel boyutu ve potansiyel getirisini içerebilir. Bunun dışında GENSED (Güneş Enerjisi Sanayicileri ve Endüstrisi Derneği), UFTP (Ulusal Fotovoltaik Teknoloji Platformu) gibi güneş enerjisi gelişimini kendilerine görev edinmiş dernekler desteklenmelidir.

1. INTRODUCTION

In the introductory chapter, background information on the topic, research problem, focus, purpose and structure of the thesis are to be evaluated.

1.1 Background

The use of electricity is an unavoidable part of almost all daily activities. People consume a large amount of energy every day and it has been increasing gradually. According to International Energy Agency (2009), energy demand will double by 2030. Currently, the world relies on conventional sources of energy, such as coal, crude oil, natural gas and nuclear power; conventional energy sources are expected to be a substantial portion of the global market in the future. Although these sources are relatively cheap now, there are two major factors to be considered when looking towards the future. First of all, these energy resources are formed after hundreds of millions of years but they are being consumed instantly. Although depletion of these energy resources will take many, many years extraction costs definitely will increase and it will cost much more money to the society. Second, the environmental challenges are substantial, with the most serious threat coming from anthropogenic interference with the global climate system. Global climate destabilization is primarily driven through the combustion of fossil fuels for energy and the resultant greenhouse gas emissions (The IPCC, 1995; The IPCC, 2001). The consensus among the 2004 Intergovernmental Panel on Climate Change and the 1993 World Energy Council's Global Energy Scenarios to 2050 is that if current trends continue, our earth will eventually reach a point of no return (Hoffert et al., 2002). Considering these two main issues, a search for a substitute to balance / replace fossil fuels has increased the importance of renewable energy.

Renewable energy especially received special attention due to its long-term, inexhaustible, environmentally friendly and reliable characteristics. This interest is also seen in its development in terms of investment amount, government support mechanisms and installed base. Global annual investment of renewable energy almost doubled in three years from $130 billion in 2008 to $211 billion. 1.320GW including hydro power, delivered close to 20% of global electricity supply in 2010, and by early 2011 renewable energy comprised one quarter of global power capacity of all sources. Last but not least, at least 119 countries had different types of renewable policy target or renewable support policy at the national level by early 2011, while that number was only 55 countries in 2005 (Ren21, 2011). Upward trend in interests towards renewable energy is expected to increase in the future due to cost reduction potential of renewable energy and fluctuating oil and gas prices.

However, non-hydro renewable energy source levels currently contribute only 3% to global electricity, 312GW by end of 2010, despite its enormous potential to provide the world's energy demand (Ren21, 2011). Among the non-hydro renewables, wind power is by far the most important energy source being used in a growing number of countries in terms of installed base so far. Solar energy is still in emerging phase.

Even though solar energy generation is not cost effective given its current level of technology advancement, it has a strong potential with increasing rate of technology development. The installed capacity of two solar technologies i.e. photovoltaic (PV) and solar thermal (concentrated solar power, CSP) reached approximately 41GW (PV and CSP are around 40GW and 1GW respectively) that is only a fraction of total installed base worldwide (EPIA, 2011a). For last few years, the PV market has been driven by falling costs, new application areas, strong investor interest due to investment attractiveness and continued strong policy support. 17GW of PV capacity was added worldwide in 2010 (compared with just under 7.3 GW in 2009), bringing the global total to about 40 GW – more than seven times the capacity in operation five years earlier. Total existing capacity of all PV grew 72% relative to 2009, with the average annual growth rate over the 2005 to 2010 period exceeding 49% (Ren21, 2011). Although the current installed base of solar is relatively limited, the IEA (2004) predicts that solar energy will contribute 20% of the world energy supply by 2050 and over 60% by 2100.

Although Turkey has proved its potential and public interest on solar by having the second largest number of solar collectors for water heating installed all over the world following China, there is no PV installation, which neglects several experimental sides for electricity generation despite high solar potential. This limited installed base is mainly due to the high cost of solar energy generation and lack of appropriate government solar energy support.

On the other hand, despite a growing level of public interest in environmental protection, very little research has been done on national or international diffusion of solar technology and only minor attention has been paid to quantitative analyses and forecasts.

Considering the positive developments about solar energy globally, import dependency of the Turkish electricity sector and the untapped solar potential in Turkey, the thesis topic targets to fill in the gap in PV technology diffusion area.

1.2 The Research Problem

PV installed base worldwide has been developed from 5GW in 2005 to 10GW in 2007 to 40GW in 2010, meaning 50% growth per year since 2005 and 61% growth per year in last 3 years (EPIA, 2011a). It is obviously one of the fastest growing markets in the world.

PV diffusion globally has intensified in several countries. For example, the installed base of the top five countries (Germany, Spain, Japan, Italy and US) accounts for almost 80% of total installation worldwide. Although many countries give incentives to PV installations, only some of them reach a certain level of maturity level in installation and Turkey is one of those countries giving government incentives but having no PV installation as of 2010 end (EPIA, 2011a).

So the wonder is why some countries reach that level of PV installation while others have not. Another point is why some countries e.g. Germany, Spain and Czech Republic have reached high level of installations (>2GW) in several years whereas the increase in other countries' installation is relatively slower. All these questions are the core of the thesis question. The question will be analyzed from a global perspective and the results will be reflected in the case of Turkey as a case study. At the end of the thesis, a policy recommendation for Turkey will also be made under the consideration of learning from other countries.

1.3 Focus

The thesis will focus on diffusion of solar energy in Turkey based on examined global diffusion patterns in today's core solar energy countries. There are following two dimensions that narrowed down the thesis scope in order to generate focused results in solar energy diffusion.

Firstly, the dimension of technology is limited to PV, meaning not included solar thermal energy. The table below shows availability of solar energy technology at different scale and scope. CSP technology penetration level is limited to only 1GW worldwide and no / limited opportunities in the mid-term are foreseen in Turkey due to technology readiness globally and the lack of a proper level of incentives locally. Since the focus of the thesis is installed base of electricity generation facilities, the applications like water heating systems of solar thermal technology are not included to the scope.

Table 1.1 : Thesis scope from solar technology and application perspectives.

		Availability		Thesis Scope	
Applications	**Explanations**	**PV**	**Solar Thermal**	**PV**	**Solar Thermal**
Power stations	in-grid, > 1MWp, ground mounted	Yes	Yes	Yes	No
Residential	off-grid, < 1MWp, roof top	Yes	No	Yes	No
Stand alone devices	off-grid, parking meters, emergency telephones, traffic signs, solar thermal (water heating)	Yes	Yes	No	No

Secondly, global diffusion patterns will be examined based on diffusion development in seven countries (Germany, Spain, Italy, France, Czech Republic, Bulgaria and Greece), which represent 75% of all PV installed base worldwide. The selection methodology of the seven countries is shown in detail in section 2.3.

1.4 Purpose

The number of publications on solar energy has increased significantly worldwide since 2005, as well as in Turkey (Celiktas et al., 2008). Many of the studies have examined the potential of solar energy in certain geographic areas or specific technological applications of solar energy. Despite the increase in the number of publications, technology diffusion in the countries has not been tapped enough yet. After having a detailed look on literature, this study opted to target on technology forecasting under the consideration of market dynamics of solar energy. The main reason for the connection between technology diffusion and market dynamics is that a technology forecaster must have a good understanding of technology life cycles and factors that influence technological development in order to develop a more valid forecast.

The role of technology forecasting in defining new market opportunities has become increasingly important. In reality, in order to improve a company's competitive position or increase its competitive advantage, it is necessary to evaluate the concept and techniques of technology forecasting by combining projection of market dynamics and advances in technology. Technology forecasting methodologies are to be evaluated in the literature review.

The main questions of the thesis are:

What are the dynamics that influence PV diffusion in a country?

What are PV diffusion patterns in today's core markets globally?

How will PV technology diffuse from installed base point of view in Turkey?

What are the key factors that affect the PV development in Turkey?

What are the key recommendations to the Turkish government considering what we have learned from today's PV markets?

As mentioned, despite the increase in number of publications in the area of solar energy, there is a room for improvement from a technology diffusion forecasting point of view, especially in the case of Turkey. There is no publication that focuses on this area. This study with a comprehensive approach enables us to have the following top five contributions to literature:

Figure out dynamics of PV diffusion i.e. which criteria are important in PV technology diffusion

Examine technology diffusion patterns in today's core markets

Develop a statistical technology forecasting model based on new product forecasting methodologies

Forecast PV diffusion in Turkey i.e. installed base development under the scenario of identified global diffusion patterns under different diffusion scenarios

Define boundary conditions for diffusion scenarios

Policy recommendations e.g. level of feed in tariffs (FIT) for different diffusion patterns, learning from other countries

1.5 Structure

This thesis has five chapters. Following this chapter, a comprehensive screening of solar related academic publications, studies, books and reports is performed in the second chapter. In the second chapter, one also can find detailed country profiles from solar diffusion perspective. The third chapter is a collection of previous studies on the topic of technology diffusion and forecasting and it relevance from solar energy perspective. Basis of statistical modeling lies in the third chapter. The fourth chapter is for our own results, discussions and outcomes. The fifth chapter is for conclusion and recommendations, including suggestions for candidates considering to start doing a Ph.D. or start writing a Ph.D. thesis.

2. LITERATURE REVIEW

2.1 Global Energy Market

Two things have transformed the electricity industry in the last two decades. The first one is the market restructuring to introduce wholesale market competition. The second one is in regards to environmental issues; renewable energy such as hydro, wind, solar, biomass are supported by governments due to worries on pollution, global warming and energy security (Alagappan et al., 2011).

In 2006, the worldwide electricity generation was 17.982TWh out of which 41% originated from coal, 20% from natural gas, 15% from nuclear, 5% from oil and 19% from renewable energy. From renewable energy sources, hydro-power is by far the largest supplier (17% of total electricity generation) whereas only 3% comes from renewable sources such as geothermal, solar, wind, combustible renewable and waste. The current fuel mix has fossil (coal, natural gas or petroleum) and nuclear fuels contributing to approximate 81% of total generation. Coal is known to have the highest carbon dioxide emissions per kWh, as well as emitting other pollutants at high levels. Still, it continues to dominate the market due to its low cost and high availability, while at the same time challenging the principles of sustainability (EIA, 2009).

In next two decades, world demand of fossil fuels is expected to increase. Burning fossil fuels releases harmful emissions and affects the local, regional and global environment (Thirugnanasambandam et al., 2009). A reliable supply of fossil fuel and the effects of its use on the environment are the two main problems in the energy market. The energy industry has to face up these challenges and find alternatives. Renewable energies (put into six main categories according to their primary source: geothermal energy, hydro energy, wind energy, wave energy, biomass solar energy) are considered a solution (at least a balancer) for today's and future's environment and security of supply problems by researchers. Solar energy has been increasing its importance due to its yet unutilized potential and steep cost reduction in the previous decades, however solar energy installations are still a fraction of the installed base.

Several things prompted the awareness for solar energy and some of them are environmental awareness and reduction in the greenhouse gases (Khan et al., 2005).

2.2 Global Solar Energy Market

2.2.1 Development of Solar market

Thus far, the pace of the PV market is set by global and local policies. Kyoto protocol and EU commitment are the two global policies that push PV diffusion.

2010 was an extraordinary year as global PV production and markets doubled. Global capacity reached about 40 GW, which is more than seven times the capacity in place five years earlier. By themselves, Italy and Germany installed more PV in 2010 than the entire world did the previous year (REN21, 2011)

It is forecasted by the IEA (2009) that solar power will contribute 20% of the world's energy supply by 2050 and over 60% by 2100. Some other external forecasts also increase the interest in solar and show that the development will utilize the potential in the long term. For example, according to WBGU, a German Advisory Council on Global Change, (2003), energy mix until year of 2100 is expected as figure 2.1 below which indicates that solar radiation has the highest energy capacity and is undeniably the renewable energy source with the greatest potential. This result shows how significant a role PV will play in meeting the world's future energy demand.

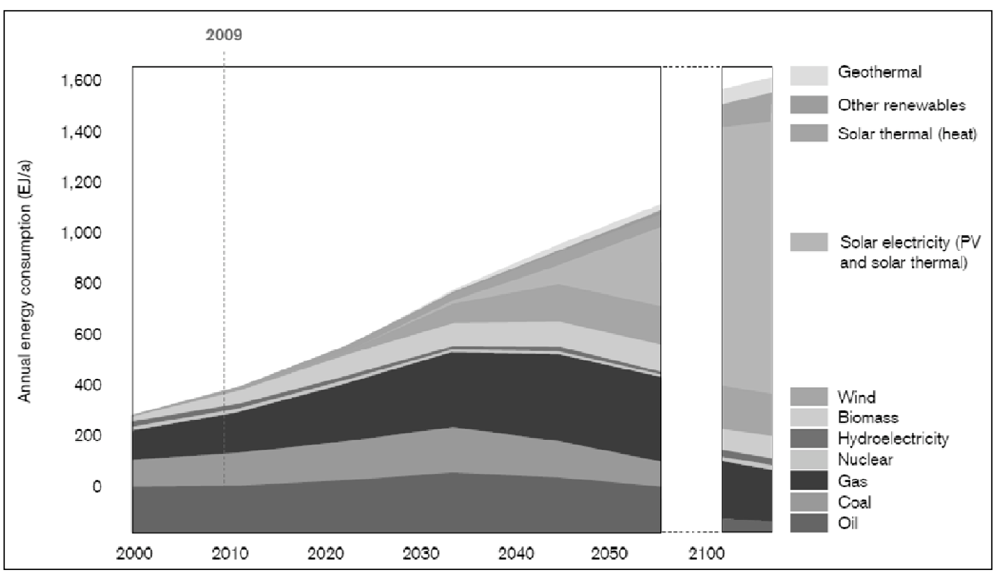


Figure 2.1: Development of Energy Mix, WBGU (2003).

2.2.2 Solar potential

Solar thermal energy is the most available energy source of all the renewable energy sources. The Sun emits energy at a rate of $3.8x10^{23}$kW, of which, approximately $1.8x10^{14}$ kW is intercepted by the earth, which is about 150 million km from the sun. After excluding reflected and absorbed part, about 60% of this amount or $1.08x10^{14}$ reaches the surface of the earth. Assuming approximately 0.1% of this energy, when converted at an efficiency of 10%, would generate four times the world's total generating capacity of about 3,000GW. This potential shows how much unutilized potential exists around the earth, and current market growth is targeted to address this potential as quick as possible under the cost considerations (REN21, 2011).

2.2.3 Development of solar technologies

Two main technologies exist in electricity generation via solar power (Meyers, 1983):

> solar thermal power, in which solar is concentrated through suitable mirror systems e.g. parabolic trough, stirling dish, to feed a conventional power plant, known as concentrated solar power (CSP) as well.
>
> PV, in which energy is produced as a direct result of the conversion of the energy of the solar ray, using the so-called PV effect.

PV and CSP technologies differ in the way of electricity generation. The PV directly converts sunlight into electricity, whereas solar thermal technologies capture the sun's heat, which is then used to drive turbines for electricity (Boyle, 1998).

The PV effect was discovered in 1839 by 19th Century French physicist Edmond Becquerel, while studying the effect of light on electrolytic cells. After a long period of time, high efficiency was reached. Photocells were used as light meters or devices to measure the light out of some light source. The PV industry is a young industry that was born in 1954, when American Bell Laboratories is thought to have developed the first silicon solar photocell. In those days, the cost of photocell was very high and was used in the powering of spacecraft and satellites. The first solar powered satellite was Vanguard 1, which was launched in 1958. Until the early 1970s, no terrestrial applications of solar photocells had been developed. The energy crisis of the 1970s greatly stimulated research and development for PV as a consequence of the 1973 oil crisis (Lesourd, 2001). The first household and industrial applications developed in the beginning of the 1970s (Razykov et al., 2011). Those days can be seen as the start of PV industry. Polycrystalline Si and thin-film solar cell technologies were developed to provide high production capacity at reduced material consumption and energy input in the fabrication process. Then and until the 1990s, the target was to obtain the maximum efficiency of converting light into electricity (Razykov et al., 2011). In the 1990s, the concept of integrating PV arrays into a building's fabric and connecting the system to the grid so that the cost of power generation and demand can be negotiated between the PV owner and the electrical supplier was introduced (Bahaj, 2001). That concept has provided a major improvement for the technology, resulting in approximately 50% growth in a year (EPIA, 2011a).

There are different sub PV technologies such as silicon-wafer-based, thin film and concentrated PV. In a nutshell, silicon-wafer-based PV is today's dominant technology, as it accounts for a 90% share in total installed PV capacity worldwide. However, there are two challenges for the development of this technology. First of all, though it is well suited for roof applications, the solar panels and the installation are costly. Secondly, module manufacturers are able to produce nearly 23% efficiency, but they are approaching the theoretical efficiency limit of 31% of a single junction silicon-wafer-based PV cells. Room for improvement exists in the areas of concentrating sunlight on cells, meaning increasing the number of junctions with different materials. Thin-film technology is another promising PV technology that can reach higher efficiency levels i.e. approximately 10% at commercial production volumes. Although thin film efficiency is relatively lower, its manufacturing cost is also much less compared to silicon-wafer-based PV technology e.g. about 1 to 5% of material needed for silicon-wafer-based PV technology, so the cost is almost half. However, some issues also exist. For example, lifetime output is not clear while silicon-wafer-base PV keeps predictable output for 20 – 25 years. Moreover, material of commercialized thin film technology is cadmium tellurium today but people are worried about the availability of tellurium and toxicity of cadmium (McKinsey, 2008).

Costs of PV electrical energy have been decreasing since 1975 because of technical progress, advances in the underlying physics of semiconductors such as silicon and also learning the effects in the industrial production of PV electricity production devices. Today, PV electricity has become competitive for conventionally-produced electricity in some niche areas (Lesourb, 2001).

2.2.4 Environmental aspect of solar energy

PV electrical production discharges no greenhouse gases which contribute to global climate destabilization. Due to the increasing importance of environmental protection, climate change and resource conservation as well as the corresponding global change in public perception, the use of solar energy is becoming more important around the world. Additionally, the global demand for clean energy is expected to continue to grow rapidly in the coming decades mainly because of;

- Finite existence of fossil fuels
- Increasing dependency of industrialized nations on import of fossil fuel
- Long-term increases in commodity prices
- Risks arising from nuclear electricity generation and storage of nuclear waste
- Global effort of industrialized countries fixed in the Kyoto Protocol to reduce the emission of greenhouse gases

Environmental awareness that solar energy is necessary to diversify energy sources has created the necessary conditions for governmental / state control. Additionally, decreasing cost (grid parity) and annual technological improvements have provided the basis of a future solar electricity production that is competitive in the short to medium-term.

2.2.5 Solar energy policies

Solar energy technologies are not yet cost-competitive with conventional energy commodities at either the wholesale or retail levels. Therefore, major deployment of solar energy is not possible unless major policy incentives are introduced.

IEA (2004) classified policies in three different categories: research and innovation policies, market deployment and market-based energy policies. The first one, research and innovation policy, is related to the development of new renewable energy technologies. The next ones are market deployment policies which enable the market introduction of new and improved technologies and encourage the development of an industry. These policies aim to differentiate a product or a service and that also provides cost-competitiveness technology and enables a sustainable level of production and market share. The last category is market-based energy policies. This creates a competitive market framework and will internalize externalities associated with both energy production and consumption.

The PV market is driven by policies, and global/local policies decide the pace of PV market development. Kyoto protocol and EU commitment are the two main global policies that drive PV diffusion. Regarding the Kyoto Protocol, the EU committed to reduce greenhouse emissions by 8% between 2008 and 2012 with respect to 1990 levels. Therefore, the EU started concrete initiatives to promote energy efficiency and renewable energy. For example, EU member countries committed to a collective 8% reduction in emissions through 2010 via a legally binding agreement. In November 1997, the European Commission (EC) proposed to double the percentage of renewable energy and set targets as 12% for 2010 (EC, 1997). A year later, the European Council issued Directive 2001/77/EC on promotion of electricity and this is a response to commitments made by EU regarding Kyoto Protocol. Directive 2003/87/EC of the European Parliament and Council established a scheme for trading greenhouse gas emissions in order to reduce emissions in the EU. One year later, Directive 2004/8/EC, the installation of co-generation plants were promoted. According to this framework, member states should show the origin of generated electricity. Directive 2009/28/EC set a target among Member States that 20% of energy consumption is to be generated by renewable sources by 2020, so called 20/20/20 targets. Since 2007, member states have had three objectives: emitting 20% less CO2 than in 1990, consuming 20% less energy (energy/GDP) and generating 20% of primary energy from renewable energy sources by the year 2020 (CEC, 2008a; Ciarreta et al., 2011; EC, 2005; EP, 2009).

In April 2009, the EC set legally binding targets and all 27 member states will attain 20% target by 2020 from 10.3% share of renewable energy sources in 2008. Share of renewable energy in electricity among EU countries varies. To achieve this goal, technological development needs to be made via industry and market deployment (EP, 2009; United Nations, 1997). Under Directive 2009/28/EC on the Promotion of the use of energy From Renewable Sources (the Renewable Energy Directive), EU member countries were obliged to submit by June 2010 NREAPs (National

Renewable Energy Action Plan), their upcoming plans to meet renewable targets. National renewable energy policies of member states can be influenced by political changes and natural disasters. In May 2011, the European Renewable energy Council called for a binding 35% target for renewable energy in Europe's final power consumption by 2030.

The table below shows the renewable energy legislations chronologically in EU based on the information above.

Table 2.1 : EU législations on renewable energy.

EU Directive	Content
Directive 1996/92/EC,	establishing common rules for the internal market in electricity by considering environmental objectives.
Directive 2001/77/EC	on the promotion of electricity produced from RES in the internal electricity market.
Directive 2003/54/EC	provision of information by electricity generators regarding the origin and environmental impact of their products.
Directive 2003/87/EC	establishment of trading system for green gas emission rights and reducing these emissions in an economically efficient way (amending Directive 1996/61/EC)
Directive 2004/8/EC	promotion of high efficient co-generations plants based on the demand in the internal energy markets.
Directive 2009/28/EC	on the promotion of electricity produced from RES (amending Directive 2001/77/EC)

The table below shows countries PV installation targets by 2015 and 2020 based on EU policy target and countries action plan submitted to EU (EPIA, 2011a). EPIA also gave estimation on possible dates when the country should reach their targets. It is obviously seen that almost all countries are expected to reach their targets earlier than planned due to PV boom in EU in last years.

Table 2.2 : PV installation targets of countries in 2015 and 2020.

MW	Target 2015	Target 2020	Target 2020 expected to reach in
Germany	34279	51753	2017-2020
Spain	5918	8367	2016-2020
Italy	5500	8000	2011-2012
France	2151	4860	2013-2015
UK	1070	2680	2014-2015
Greece	1270	2200	2017-2020
Czech	1680	1695	2010
Belgium	713	1340	2013-2014
Portugal	540	1000	2016-2020
Austria	179	322	2013-2014
Bulgaria	220	303	2013-2014
Slovakia	160	300	2011

Solar energy support policies will lead to the increase of shares of solar energy although there are some obstacles because of lack of long term policy and stability. A variety of policies like FIT, renewable portfolio standard, tax credits, pricing laws, production incentives, quota requirements, trading systems etc. have been developed and implemented to promote the use of renewable energy (Kissel and Krauter, 2006). In 95 countries, solar power generation policies had been implemented by the end 2010, and these policies are the way to support renewable energy development (REN21, 2011). Detailed explanatory analysis on policy schemes are provided by REN21 (2011), Timilsina et al. (2011), Campoccia et al. (2009), Ciarreta et al. (2011), Solangi et al. (2011).

The feed-in tariff (FIT) is the most common implemented policy (26 states and 61 countries at least by the end of 2010). In 2010, FIT focused on revising existing policies for the countries that exceed expectations. In 2010 and early 2011, new FIT policies were implemented in some developing countries. To sum up, FIT is the primary mechanism in support of solar energy development (EPIA, 2010). Additionally, the reviews done by different authors show that FIT is the most effective policy instrument among all others. For example, a study evaluating renewable energy policies in EU countries found that the FIT is the most effective policy instrument to promote solar, wind and biogas technologies (CEC, 2008b). According to a study conducted by Tabbush (2011) on the effectiveness of support systems wind power case, FIT for wind has proven to be cost effective with an off take price of Euros 76.5/MWh which is 20% – 30% above current European power prices. FIT enables a high level of diffusion with relatively cheaper cost.

Nonetheless, there are some debates surrounding the effectiveness of FIT. Tabbush (2011) raised his concerns on the effectiveness of FIT mechanism for less mature technologies, mainly due to the limited push on the value chain for cost reduction and the possibility of a high level of government liability on long term FIT payments. It is stated that each country has their own specific conditions and should make its own decision based on country's circumstances and objectives (Lipp, 2007; Hvelplund, 2001).

According to Ekins (2004), no optimal model has emerged, and most likely none will emerge in the context that is shaped by different histories and cultures. Winnerlein

(2009) also supports this and pointed out that energy decisions in a new investment are made on a national basis.

2.2.6 Economies of solar

The first large PV companies were the large oil companies that invested in the development of solar systems in the second half of the 1970s. Arco Solar was the most active company at that time. Many of those companies disappeared because of the heavy and long-term research that was required in order to enlarge the market. Another company actively involved in solar systems development was Amoco. After a while, the oil industry dropped back from PV industry. Exxon's solar power corporation ceased its activities at the very time. Others were sold to electronics companies. Arco Solar was sold to Siemens, whereupon Siemens developed it for a while before selling it to Shell Solar. There is increasing interest from the electronic industry in PV companies, which is a logical strategic move because of the synergies and economic scope and scale. Utility companies are an emerging actor for ownership of PV industries for the same reasons (Lesourd, 2001). Rapid increase of Chinese players' activities in PV has developed a more global supply chain and this has forced the overall PV system costs downward. For example, Chinese crystalline silicon manufacturers made an impact of a 40% reduction in module costs, which is approximately half of the system cost (EER, 2010b).

Module cost and cell efficiency are the two major factors that affect demand for PV systems. The price of the PV module and the cost of balance system are two main components of the PV system. PV module retail price index has declined between 2001 and 2011. In regards to this, the price/Watt peak in Europe has declined from €5.5 in 2001 to €2.66 in June 2011. On the other hand, in the US, the decline is from $5.4 in 2001 to $3.1 in June 2011 . The cost of electricity generated by the PV system is decreasing because of the slump in module prices in 2011. PV module is efficient in generating electricity. Technological developments have improved the PV modules efficiency since 2004. The efficiency is expected to increase from 15% in 2010 to 22% in 2020 (URL-4, 2011).

By 2020, the US Photovoltaic Industry aims to bring PV modules to less than USD 50 cents / Watt. At these levels, solar PV electricity could effectively compete with fossil-fuel generated electricity.

The dramatic decline in module prices has been causing an increase in diffusion. However, it is speculated that solar energy might be competitive with fossil-fired electricity and it is predicted that PV will be dominant energy worldwide in optimistic scenarios. However it is for sure that the solar revolution can only be realized when PV electricity becomes cost-competitive. Keeping in mind all these optimistic predictions, everyone agrees that diffusion of PV is seen as a major step for fighting climate change (Yang, 2011).

Although there has been a significant decline in cost of PV, it still has the greatest cost range among all other energy generation technologies (Evans et al., 2009). Both improving PV efficiency and the reduction of cost of cells are still required. Cost reduction will be achieved via (i) higher conversion efficiency, (ii) less material consumption, (iii) application of cheaper materials, (iv) innovations in manufacturing, (v) mass production and (vi) optimized system technology (ISPRE, 2009).

The economics of PV systems depend on these variables:

> Capital costs expressed in monetary term/Watt-peak. A Watt-peak is the power of a cell with an electrical power of 1 W submitted to standard sunlight of 1000 W/m^2.
>
> The equivalent annual time of exposure to sunlight, sometimes called the irradiance of the system, or the actual quantity of energy received in kWh/kWp (Chabot, 1993). Although the detailed calculations of annual isolation in terms of energy received by m2 of cell surface can be performed and gives rise to complex calculations, it has become customary in photovoltaic cell economic calculations to use the annual duration of sunshine (Pulfrey, 1978; Chabot, 1993). This is equal to the total number of hours in a year (8760), multiplied by a load factor, also called the d.c. capacity factor.

The cell does not use marketed fuel as a primary source therefore the operating costs are only the maintenance costs. The economic lifetime of the system is equal to its technical lifetime. The lifetime of PV systems are assumed to be a 20-year life-time. With grid-connected and utility applications a 30-year lifetime is assumed. Although some duration tests have been conducted no actual PV plant has yet reached 30 years. Lifetime of 25 or 30 years is expected (Kurosawa et al., 1997).

PV market is often compared with fossil fuel plants. PV systems are expected to generate electricity at an equal cost for natural gas and coal-fired plants, which is the dominating electricity generation technology of today and the near future. According to some of the estimates published in the literature, this breakeven level of electricity cost can be obtained with a price of PV modules between $0.50/Wp and $1.00/Wp (Neij, 1997; IEA, 2000).

Such researches always keep comparing electricity generation cost of PV versus electricity generation cost of utilities via other technologies. However, a real comparison should be made using electricity generation cost of PV versus retail price of electricity considering self or cogeneration PV option (Byrne et al. 2004).

Based on Massini and Frankl's (2002) findings, where PV is competitive the role of small niches is getting important. These niches are too small to affect the economics of a technology but in PV industry it is possible to generate economies of scale. If the market demand in these niche segments is sufficiently large to justify investments and generate improvements then it results a cost decrease and might trigger concurrently cost reduction towards competing technologies. PV systems could be economically attractive in larger markets without benefiting from external support. This will go on until the competing technologies decrease their cost versus PV. For example, (Lesourd, 2001) states that a few years ago, uses of PV electricity are already competitive in remote areas where grid connection is not available or is costly. Village power, daily uses and lighting can the mentioned as such examples. Additionally, PV systems may be used in developing countries where grid-connected power is deficient or unavailable.

2.3 Solar Energy Development For Selected Countries

Renewable energy is growing tremendously due to price reductions and policy support in some of the key markets. However these technologies are expected to become even more common because of the side effects of high fossil fuel and its negative effects on greenhouse emissions. Although solar energy is the most significant renewable energy potential, solar energy has diffused only to the countries where FIT is available. 9 out of the top 10 PV markets are located outside the world's Sunbelt, countries around the Equator. By 2030, PV potential in Sunbelt countries could range from 60 to 250 GW by 2020 and from 260 to as much as 1.100 GW by 2030 (EPIA, 2010).

The PV market was dominated by Germany and Japan until 2007 (65% of PV total installed base of 7GW as of 2007 end). Since 2007, the impressive growth of the solar energy industry has made it one of the fastest growing industries worldwide. In the coming years, it is expected to obtain a larger share in the energy market. However, the biggest driver for the market growth is policy supported by governments. Without these policies, such big growth in the market cannot not happen (EPIA, 2011b).

By 2015 – 2017, unsubsidized solar power will cost no more to end users in many markets than electricity generated by fossil fuels or by renewable alternatives to solar exist today such as in California and Italy. By 2020, global installed solar capacity will be 20 to 40 times higher its level today (Lorenz et al, 2008).

Based on a published report by EPIA (2011a), the total PV installed base development for the world and selected countries having >1GW installations is shown in the table below, sorted by total PV installations by end of 2010. Germany is the leading country by far with 17.2GW PV installation by end of 2010 while new countries e.g. Spain, Italy, Czech Republic have been popping up in the top list of countries in last 3 years. As seen at the table below, the share of the top 7 countries reached its highest level in 2008 with 86% of worldwide PV installations and have maintained this level over the past few years despite the doubled worldwide installed base in two years.

Table 2.3 : PV Installed base development by Country.

GW	2000	2005	2006	2007	2008	2009	2010
Germany	0.1	2.0	2.8	4.0	6.0	9.8	17.2
Spain	0.0	0.0	0.1	0.7	3.5	3.5	3.9
Japan	0.1	1.4	1.7	1.9	2.1	2.6	3.6
Italy	0.0	0.0	0.1	0.1	0.5	1.2	3.5
US	0.3	0.5	0.6	0.8	1.2	1.6	2.5
Czech Rep.	0.0	0.0	0.0	0.0	0.1	0.5	2.0
France	0.0	0.0	0.0	0.1	0.2	0.4	1.1
Others	0.9	1.4	1.6	1.9	2.2	3.2	5.7
Total	**1.5**	**5.4**	**7.0**	**9.5**	**15.7**	**22.9**	**39.5**
Share of top 7	*40%*	*74%*	*77%*	*80%*	*86%*	*86%*	*86%*

The EU's share of the global market has remained constant for several years. While Japan was the clear leader until 2005, the EU took prime position when Germany's market started to grow under the influence of well-designed FITs. Since then, the EU has retained leadership without much challenge from other markets. Outside the EU, only Japan and the USA have more than 1 GW of installed PV capacity, although China has greater potential than today's installations.

Some of countries need to be analyzed deeply in order to have a better understanding on PV diffusion in countries. The selection criteria of focus countries are as follows. Countries with two "yes" out of three criteria will be focused:

Installed base in 2010 >1GW: Countries with >1GW installed base account for 86% of total worldwide installed base. So, these countries are assumed to represent general pattern of diffusion.

FIT in place as support mechanism: FIT is named as the most effective support mechanism among all. So, only countries with FIT in place are to be analyzed.

Announced attractive FIT (as of 2010 January): In order to understand how the PV market kicks-off, countries that announced ambitious FIT's are to be included to the deep dives.

Table 2.4 : Decision framework for focus country selection.

	Criteria 1: Installed base in 2010 >1GW	**Criteria 2: FIT in place**	**Criteria 3: Ambition FIT in place**	**Decision to keep in the focus**
Germany	Yes	Yes	No	Yes
Spain	Yes	Yes	No	Yes
Japan	Yes	No	No	No
Italy	Yes	Yes	Yes	Yes
US	Yes	Only some states	No	No
Czech Rep.	Yes	Yes	No	Yes
France	Yes	Yes	No	Yes
China	No	Yes	No	No
Belgium	No	No	No	No
Greece	No	Yes	Yes	Yes
Austria	No	Yes	No	No
Portugal	No	Yes	No	No
Canada	No	Only some states	No	No
Korea	No	No	No	No
Chile	No	No	No	No
Bulgaria	No	Yes	Yes	Yes

Based on the decision framework for the focus countries above, Germany, Spain, Italy, Czech Republic, France, Bulgaria, Greece are to be deeply analyzed.

Considering that these 7 countries represent 70% of total worldwide installed base, it is believed that this will provide the analysis to give a general pattern on PV diffusion. Especially, Greece and Bulgaria are meant to be in the focus because these countries published their subsidy system in the recent years; however no diffusion has been observed. As a potential learning point for global diffusion pattern, these two countries will be deeply analyzed within the focus. Due to the limited number of historical data especially for Greece and Bulgaria, it is known that validation and forecast for these countries might result in relatively poor quality but it is also important to keep them in the focus for global pattern recognition purpose.

Lüthi (2011) suggested analyzing PV diffusion in four phases which is adopted from Villiger et al. (2000):

1. Introduction: PV is available on the market
2. Early growth: The market share is increasing slowly but still far from sustainable growth
3. Take-off: PV becomes a profitable business with strong growth rates
4. Maturity: Grid parity is reached

In the following section, the selected 7 countries will be analyzed deeply from policy, economics and PV diffusion perspectives. The order of countries will be based upon its PV installed base at the end of 2010. FITs are analyzed upon their announcement, starting in 2004. Economic values e.g. IRR, system cost will be deepened as long as they are available.

2.3.1 Germany

a. Policy

In Germany, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) is responsible for the renewable energies within the Federal Government. The Renewable Energy Sources Act (EEG) has had a significant impact on PV market in Germany. EEG determines the procedure for grid access for all renewable energies and FIT. The goal is to set the expansion of renewable energy sources.

Until 2000, PV installation in Germany was limited, but when the law expired at the end of 1990s, a new legislation by EEG was put into force and PV industry woke up. With the legislation of "100.000 roofs program", which enabled low interest loans to investors, the PV market went into kick-off phase. The most significant change was the tariff level. When the 350MW cap was reached by mid-2003, earlier than expected, the Interim Photovoltaic Act was adopted in 2003 in order to maintain the PV diffusion (Haas et al., 2011).

In the following few years, it was obvious that a dynamic industry had emerged (BMU, 2007). Since the Interim Photovoltaic Act was initiated in 2004, the PV market has shown significant growth. Even while the contribution of it to overall consumption reached only 0.5% in 2008; it was widely used in Germany, especially among residential homes (BMU, 2008). Germany has become the world's most important PV market in the last few years. In 2009, 64.700 jobs were created thanks to EEG's policies. Electricity production from renewable sources rose to 12.5% of the total consumption (Mark and Nick-Leptin, 2010). As seen in the success story of Germany, EEG played a significant role in success story of Germany.

Renewable energy is on the top of the agenda of the Germany political life. The current government defined its coalition agreement based on a new renewable era to be welcomed. Considering the EU renewable targets in 2010 and 2020, one can say that all necessary steps have been taken (Wissing, 2010). In August 2010, the German National Renewable Energy Action Plan was published. The action plan outlines what the plan is to reach a target of renewable energies' share in gross domestic energy consumption by 2020. Concerning renewable energies, it states that this energy source will contribute the major share to the energy mix of the future (IEA PVPS, 2011).

For PV, EEG with its FIT is successful as measured by market growth over the years. With the FIT, the price for PV-generated electricity is fixed over a period of 20 years. The table below was prepared to show the development of FIT in Germany (BMU, 2007; BMU, 2008; URL-1, 2011; Lüthi, 2010).

Table 2.5 : FIT historical development in Germany.

(€ct/kWh)		Ground			Roof-top				BIPV		
		all sizes	all sizes brownfield	all sizes farmland	<30kW	30-100kW	100-1000kW	>1MW	<30kW	30-100kW	>100kW
1998					8.77						
1999					8.77						
2000					50.6						
2001					50.6						
2002					48.1						
2003					45.7						
2004		45.7	45.7	45.7	57.4	54.6	54.0		62.4	59.6	59.0
2005		43.4	43.4	43.4	54.5	51.9	51.3		59.3	56.6	56.1
2006		40.6	40.6	40.6	51.8	49.3	48.7		56.3	53.8	53.3
2007		38.0	38.0	38.0	49.2	46.8	46.3		53.5	51.1	50.6
2008		35.5	35.5	35.5	46.8	44.5	44.0		50.8	48.6	48.1
2009		31.9	31.9	31.9	43.0	40.9	39.6	33.0	43.0	40.9	39.6
2010	Jan-Jun	28.4	28.4	28.4	39.1	37.2	35.2	29.4			
	Jul-Sep	25.0	26.2	0.0	34.1	32.4	30.7	25.6			
	Oct-Dec	24.3	25.4	0.0	33.0	31.4	29.7	24.8			

b. Economics

Germany has relatively lower solar irradiation conditions and the government gives quite a lot of support for industry development in order to enable the investors to generate profits. So, this situation led concerns about EEG's economic efficiency and distribution effects for renewable energy technologies (Wnad and Leuthold, 2011). The commitment of EEG has not supported by everybody; some politicians and members of academia criticize the government's commitment towards PV industry (Wissing, 2010).

Changes in PV FIT in Germany have not ruined developers and investors' confidence in the market since the German government stated that FIT cuts are done in a way that it reflects falling cost and not cause a dramatic increase in electricity prices. For example, in late 2008 it was decided to hasten the degressive rate of the EEG PV feed-in tariff in order to stimulate a stronger PV price reduction, but this adjustment didn't change the view of investors in a negative way. Wissing (2010) and Madlani et al. (2010) shows the development of system prices in the table below. One can see the significant drop in the previous 5 years in the system prices of PV plants.

Table 2.6 : System price development in Germany.

System Prices (€/kW)	2004	2005	2006	2007	2008	2009	2010	Source
Applications <10MWp	5300	5600	5400	5500	4200	3200	2700	Wissinger (2011)
Yearly change (%)		*6%*	*-4%*	*2%*	*-24%*	*-24%*	*-16%*	
Overall	8140	8197	7197	4422	4383	3588	3077	Madlani et al. (2010)
Yearly change (%)		*1%*	*-12%*	*-39%*	*-1%*	*-18%*	*-14%*	

Shah and Greenblatt (2010) estimated that the Germany solar electricity burden due to the installations should be about 4 billion Euros in 2010. The Federal Ministry of the Environment projected that the economy will earn positive return from PV investments in 2026 (Nitsch, 2007).

Compared to the previous years, the downward revision of electricity feed-in tariffs in Germany has had little impact on module prices compared to a high rise in IRRs on solar projects in 2009. Taking 2009 tariffs, the cent €3 – 4/W reduction in construction costs enabled IRRs to reach 12 – 15% on ground and roof installations. To balance investors' profit and liabilities on government side, the cut in feed-in tariffs that came into effect on 1 January reduced IRRs to around 8 – 10% (Laurens, 2010).

In amending the EEG, policy makers provide a balance, since the PV industry is in development phase and the objective is to provide incentives for further cost reduction (Nitsch, 2007). The EEG tariff system acted on the shared burden principle and was very effective. After the debates on reduction of FIT in 2010, a 13% decrease in July and 3% decrease in October 2010 were made. An additional decrease in January 2011 reduced Germany's FITs to much lower levels compared to other EU countries. The "corridor" concept is to allow the adaptation of the level of FITs according to market growth. This concept will lead to a 15% decrease in mid 2011. In 2012, the decrease will range from 1.5% to 24%, depending on market growth (REN21, 2010).

The German EEG provides long time security to its investors. Decisive actions were taken, no negative changes have occurred, and not allowed potential problems. Now, PV gets support from both Conservatives and Social Democrats. (Lüthi, 2010). In the following table, IRR values since take-off time are listed from different sources.

Table 2.7 : IRR of PV investment in Germany.

Application Type	2004	2005	2006	2007	2008	2009	2010	Source
IRR Overall	7.5%	8.2%	8.3%	8.7%	8.9%	8.5%	9.5%	Shah V. and Greenblatt J. (2010)
IRR Overall						6.2%		Dusonchet and Telaretti (2010)
IRR Overall							7.5%	Müller (2010)
IRR Ground Mounted							7.0%	DeLine (2010)
IRR Ground Mounted							7.8%	Madlani et al. (2010)
IRR Rooftops						9.5%	9.8%	Madlani et al. (2010)
IRR Rooftops							8.0%	Shah V. and Greenblatt J. (2010)
Average	**7.5%**	**8.2%**	**8.3%**	**8.7%**	**8.9%**	**8.1%**	**8.3%**	

Germany Trade & Invest, an investment company made a list of 70 companies that are in the PV production business, and they create a turnover of 8.6 billion EUR. In addition to this, 62 PV equipment manufacturers generated additional turnover of 2 billion EUR. Also, the development of the industry employed 63.000 workers in handcraft and trade companies in Germany (IEA PVPS, 2010).

c. Diffusion

Germany is the market leader worldwide for solar PV systems installation. It had a total installed capacity of 17.2 GW by the end of 2010 (EPIA, 2011a). Lüthi (2010) pointed out that the introduction, early growth and take-off phases of diffusion took place between 1990 – 1998, 1998 – 2003, 2004 – 2008, accordingly. Considering the development of PV installed base, we might also include 2009 and 2010 as part of the take-off phase of PV diffusion.

Lüthi (2010) states that in the growth phase, the feed-in tariff would not be enough to provide an incentive to PV alone. Low-interest loans and subsidies should be combined at the same time. These financial incentives are supportive for small firms, entrepreneurs and farmers. But still, this is not enough. To ensure return on investment (ROI), the level of support should be higher than the marginal costs of generation. If it is not, the PV growth decreases. When the “100,000 roofs program” stopped, the domestic PV industry saw a decrease in demand. The Interim Photovoltaic Act introduced a higher feed-in tariff to prevent lay-offs, which would in turn affect the industry.

The German PV market grew impressively. PV systems were economically attractive because of a decrease in system prices. There was a decrease in EEG tariffs in 2010, which explained the background of a decrease in system prices (Wissing, 2010). For 2010, 7.4GW PV were installed, i.e. generating 12TWh electricity which is approximately 2% of the total consumption. All renewable energies together are expected to have a share of 17% (EPIA, 2011a). The chart below explains the PV diffusion in terms of installed base in MW (IEA PVPS, 2011).

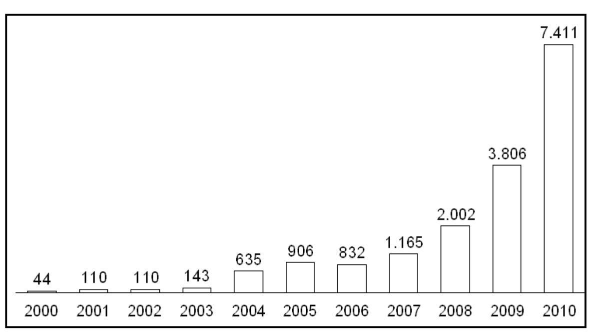


Figure 2.2 : Annual PV installations (MW) in Germany.

Because of the continuous governmental financial support, the solar sector matured in Germany, and supportive procedures greatly helped the development. (Campoccia, 2009). The corridor concept hinders the speculative PV diffusion. EEG's policy explains how Germany has sustainable PV diffusion instead of peaks and valleys (REN21, 2010).

The German National Renewable Energy Action Plan set a target of a 38,6% share of renewable energies in the sector by 2020. In the PV sector, it is estimated there will be future development of 3.5 GW from 2012 to 2020 annually. Therefore, an installed capacity of 34.3 GW by 2015 and 51.8 GW in 2020 is forecasted (URL-1, 2011).

2.3.2 Spain

a. Policy

Spain imports 80% of its energy consumption. The government has put an emphasis on renewable energy in order to balance its energy mixture. Because of the surface area and investments in solar energy plants, Spain has a key role in the implementation of renewable energy technologies worldwide, especially in Europe (EPIA, 2011a).

The renewable industry has shown significant growth in Spain. At the core was a decision by the Spanish government to implement FIT to promote the use of renewable energy, via Royal Decree 2818/1998. Royal Decree 1663/2000 provided simplified conditions for the connection of PV producers to the low voltage grid. Royal Decree 841/2002 implemented new regulations on electricity production in the special regime. Royal Decree 1432/2002 approved the average electricity tariff for reference tariff (Ciaretta, 2011). In 2004, there was a new implementation which was brought by Royal Decree 436/2004, which superseded previous implementations. This decree affected the Spanish market in a very positive way. The national PV target of 135 MW total installed base by 2010 was actually surpassed at the end of 2007.

The Royal Decree 436/2004 increased the level of FIT, reduced the administrative lead-time (by encouraging coordination between different administrative levels) and facilitated access to the grid (Lüthi, 2010). In 2005, the government approved the Renewable Energy Plan (2005 – 2010), which aims to meet the target of supplying

12% of the country's primary energy needs and 30% of its demand for electricity from renewable sources by 2010 (Diez-Mediavilla at al., 2010). A new Royal Decree 661/2007 was introduced in 2007, which regulated the production of electricity. One year later the government announced major incentive reductions for solar PV installations (Salas and Olias, 2009).

Until 2009, Spain was known as the most successful country for promoting usage of renewable energy sources, and the European Commission praised the effectiveness of the Spanish support scheme due to its low cost compared to other countries (European Commission, 2005). Two major factors support that: political commitment and support scheme (Gonzalez, 2008). However, policy changes in 2009 led Spain into a chaotic environment both for investors and employees (EER, 2009). The table below shows the development of FIT by year (Gonzalez, 2008; Lüthi, 2010; Wissing, 2010).

Table 2.8 : FIT historical development in Spain.

(€ct/kWh)	Ground mounted			Roof-top		
	100kW - 2MW	2MW - 10MW	10MW - 50MW	<5kW	5kW - 20kW	20kW - 100kW
1998				39.6	21.6	21.6
1999				39.6	21.6	21.6
2000				39.6	21.6	21.6
2001		No FIT		39.6	21.6	21.6
2002				39.6	21.6	21.6
2003				39.6	21.6	21.6
2004				39.6	21.6	21.6
2005	22.0	22.0		42.0	42.0	42.0
2006	23.0	23.0		44.0	44.0	44.0
2007	41.8	41.8	22.9	44.0	44.0	44.0
2008	41.8	41.8	22.9	44.0	44.0	44.0
2009	32.0	32.0		34.0	34.0	32.0
2010	29.0	29.0		34.0	34.0	32.0

PV installation target of Spain is 5.918 MW and 8.367 MW by 2015 and 2020 respectively (European Commission, 2009; NREAP, 2010). Considering the 3.893 MW PV installed base by 2010 (IEA PVPS, 2010), it is expected that Spain will reach its targets of 2015 and 2020.

b. Economics

The Spanish PV industry has shown improvement with the introduction of a sufficiently high feed-in tariff, which is lower than the German FIT. However, the Spanish tariff is paid over the life of the PV installation and the solar yield is 1.5

times higher than Germany (Lüthi, 2010), thus it provided a much higher return to the investors.

The Spanish FIT provides attractive conditions for PV plants. Many local and foreign investors were attracted by the high rates of return (>10%) after the introduction of the Royal Decree 436/2004 (Sieber, 2007). In addition to this, Spanish banks were also very willing to give loans for the PV (Gellings, 2006).

In Spain, policy changes happen quicker than in Germany. The delay of the Renewable Energy Fund caused an uncertainty among bankers and project developers in June 2006.

Berq (2011) and Madlani et al. (2010) shows the development of system prices at the table below.

Table 2.9 : System price development in Spain.

System Prices (€/kW)	2004	2005	2006	2007	2008	2009	2010	Source
Overall	8140	8197	7197	4422	4383	3588	3077	Madlani et al. (2010)
Yearly change (%)		*1%*	*-12%*	*-39%*	*-1%*	*-18%*	*-14%*	
Overall					6500	4200		Berg (2011)
Yearly change (%)						*-35%*		

High IRR values for PV installations because of the high FIT through 2009 triggered rapid growth. In the table below, IRRs values calculated by other authors are listed.

Table 2.10 : IRR of PV investment in Spain.

Application Type	2004	2005	2006	2007	2008	2009	2010	Source
IRR Overall							10.0%	Müller (2010)
							13.0%	Müller (2010)
						6.2%		Dusonchet and Telaretti (2010)
	6.1%	6.4%	7.1%	10.0%	13.1%	11.7%	13.0%	Laurens (2010)
IRR Ground Mounted							15.0%	Shah V. and Greenblatt J. (2010)
							12.4%	Madlani et al. (2010)
IRR Rooftop							12.6%	Madlani et al. (2010)
Average	**6.1%**	**6.4%**	**7.1%**	**10.0%**	**13.1%**	**9.0%**	**12.7%**	

c. Diffusion

Lüthi (2010) pointed out that the introduction, early growth and take-off phases of diffusion took place between 1997 – 2004, 2004 – 2006, 2006 – 2008 accordingly. The Spanish feed-in tariff, which is not characterized by an annual reduction as in Germany, provides excellent conditions for PV plants. Despite high expectations, the installed capacity increased slowly until mid-2006. One of the reasons for this is that because the applications changed so quickly, it challenged the administrative procedures and it overran the authorities. Because of the high rate of return, many submissions were made based incomplete projects. In addition to these, a lack of expertise, approving authorities and electricity problems can be blamed as well Gellings (2006).

In 2008, Spain had more than 40% of the world's total PV installations, which made Spain the fastest growing solar PV market in the world. As the market boomed, the effect of the global financial crisis led the government to revise the highly attractive PV FIT regime in 2008. Therefore, all Spanish entrepreneurs collapsed and the market was left open to better-financed players. The chart below shows the PV diffusion in terms of MW installed. The following chart shows the PV diffusion in terms of MW installed (IEA PVPS, 2011).

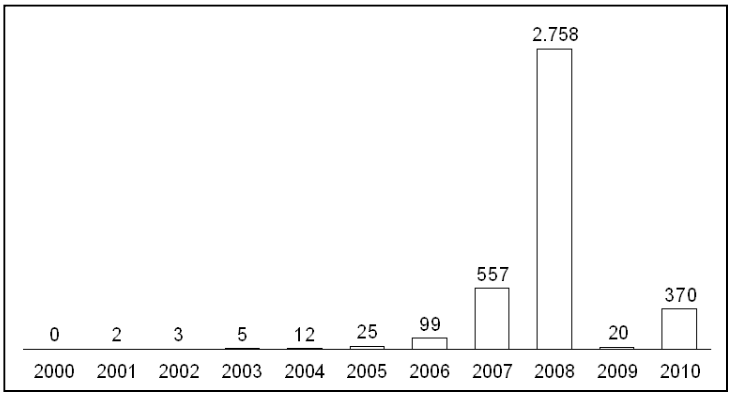


Figure 2.3 : Annual PV installations (MW) in Spain.

Some authors believe that the Spanish system is one of the major success stories. Hass et al. (2011) claim that it has managed to bring about a significant increase in deployment at moderate support levels within a short period of time. Continuity and stability of the renewable energy policy even under changing governments have contributed significantly to the success of this policy instrument. On the other hand, some authors criticize the Spanish way in PV diffusion. For instance, Lüthi (2010) and EPIA (2011b) commonly state that unlike Germany, Spain had to reduce retroactively the number of hours for which PV installations were eligible to receive FIT. The decision was made in order to mitigate the long-term risk of big government liabilities towards PV investors, but retroactive changes in PV FIT have destroyed the confidence of investors, since the economic crisis limited the government's flexibility and increased the concerns about its commitment to cover FIT liabilities. Additionally, the resulting complexity of the process and the required permissions, particularly for rooftop development, has slowed the market significantly. The main reason is the extraordinary increase in government liabilities caused by the market boom in 2007 and 2008 due to uncontrolled PV diffusion, from the thesis authors' perspective.

Similar concerns on Spanish solar boom and its implications were also shared by Iberdrola, one of the leading Spanish utilities, on October 27, 2011 at company business conference. Galan, Chairman of Iberdrola, stated that

> It is very worrying that the conventional utilities are trying to reduce the risk of nuclear/hydro taxes by arguing for cuts in solar remuneration. The reason for the Spanish system to have created a bubble, which is the term that has been used by the European Regulator Council, has to do with the massive implementation of a non-mature technology, which is the solar technology. So this situation could become much more severe in the next few years if we allow the errors made with the PV plants to be made again with solar thermal power (CSP) generation. The 2,500 megawatts that have been pre-registered for this technology could provoke an additional cost of EUR2b in premiums. So therefore, the massive deployment of CSP plants has no justification, neither from the energy, economic nor environmental point of view.

2.3.3 Italy

a. Policy

In July 2005, Conto Energia was launched following the announcement of FIT in 2007. Through 2008, PV tariff regime was set. At first, political and bureaucratic delays in the application process affected PV systems installation. The incentive program was capped at 1.2 GW of cumulative power, which can be supported by the tariff (Focacci, 2009). As a result, an increasing number of domestic and international developers are scaling their activities to advance the rooftop and ground-based segments. Finally, the Italian market kicked off at scale in 2008 with the launch of the enhanced tariff (EER, 2009). The table below shows the development of FIT by year (IEA PVPS, 2010; European Commission, 2009; NREAP Italy, 2010).

Table 2.11 : FIT historical development in Italy.

	Ground mounted			Partially integrated			Building integrated		
(€ct/kWh)	1-3kW	3-20kW	>20kW	1-3kW	3-20kW	>20kW	1-3kW	3-20kW	>20kW
2004	No FIT available								
2005									
2006									
2007	40.0	38.0	36.0	44.0	42.0	40.0	49.0	46.0	44.0
2008	40.0	38.0	36.0	44.0	42.0	40.0	49.0	46.0	44.0
2009	39.2	37.2	35.3	43.1	41.2	39.2	48.0	45.1	43.1
2010	38.4	36.5	34.6	42.3	40.3	38.4	47.1	44.2	42.3

In Italy, PV installation target is 5.500 MW and 8.000 MW by 2015 and 2020. Since 3.502 MV PV were installed by 2010, it appears that Italy can reach its targets of 2015 and 2020. Italy tracks the process and has green certificates that show if electricity came from renewable sources. The certificates are differentiated for different technologies and will be released for 15 years (IEA PVPS, 2010, NREAP Italy, 2010)

b. Economics

Because of Italy's high solar resources and retail electricity prices, Italy is expected to be the first European country to achieve grid parity. This fact will be taken into account at the time of FIT revision when 1.2 GW cap is reached. Investors consider PV as a safe investment since FIT is guaranteed for 20 years with relatively better solar sources and a quick payback period. In Italy, the payback period is 10 years, one of the shortest in Europe (EER, 2009). Calculated IRR values by different sources are listed at the table below:

Table 2.12 : IRR of PV investment in Italy.

Application Type	2007	2008	2009	2010	Source
IRR Overall			12.8%		Dusonchet and Telaretti (2010)
				15% - 20%	Müller (2010)
	10.3%	10.8%	10.6%	9.9%	Laurens (2010)
IRR Small Scale		10.0%	16.0%	20.0%	Laurens (2010)
				15.9%	Madlani et al. (2010)
IRR Large Scale		8.6%	14% - 18%	11.9% - 19%	Laurens (2010)
				16.0%	Madlani et al. (2010)
				12.0%	DeLine (2010)
Average	**10.3%**	**9.8%**	**14.2%**	**15.5%**	

On the other hand, there is a cost to this generous support. Avack (2010) states that Italian rate-payers will have to pay for the next 20 years for installations commissioned in 2011, a cost between Euro 17.5 billion and Euro 21.2 billion i.e. 1.1% to 1.3% of Italy's GDP. However, the government decided to reduce the FIT in 2011. This decision created significant uncertainty in the market. The main motivation for this revision is to keep liabilities within a certain level (EPIA, 2011a). The PV market in Italy offers an attractive business opportunity to the investors.

In parallel to PV diffusion by years, system prices also show reduction. The table below is prepared for the system prices in Italy.

Table 2.13 : System prices in Italy.

System Prices (€/kW)	2007	2008	2009	2010	Source
Overall	5102	5113	5023	4308	Madlani et al. (2010)
Yearly change (%)		*0%*	*-2%*	*-14%*	
For 1-3 kW systems	6500	6000	4500		IEA PVPS (2010)
Yearly change (%)		*-8%*	*-25%*		
For ground mounted systems		5100	4200		Berg (2011)
Yearly change (%)			*-18%*		

c. PV diffusion

Italy's FIT established in 2008 kicked-off the market development. Incentives were categorized into three headlines: non-integrated, partially integrated and building-integrated; PV systems and developers receive these incentives. Until 1.2GW cap are installed, the incentive regime will continue. Foreign companies drove to Italy since these are the most attractive incentives in Europe (EPIA, 2011b).

The Italian market kicked off in 2008 with the enhanced tariff and this attracted the developers seeking new locations beyond Spain. Further contributing to market growth has been a push to reduce permitting challenges that have hung over the market in 2008. Favorable government support, high retail electricity prices and the PV's ability to meet the demand will push Italy's growth.

PV development in Italy was slow until 2009, because of the permissions process. Since local and regional authorities are unfamiliar with PV and national guidelines, the permission and grid-connection process was restricted. In 2010, Italy had another kick in the PV diffusion, as the permitting process was simplified and there was a modest reduction in FIT compared to other parts of Europe. Authorities expect continuous growth in the Italian PV market (Avack, 2010). EPIA (2011a) expects a continuous diffusion in the Italian PV market but Avack (2010) raised his concerns on the potential of a boom due to the extremely attractive FIT. However, a significant uncertainty occurred in 2011. Due to the Italian government's intention to revise the FIT downward, it is expected to negatively affect the positive mood of PV diffusion in Italy. In the table below, the PV diffusion in terms of MW installed is shown (IEA PVPS, 2011).

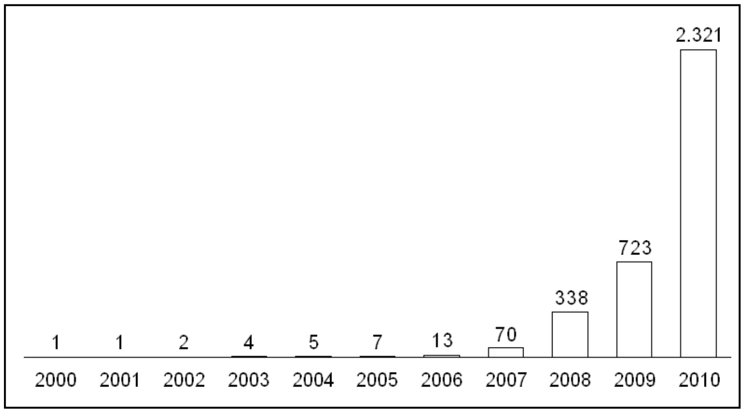


Figure 2.4 : Annual PV installations (MW) in Italy.

Solar Plaza (2011) stated that Italy could become the number one solar PV market in 2011 in terms of new installations, after Germany cut its solar feed-in tariff by 13%, as stated in the previous chapters. Additionally, GSE (2011), the Italian renewable energy regulator, states that PV installations may reach 12GW at the end of 2011, more than trebling its size in 2010. Italy will reach its 2020 target of 8GW in 2011. It obviously shows that an attractive IRR combined with a relatively smooth administrative process can kick-off the market.

2.3.4 Czech Republic

a. Policy

A law was passed on the promotion of Production of Electricity from Renewable Energy Sources in 2005, and the FIT for 20 years is guaranteed. The Energy Regulator sets the annual prices. The producers can choose two support schemes: fixed FIT or market price + Green Bonus (Jäger-Waldau et al., 2011).

Electricity consumers bear the cost of PV subsidies according to the government regulations. Therefore, 1.5 GW PV installations resulted in an increase in household electricity prices of 5% and 16% in 2010 and 2011, respectively. After extreme pressure on Czech government, it was decided to cut the FIT in order to limit the expenditures coming from FIT. In regards to this, the Energy Regulatory Office of the Czech Republic (ERU) took action in 2011. First, the ERU cut the FITs by almost 50%; second, the PV systems (excluding roof tops up to 30kW) that went into operation between January 1st 2009 and December 31st 2010 were subjected to a 26% tax. Also, the ERU hindered all state support (URL-2, 2011).

The Czech Renewable Energy Action Plan has set a target for PV at 1.680 and 1.695 MW by 2015 and 2020, respectively, which already has been surpassed with 1,925MW installations by the end of 2010, In the table below, one can see the development of FIT in Czech Republic over the years (IEA PVPS, 2010; European Commission, 2009; NREAP Czech Rep., 2010).

Table 2.14 : FIT historical development in Czech Republic.

CZK/MWh	Feed-in-tariff		Electricity Price + Premium	
	<30kW	>30kW	<30kW	>30kW
2004	No FIT		No FIT	
2005				
2006	6710		5730	
2007	14080		13100	
2008	13460		12650	
2009	12890	12790	11910	11810
2010	12250	11280	12150	11180
2011	7500		6500	

b. Economics

In general, it is obvious that the Czech government provided generous FIT for PV system investors, considering the 2GW installation in the two year period from 2008 to 2010. Dusonchet and Telaretti (2010) analyzed the financial return of FIT mechanisms in Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic and Slovenia. Their analysis shows that the most attractive IRR was found in the Czech Republic until recent changes. It is also seen in the diffusion of PV in those countries. For instance, while the Czech Republic has reached almost 2GW PV installations, none of the other countries have more than 100MW PV installations so far. For example, Simonek (2011) stated that in 2011, ERU set a new regulation that states that the new FIT should guarantee a 7% post-tax project IRR, though module prices have decreased in the recent years and FIT was cut by almost %50 in order to avoid further speculation. In the table below, IRR figures calculated by other authors are listed.

Table 2.15 : IRR of PV investment in Czech Republic.

Application Type	2008	2009	2010	Source
IRR Overall	18.0%	18.0%	18.5%	Shah V. and Greenblatt J. (2010)
		17.0%	17.5%	Müller (2010)
IRR Large Scale	14.0%	14.0%	11.0%	Madlani et al. (2010)
IRR Small Scale	16.5%	15.0%	12.5%	Madlani et al. (2010)
Average	**16.2%**	**16.0%**	**14.9%**	

Although most of the countries having interest in PV are part of IEA PVPS, the Czech Republic is not one of them. For this reason, no data regarding PV system prices is available.

c. PV Diffusion

Both high FIT rates and reduction in PV equipment costs positively affected the Czech Republic during the two year period from 2008-2010, when the country went from zero capacity in 2008 to nearly 2GW capacity by the end of 2010. The Czech Republic became the third largest PV installation country worldwide following Germany and Italy. This uncontrolled development received attention from the Czech government and grid operations (EPIA, 2011a).

Starting January 1, 2011, the Czech government decided to cut the FIT by 50%. This caused the Czech PV industry to suffer similar consequences as Spain, as has been previously documented. This reduction had a negative effect on PV investors, and government support in the PV industry started to be questioned. Due to these changes, a significant drop in the PV industry expected (Simonek, 2011). The Czech case represents an example of what should be avoided with FIT, i.e. allowing for too high of a rate of return on investment, thus leading to unsustainable market development (EPIA, 2011a). The graph below shows how annual PV installations developed in Czech Republic (IEA PVPS, 2011).

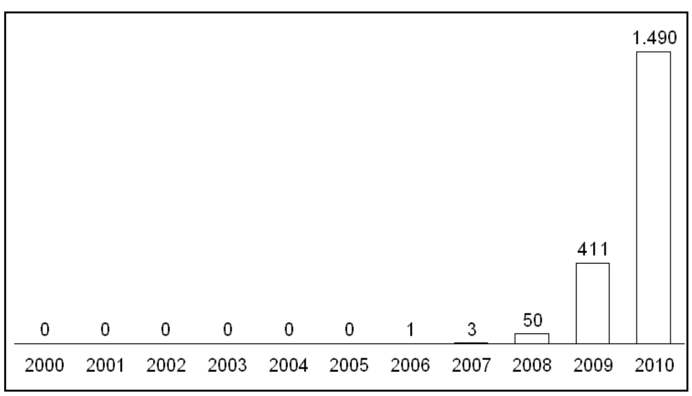


Figure 2.5 : Annual PV installations (MW) in Czech Republic.

2.3.5 France

a. Policy

Until 2007, only tax credit support (40% in 2005 and 50% in 2006) was available in France, and this was not enough to trigger PV diffusion of more than approx. 75MW.

Two Decrees by the Ministry of Industry were issued as a legal framework for FIT in France. However, the trigger point was the announcement of "Grenelle of the Environment" in late 2007 and it increased public concerns about FIT liabilities, which might resulted from PV diffusion (Durand and Jacquin, 2009). FIT for PV systems are composed of a basic tariff, for non integrated PV systems (NIPV) and a bonus in the case of building integrated PV systems (BIPV). These are accompanied by other financial incentives such as the tax credit for individuals (50% of materials costs), the reduced VAT of 5.5% (if the equipped host building is more than two years old) and the accelerated investment depreciation for companies (EER, 2009).

In November 2008, FIT guarantee period was extended from 20 years to 25 years, which provided a transparent process and long-term certainty. This appears to have stimulated PV investment. In January 2010, the government announced new rates for PV FIT. This kicked-off the PV diffusion and 719 MW installations in 2010. It resulted in a boom on government liabilities as well, therefore, a 12% FIT cut was applied by the government. In addition to this, the French government set different FIT levels for different locations in order to have a reasonable return for the investors of the investments at different locations. The following table shows the development of FIT by year (IEA PVPS, 2010; EER, 2009; NREAP France, 2011).

Table 2.16 : FIT historical development in France.

(€ct/kWh)		Continental France		Overseas Depts & Corsica
		Northern	Southern	
2007	Roof top and ground mounted	30.0		40.0
	BIPV	55.0		55.0
2008	Roof top and ground mounted	31.2		41.6
	BIPV	57.2		57.2
2009	Ground based	32.8		43.7
	Roof top, commercial	45.0		45.0
	BIPV	60.2		60.2
2010	Roof top and ground mounted	33.12	27.6	35.2
	BIPV residential <3kW	58		
	BIPV residential >3kW	51		
	BIPV for education or health buidlings	51		
	"Simplified" BIPV systems	37		

The France Renewable Energy Action Plan has set a target for PV at 2.151 and 4.860 MW by 2015 and 2020, respectively. It is expected that France will reach its targets of 2015 and 2020 (IEA PVPS, 2010; European Commission, 2009; NREAP France, 2010).

A new incentive scheme for PV was introduced by the government in 2011. The FIT system will be applicable for rooftop installations up to 100kW whereas rooftop installations over 100kW and ground mounted PV systems over 250kW will be subject to the tender. Therefore, the government aimed to limit the subsidy payment liabilities and extreme income guarantees to PV investors (IEA PVPS, 2010; EER, 2009; NREAP France, 2011).

b. Economics

As seen in the table related to IRR values below, economic attractiveness of a PV investment has increased and reached 12% of IRR in 2009.

Table 2.17 : IRR of PV investment in France.

Application Type	2007	2008	2009	2010	Source
IRR Overall				15.0%	Müller (2010)
			11.6%		Dusonchet and Telaretti (2010)
	10.4%	11.0%	12.9%	11.0%	Laurens (2010)
IRR Small Scale				10.6%	Madlani et al. (2010)
				11.0%	Shah V. and Greenblatt J. (2010)
IRR Large Scale				12.7%	Madlani et al. (2010)
Average	**10.4%**	**11.0%**	**12.3%**	**12.1%**	

In parallel to PV diffusion by years, system prices also have experienced significant reduction. The table below is prepared for the system prices in France.

Table 2.18 : System prices in France.

System Prices (€/kW)	2004	2005	2006	2007	2008	2009	2010	Source
Overall	13.000	11.600	8.120	5.200	5.120	5.000	N/A	Durand and Jacquin (2010)
Yearly change (%)		*-11%*	*-30%*	*-36%*	*-2%*	*-2%*		

c. PV Diffusion

The growth shows that the seed stage of the PV industrial sector is completed. The development process is now in a more mature phase and the cost of materials and facilities are declining. IEA PVPS (2011) states that the PV industry has created 25.500 jobs including downstream and upstream in France.

The cumulative PV installed base reached 1.149MW in 2010, a 6-fold increase in 2 years. As of the of 2010, a total of 4GW in projects had been submitted. These results show how a large amount of investors were attracted by the “Grenelle de l' Environnement” plan of action, launched in 2007 which targeted 1.100MW installed by late 2012 and 5.400MW in 2020(IEA PVPS, 2011). The French PV market has become active after Spain and Italy. French regulators put measures to trigger the French market. French regulators had streamlined permitting and grid connection processes, and so the market become more attractive for local and foreign project developers. Moreover, the investment by the national Energy sector champions e.g.

EDF, GDF Suez in the PV industry, added further confidence in France's potential (EER, 2009). As a result of France's actions, the annual installed base increased from 250MW in 2009 to 719MW in 2010 (IEA PVPS, 2011). On the other hand, the French renewable energy association Syndicat des Energies Renouvelables (2011) criticized the complexity of the second call for tenders for PV systems. The tender aims to install PV plants (including ground mounted) with a power up to 250kW. It is claimed that the goal of 500MW established by the French government will not be reached in the two year period 2012 – 2013. The graph below shows how annual PV installations developed in France (IEA PVPS, 2011).

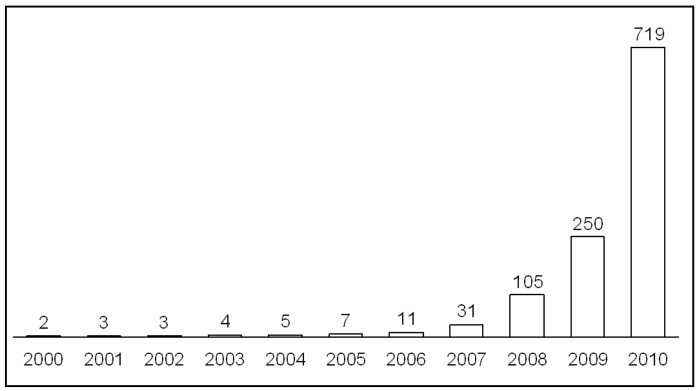


Figure 2.6 : Annual PV installations (MW) in France.

In order to prevent a windfall effect, considering the continued productivity and lower cost modules on the market, the Government revised tariffs for PV electricity to get support for this new development phase. Purchase price has decreased 12% since 2010. Additionally, a new customized FIT in March 2011 for different application areas and locations mitigated the weight of PV FIT on the government budget. This received a positive reaction for the sake of establishing a long term sustainable market instead of fluctuating market (IEA PVPS, 2010; EER, 2009; NREAP France, 2011).

2.3.6 Greece

a. Policy

Although Greece was the first country in Europe to install wind parks in 1982 and one of the first to install a PV park of 100 kW in 1983, it did not focus on increasing its renewable energy capacity.

The first PV FIT was introduced in June 2006, but received no interest among investors, due to the unfavorable investment conditions. A new feed-in-tariff was introduced in 2009, which was guaranteed for 20 years. For small rooftop PV systems an additional programme was introduced in 2009, which covers rooftop PV systems up to 10kWp (both for residential users and small companies). In June 2010, Greece acted to remove the bureaucratic barriers in front of PV diffusion via new measures. In 2010, about 150MW of new installations were carried out bringing the total capacity to about 180MW. In 2011, the tariffs decreased by 6.8 – 8.5%, depending on the size and location of the installation (Jäger-Waldau et al., 2011). The historical development of FIT in Greece is shown in the table below (EER, 2009; NREAP Greece, 2011).

Table 2.19 : FIT historical development in Greece.

	Mainland		Island	
€/MWh	<100kW	>100kW	<100kW	>100kW
2006	45.0	40.0	50.0	45.0
2007	45.3	40.3	50.3	45.3
2008	45.5	40.5	50.5	45.5
2009	45.0	40.0	50.0	45.0
2010 Feb	45.0	40.0	45.0	40.0
2010 Aug	44.1	39.2	44.1	39.2

The Greece Renewable Energy Action Plan has set a target for PV at 1.270 and 2.200 MW by 2015 and 2020, respectively (NREAP Greece, 2010).

b. Economics

Greece has provided one of the most attractive FIT, considering its high solar resources and an about-average base tariff rate. The table shows the level of IRR over the years based on available sources.

Table 2.20 : IRR of PV investment in Greece.

Application Type	2006	2007	2008	2009	2010	Source
IRR Overall				12.9%		Dusonchet and Telaretti (2010)
	6.0%	10.2%	11.3%	13.7%	17.5%	Laurens (2010)
IRR Large Ccale					10.7%	DeLine (2010)
Average	**6.0%**	**10.2%**	**11.3%**	**13.3%**	**14.1%**	

As Greece is not part of IEA PVPS countries, no transparency was provided for the system cost.

c. PV Diffusion

Greece is in the very beginning of PV diffusion i.e. in introduction phase (Lüthi, 2010). Considering the generous IRR level without an annual cap, Greece's PV market has been one of the most attractive PV markets in the world for last 2 - 3 years. This situation has attracted 30,000 applications for small projects with 5.2GW in capacity and 1,688 applications totaling 4.3GW for large projects, which is over fourfold the 2.2GW PV target by 2020 (Mccrone, 2011). However, the installed base of only 150MW by 2010 shows that the market has been in the death grip of the Greek bureaucracy, which proved itself unprepared for the flood of interest in the Greek PV market, as expressed by 9.5GW of backlogged applications. Despite the highest FIT for PV in Europe, the market only picked up sharply in 2010, reflecting the improvement in the FIT process in June 2010. It is also reflected in the approved number of projects. For example, the Greek government approved 1.8GW of solar PV projects by the end of 2010, compared to 393MW a year earlier (Mccrone, 2011).

Although the Greek government stands behind the current attractive FIT, many analysts think it is not sustainable under the current economic conditions in Greece, as well as the reduction in PV system costs. Otherwise, Greece would be a candidate for a similar diffusion pattern, much like Spain and the Czech Republic experienced. This is why it would seem unlikely that the government would allow PV installation to surge as it did in Spain in 2008 or the Czech Republic in 2010. The slow permitting process has saved the government from having to take sudden action. The fact remains however that if you get the projects permitted, built and connected, a developer in Greece can benefit from one of the highest returns in the world from PV (Mccrone, 2011; IEA PVPS, 2010; EER, 2009). The government would not allow PV installation to rise and fall as happened in Spain in 2008 and the Czech Republic in 2010. The permit process takes so long that it hinders the government from taking unexpected action. Once one gets all the required permits, it is obvious that the developer in Greece can benefit from one of the highest returns in the world from PV (Mccrone, 2011; IEA PVPS, 2010; EER, 2009). The following figure shows how the PV installed base has been developed over the years (IEA PVPS, 2011).

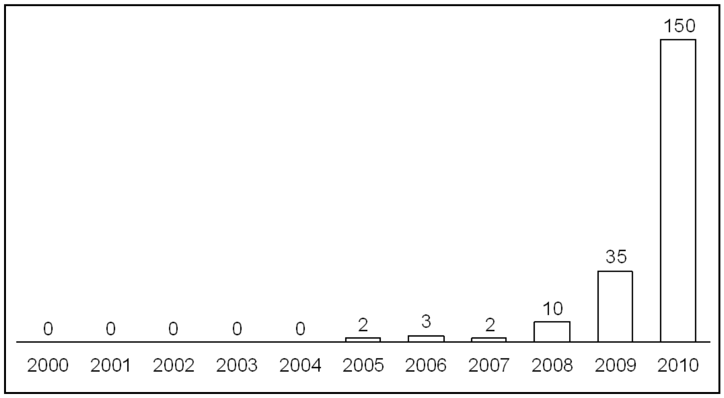


Figure 2.7 : Annual PV installations (MW) in Greece.

2.3.7 Bulgaria

a. Policy

The Energy Act by the Ministry of Economy, Energy and Tourism in 2003 and Renewable and Alternative Energy Sources and Bio fuels Act by the Ministry of Economy, Energy and Tourism in 2007 form the main legal framework for renewable energy in Bulgaria. This legal framework obligates electricity suppliers to purchase all green electricity from generators with capacity up to 10MW. In 2009, new FIT values were introduced by the State Energy and Water Regulatory Commission. Although Bulgaria has relatively higher solar potential, priority access to the grid is not given to PV plants and the investment submission process is very complex (Dusonchet and Telaretti, 2010). The historical development of FIT for Bulgaria is shown at the table below (EER, 2009; NREAP Greece, 2011).

Table 2.21 : FIT historical development in Bulgaria.

BGN/MWh	<5kWh	>5kWh
2006	Not FIT	
2007		
2008	393	372
2009	823	755
2010	793	728

The Bulgarian government introduced a law about PV regulations in May 2011 which fixed the tariff for 20 years instead of 25 years. A few months later, in order to adapt to the falling prices of PV components, and with consideration to project sizes, Bulgaria reduced the fixed premiums paid for solar power from 31% to 13% for different application scales (Roca, 2011). The Bulgaria Renewable Energy Action

Plan has set a target for PV at 220MW and 303MW by 2015 and 2020, respectively (NREAP Bulgaria, 2010).

b. Economics

Until 2011, the high rate of return attracted investors, but the market has not picked up due to administrative hurdles. With the new law, announced in May and revised in June 2011, PV projects might now generate double digit IRR. Given that Bulgaria has one of the lowest corporate tax rates of 10% in Europe, the IRR potential in Bulgaria is one of the highest in the PV world (Simonek, 2011).

Table 2.22 : IRR of PV investment in Bulgaria.

Application Type	2009	2010	Source
IRR Overall	20%	20%	Müller (2010)
	25%	25%	Müller (2010)
	14%	16%	Laurens (2010)
Average	**19%**	**20%**	

As Bulgaria is not part of IEA PVPS countries, no transparency was provided for the system cost.

c. PV Diffusion

Despite the attractive announcement and IRR values, the law guaranteeing the FIT for 20 years in Bulgaria has thus far, not achieved the expected results (Simonek, 2011). The new tariff levels remain attractive and still could attract investors, but many of them did not feel secure to invest in Bulgaria due to the unclear permit regulations (Roca, 2011). However, market conditions in 2011 i.e. high IRR and streamlined administrative processes may yet trigger a PV boom in Bulgaria. From a diffusion perspective, it might result in similar pattern as observed in Spain or the Czech Republic, in whom the high IRR caused uncontrolled PV diffusion. The following chart indicates how the PV installed base has developed over the years (IEA PVPS, 2011).

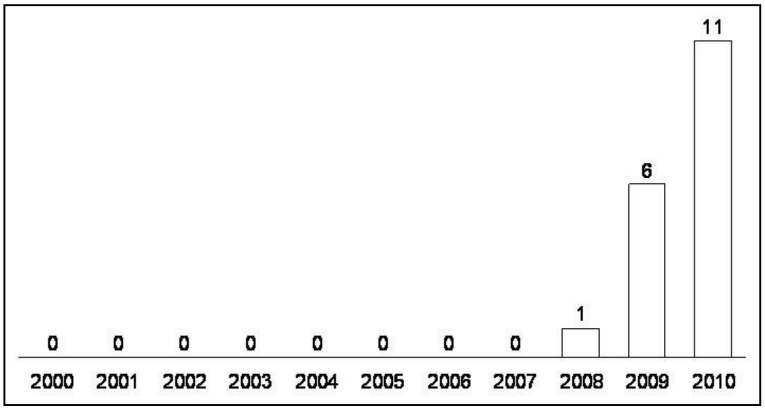


Figure 2.8 : Annual PV installations (MW) in Bulgaria.

2.4 Solar Energy in Turkey

2.4.1 Potential

The solar radiation potential in different cities has been performed by several researchers using different methodologies in Turkey. Some recent examples are as follows: Ulgen and Hepbasli (2009) validated eight new models for estimating the monthly average daily diffuse solar radiation on a horizontal surface in three big cites i.e. Istanbul, Ankara, Izmir, and thus, the most accurate model is selected for guiding future projects. Sözen et al. (2005) worked on the solar energy potential in Turkey using artificial neural networks. In order to train the neural network, meteorological data for 4 years (2000–2003) from 12 cities (Canakkale, Kars, Hakkari, Sakarya, Erzurum, Zonguldak, Balıkesir, Artvin, Corum, Konya, Siirt, Tekirdag) spread throughout Turkey were used as training data at nine stations and testing data at three stations. Meteorological and geographical data (latitude, longitude, altitude, month, mean sunshine duration, and mean temperature) were used as inputs to the network. The output is solar radiation. The maximum mean absolute percentage error was found to be less than 6.78% and the correlation coefficient value is to be about 99.7768% for the testing stations. These values were found to be 5.283 and 99.897% for the training stations. Bulut and Büyükalaca (2007) developed a simple model for estimating the daily global radiation based on a trigonometric function. Saylan et al. (2002) focused on the solar energy gain on vertical surfaces for heating and cooling systems in big cities, such as Istanbul, Ankara and Izmir, by estimating for different orientations using hourly solar radiation measurements.

Turkey’s solar energy potential is quite high because of its geographical position, which offers it an annual sunshine duration of 2640h and an average radiance of 1.311kWh/m2 per year (3.6kWh/m2 per diem), according to EIE. Turkey’s annual solar energy potential and sunshine duration changes from May to August, and the potential is calculated around 380billion kWh. The southeastern Anatolian region has the highest amount of solar energy, followed by the Mediterranean Region (URL-2, 2011). One can see the solar potential map of Turkey (Suri et al., 2008) below.

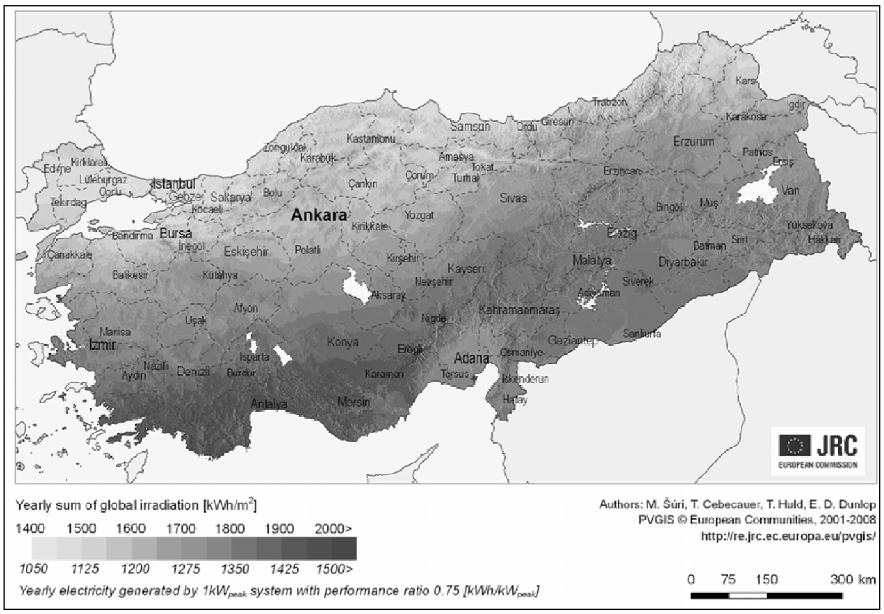


Figure 2.9 : Global irradiation and solar electricity potential.

Some authors have been working on the potential of specific applications. For example, Yilmaz and Kundakci (2008) recommended the flat south facade of an existing building in Istanbul to be renovated, applying the Trombe Wall Principle, which is a well-known indirect passive solar gain system. Bayrakci and Kocar (2011) investigated renewable applications in agriculture and evaluated the usage of solar energy in the area of greenhouse heating / cooling, food drying, solarization and irrigation.

2.4.2 Policy

The main framework for legislation took place in 2005 with the Law on the Utilization of Renewable Energy Resources for the Purpose of Generating Electricity, and amendments subsequently followed it: the 2001 Electricity Market

Law, 2007 Energy Efficiency Law and the 2007 Law on Geothermal Resources and Natural Mineral Waters are relevant legislations.

The current legislation for renewable energy was announced by the Turkish government in December 2010. It regulates the FIT for all forms of renewable energy sources. In regards to solar, the legislation has a cap of 600MW installation until the end of December 31, 2013, and guarantees a price of USD 13.3 cents per kWh. However, the government has commited to buy produced electricity only for 10 years, contrary to the common practice of 20 years in other countries e.g. Germany, Spain. Additionally, a bonus system for using "Made in Turkey" components is in place. The structure of FIT is illustrated at the figure below. Considering the unavailability of cell, inverter and focusing material (relevant for CSP technology anyhow) for suppliers by local manufacturers in Turkey, only a total of an additional 2.1 USD cents can be granted as of 2011 with the composition of elements in new FIT illustrated below.

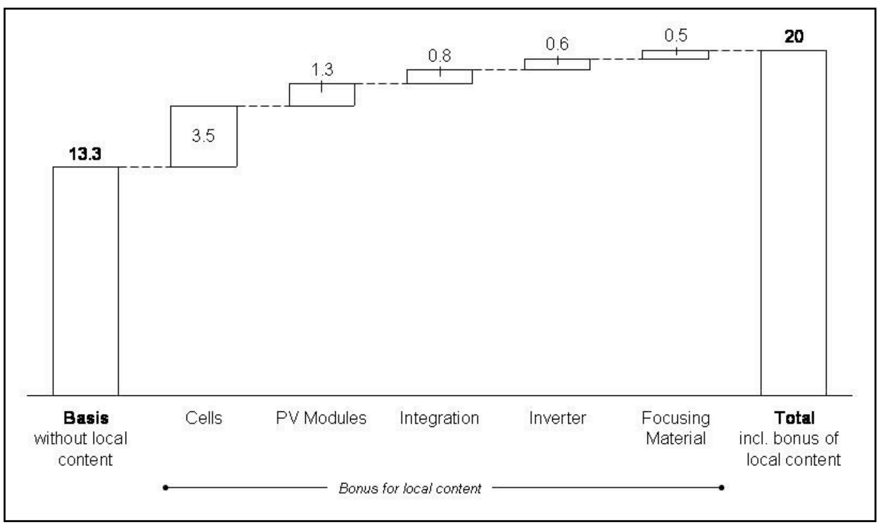


Figure 2.10 : New FIT in Turkey (USD cents/kwh).

2.4.3 Economics

Boust et al. (2011) points out that the current unfavorable FIT conditions will not be able to attract investors to invest in PV in Turkey, but rather might enable just one or two small lighthouse projects.

Neidlein (2011) elaborated on a new solar FIT in PV Magazine, a reference media for PV industry, based on his interpretations and expert opinions in Turkey. He states that the new FIT provides an unacceptably low FIT for solar and falls short in covering expectations, although it is improved over the previous FIT.

The new legislation to use more renewable energy should have been much more encouraging. It’s a start, but the tariffs are too low to attract international investors (Cetin and Egrican, 2011).

2.4.4 Diffusion

Turkey has abundant solar potential compared to most of the other European countries, but this potential has only been addressed for domestic hot water production, mainly in the sunny coastal areas at the moment. Turkey has the second largest quantity of installations for water heating systems worldwide, following China. The diffusion of solar powered water heating indicated the potential of the market for electricity generation in Turkey as well (REN21, 2010). In addition to these, the usage of PV batteries is increasing with the implementation of volume heating, also known as solar architecture (Eris, 2002). On the other hand, although Turkish people are knowledgeable about solar heating collectors and wind energy, widespread knowledge about the potential of solar electricity potential currently does not exist.

According to many environmentalists, market analysts and solar developers, the solar industry in Turkey could become one of the biggest in the world if the government offered solar producers as much regulatory and financial support as the governments of Germany and Spain, which offer solar producers generous feed-in tariffs (Cetin and Egrican, 2011).

Although solar potential exists and significant success has been achieved in the installation of solar water heating systems, similar success in the short to mid-term is not yet forecast for solar energy. Based on Lüthi’s diffusion model (2010), Turkey is not even entered into start-up phase, as there are only 5MW installations active, and they are for test purposes. No foreseeable kick-off is in the near horizon, assuming current market conditions. This conclusion has been supported by Neidlein’s interview (2011) with Mehmet Özer, the president of Turkey’s Association of Solar Electricity Producers and Photovoltaic Industrialists Businessmen. He states that there is no way that 600MW of capacity can be reached under these conditions. He claims that with all the bureaucratic procedures involved, only a few pilot projects with a capacity of at most 50MW will be in place by 2013. According to Özer, it is a total failure, full of inconsistencies which discourage not only local investors, but international investors as well. In the article by Neidlein (2011), Asuman Kilic, Chair of the Solar Power Plant Investors' Platform, shares the same pessimism, criticizing the level of FIT as well.

Cetin and Egrican (2012) stated that non-profit organizations and researchers are continuing their efforts to create a solar energy roadmap for Turkey. For example, UFTP (the National PV Technology Platform in Turkey) completed a PV roadmap for Turkey in October 2009. The following objectives were identified:

> Establish the first solar energy plant with a capacity of 20MW by the second quarter of 2012.
>
> Install a power target of 4GW by 2020, locally produce 50% of panels, cells and inverters by 2020.

There is no official PV installation target communicated as of yet. The Electricity Market and Security of Supply Strategy paper in 2009 only states a target to generalize the use of solar energy for generating electricity, ensuring maximum utilization of the country's potential. However, the following forecasts have been made by various research entities:

> EPIA (2010) forecasted the PV installed base in Turkey 1.7GW to 5.7GW by 2020 and 7.3GW to 24.4GW by 2030 depending on different development scenarios
>
> Turkish National PV Platform projects 4GW by 2020 and 8 – 10GW by 2023
>
> ICAT (The International Center of Applied Thermodynamics) estimates 4.8GW by 2020 and 7GW by 2030.
>
> EIE (General directorate of electrical power resources survey and development administration) expects a total of 5GW by 2023 of Solar PV

Celiktas and Kocar (2010) evaluated Turkey's renewable energy future using the Delphi method. The results found that 50% of Turkey's energy demand could be met by renewable energy around 2030. This result shows a much more optimistic result than the European Union's target of 20% renewable energy by 2020.

2.4.5 Academic publications

Studies in the field of renewable energy in Turkey between 1980 and 2008 were examined by Celiktas et al (2009). The study shows that a total of 311 publications on solar energy systems were published between 1980 and 2008 out of 1.555 studies in renewable energy i.e. the second highest proportion of articles in renewable energy papers with 20%. Most of the studies focused on generating hot water with the utilization of solar systems, which is in sync with local industrial applications. This research effort eventually catapulted the country to second place globally after China in terms of existing capacity as of 2007(REN21, 2011). On the other hand, it is noted that there was a significant increase in terms of publications in solar cells and PV since 2005. This may yet enhance industry growth in Turkey, as it does not have existing capacity in this field (Celiktas et al, 2009). However, the classification of publications in various subgroups of solar energy in the analysis by Celiktas et al. (2009) is not mutually exclusive. For example, a subcategory of artificial neural networks is created in parallel to radiation which might potentially overlap. So, in this thesis, no reference is given to the subcategory created by Celiktas et al. (2009).

Another analysis was conducted in the thesis database of Yuksekogretim Kurulu (YOK – Turkish Higher Education Board). 101 theses (therein 82 master, 19 Ph.D.) were searched for the key words of solar energy in the title. Most of the theses are on the specific technical implementation areas of solar energy e.g. solar thermal heater, except Kececioglu (1990) who analyzed solar energy with a comprehensive framework instead of a specific application of solar energy.

Another analysis was done in the Science Direct database. They analyzed how many articles had been published with the keywords of solar and Turkey together. The result (as of October 2011) is shown in the figure below. The figure shows that the interest in solar gained traction in 2004, was almost idle in the years of 2008, 2009 and 2010, and started to re-surface again in 2011. The most plausible reason for the re-emergence of published articles in 2011 was the increased interest in solar by companies and universities due to announcement of a new solar FIT by Turkish government.

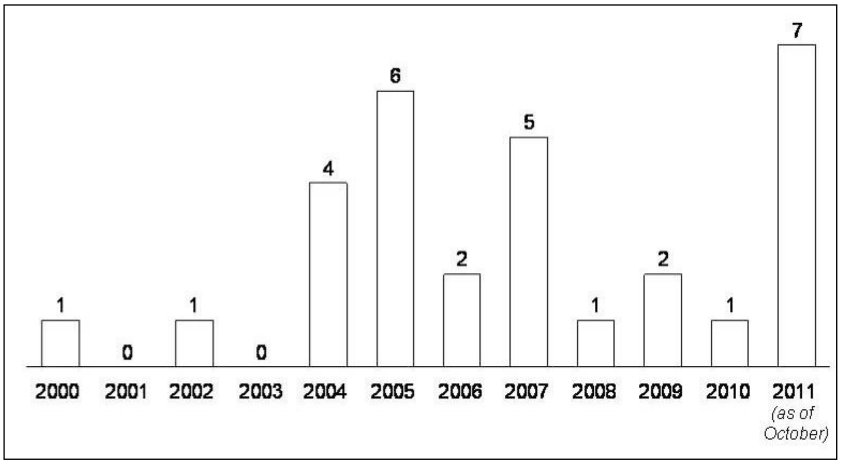


Figure 2.11 : Number of publications with key words of solar and Turkey.

When one analyzes the focus of articles, the dominating topics are solar potential and solar applications e.g. solar thermal heater and overall developments across countries. No in-depth analysis has yet been conducted in the area of technology diffusion of PV, analyzing it in a global perspective. These results also show why the focus of this thesis makes sense and contributes to the literature.

3. TECHNOLOGY DIFFUSION AND FORECASTING

Key facts on technology diffusion, applications in renewable / solar area and modeling of technology diffusion will be discussed in this section. According to Metcalfe (1988), the literature in this field can be categorized into two dominant research families:

- those defining the mechanisms and patterns of diffusion: this basically looks at the rate and total amount of adoption in a given population in a certain period of time, using curve fitting exercises
- those trying to understand and characterize the decision-making structure and process in regards to technology adoption: it tries to explain it in terms of individual decision-making based on rational choice

These two families have been supported by two models: the epidemic model and the rational choice model. This thesis focuses on the first type of diffusion pattern.

The role of technology forecasting in defining new market opportunities and product life cycles have become increasingly important. In order to develop a good forecast, a technology forecaster must have a good understanding of the technology life cycles and factors that influence technological development and rate of innovation. The first step in technology forecasting is to understand the process of growth and diffusion of a technology.

The technology life cycle theory provides a useful model helping to evaluate and understand the technology performance and goals (Sadeghi et al., 2007). Rogers (1962) was the first who discussed the theory of adoption and diffusion of new products. He regards diffusion as a five stage process: awareness – interest – evaluation – trial and adoption. Later, it referred to different stages and evolved inline with market development as innovators, early adopters, early majority, late majority and laggards. The diffusion process changes product to product, depending on various criteria. Based on Rogers' original definition, adopters are influenced in the timing of adoption by the influence of a social system. We will consider the increase in adopters by time, as the influence (pressure) increases on later adopters e.g. late majority, laggards, as seen in the figure below.

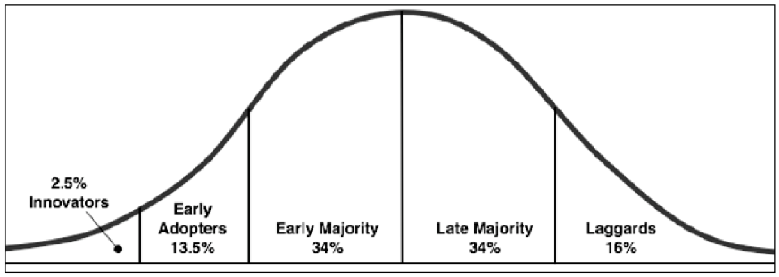


Figure 3.1 : Technology adaptation lifecycle by Rogers (1962).

In short, innovators (2.5% of total potential adopters) are risk takers who have resources and eager to create new things (products/technology/ideas), some of which end up in failure. Early adopters (13.5% of total potential adopters) are more selective about the technologies they use, they are defined as "one to check in with" for new information, and they eliminate others' doubts about a new product/technology/idea by adopting it. The early majority (34% of total potential adopters) wait before adopting new products/technology/ideas. After they see the results and how they can benefit from it, they are willing to adopt it. The late majority (34% of total potential adopters) adopt new ideas in reaction to pressure from peers and economic necessity. Uncertainties should be resolved before adoption. Laggards (16% of total potential adopters) are more traditional and make decisions on past experiences. They are not able to assume the risk of uncertainties in new things (products/technology/ideas).

High-tech marketing expert Geoffrey Moore described a chasm in the technology adoption lifecycle (Moore, 2001). The chasm is between visionaries and pragmatists. Visionaries are early adopters of brand new technologies. They are eager to try unfamiliar products. These early adopters form a separate market from mainstream consumers. Mainstream consumers are pragmatists, who are careful to examine the proven benefits of a product.

A product lifecycle is divided into four stages from a marketing perspective: introduction - growth – maturity and decline (Kotler, 2003). In the introduction stage, sales growth is relatively slow since the product is generally launched into the market with little awareness. Secondly, quick sales growth is expected in the growth stage, which results from wider acceptance of the product by the market. When the market is saturated, it means that the product enters the mature stage, and consequently sales decline and a substitute product is introduced into the market. This product lifecycle is usually modeled using growth curves or S-curves, which have an inflection point and upper limit (Mahaian et al., 1990; Morrison, 1996).

These phases are always the topic for technological forecasting in order to understand the development of a product life cycle and technological diffusion. The study of growth and diffusion phenomena has become of great interest to many disciplines, as may be seen in the numerous articles published in several areas.

3.1 Technology Diffusion Frameworks In Solar

The IEA (1993) studied the potential for PV diffusion, using PV development price. PV is expected to take over progressively, from which viable technology is used for radical techno-economic improvements, which secures its success. Although the IEA report dates back to 1993, it gives a nice overview of a PV diffusion model from the perspective of meeting the cost of electricity generation at certain locations.

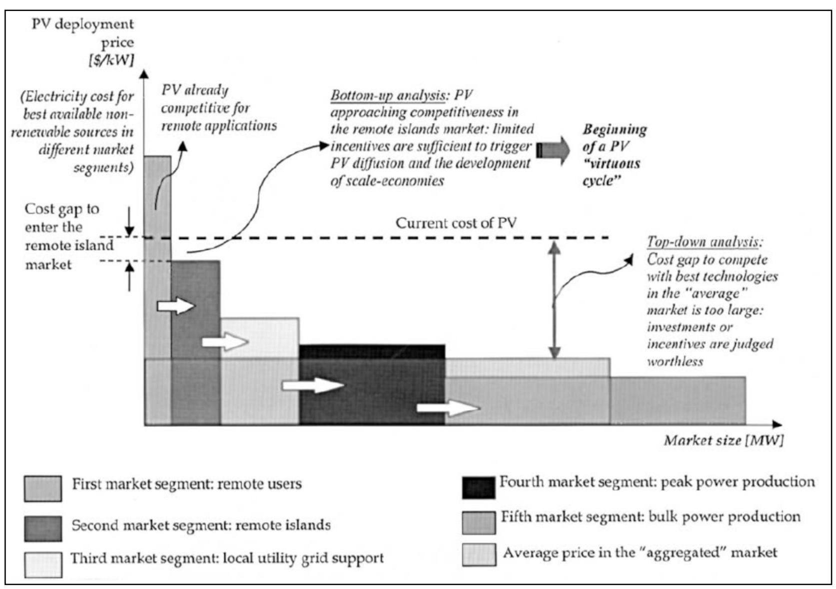


Figure 3.2 : PV, likely market diffusion stages (IEA, 1993).

In light of the IEA study (1993), Lüthi (2011) suggested analyzing PV diffusion in four phases, which was adopted from Villiger et al. (2000):

1. Introduction: PV is available on the market.

2. Early growth: The market share is increasing slowly but still far from sustainable growth.

3. Take-off: PV becomes a profitable business with strong growth rates.

4. Maturity: Grid parity is reached.

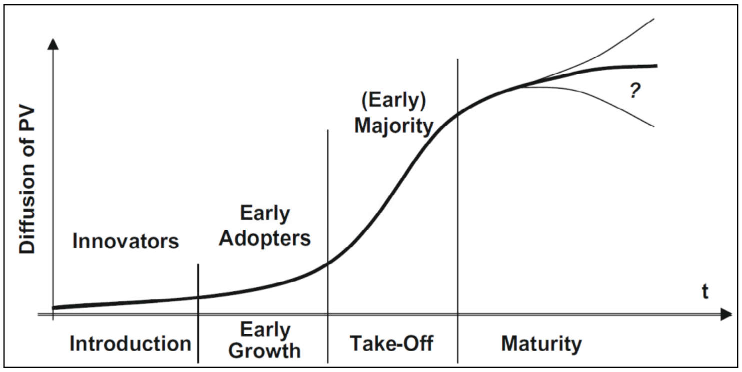


Figure 3.3 : Phases of PV diffusion (adapted from Villiger et al. (2000).

Gouchoe et al. (2002) claim that the diffusion of PV can be measured in various ways, such as installed capacity, the number of renewable energy businesses established or jobs created, the amount of energy produced or the measurement of performance relative to program goals. The most commonly used diffusion parameter is installed base.

There are three published studies focusing on PV diffusion patterns. However, only a few of them include statistical modeling as a basis. Lüthi (2010) elaborated on the diffusion variables qualitatively and identified diffusion variables. It is one of a few studies examining the balance of risk vs. return and it also gives some ideas on recognizing diffusion patterns of PV. However, the study didn't address / name any diffusion patterns. He mainly analyzed the variables rather than recognizing diffusion patterns. This article will be evaluated in detail.

Another study was done by EPIA (2011b). In the report, three diffusion patterns are identified, as seen in the figure below. It is stated that:

"Sustainable market growth allows the industry to develop and creates added value for the society and the economy as a whole. A critical aspect of sustainable development is ensuring adequate levels of profitability that in turn ensures the availability of capital for investments while avoiding speculative markets.

Consequently, investments in PV projects need to be at par with other investments of equivalent risk level"

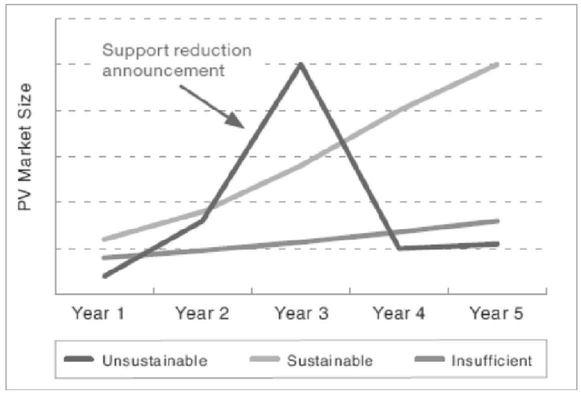


Figure 3.4 : PV market development under different support strategies.

EPIA (2011b) also elaborated on the correlation between return and diffusion speed. According to the analysis, while more than a 12% IRR value might cause a boom in PV diffusion in a country, and an uncontrolled market boom can result/results in a heavy payment commitment of government budgets for a long period of time, an IRR lower than 6% is considered an unsustainable support mechanism.

EER (2010a) has categorized Europe's solar PV sector into three main market types: maturing, scaling, and emerging. They reflect each market's status in the overall development environment and the intensity of competition. According to analysis done by EER (2010a), short-term growth is a function of feed-in tariffs (FIT) and solar resources, whereas the longer term potential will be related to renewable demand and site availability. Still immature, the solar PV sector is years away from reaching maturity. With Germany and Spain the closest to achieving this status, the markets will continue to be fragmented and ripe with development opportunities in the near to mid-term. However, the study analyzed the level of maturity based on a one year snap shot, rather than as a development story over the years.

3.2 Technology Diffusion Dynamics of Solar Energy

In the literature, there are several studies that focus on the development dynamics of PV in the countries. Most of studies approach the problem from only a few angles e.g. economic, political. There are just few studies that provide a comprehensive PV diffusion pattern.

It is generally agreed that an effective energy policy requires a combination of measures; these can be listed as regulatory instruments, financial incentives and information provision. These measures are to be adapted to the situations of each particular country (Speed, 2009).

Ways of measuring diffusion of PV might vary: reduction in technology costs in time, number of renewable energy businesses established during a program, amount of energy produced after that program, number of participants, capacity installed, or measurement of performance relative to program goals (Gouchoe et al., 2002).

Using new renewable energy technologies as a case study are now widespread since energy modeling applications are used. Although renewable energy technologies can be economically attractive, they are not considered by energy policy modeling studies.

In the table below, one can find the main contributing studies which evaluated the variables of PV diffusion, and the most relevant examples from renewable and wind. In the table, the variables which are examined by the authors are marked with “1”. As it was stated previously, a comprehensive picture of diffusion has not been in detailed in the literature. Although there is a common understanding about diffusion patterns at high level e.g. economical, political, variables vary at detail. The variables elaborated on by different authors are listed in the following table. A further analysis of the articles follows the table.

Table 3.1 : Main studies contributing PV diffusion in the countries.

	Authors, Year	**Lütfi (2010)**	**EPIA (2010)**	**Guidolin and Mortarino (2010)**	**Rao and Kishore (2009)**	**Rio and Unruh (2007)**	**Kumbaroglu et. al (2008)**	**Lund (2006)**	**Iberholt (2002)**	**Peter et. al. (2002)**	**Massini and Frankl (2002)**
	Application Area in Renewable	Photovoltaic	Photovoltaic	Photovoltaic	Wind	Photovoltaic	Fossil and renewables	All renewables	Wind	Photovoltaic	Photovoltaic
	Regional Focus	Germany, Spain and Greece	Sunbelt countries	Australia, Austria, Canada, France, Germany, Italy, Japan, Sapin The Netherlands, UK and USA	4 states in India	Spain	Turkey	None	Denmark, UK and Germany	Emerging Countries	Remote islands in southern Europe
	Used method	Explanatory analysis	Explanatory analysis	Bass Model and Generalized Bass Model	The Bass model	Evolutionary economics framework	Real options	S curves	Learning curve	Roger's model	Learning curve
Political	**Overall**	1	1	1	1	1		1	1	1	
	Legal Framework	1	1		1	1		1	1	1	
	Level of Tariff	1			1			1		1	
	Duration of tariff	1									
	Policy Stability	1									
	Cap	1									
	Administrative Processes	1				1					
Solar Potential	**Overall**			1		1	1				1
Cost of electricity generation	**Overall**	1	1	1	1	1	1	1	1	1	1
	Capital Expenditures					1	1	1			
	Build of Plant					1					1
	Components cost					1	1	1	1	1	1
	Operating Expenditures			1			1				1
	Service Maintenance						1				1
	PV Lifetime										1
	Infrastructure		1		1	1					1
	Wheeling Charges				1						
	Land availability				1						1
	Grid Access	1	1		1	1					
Knowledge	Knowledge	1	1			1				1	
Others	Electricity price						1				
	Environmental concerns			1						1	
	Financial Conditions		1	1		1	1			1	

Lüthi (2010) analyzed the deployment of PV in Germany, Spain and Greece from the return factor (level of tariff, duration of tariff and solar resource) and risk factor (PV policy stability, cap, administrative process) points of view. The author stated that deployment is not a result of only the level of tariff or solar potential, deployment is a combination of both of these aspects, et al. For example, in Germany, the PV market is booming although solar potential is not that attractive. Meanwhile, in Greece, despite a more attractive FIT in place, the PV market is still in its early phases. The main reason for this reluctant deployment is due to administrative hurdles, grid access and the risk of policy changes.

EPIA (2010) listed the main hurdles for PV development in Sunbelt countries as PV know-how & perception, policy support / level playing field, finance, grid infrastructure, implementation & service. When PV know-how lacks, it prevents PV penetration, though it is already a competitive technology. Though there have been some improvements, lack of policy support is still a barrier. In addition to this, administrative barriers exist because of the novelty of the technology and / or lack of experience at local, regional and national levels. Large projects with political support are able to receive financing, whereas the willingness of financial institutions to finance smaller PV projects tends to be limited. The lack of financing is highly correlated with the lack of PV know-how and policy support. When policy support becomes reliable and the known benefits of PV spread, financing options can be expected to emerge. To expedite this development, financial instruments need to be an active part of awareness building. Immature grid and lack of management hinders the absorption of intermittent power sources and increases operative challenges for grid operators. Development of knowledge in PV systems and services is expected to reduce the cost and lead time; however, lack of knowledge in a new market causes higher cost and longer leads times in the beginning. Therefore, PV market development slows down and can put off local investors.

Research regarding the diffusion of PV systems in 11 different countries was conducted by Guidolin and Mortarino (2010). They proposed an innovation diffusion framework based on Bass Model (BM) and Generalized Bass Model (GBM) to analyze and forecast national adoption patterns of PV installed base. They have examined the diffusion i.e. installed base development under political, solar potential, environmental concerns and financial conditions. We will further evaluate the results of the forecast in the following chapters.

Rao and Kishore (2009) developed a Composite Policy Index in order to quantify the impact of external influences. Their Composite Policy Index includes the variables of preferential tariff, wheeling charges, banking, additional state incentives, third party sales, availability of adequate transmission facilities and land availability for installations.

Rio and Unruh (2007) analyzed the dynamics that block or expedite the diffusion of renewable energy technologies using an evolutionary economics framework. Technological, organizational, industrial, social and institutional factors are evaluated in the framework that was developed by the authors. The paper suggests that the main cause for locking-out wind and PV are return on investment and financing.

Kumbaroglu et. al (2008) worked on how learning curves for renewable technologies can be integrated into a dynamic programming model. They mainly focused on a levelized cost of electricity (LCOE), including financial conditions and environmental effects. As a result, they point out that because of renewable energies' high cost, the diffusion of renewable energy only occurs if targeted policy exists. The study is one of the most comprehensive studies done in regards to the energy mix (including solar) of Turkey from a long term perspective. The high level of technicality of the paper hinders deriving a conclusion out of the massively analytical work, thus it would have been better if the authors had concluded their key findings in a management style communication.

Lund (2006) analyzed the market penetration rates of new energy technologies. The analysis showed that the exponential penetration rate may change from 4% to over 40% per year. The corresponding cannibalization from a 1% to 50% share of the estimated market potential may vary from less than 10 years up to 70 years. It is also explicitly mentioned that public policies and subsidies significantly impact the penetration of new technologies.

Ibenholt (2002) analyzed the development of wind energy in Germany, Denmark and the United Kingdom, using a learning curve for cost and production capacity. The result shows that development of wind energy is highly correlated to the potential of renewable energy (aerodynamic condition in this case) and different policy instruments.

The factors that influence the adoption of solar-based technology are analyzed and identified using Rogers' model by Peter et al. (2002). The crucial factors for a broader diffusion of PV systems are defined as financial incentives, government-led initiatives, reduction of investment costs, increase in reliability, dissemination of information and environmental awareness in the article.

Masini and Frankl (2002) stated that most researchers do not agree that PV systems will play a significant role in the future. The paper argues that "top-down" studies that compare the average cost of renewable and nonrenewable energy sources result in a more pessimistic approach than reality. After they detailed four different local and global cost estimation scenarios in five countries, the researchers stated that in two markets, such as building integrated systems for bulk electricity production in remote islands and building integrated systems for domestic grid support, PV technology can be competitive due to the high cost of electricity generation in the aforementioned two markets.

Niej (1997) examined experience curves to analyze the prospects for diffusion and technology adoption of renewable energy technologies. The results indicate that there is a larger cost reduction possibility in renewable energy technologies (especially if wind turbines and PV are analyzed) compared to conventional energy technologies. Additionally, the analysis shows that policy instruments can contribute to the diffusion and technology adoption of renewable energy technologies.

According to EPIA (2009), although some customers are willing to install PV with a negative Internal Rate of Return (IRR) (due to their subjective evaluation on CO_2 avoidance, security of supply rather than higher levelised cost of PV energy versus grid electricity); the mass market is motivated to install PV by the return on the investment (ROI) and the overall attractiveness of its value proposition.

Byrnea et al. (2004) also used 10% cap on PV-generated electricity, which is in the lower range of research projections. However, the assumption of a 10% limit is relatively conservative compared to other studies. The technical limit for grid use of a fluctuating energy generation sources is generally thought to be around 30% (Kelly and Weinberg, 1993). Perez et al. (1993) suggested that for PV, it can be upwards of 20%.

Lund (2010) (cited to Rogers 1995 and Lund 2001) stated that energy diffusion and adoption can be linked to the following factors:

availability and the spreading of information among market actors and users

cost and risk factors associated with the new technology

public support (e.g. financing, standards)

corporate perception of the new technologies (e.g. opportunity or threat)

volume and size effects (e.g. size of companies, number of users, market volume).

The diffusion variables mentioned by different authors are classified below. The chart gives an overview of what variables potentially influence PV diffusion. This group of variables is supposed to be the basis for statistical modeling later on.

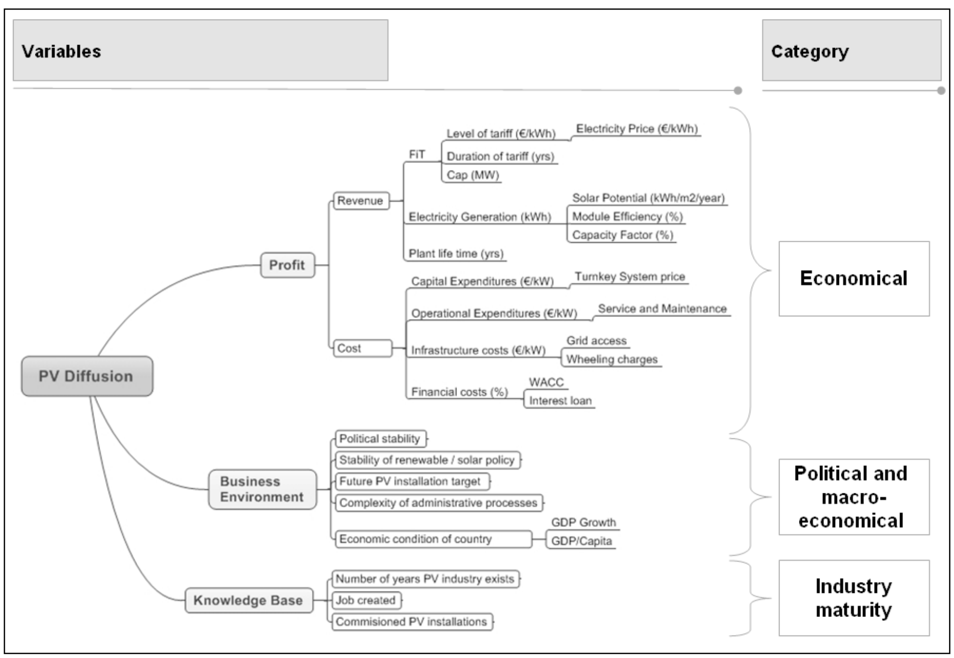


Figure 3.5 : Classification of diffusion variables.

3.3 Technology Forecasting Methodologies

Ayres (1969) and Makridakis and Wheelright (1978) have listed a large number of techniques of technology forecasting. In the following table, a summation of these techniques is listed by Mishra et al. (2002). Many additional techniques have been published subsequently, such as nominal group technique, growth model, and the analytic hierarchy process later on.

Table 3.2 : An overview of technology forecasting techniques (adopted from Mishra et al., 2002).

Subjective assessment methods	Exploratory methods of TF	Normative approaches to TF
(i) Jury of executive opinion	(i) Scenario developments	(i) OR models and simulations
(ii) Sales force composite methods	(ii) Delphi approach	(ii) Network techniques
(iii) Formal surveys and market research-based assessments	(iii) Cross-impact matrices	(iii) System of Opportunities and Negatives (SOON) charts
(iv) Individual subjective probability assessments	(iv) Curve fitting and envelopes	(iv) Relevance trees, Planning Assistance Through Technical Evaluation of Relevance Numbers (PATTERN)
	(v) Analogy methods	(v) System dynamics
	(vi) Morphological research	(vi) Dynamic modeling
	(vii) Catastrophe theory	(vii) Phenomenological modeling
	(viii) Trend extrapolation	
	(ix) Simple analytical models	
	(x) Multivariate analysis	
	(xi) Game theory	
	(xii) Growth models	
	(xiii) Input–output models	
	(xiv) Contextual mapping	
	(xv) Monitoring	
	(xvi) System for Event Evaluation and Review (SEER)	
	(xvii) Brain storming	
	(xviii) Substitution analysis	
	(xix) AHP	
	(xx) NGT	

Products and services in many areas are replaced by new technologies in a short period of time due to the fast introduction of new technologies in order to satisfy customers. For instance, the current product lifecycle for consumer electronics (e.g. cell phones and computers) is less than one year. In the 1960's it was about 10 years and in the 1980's it had been reduced to 5 years. Because of the shorter life cycle of products, less historical data is available for researchers and decision makers. Therefore, a smaller dataset must be used for forecasts of new electronic products and services (Wu, 2007). A small dataset is defined as a dataset that has short time intervals with fewer than 30 data points (Hasted and Ehlers, 1989).

Since solar energy is a newly developing technology, researchers face a shortage of historical data. For example, as there is no historical data in Turkey, if such data is not required in a study, the researchers will instead focus on technology forecasting techniques. With consideration to limited or no historical data and/or short product life cycles, many of techniques listed above are eliminated.

The most recent comprehensive analysis of diffusion models was done by Meade and Islam (2006), and they divided their analysis into two types of models; cumulative adoption models and linearised trend non-linear autoregressive models. Bass model, cumulative lognormal, cumulative normal, Gompertz, log reciprocal, logistic, modified exponential and Weibull fall into the group of models of cumulative adoption whereas Harvey, Floyd, Sharif and Kadir, KKKI and SBB (Sharma, Basu and Bhargava) are classified as linearised trend and non-linear autoregressive models.

In the following figure, Wilson and Keating (2007) provided another framework on forecast methodologies.

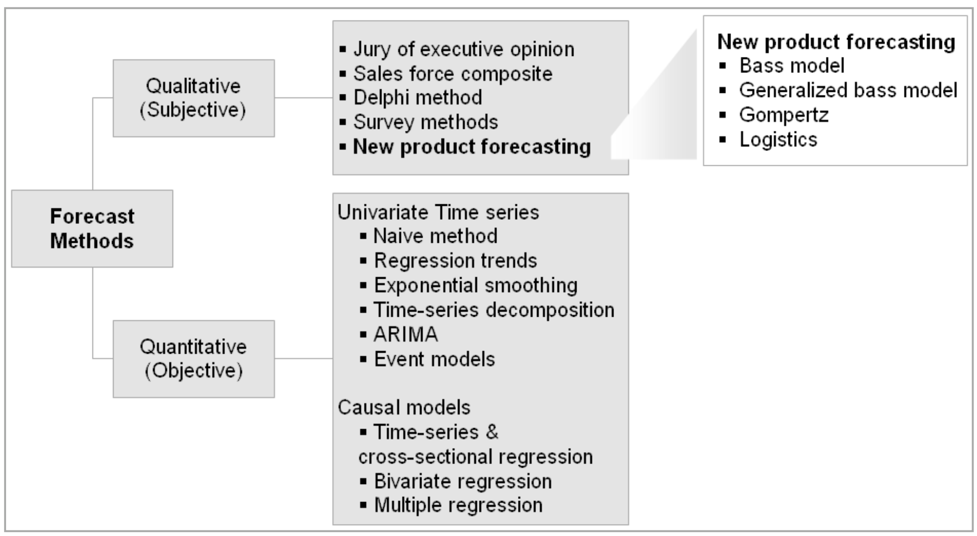


Figure 3.6 : Forecasting methodologies at glance.

Cross-country implementations of diffusion models with a comprehensive investigation were analyzed (Meade and Islam, 2006). It was concluded that modeling the diffusion of the same innovation in different countries offers several benefits. For instance, overcoming the lack of historical data in later-adopting countries is possible with a reference to the same technology diffusion in an earlier adopting country. In addition to this, the modeling impact of country specific dynamics on the diffusion process provides a perspective into country specific differences from the rate of adoption of the innovation view. Research is needed in forecasting new product diffusion with little or no data, forecasting with multinational models and forecasting with multi-generation models. The growth models are generalized in order to take into account innovations at different stages of diffusions in different countries (Gatignon et al., 1989).

Growth curves (the first derivative of the product lifecycle curve) are commonly used in technology forecasting for new products (Levary and Han, 1995; Meade and Islam, 1998) because technology product growth is often very slow during the introduction stage. This stage is then followed by rapid exponential growth when barriers to product adoption fall. The growth approaches a market share limit, which then reflects the saturation of the market. The curve also models an inflection or break point. Many growth curve models have been developed to forecast the penetration rate of technology-based products, with the simple logistic curve and the Gompertz curve the most frequently referenced (Marrison,1996; Meade and Islam, 1998).

Lackman (1993) reported that the simple logistic and the Gompertz models are suitable for forecasting high-technology products. In many practical situations, predictions of new product sales are desirable before sufficient data are available for model estimation. In the case of limited or no data like the question of this thesis, forecasting by analogy can be implemented. Lenk and Rao (1990) developed a hierarchical Bayesian approach for using data related to previous innovations to forecast technology diffusion. The information is used in a cross-sectional manner but the time horizon in the approach is based on a common time period of introduction, rather than calendar time. The advantage of this approach compared to others is that the experience of other technology diffusions informs the parameter estimation for the series of interest. Application of the hierarchical Bayesian approach for forecasting sales of recorded music in the pre-launch stage was worked on by Lee (2003), but this approach is used less in practice.

Different technology forecasting methodologies were analyzed and explained that traditional forecasting models, such as the simple logistic and Gompertz models, require an upper limit of the curve which is difficult to forecast in the beginning. This makes the forecasts unreliable and inaccurate at times. Therefore, a time-varying extended logistic model with flexible capacity is proposed, where the upper limit of the curve is dynamic over time, not constant (Trappey and Wu, 2008).

Since new products such as solar energy are lacking historical data, most of the forecasting techniques cannot produce satisfying results. In order to overcome this obstacle, forecasters use a number of models called diffusion models such as the Gompertz Curve, Logistics Curve, Bass Model and GBM. These models are also called S-curves, growth models, saturation models, or substitution curves (Wilson and Keating, 2007). Each model has different pros and cons, considering the situation. In regards to this, assessment of the models will be evaluated in the next chapter and the results will be compared.

3.3.1 Bass Model

The Bass Model, BM, proposed by Bass (1969), describes the diffusion of an innovation, depicting its characterizing phases of launch, growth, maturity and decline. Its purpose is to forecast the development over time of a new product's growth, as a result of the purchase decisions of a given set of adopters.

The most widely used model to forecast the demand for new products is the Bass diffusion model, because it can describe the S-shape penetration curve of new products with meaningful variables such as the innovation factor and the imitation factor (Mahajan et al., 1990; Maede and Islam, 2006).

The Bass model is a relatively simple model in which only three parameters are used by the researchers. The Bass diffusion model can describe the S-shape diffusion curve of a new product using the innovation factor and the imitation factor. This model is based on the assumption that the probability of adoption of a new product or technology at times is the sum of the probability of adoption by a innovator group and the probability of adoption by an imitator group (Bass, 1969). The innovation factor and the imitation factor refer to the probability of adoption by an innovator group and by an imitator group, respectively. While the probability of adoption by an imitator group, represented by q, is dependent on the number of previous adopters, the probability of adoption by an innovator group, represented by p, is independent of the number of previous adopters. The original equation, which Bass (1969) refers to as the "Bass Model Principle", directly expresses the basic principles of the Bass Model as seen below:

$$\frac{f(t)}{1-F(t)} = p + \frac{q}{M}\left[A(t)\right] \qquad \textbf{(3.1)}$$

M: ultimate number of purchasers of the product (potential market) t: time

p: coefficient of innovation

q: coefficient of imitation

f(t): The portion of the potential market that adopts at time t

F(t): The portion of the potential market that has adopted up to and including time t

A(t): The cumulative number of adopters up to and including time t

Additionally, there are other representations of the Bass Model using different symbols and what may seem to be a different equation, but they are in fact all equivalent and can be obtained from the Bass Model principle.

Bulte (2002) also evaluated two cases i.e. classical cumulative S shaped diffusion curve and the classical bell-shaped diffusion curve to see the impact of p and q on the shape of S curved diffusion. A high level of differences is seen in Figures 3.7 and 3.8 below.

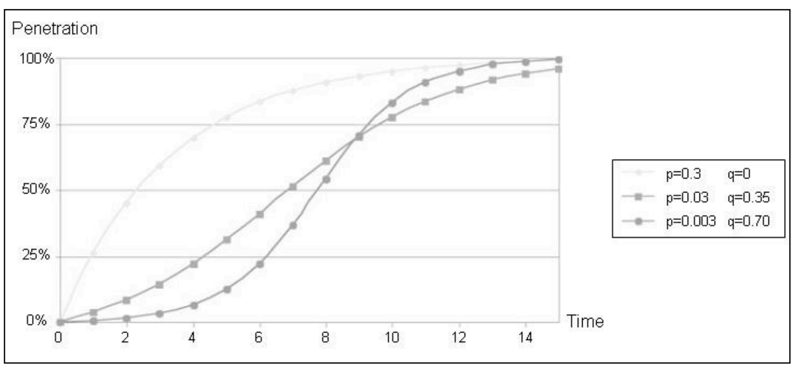


Figure 3.7 : Classical cumulative S shaped diffusion curve.

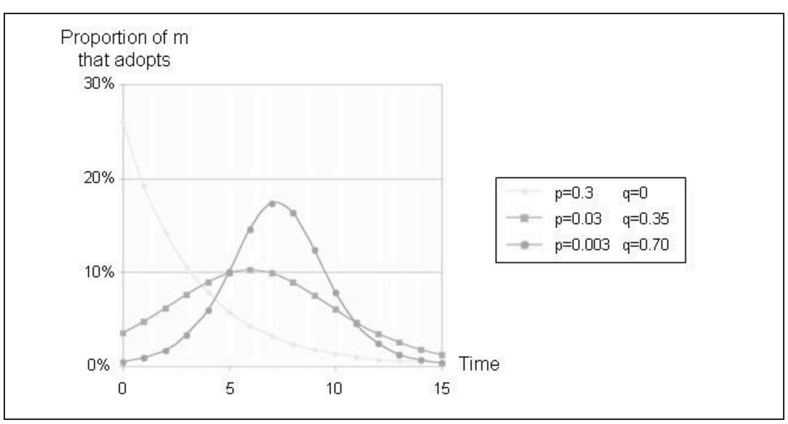


Figure 3.8 : Classical bell-shaped diffusion curve.

Since only three parameters define the shape of Bass model, it is critical to determine which values are best suited for the problem. There are two well-known studies which elaborated on the previous applications, and they came up with proposals for the p and q values. Sultan et al. (1990) developed a meta-analysis, which is considered a beneficial contribution to forecasting with limited data. They found that the coefficient of innovation was fairly stable across the 213 applications they examined, with an average value of 0.03. They also found that the coefficient of imitation is far more variable above its average of 0.38. The results also showed that the diffusion process is influenced more by factors such as word of mouth, rather than by the innate innovativeness of consumers. Secondly, Bulte (2002) built up a database of 1.586 sets of p and q parameters from 113 different recent articles. Bulte (2002) also recommended customizing the p and q parameters based on the general adoption pattern of the countries. For example, a higher q value can be used for countries with a collectivist mentality e.g. Japan, as opposed to an individualistic mentality e.g. USA. Additionally, he points out that there are systematic product differences in diffusion patterns.

Bass et al. (2001) developed a pre-launch forecast of subscriptions to satellite television for a 5-year horizon, using the Bass model. The Bass model was run with data chosen by a mixture of analogy while collecting intentions data from potential consumers. According to the authors, the forecast accuracy of their study can be considered high. Meade and Islam (2006) stated that there is still a significant demand for more accuracy in the diffusion models with no or limited data.

However, the Bass Model cannot examine external variables that can affect diffusion, such as marketing and cost reduction effects. As well, it cannot consider that the innovation factor and the imitation factor are varied by time due to the lack of influence of external variables (Bass et al.,1994).

3.3.2 Generalized Bass Model

As the technology diffusion process is affected by many dynamics, Robinson and Lakhani (1975) added marketing variables into the models and analyzed optimal pricing policies associated with the diffusion of new products. Bass, Krishnan and Jain (1994) developed a GBM which enables the integration of a mix of marketing variables in the modeling of new product diffusion in order to overcome difficulties in the Bass model. The authors reached it by introducing a "current marketing effort" factor into the original function of the Bass model.

GBM diffusion is a developed version of the Bass diffusion model. In GBM, the mapping function x(t), which describes the current effect of the decision variables on the conditional probability of adoption at time t. The equation appears below,:

$$\frac{f(t)}{1-F(t)}=\left[p+\frac{q}{M}\left[A(t)\right]\right]x(t) \qquad \textbf{(3.2)}$$

M: ultimate number of purchasers of the product (potential market)

t: time

p: coefficient of innovation

q: coefficient of imitation

f(t): The portion of the potential market that adopts at time t

F(t): The portion of the potential market that has adopted up to and including time t

A(t): The cumulative number of adopters up to and including time t

x(t): The function of exogenous variables at time t

Guidolin and Mortarino (2010) stated that GBM's structure is quite general, which also allows the opportunity to take other exogenous variables, rather than only marketing strategies, into account. This is because x(t) influences the anticipation or delay adoptions rather than increasing or decreasing number of adaptors.

Park et al. (2011) stated that GBM has some strong advantages when compared to other diffusion models that also consider the effects of external variables. First, when there are no external variables added, or they are constant over time, in GBM the equation turns into typical Bass model. Therefore a certain level of consistency with the Bass diffusion model can be achieved. Second, it is possible to consider the p, q, and m coefficients as separate functions of decision variables. Hence, the meaning of the innovation factor and imitation factor can be maintained, but it enables researchers to increase their forecast quality by enriching the input variables. Third, the generalized Bass diffusion model has a closed form, which helps it to more easily understand the behavior of the model throughout the diffusion.

3.3.3 Logistic

The logistic growth model has been widely used in different areas, from human population growth to oil development (Hubbert, 1962). Many industries such as farming, manufacturing, energy and service sectors have used this approach. Analysts have considered this approach as technological change brought about by learning-by-doing. The learning curve describes that average production costs can decrease exponentially with increases in cumulative production. (Arrow, 1962).

In brief, a profile of Logistic methodology is as follows:

Has an upper limit.

In the beginning, it increases by slow measures before acceleration increases. When it reaches its upper limit, acceleration gets slower.

In classical logistic function, the upper limit, A, is a constant and "time" is explanatory parameter. The impact of time is determined by β. With a bigger β, the equation reaches upper limit in a shorter time

General diffusion view is as follows:

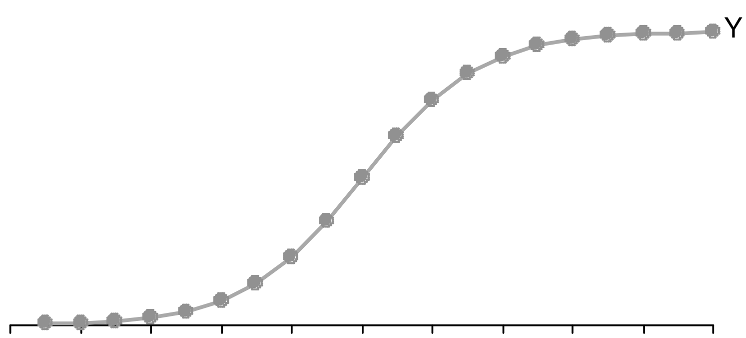


Figure 3.9 : General diffusion pattern in Logistic.

A typical learning curve over time can be expressed as a one-factor power function:

$$Y(t) = \frac{A}{1 + e^{-\beta t}} \qquad \textbf{(3.3)}$$

Y(t): cumulative value

A: maximum value of Y(t) i.e. upper limit

β: coefficient i.e. impact of time

e: 2.718282

3.3.4 Gompertz

The Gompertz model was used for the first time in 1825 by Benjamin Gompertz, in order to calculate mortality rates. Many years later, it was applied to technology forecasting (Martino, 1993). The model showed that the mortality rate increases in a geometric progression. Therefore, when death rates are plotted on a logarithmic scale, a straight line known as the Gompertz function is obtained. The Gompertz function is as follows:

$$Y(t) = Ae^{-\beta t} \quad \textbf{(3.4)}$$

Y(t): cumulative value

A: maximum value of Y(t) i.e. upper limit

β: coefficient i.e. impact of time

e: 2.718282

The Gompertz curve is best used in situations when the maximum value is approached, thus making it difficult to achieve an increase in the growth rate (Wilson and Keating, 2007).

3.4 New Product Diffusion Applications

In this section, studies using technology forecasting (not only renewable energy related) will be explored. According to Meade and Islam (2006)'s 25-year review of technology forecasting, 70% of studies are done in the area of marketing, forecasting, operational research and management science. They also deeply investigated the applications of technology forecasting in their 25-year review. From an industrial application perspective, technology forecasting is heavily used in consumer durable goods, agriculture innovations, telecom innovations, retail services and in industrial processes. For example, a search of the key words of "technology forecasting" and "communication" generates 50 results from the database of Science Direct. A few examples are as follows. Michalakelis et al. (2008) examined the diffusion rate of mobile telephony subscriptions in Greece using the Bass and Gompertz models as well as some representatives from the logistic variants. A correlation between the diffusion speed and the number of competing operators, as well as other socioeconomic and regulatory aspects is found. Gamboa and Otero (2009) examined the diffusion pattern of mobile telephones in Colombia using the Gompertz and the Logistic model. They found that the diffusion patterns were best characterized using the Logistic model. Frank (2002) studied the diffusion of wireless communications in Finland using the Logistic model. The results of the study show that the economic situation has affected the relative growth rate, and that the wireless network coverage has affected the number of potential adopters.

In addition to single country examples, another application area is multi-country modeling for a single product, which is more relevant for this thesis. For example, Kalish et al. (1983) used a diffusion model normatively to examine under which conditions sequential entry and simultaneous entry strategies should be selected when entering international markets.

The Logistic method was used by Gruber and Verbovan (2001) for modeling the diffusion of telecommunications within the EU. The introduction of digital mobile phones is the result of stagnation, due to the capacity limits of analog technology. The study indicates that a positive and strong correlation exist between the timing of introduction and the subsequent rate of adoption, but penetration levels between early and late countries is expected to emerge relatively slower.

The variables affecting the cross-country diffusion of the internet were examined by Kiiski and Pohjola (2002). They found out that the main determinants of diffusion are GDP per capita as well as access costs for internet hosts per capita, which is an independent variable.

A multinational Bass model was developed by Kumar and Krishnan (2002), and it combines simultaneous effects and lead-lag effects. Their framework allows that the first country to introduce a technology has an affect on later adopting countries' rates of adoption. Alternatively, it also allows the later countries' adoption rates to affect earlier adopting countries. Additionally, it allows the adoption in different countries to have a simultaneous effect.

Although public awareness is growing about environmental protection, minimal research has been done on clean technology, and minor attention has been paid to quantitative analyses and forecasts (Dalla Valle and Furlan, 2011). Diffusion model applications in renewable energy and in the literature are detailed in a study by Rao and Kishore (2010), which pointed out that there is a limited use of diffusion models in the renewable energy area. They made the following statement:

> The applications of diffusion models have been mainly limited to commercial products with little or no linkages to government policies. The challenge now is to build up experience in applying diffusion models to analyze diffusion of renewable energy technologies. The demand for renewable energy technologies is being created by the government through a set of policies incentives and regulations. Since renewable energy technologies face many market barriers, research so far has mainly dealt with the subject of challenges and analysis of barriers that constrain the diffusion of renewable energy technologies. There is a need for systematic study of renewable energy technologies diffusion using diffusion theory and models.

Until now, the usage of technology forecasting in wind power is wider than solar, but still very limited. Since 2005, only a few attempts have been made to model the technology diffusion of wind power: (a) Diaz-Rainey (2005), with a diffusion pattern based on logistic and loglogistic models; (b) Söderholm and Klaassen (2007), with a simultaneous innovation-diffusion econometric model, based on a learning curve, applied to some European countries and (c) Usha Rao and Kishore (2009), with a Bass model for selected states in India. Incentive schemes have been explicitly included in the model by Söderholm and Klaassen (2007), while Usha Rao and Kishore (2009) evaluated the correlation between diffusion growth and a composite policy index.

Some of the most relevant articles have already been discussed in the chapter “Technology Diffusion Dynamics of Solar Energy”. In this chapter, a further literature review has been completed so as to get a better understanding about forecasting methodologies in the area of renewable energy. Table 3.3 below shows the most relevant articles published in the area of renewable energy (particularly solar).

Table 3.3 : Literature review with technology forecasting methodology focus.

Authors, Year	Used models in the research	Application Area
Cross-country diffusion models		
Guidolin and Mortarino (2010)	Bass Model and Generalized Bass Model	Diffusion of photovoltaic technology in 11 countries
Lund (2006)	S curves	Penetration rates of new energy technologies
Desiraju et al. (2004)	Logistic Model	Diffusion of new pharmaceutical drugs in developing and developed nations
Massini and Frankl (2002)	Learning approach	Solar PV systems in southern Europe
Ibenholt (2002)	An equation of a learning curve	Compares utilization of wind energy in Denmark, Germany and United Kingdom
Islam and Fiebig (2001)	Bass Model	Multi-national study to estimate the saturation levels for fixed line telephony in 46 supply-restricted countries.
Exlanatory works on solar dynamics		
Lütfi (2010)	Explanatory analysis	Deployment of PV in Spain, Greece and Germany
Rao and Kishore (2009)	The Bass model / mixed influence model	Diffusion of wind in different States of India by linking it to a policy index
Rio and Unruh (2007)	Evolutionary economics framework	Diffusion dynamics which block or expedite the diffusion of wind and solar PV
Lund (2006)	S curves	Penetration rates of new energy technologies
Peter et al. (2002)	Roger's model	The factors that influence the adoption of solar-based technology
Isoard and Soria (2001)	Learning curve	Econometric estimation of learning curve in Solar PV and wind

Research regarding the diffusion of PV systems in 11 countries was conducted by Guidolin and Mortarino (2010). They proposed an innovative diffusion framework based on the Bass Model to analyze and forecast the national adoption patterns of PV installed base. The researchers stated that the time series available for model fitting is very short, and thus forecasts can generate results only as "likely trends" for the future installed base development. In conclusion, they generated forecasts until 2010 for 11 countries using the Bass Model, and they discovered that GBM takes into account external dynamics like incentive measures in development of installed base. After applying the same methodology to all of the 11 countries, they generated charts which included actual and validated data in a graph. The chart below shows the result of France as an example (FRAobs: actual and FRApred: estimated). As seen in the graph, the forecasted figures fit the actual data as of study date very well.

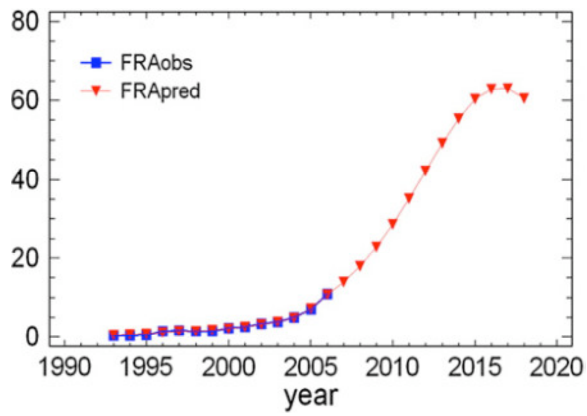


Figure 3.10 : Development of PV installed base in France (Guidolin and Mortarino, 2010).

Since Guidolin and Mortarino's (2010) study is the most relevant study to the topic of this thesis, special attention has been paid to its results. Using the Bass Model, the authors used data through 2006 to generate the results. As actual installed figures until the end of 2010 are available from EPIA, we have a chance to check the validity of the estimates. Although estimated figures are not published by the authors, results for Germany and Japan, the two most advanced PV markets, are simulated from scratch again, and the results achieved the same p, q and m values as Guidolin and Mortarino (2010). Additionally, in the figure below, the article's results are compared with actual PV installed base.

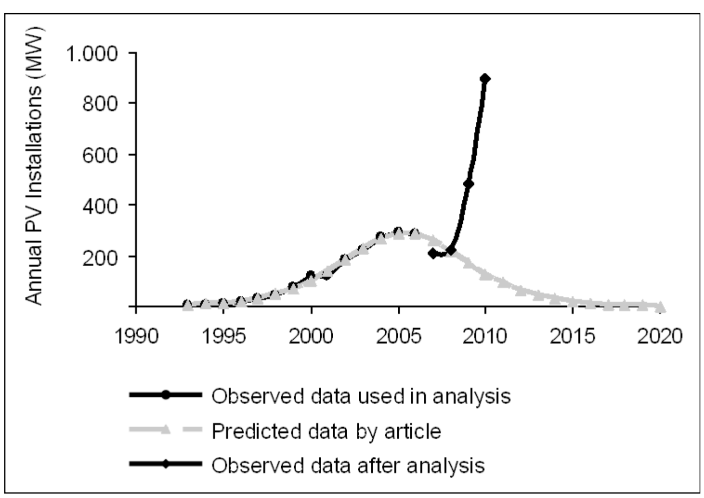


Figure 3.11 : Validation and forecast for Japan by Guidolin and Mortarino (2010).

Although ~130MW PV installation in 2010 in Japan is estimated by the authors, actual data is 900MW. The figure below shows similar result for Germany. Although only 75MW is estimated by the model, the actual data is 7.408MW PV installation in 2010. These two examples reflect poor forecasting and far being representing a “likely trend” as targeted. The suggestion of taking exogenous variables into account appears to be a requirement in the modeling in order to generate high quality estimations.

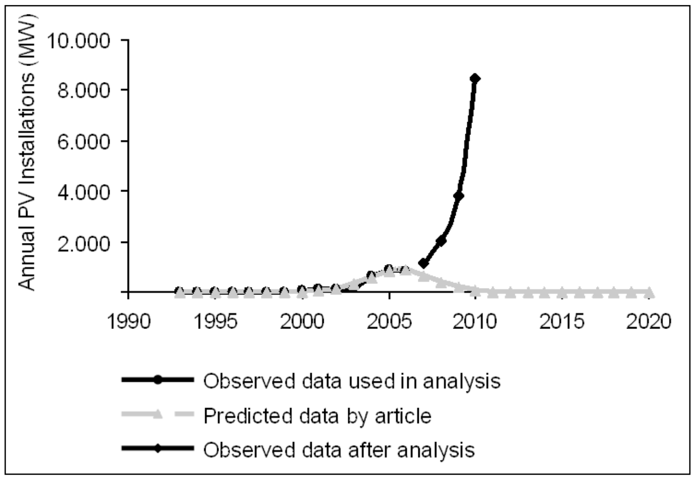


Figure 3.12 : Validation and forecast for Japan by Guidolin and Mortarino (2010).

Lund (2010) analyzed the market penetration rates of new energy technologies. The analysis shows their penetration rate may change from 4% to an exponential 40% + per year. The corresponding market-share gains from 1% to a 50% share of the estimated market, can vary from less than 10 years up to 70 years. Their analysis also explicitly mentioned that public policies and subsidies significantly impact the penetration of new technologies.

Desiraju et al. (2004) examined the market characteristics for prescription drugs in developing and developed countries (15 countries in total), using a hierarchical Bayesian framework. It was determined that there are differences in the diffusion speed and maximum penetration potential between developing and developed nations. Developing countries tend to have lower diffusion speeds and maximum penetration levels. Developed countries have higher diffusion speeds. Per capita expenditures on healthcare have a positive effect on diffusion speed (especially for developed countries), while higher prices tend to decrease diffusion speed.

Massini and Frankl's (2002) findings are mainly driven by the realization of scale economies and by the occurrence of learning-by-doing at the manufacturing level. These small niches are significant where PV is already competitive or close to competitiveness. Though these niches are too small to modify the economics of a mature technology, it is generally large enough to generate economies of scale for the PV industry. In this respect, Massini and Frankl's study is inline with the IEA (1993) report on staged diffusion pattern as discussed before.

Ibenholt (2002) focused on the diffusion of wind power in the three countries in Europe i.e. Germany, Denmark and United Kingdom with the biggest installed base. The result of diffusion dependency on FIT and wind energy potential in the country is not a surprising result, however, the authors contributed to the literature especially by linking the findings to cost and production capacity points.

Islam and Fiebig (2001) expanded on the GBM approach of Jain et al. (1991) in order to enable a multi-national study to estimate the saturation levels for fixed line telephony in 46 supply-restricted countries. Pooled cross-sectional estimates were used to forecast supply-restricted demand where little or no data is available. To leverage these findings in the modeling phase was the main target.

According to Lüthi (2010), diffusion variables are classified under return and risk topics as seen in the table below. While return attracts PV investments, risk dimension limits the diffusion. According to a literature review done by the author of this thesis, Lüthi (2010), among all authors on the topic, pointed out the best differentiations and reasons among PV diffusion in the countries from the perspectives of return and risk.

Table 3.4 : Diffusion variables and level of diffusion for three countries, Lüthi (2010).

	Germany	Spain	Greece
Return	+	++	++
Level of Tariff	+	+	++
Duration of tariff	+	++	+
Solar radiation	0	++	++
Risk	++	(+) - -	(- -) -
PV policy stability	++	(+) - -	0
Cap	++	- -	++
Administrative process	++	+	(- -) -
Level of diffusion	High	Medium	Low

The influence of return and risk factors on the level of diffusion (2008)
(++ = very favorable; + = favorable; O = medium; - = unfavorable;
- - = very unfavorable; ( ) situation in 2006).

The diffusion of solar energy can be measured using different variables, such as installed capacity, amount of energy produced, number of renewable energy businesses established, number of jobs created, accomplishment of renewable target etc. (Gouchou et al., 2002 in Lüthi, 2010)

Rao and Kishore (2009) used the Bass model for the forecasting of the installed base of wind energy in four states of India. Although the wind energy installed base is highly dependent upon energy policies (each state has different policy set), the Bass model's validity is proven/shown/reflected. Additionally, they developed a composite policy index based on variables such as land availability for installations, preferential tariffs, wheeling charges, additional state incentives, third party sales, availability of adequate transmission facilities. They determined that there is an association between diffusion variables and the composite policy index.

The study of Rio and Unruh (2007) analyzed the diffusion dynamics that block or expedite the diffusion of renewable energy technologies. The paper posits that the main causes of locking-out wind and PV are return on investment and financing. This finding is another step to linking diffusion to economic concerns, which is the heart of this thesis too.

Isoard and Antonio (2001) explored the contributions of the effects of learning and returns to scale in the capital costs reduction pattern experienced by renewable energy technologies (the authors analyzed wind and PV technologies). It is widely known that at low production levels, the long-term unit cost curve may show increasing returns to scale, whereas with a high level of production, decreasing returns to scale may occur. The results show that learning-by-doing and returns to scale have both been found to be significant and innovation-specific in the case of wind and solar PV Technologies. The paper indicates that renewable energies require initial support from technological policies before they can take full advantage of the scales of production.

Dusonchet and Telaretti (2010) performed an economic analysis of the main support mechanisms as implemented in the same countries, based on the calculation of the cash flow, the Net Present Value (NPV) and the Internal Rate of Return (IRR) indices. Their analysis shows that in some situations, support policies can be inconvenient for the owner of the PV-based generation system, and that in many cases, the differences between the implementation of the same support policy in different countries, can give rise to significantly different results. Depending on the convenience of the implemented support strategies, countries can be grouped into four categories i.e. countries with the most profitable support strategies, good strategies, less convenient support strategies and poorly implemented support strategies.

The development of a PV project would be acceptable to investors if IRR is equal to or greater than the required rate of return (Rehman et al., 2007).

A personal interview was organized on January 2011 with Dr. Saliger, who is responsible for renewable energy market forecasting and market dynamics at Siemens AG, one of leading worldwide renewable technology companies. According to Saliger (2011), the main diffusion variables are balance of IRR and risk understanding. For instance, although Greece provides one of the best investment environment with high IRR (11% - 15%), the installed base has not been ramping up at the same pace of IRR value, due to the high uncertainty about administrative processes and government stability. On the other hand, Germany offers a relatively modest IRR (8%), but its installed base has been ramping up very quickly due to a stable commitment towards renewable energy and accumulated knowledge on PV throughout the years.

3.5 Discussion of New Product Forecasting Methodologies

Timing of adoption is affected not only by endogenous mechanisms but exogenous dynamics as well. On the other hand, until now, there have not been many efforts made to unify the endogenous and exogenous mechanisms. For clean technology (Montalvo and Kemp, 2008), the main factor that exogenously affects the rate of adoption is represented by incentive schemes.

The Bass, GBM, Gompertz and Logistic models are the most commonly used methodologies in the literature. In order to shed more light on the profile of these forecasting methodologies, the following table has been prepared.

Table 3.5 : Profile of new product diffusion methodologies.

	Bass	Generalized Bass	Logistic	Gompertz
Description	▪ Run with small data set, 3 – 10 data ▪ Medium to long term forecasting ▪ No option to intervene with other variables	Addition to Bass: ▪ Possible to include exogenous variables	▪ Assumes diffusion influenced by previous adopters ▪ Option to include exogenous variables	▪ The point of inflection is fixed at 37.79% of the upper limit ▪ More difficult to achieve an increase in growth as the max. approaching
Modeling equation	Y_t = m*[1-exp(-(p+q)*t)]/ [1+(q/p)*exp(-(p+q)*t)]	Y_t = m*[1-exp(-(p+q)*t)]/ [1+(q/p)*exp(-(p+q)*t)] *X_t	$Y_t=L/(1+ae^{-bt})$	▪ $Y_t=L/e^{-ae^{-bt}}$
Most relevant examples	▪ Cross country PV diffusion in 11 countries by Guidolin and Mortarino (2010) ▪ Wind diffusion in states in India by Rao and Kishore (2009) ▪ Wind diffusion in EU, US and 4 countries by Valle and Furlan (2011)			
Bottlenecks	▪ Fixed curve → no flexibility ▪ Highly depending on initial values	▪ Highly depending on initial values		▪ Fixed curve → no flexibility ▪ Highly depending on initial values
Decision to include in modeling	No, due to lack of flexibility to include exogenous variables	Yes	Yes	No, due to lack of flexibility to include exogenous variables

Y_t: the number of people who already adopted before the time
p: people intrinsic tendency, speed of takeoff,
q: word of mouth, imitation
m: total market, consumers
X_t: exogenous parameters equation

Y_t: the number of people who already adopted before the time
L: Upper limit of Y
e: natural number 2,71
a and b = coefficients describing the curve

The methodologies flexible enough to include exogenous variables are deemed to be the appropriate selected methodology. These models allow for the inclusion of the innovative and imitative behavior of the adopters of a particular technology, as well as an assessment of the strength of the incentive policies offered by the local governments in a given country. For this reason, the Bass and Gompertz models are eliminated due to their lack of flexibility when including exogenous variables. Additionally, they have a high sensitivity regarding difficult to guess initial values, which will be discussed in the next paragraph. Eventually, GBM and Logistic were chosen to be the methodologies to be focused on in the model. A similar approach was also implemented by Guidolin and Mortarino (2010) and Desiraju et al. (2004).

Although it is not the focus of this thesis, a deep analysis has been completed to verify the sensitivity of initial values in the Bass Model, in the case of PV installed base in Germany. Using the same dataset of installed base of 1992 – 2010, a forecast until 2020 is run based on randomly selected initial values in the chart below. One might see calculated p, q and m values accordingly. As seen, predicted results vary from <1.000MW (Chart A) to 900.000MW (Chart C), which is illogical. A high dependency on initial values is the root cause of why the Bass and Gompertz methodologies were not selected.

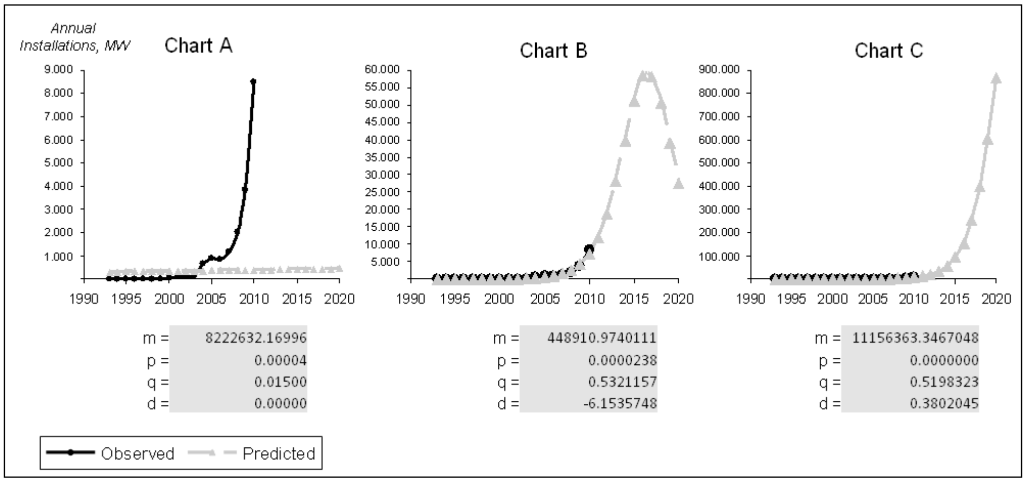


Figure 3.13 : Bass model forecasts for Germany based on different initial values.

4. SOLAR ENERGY DIFFUSION PATTERNS, MODEL AND TURKEY

4.1 Characteristic of the problem

An immature industry such as PV has certain characteristics; e.g. lack of historical data, unavailability of country specific fundamental information etc. In the thesis, the following challenges are addressed in the modeling phase:

- Limited historical data on solar globally. For example, Japan has more than 100MW annual installation only since 2000, Germany since 2001, Spain since 2006, Italy and France since 2008.
- Key diffusion variables e.g. installation cost and level of FIT often fluctuate due to changes in government policies from country to country, and also fluctuate over time due to the immature level of the technology and unplanned cost of FIT by governments.
- No historical data on the solar installed base data of Turkey exists yet. Only some experimental installations are available for a total of 5MW installed base at the end of 2010 (EPIA, 2010). This total of 5MW PV installation does not provide any basis for analysis. This situation limits the number of modeling methodologies that can be used, and thus leads to a situation whereby there won't be a validation possibility with observed / predicted data in the case of Turkey.
- Mixed messages from the Turkish government are received on its commitment to PV development in the future.

4.2 Proposed Methodology

Since there is no installed base of solar power in Turkey, cross-country diffusion comparisons will be the core approach to the problem. As stated by Guidolin and Mortarino (2010), though a global analysis of the PV sector would be certainly useful, authors of the article find a country-level study more interesting. This is so because many countries have begun to invest much effort in supporting the PV industrial sector and, in parallel, have introduced incentive measures to stimulate the domestic demand of PV systems using different strategies and obtaining different results. As stated by Meade and Islam (2006), if an innovation is available in different countries at different times, it is desirable to be able to use the data from earlier adopting countries to predict the diffusion in later adopting countries. As discussed in the literature, a multi-country analysis on new product diffusion was performed by other researchers e.g. Rao and Kishore (2009), Desiraju et al (2004), Ibenholt (2002), Massini and Frankl (2002), Isoard and Soria (2001) and Islam and Fiebig (2001).

In technological diffusion, it is well known that the timing of adoption is affected not only by endogenous mechanisms, but also by exogenous dynamics. As Lüthi (2010) stated, the deployment of PV in a country is a combination of numerous variables, not just one criterion.

The challenges above are examined in literature review with examples from the renewable energy and non-renewable energy areas. In this case, most forecasting techniques cannot produce satisfying results. To overcome the above difficulties, forecasters use a number of models that generally fall in the category called diffusion models, such as Gompertz, Logistic, BM and GBM. As discussed in the previous chapter, we will be focusing on Logistic and GBM, due to the lack of flexibility of the Bass and Gompertz models when taking exogenous variables into account. However, no ready to run software and / or add-in has been found to work on these models. EViews version 7.2 and MATLAB 2009 software are to be used as a platform for modeling.

As suggested by Gouchoe et al. (2002), the diffusion of PV will be measured with the installed base.

Based on the explanations above, the following process has been identified. The target is to develop a global diffusion model and validate it for Turkey using different scenarios based on global diffusion patterns.

Table 4.1 : Process of proposed methodology.

Phases	Identify global diffusion patterns	Develop statistical global diffusion model	Generate results for selected countries and Turkey	Set recommendations for Turkey
Work Packages	▪ Review literature ▪ Select focus countries ▪ Group countries with similar development patterns ▪ Set key diffusion dimensions	▪ Literature review ▪ Set statistical methods to follow ▪ Gather data ▪ Run / validate	▪ Analyze current FIT ▪ Identify future diffusion scenarios ▪ Validate results with external forecasts / government targets	▪ Develop recommendations for PV policy maker in Turkey
Key Deliverables	▪ List of focus countries ▪ 4 diffusion patterns ▪ 3 diffusion dimensions ▪ List of variables influencing diffusion likely	▪ Logistics and GBM methods selected ▪ Data sheet, >10k cell ▪ Developed global diffusion model (>99% associated with actual)	▪ Forecast for selected countries and Turkey ▪ 3 scenarios developed for Turkey based on global diffusion patterns	▪ List of recommendations
Spend time relatively	High	High	Medium	Low

In this thesis, the author attempts to fill in the gaps with regard to solar power technology by (a) identifying diffusion patterns in the focus countries by recognizing patterns (b) modeling exogenous dynamics in the framework of the GBM and Logistic to overtake the models proposed by Söderholm and Klaassen (2007); while simultaneously including the exogenous mechanisms by including local market conditions e.g. incentive schemes in the model, extending the model of Usha Rao and Kishore (2009), in a multi-country analysis which will be the basis for forecasting for Turkey. Moreover, (c) forecasts to be done for Turkey for different diffusion scenarios based on the most reliable models are provided and (d) policy recommendation will be performed based on the knowledge we gain from analyzing other countries.

Completing the four steps proposed in the research methodology took more than 2 years, and relatively more time spent on identifying the diffusion patterns and developing a statistical model versus other steps.

4.3 Data

Due to the lack of PV installations in Turkey, most of the data used in the modeling is related to global markets. This situation brings us the advantage of having access to relatively structured data, although a local language barrier emerges in data gathering to some extent.

There are three international, well-known and reliable information sources, EPIA, IEA PVPS, REN21. All three have published important information on PV markets. EPIA (European Photovoltaic Industry Association) is the association that represents the PV industry in front of political institutions at the European and International level, and publishes not only analytical quantitative reports also qualitative legal framework related studies. IEA PVPS (IEA Photovoltaic Power Systems Programme) is one of the collaborative R&D Agreements established within the IEA (International Energy Agency) and, since its establishment in 1993; the PVPS participants have been conducting a variety of joint projects in the application of PV. Turkey is one of the 25 PVPS members. REN21 targets the promotion of wise government policies that will increase the worldwide use of renewable energy.

Country specific data is derived from academic articles; from National Renewable Energy Action Plans, a mandatory report for EU countries; SolarBuzz, a free web-based access web site and Bloomberg,, a well-known information source for renewable / solar energy. For example, installed base figures are collected from country reports published by EPIA and system costs by IEA PVPS.

Most of data before 2003 is not available from our information sources. The following table shows the evaluation of availability / access and transparency of diffusion for focus countries. Germany, Spain and France have relatively higher data availability and transparency of diffusion from the thesis author's perspective.

Table 4.2: Evaluation of data availability and transparency of focus countries.

Countries	Installed PV in 2010	Data Access / Availability	Transparency of diffusion
Germany	18.345	●	●
Spain	3.798	●	●
Italy	2.400	◕	◕
Czech Rep.	1.820	◑	◕
France	1.155	●	●
Greece	204	◕	◕
Bulgaria	32	◕	◕

● : High ○ : None

As PV diffusion in most of the focused countries is in the emerging phase, the amount of data potentially available is limited. The table below shows which data can potentially be available by year (marked as yes), and the reason if it is not available (marked as no). As a result, a maximum of 32 sets of data can be found for all of the focus countries.

Table 4.3: Evaluation of data availability for focus countries.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Germany	No (No collectively exhaustive data)				Yes	Yes	Yes	Yes	Yes	Yes	Yes	No, (no data available yet)
Spain	No (No major PV activity yet)				Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Greece	No (No major PV activity yet)						Yes	Yes	Yes	Yes	Yes	
Italy	No (No major PV activity yet)							Yes	Yes	Yes	Yes	
France	No (No major PV activity yet)							Yes	Yes	Yes	Yes	
Czech Republic	No (No major PV activity yet)								Yes	Yes	Yes	
Bulgaria	No (No major PV activity yet)									Yes	Yes	
Turkey	No (No major PV activity yet)											

4.4 Solar Diffusion Patterns

In this chapter we will be searching for diffusion patterns, so in the first sub-chapter we will look for pattern recognition. The second sub-chapter is for understanding the reasoning behind diffusion patterns and finally, in the last sub-chapter, the characterization of diffusion patterns is to be deepened.

4.4.1 Recognition

As the key indicator for PV diffusion in countries is installed base, its development through the years is to be explored. The figure below shows how PV has been diffused in the 7 selected countries. However, it is almost impossible to derive a conclusion on the segmentation of countries and to recognize any diffusion patterns from the chart below.

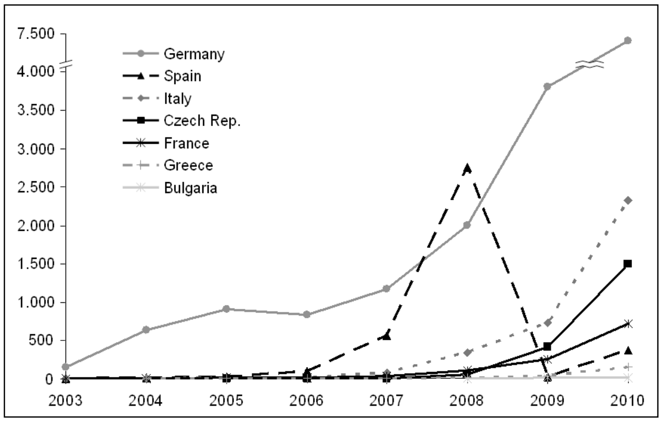


Figure 4.1 : PV diffusion in selected 7 countries, Annual MW installations.

In order to determine different diffusion patterns, years are normalized, meaning the year of PV kick-off will be named as "year 1" and sequential years will be represented as "year 2", " year 3" and so on. However, diffusion patterns are still not visible.

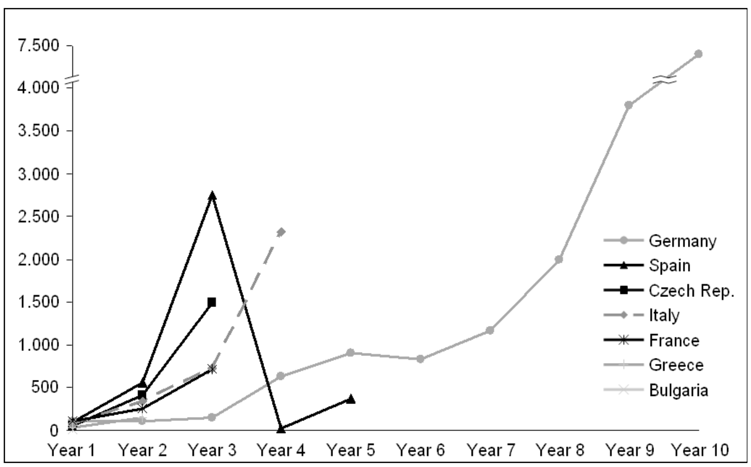


Figure 4.2 : Normalized PV diffusion in 7 countries, Annual MW installations.

Another segmentation is to be done according to the similarities of annual PV installation development. This change enables us to see an existing pattern for the countries. For example, the first trial is done for Germany and the US (included in the analysis only for comparison purposes despite it not being one of the focus countries). Year 1 for Germany is 2001 and for the US it is 2006. From the point where Y1 is plotted , the ramp-up in both countries looks quite similar, as seen in the chart below. On the other hand, Spain falls into entirely different diffusion pattern.

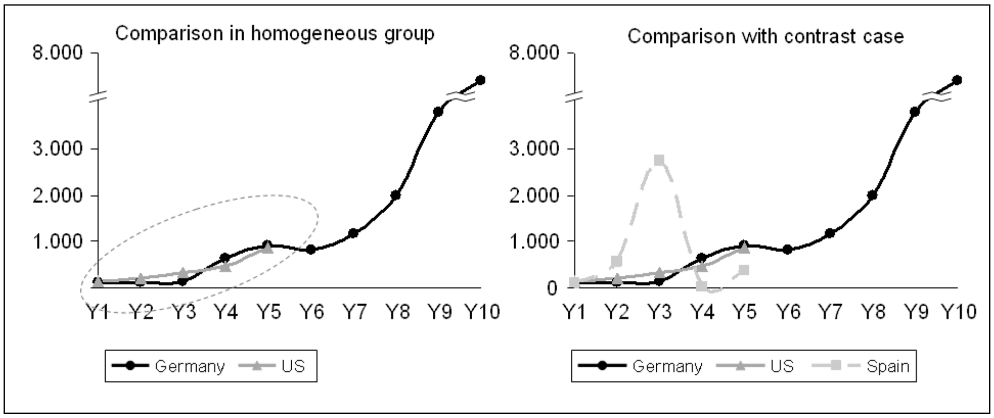


Figure 4.3 : Normalized PV diffusion in Germany and US, Annual PV, MW

As stated by EPIA (2011b), a sustainable diffusion pattern is clearly seen in Germany, where the attractiveness of PV investments are always adjusted to the market dynamics e.g. price drop in modules in order to avoid any uncontrolled jump in installed base.

Another pairing of countries is Spain and the Czech Republic. A contrast case is done with Germany, which is remarkably different when compared with Spain and the Czech Republic. Year 1 for Spain is 2006 for the Czech Republic it is 2008 Czech Republic. The installed base in Spain and the Czech Republic show a similar diffusion pattern due to the establishment of a highly attractive FIT, which resulted in a boom and then a retroactive FIT adjustment, which led to a slump in installations. For the Czech Republic, the estimated installed base of PV in 2012 (year 4) has been provided to better understand the diffusion patterns.

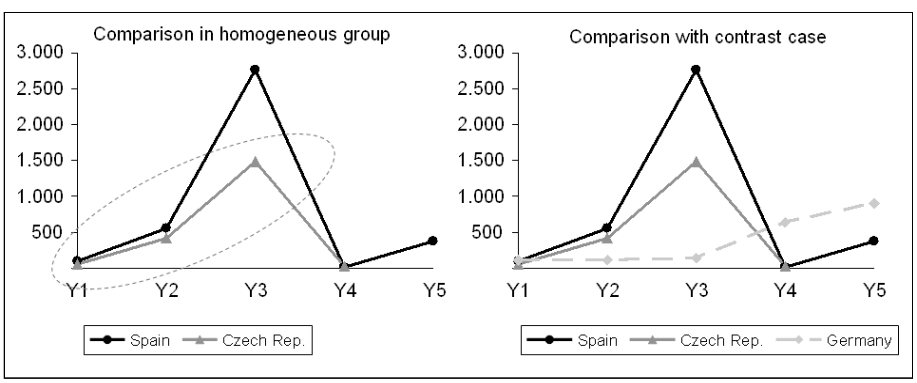


Figure 4.4 : Normalized PV diffusion in Spain and Czech Rep., Annual PV, MW.

Considering EPIA (2011b)'s statement on the association between IRR levels of PV investments, Spain and the Czech Republic both fall into the definition of an unsustainable diffusion pattern.

France and Italy are paired under a different group as well. A comparison is done, using a contrast case with Germany and Spain. Year 1 for Italy is 2007 and for France Y1 is 2008.

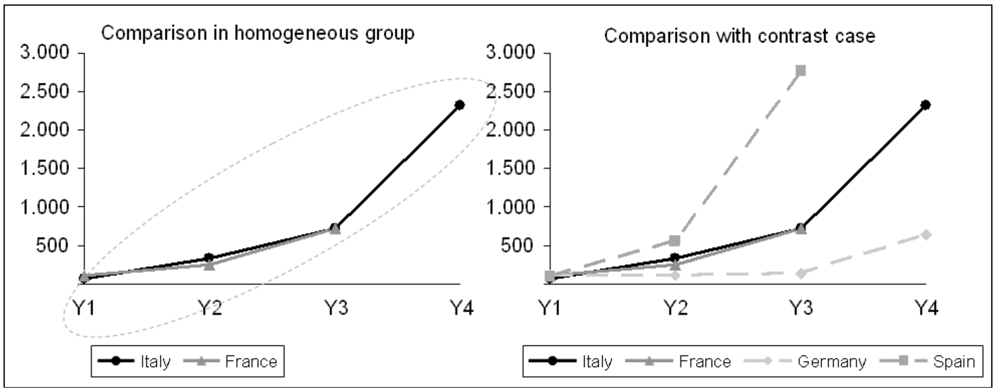


Figure 4.5 : Normalized PV diffusion in Italy and France, Annual PV, MW.

The PV market in these countries has not kicked-off yet despite relatively higher FIT grants to the investors. Kick-off conditions will be a topic for further investigation in this thesis in order to understand the reason and to shed some light in the case of Turkey. The comparison of Greece and Bulgaria uses Spain as its contrast case. Year 1 for Greece is 2009 and for Bulgaria Y1 is 2010.

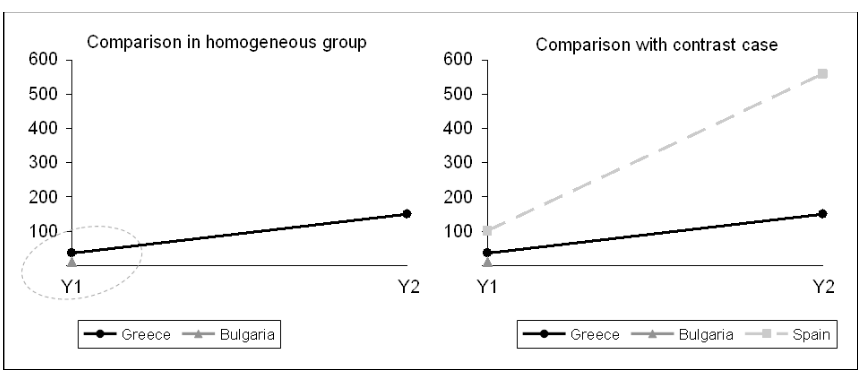


Figure 4.6 : Normalized PV diffusion in Bulgaria and Greece, Annual PV, MW.

The analysis above shows us that four different diffusion patterns of PV installation existed through 2010. Germany and the US are relatively conservative in diffusion speed (gradual increase and no fluctuation), which is sustainable for years, whereas Spain and the Czech Republic have an entirely opposite diffusion pattern, meaning fast and unsustainable. For example, Germany and the US reached 900MW PV annual installed base in year 5, while Spain and the Czech Republic reached annual installation of 1.5GW and 2.8GW respectively by year 2. A slump in installation followed this peak. The success story of Germany reflects the sustainable program that was established by EEG (Mark and Nick-Leptin, 2010). The corridor concept limits speculative PV diffusion. This policy by EEG is one of the main reasons why Germany has sustainable PV diffusion, rather than a peak to trough pattern, as seen in Spain and the Czech Republic (REN21, 2010). On the other hand, many authors criticized the development of Spanish PV market despite the fact that a few authors still consider Spain a success story. Lüthi (2010) and EPIA (2011b) frequently stated that the main negative consequence in Spain was the speculation issue. This is in large part due to the high rate of return and subsequent retroactive action by Spanish government, which has destroyed the confidence of investors not only in Spain but also globally.

Another pattern has been observed in Italy and France. These two countries follow a similar path of diffusion in year 1 (~100MW), year 2 (~300MW) and year 3 (700MW). Their diffusion speed is faster than Germany's first few years, whereas they are much more conservative when compared with Spain and the Czech Republic.

The case of Greece and Bulgaria is not really a true diffusion case, since the market only achieved 150MW for Greece in year 2 and only 11MW for Bulgaria in year 1. This diffusion (?!) case is a relevant case as it explains why some markets have kicked-off and ramped-up while other countries e.g. Bulgaria and Greece have not been triggered yet.

Countries showing different diffusion patterns and the characteristics explained above are summarized in the table below. In order to create a common understanding about diffusion patterns through Ph.D. thesis, diffusion patterns are named as well.

Table 4.4: PV diffusion patterns, characteristics and proposed names.

Countries	Main characteristics	Proposed name for diffusion patterns
Germany	* Reasonable return commitment (8% IRR on evarage) with strong and stable gov't commitment * Transparent and structured administrative processes * Long term commitment on PV industry	Sustainable
Spain, Czech Republic	* Short-term boom due to high IRR (>12%) with low administrative process * Uncontrolled progress of PV diffusion * High level of gov't liability caused due to peak -> retroactive actions likely	Unguided missiles
Italy, France	* High return commitment (12% IRR on average) * Hurdles in the beginning are removed with transparent administrative processes * Risky in long run due to high FIT payment	Fast catchers
Bulgaria, Greece	* Not waken market yet due to different reasons e.g. financial stability, lack of transparency on administrative processes * Trigger conditions not met yet	Lacking trigger

4.4.2 Root cause investigation

The following deep analysis has been conducted according to country specific information gathered in the literature review. Two milestones have been marked on the table for focus countries. First milestone (triangle shaped) shows when the first FIT is introduced in the respective country and the second milestone (diamond shaped) indicates when annual PV installation reaches the level of 100MW. In the table, the main enabler for market kick-off is also listed. Obviously, duration between year of FIT introduction and year of market kick-off varies country to country.

Table 4.5: Evaluation of data availability and transparency of focus countries.

Country / Year	<2000	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Germany	▲ Electricity FIT in 1991		◆ EEG in place									
Spain	▲ Purchase guarantee for PV in place							◆ * Intro new attractive FIT * Target announced				
Italy									▲ Announced FIT	◆ New FIT in place		
Czech Rep.							▲ Announced FIT			◆ FIT becomes even more attractive due to drop in prices		
France	▲ Tax credit support in place									◆ New gov't FIT in place		
Greece								▲ Intro new attractive FIT				
Bulgaria									▲ Anouced FIT			
Turkey			▲ Announced FIT (incl. wind)									

▲: Introduction of first FIT ◆: Market kick-off

Certain variables lead to early or late market kick-off when compared to other countries. The following question thus arises: Why is market kick-off quicker in Czech vs. Germany. Why hasn't Bulgaria PV diffusion kicked-off? The reason is that while announcing FIT is an important step in PV diffusion, it is not sufficient to cause market kick-off by itself. From now on, the conditions required for market kick-off will be named as "trigger conditions".

Accumulated PV installation in the Czech Republic grew from almost scratch to 2.3GW installation in only 2 years, while Germany reached 2GW accumulated installed base only 9 years after market kick-off. A number of questions can be raised in other cases as well. However, the main wonder is why some countries ramp-up faster than others. These variables are to be investigated under the name of "diffusion speed".

Last but not least is from the perspective of until what point will PV installations continue to grow as in Germany, or similar to Spain and the Czech Republic, both of which had to curtail ambitious FITs for PV. The situation calls for definition of "upper limit".

These questions call for three major dimensions in regards to kick-off, ramp-up and the stagnation level.

1) Trigger conditions i.e. market kick-off: PV diffusion kicks in only if trigger conditions are met.
2) Diffusion speed: PV penetrates countries at different speeds.
3) Upper limit: Countries reach saturation level at different levels.

The chart illustrates how these dimensions fit diffusion phases developed by Villiger et al. (2000)

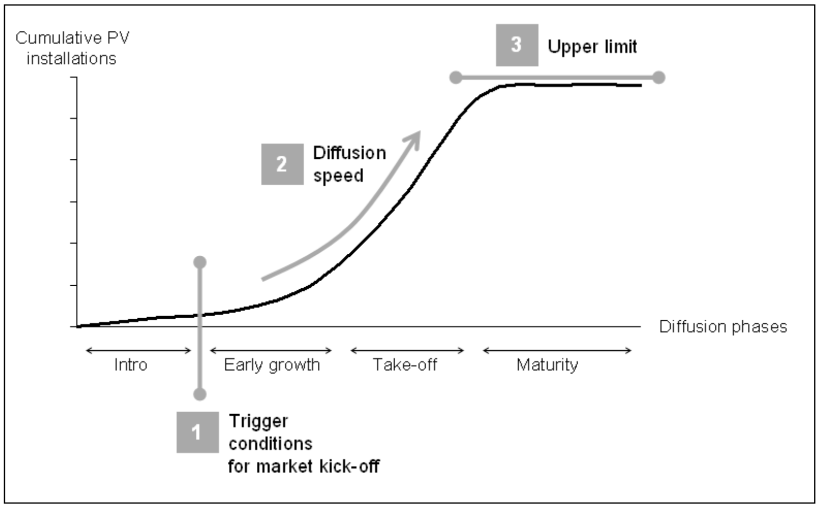


Figure 4.7 : Diffusion dimension vs. diffusion stages.

Based on several studies by other authors e.g. EPIA (2011b), EER (2011), Lüthi (2010), the following dimensions were determined.

Trigger conditions: The table below shows what the trigger conditions are for market kick-off and how to qualify and quantify them accordingly, based on a collection of different studies. All of the trigger conditions have to be in place at the same time for proper kick-off.

Table 4.6: Trigger conditions for PV diffusion kick-off.

#	Variables	Sub-variables	Minimum requirements
1	PV investment is profitable for the investors	* IRR meets market expectations	* IRR>6%
2	Clear government commitment exists	* short and long term targets exist (inline with plan of energy mix) * 1 year visibility into incentives	* Target of 1, 3 and 10 years exist * FIT of next 1 year communicated
3	Streamlined administrative process in place	* Transparent permitting process * Reasonable project throughput time	* Simple and documented process * Duration of permitting <8 months
4	Solar resources enables to generate reasonable level of output	* Solar resources (kWh/m2) in the country	* Solar resources>800kWh/m2

Diffusion speed: Although countries in the same diffusion pattern show a similar development pattern, variables for diffusion speed change country to country. So, the following criteria set is identified and classified into two groups, core and supportive, depending on their expected influence on diffusion speed.

Table 4.7: Variables for diffusion speed.

Core vs. Supportive	Variables	High level hypothesis	Supportive arguments
Core	IRR level	Higher IRR leads higher speed	Spain 13% IRR with 2.8GW installation in 2008 9% IRR with 20MW installations in 2009
Core	Knowledge base	Bigger knowledge base build, higher speed in diffusion expected	Although Germany maintains same IRR level, 8%, for years, every year annual PV installations increase
Core	FIT	Higher IRR leads higher speed	Higher FIT set by the government is the main input for higher IRR, it consequently resulted in higher IRR
Core	Duration of administrative processes	Shorter administrative process leads faster diffusion	Czech Republic reaches peek in a year due to over-eased administrative process vs. Greece is still not awaken due to long administrative process
Supportive	GDP (growth and per capita)	Higher GDP (growth and per capita) enables faster diffusion	Better economic strength (growth and/or per capita) has greater potential for higher government liabilities for PV FIT payments
Supportive	Political stability / violence:	Higher fluctuation in political scene and violence leads slower diffusion rate	Germany with stabile political environment enables stabile market

Upper limit: In the analysis, it is seen that Spain and the Czech Republic reached their upper limits because no further important PV market stimulus was expected. The main reason for reaching the level of stagnation varies country to country. For example, the Czech Republic reached its 2020 target of 1.7GW in 2010, so there is no real motivation to push further PV installation. The Spanish market has been stagnant due to a yearly cap of 400MW, implemented to limit government liabilities towards PV installations. The table below shows the set of criteria that are considered to be relevant.

Table 4.8: Variables for upper limit.

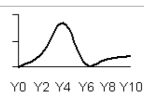
Variables	High level hypothesis	Supportive arguments
Country's PV target	Higher ambition level of national PV target leads the higher upside potential for PV	Czech Republic reached 1.7GW target of 2020 in 2010 so it is a blocker while it is different in Italy, France seeking PV installations e.g.
Solar potential	Higher solar potential enables higher upper limit for PV installation	Higher solar potential requires relatively lower FIT to reach same IRR value. So, it creates less liabilities for to the gov't and enables higher upper limit
Grid allowance for PV	Higher grid allowance for PV has higher upper limit for PV installations	Not observed yet but relevant in the future. Due to fluctuation in electricity PV generation, grids allow PVs to some extend
GDP (growth and per capita)	Higher GDP (growth and per capita) enables faster diffusion	Better economic strength (growth and/or per capita) has greater potential for higher government liabilities for PV FIT payments
FIT liabilities (as % of GDP) of government	Higher liability of government leads slow down in diffusion	Czech Republic pays %0.5 of GDP to PV FIT and it is a death market now while Germany pays only %0.2 of GDP

4.4.3 Reflection

So far, four PV diffusion patterns (sustainable, unguided missiles, fast catchers and lacking trigger) for the seven focus countries have been identified as well as three diffusion dimensions (trigger conditions, diffusion speed and upper limit). In this section, the target is to link these two perspectives.

As PV has been diffusing in the five countries excluding Greece and Bulgaria, the market has already been triggered. However, the triggered PV diffusion shows a different speed in the countries. For instance, "unguided missiles" show quick peak followed by a slump for one or two years, while the sustainable pattern show relatively conservative diffusion speed. Among the seven countries, Spain and the Czech Republic are at their upper limit of PV diffusion, while Germany, Italy and France still appear to be promising markets for PV, due to the gap between their respective 2020 PV target and the current installed base. In the table below, these points are simplified and shown in order to link identified diffusion patterns to diffusion dimensions. A chart of typical development shows representative development in different diffusion patterns.

Table 4.9: Reflection of observed diffusion patterns and diffusion dimensions.

	Diffusion patterns	Typical development	Countries	Trigger conditions met	Diffusion speed	Upper limit (first boundaries)
1	Sustainable		▪ Germany	Yes	Moderate; evolving by time	• Narrowing grid allowance for PV • Reaching PV target
2	Unguided missiles		▪ Spain ▪ Czech Rep.	Yes	Very high; fluctuating	• Heavy FIT liabilities of gov't • Reaching PV target
3	Fast catchers		▪ Italy ▪ France	Yes	High	• High FIT liabilities of gov't • Reaching PV target
4	Lacking trigger		▪ Greece ▪ Bulgaria	No	N/A	N/A

4.5 Modeling

4.5.1 First trials on PV diffusion in the countries

Solar irradiation (solar potential) and the level of feed-in tariff are the most commonly examined variables related to PV diffusion, and are the basis for much research e.g. Tiris and Tiris, 1996; Kaygusuz, 1999; Togrul et al., 2000; Sozen et al., 2005. The author intended to test these hypotheses as follows:

H_0: Installed base is associated with countries' solar potential

As it is seen in the following figure, based on solar irradiation (Šúri et al., 2007) and cumulative installed base (IEA PVPS, 2010; EER, 2011), the correlation coefficient is calculated as 2%, meaning that only 2% of the change in installed base is explained by solar irradiation. In other words, no visible correlation exists between solar irradiation and installed base. For example, when comparing Germany and Chile: Chile has the highest solar irradiation in the world, 2.400kWh/m^2, but less than 100MW of installation exists, whereas Germany has ~17GW installed PV with 1.157kWh/m^2 solar irradiation. Null hypothesis is rejected.

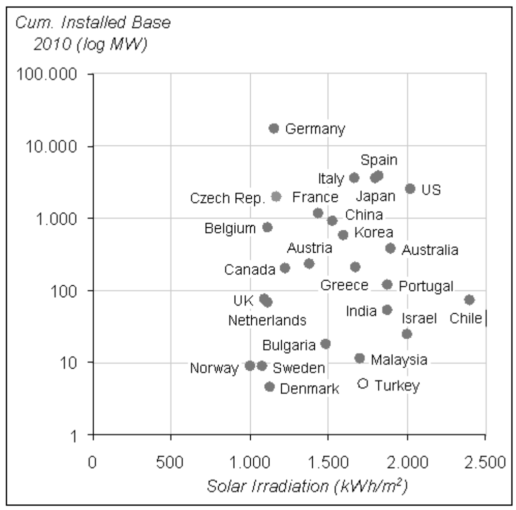


Figure 4.8 : Cumulative installed base (log MW) vs. solar irradiation (kWh/m^2).

Another analysis is related to the association between the level of FIT and installed base in year X.

H_0: Installed base is associated with level of FIT

In order to conduct this analysis, the average level of FIT in 2010 and installed PV in 2010 data are collected for the focus counties. The figure below shows the graphical perspective of the relation.

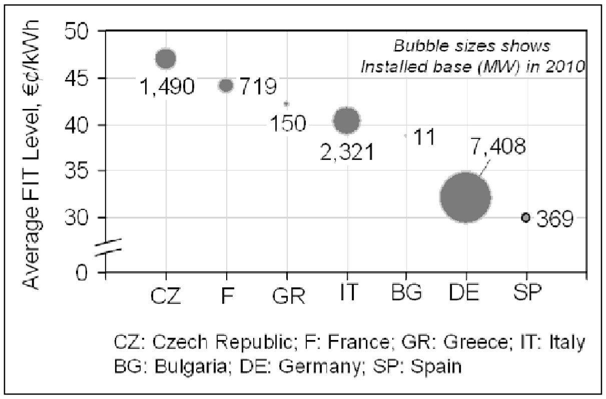


Figure 4.9 : Cross-country comparison of FIT level and installed base, 2010.

Correlation coefficient is calculated as 13%, meaning that only 13% of the changes in installed base are explained by FIT. Null hypothesis is rejected.

The analysis below was done only for Germany, starting in 2004, in order to avoid being influenced by country specific variables (I do not understand). Although the average FIT level has been dropping every year, in a negative correlation, the cumulative installed base has been increasing . Despite a drop in FIT, the main enabler for increasing PV installation in Germany has been the gradual decrease in PV installation prices over the years.

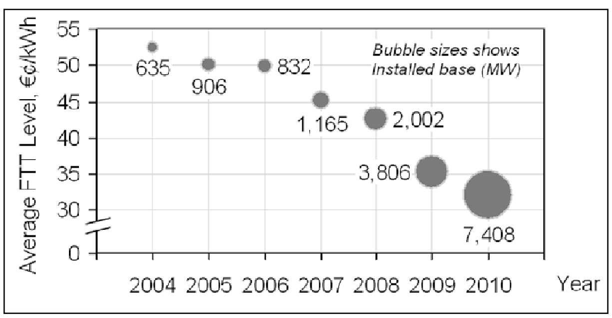


Figure 4.10 : Average FIT level vs. installed base, 2010 in Germany case.

Based on the initial hypothesis, no relationship has been found to explain PV installed base development. Since PV diffusion is not dependent on just one criterion, a model has to be worked out.

4.5.2 PV Diffusion Model Variables

Variables that can influence the diffusion of PV were discussed in both the chapter of literature review and in the chapter of diffusion patterns. The target of this section is to include grouped exogenous variables into modeling and to test their strength and /

or direction of association with PV diffusion. One might consider the below variables for modeling, along with their explanations definitions:

Annual / cumulative installed base (y1 / y2, MW): Annual installed base indicates how many MW PV installations are connected to the electricity grid in a respective year, while cumulative installed base shows the total MW of grid connected PV installation through a certain period. As previously mentioned, installation base is the most commonly used variable for evaluating technology diffusion of energy technologies. It is a dependent variable that is to be modeled. Historical data going back to 1991 can be easily found on the website of EPIA and IEA PVPS, but researchers should bear in mind that PV technology started diffusing in ~10 countries only after 2007. The data has been given in previous chapters.

Internal rate of return (IRR) (x1, %): Is a rate of return used in capital budgeting to measure and compare the profitability of investments. Basically, it is an indicator that combines all the variables mentioned under the return dimension of PV installations. As IRR terminology in PV diffusion has started to be referred to more frequently, this variable will be the main part of our modeling.

Data availability varies country to country. For example, one might find a few dozen studies on IRR calculation for Germany, while only several studies are available for the Czech Republic. The author also approached EPIA, who always refers to the association between IRR and PV diffusion, but no response has been received despite several attempts. Although gathering fully comparable IRR values is not possible, when one considers that PV is an emerging technology worldwide, the author placed a maximum effort on the standardization of IRR values. For example, the author has selected IRR values which have similar assumptions at high level e.g. equity ratio, plant size etc. for a country. This data has been given in previous chapters. Despite the difficulties in data gathering for other countries, future IRR calculation for Turkey for has been done by the author, based on a Microsoft Excel-based tool.

Situational trigger conditions (x2, 1/0): Four minimum requirements for meeting trigger conditions have previously been identified. When a country meets these four requirements at the same time, it is assumed that trigger conditions will be met and PV diffusion in the country is ready to pick-up. The data of trigger conditions and the evaluation of minimum requirement are listed in appendix A.

Triggered IRR (x12, %): As long as all four of the trigger elements are met, no IRR is meaningful for PV diffusion. In order to take trigger conditions into account, triggered IRR values are generated. The data of triggered IRR are listed in appendix B.

$$x12 = x1 * x4 \tag{4.1}$$

Knowledge base (x3): Countries have developed their PV industries e.g. module manufacturing, installation capabilities, public awareness and research base over several years. The following three alternatives can be considered for quantifying knowledge in the countries. The data is also shown in appendix C.

> Number of years >100MW PV installation (# of years): Many countries have only several MW PV installations, and in general, these installations are due to experimental projects as opposed to building up industry-wide knowledge. The 100MW threshold level has been set to differentiate the experimental level from real industry-wide knowledge. One point is added for each year after reaching 100MW cumulative PV installations.
>
> Cumulative installed base (MW): As installations are increasing, the local PV industry has been building up knowledge in engineering, installation, commissioning and project management. Within this parameter, this know-how is to be measured by cumulative installed base.
>
> Installed base of previous year (MW): As similar to cumulative installed base, another option is to consider only the installation of the previous year.

FIT (x4, €ct/kWh): FIT refers to the premium, tariff or payment to the PV industry, which is relatively expensive compared to conventional technologies for electricity generation. In general, different scales of PV installations receive different levels of FIT, however in reality, installed base data is not differentiated into scales like that of FIT. For this reason, the average FIT is to be used in modeling. This data is collected from the websites of EPIA, EIA PVPS as well as relevant country-specific studies. The data was shown and discussed in the chapter of country profiles.

Solar Potential (z1, kWh/m2): This is the amount of solar energy that arrives to the earth's surface over the course of a year, called yearly global irradiation. Minimum, average and maximum values for each country are available. In this thesis, average figures will be used. Data is available from the EPIA website and is shown in appendix G.

GDP per capita (z4, $): PV diffusion can currently only be triggered by government incentives due to the non-competitive cost of PV generated electricity when compared to fossil fuels. It is assumed that GDP per capita represents the ability of an economy to show flexibility to initiate / maintain a government subsidized PV industry. Past data is easily found on the websites of various institutions e.g. IMF, CIA Fact Book, Global Insight etc. In this thesis, the database of Global Insight (www.globalinsight.com) will be used. The data is shown in appendix D.

GDP growth (z5, %): This is another variable to measure economic stability. For the sake of consistency, the database of Global Insight will be used, as was done for GDP per capita. The data is shown in appendix E.

PV installation target 2020 (z6, MW): EU countries made a commitment for a 20/20/20 target for renewable energy. This effort brings forth a commitment towards PV installations by 2020. These targets are accessible in the countries respective National Renewable Energy Action Plans, which are published at EU website. This data was previously detailed in Chapter 2.

Political Stability (z7, index): As PV diffusion is highly correlated with governmental decisions on FIT, political stability allows sustainable diffusion of new technologies. Data is gathered from the website of the "Worldwide Governance Index" project by the World Bank. The governance index includes six sub-variables, including one which is defined as "political stability with no violence". This data varies from -2.5 to +2.5. For simplicity purposes, the author normalized the values to 100. The normalized data is shown in appendix F.

4.6 Solar Diffusion Model Parameter Estimates And Validations

4.6.1 Logistic regression estimates and validation

In a PV diffusion case, the following topics need to be considered:

> Since the data are collected from different countries, each country should have their own upper limit, A, and diffusion speed, β.
>
> Upper limit, A, and diffusion speed, β, should differ country to country

There is no possibility to run logistic function / variables separately for each country as the number of observations is not sufficient.

Typical logistic function is as follows:

$$Y_{it} = \frac{A_i}{1+e^{-\beta_{it}}} \qquad \textbf{(4.2)}$$

where,

Y(t): cumulative value

A_i : country upper limit;

β_i : country diffusion speed

e: 2.718282

The original logistic function has a fixed value for the upper limit, however, a flexible upper limit changing from country to country is required. A function needs to be developed in order to reflect country specific variables. In the end, variables influencing the upper limit e.g. solar target, GDP per capita, can identify what the value of A should be. Additionally, it should be different for each country. Likewise, the level of IRR and knowledge base should affect diffusion speed. Therefore, a regular logistic function has been improved in a way that A and β can be a function of exogenous variables. The function, called "improved logistic", is shown below:

$$Y_{it} = \frac{\beta_0 + \beta_1 z_{1it} + \beta_2 z_{2it} + \ldots}{1+e^{-(\alpha_0+\alpha_1 x_{1it}+\alpha_2 x_{2it}+\ldots.)}} \qquad \textbf{(4.3)}$$

Where z´ are the explanatory variables for the upper limits of the countries and x´ are the diffusion speed variables of the countries.

After including all potential variables for upper limit and diffusion speed, the following modeling result has been generated by EViews.

Table 4.10: Modelling result of "improved logistic".

Dependent Variable: Y1				
Method: Least Squares				
Date: 12/09/11 Time: 13:25				
Sample: 1 32				
Included observations: 32				
Convergence achieved after 87 iterations				
Y1=(C(1)+C(2)*Z6+C(5)*Z4)/(1+EXP(C(3)+C(4)*X12+C(6)*Z5+C(7)*X3))				
	Coefficient	**Std. Error**	**t-Statistic**	**Probability**
C(1)	589180.4	337006.1	1.748278	0.0927
C(2)	-3.7017	2.0964	-1.7657	0.0897
C(5)	-9.2764	5.7638	-1.6094	0.1201
C(3)	9.6244	0.5319	18.0959	0.0000
C(4)	-17.9562	2.5488	-7.0449	0.0000
C(6)	-8.5607	3.3271	-2.5730	0.0164
C(7)	-0.7147	0.0773	-9.2407	0.0000
R-squared	0.972406		Mean dependent var	851.625
Adjusted R-squared	0.965783		S.D. dependent var	1505.341
S.E. of regression	278.4557		Akaike info criterion	14.28704
Sum squared resid	1938440		Schwarz criterion	14.60767
Log likelihood	-221.5926		Hannan-Quinn criter.	14.39331
Durbin-Watson stat	1.935812			

Then the "improved logistic" function (Y1p: predicted annual install base) will be as follows:

$$Y_{1p} = \frac{589180.3 - 3.70165 * Z6 - 9.27643 * Z4}{1 + e^{-9.6244 - 17.95619 * X12 - 8.56068 * Z5 - 0.71470 * X3}} \qquad \textbf{(4.4)}$$

The following key results are pointed out:

Considering 0.972 value of R^2, the predicted data fit the observed data very well. R^2 is the statistical measure of how well the regression line approximates the real data points.

Variables of X12 (triggered IRR), X3 (knowledge base) and Z5 (GDP growth) are statistically significant for determining diffusion speed, considering any acceptance level, 0.1 or 0.05.

Variable of Z6 (PV target 2020) is statistically significant for determining the upper limit considering acceptance level of 0.1.

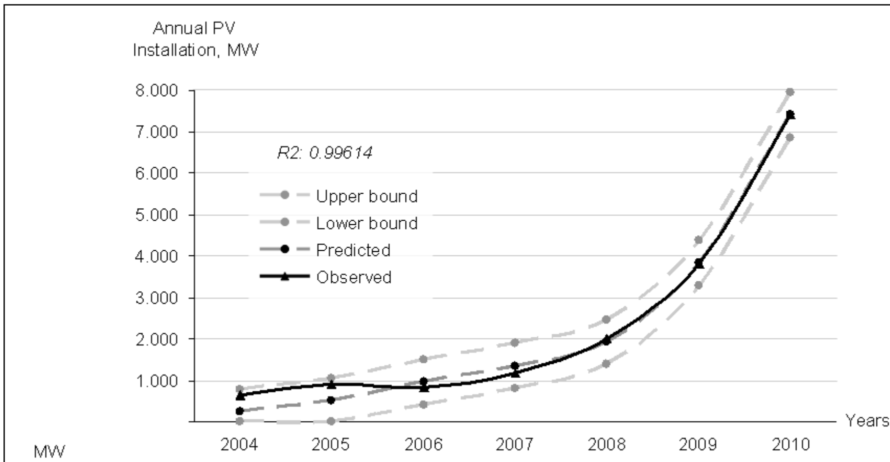
Variable of Z4 (GDP per capita) is not considered as statistically significant for determining the upper limit, as it is not meaningful at any acceptance level, 0.1 or 0.05, due to the probability of 0.1201. However, it is still kept in the equation because of the tolerable difference between the probability and acceptance levels for acceptance level of 0.1 at non-linear functions.

In order to see how the predicted data fit observed data, validation work has been performed for each country separately. The common practice uses a calculation of confidence intervals (upper bound, Y1pu, and lower bound, Y1pl) at 95%, confidence interval as below. In the case that the result of the lower bound calculation indicates a negative annual installed based, that value is considered zero, as there is no option to have negative annual installed base.

$$Y_{1pu,1pl} = Y_{1p} \pm 1.96 * s.e. \qquad \textbf{(4.5)}$$

The figures below show country specific validation results for annual installed base in graphical and table form.

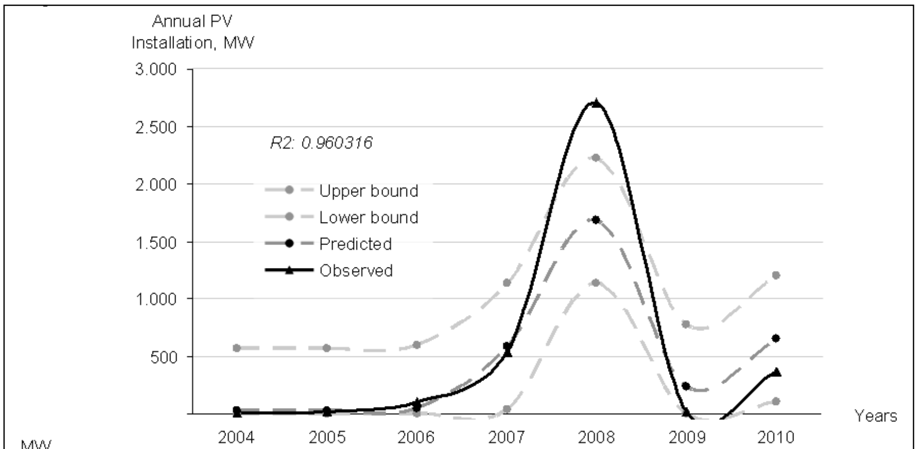
As seen in the chart below, the model predicts Germany's results pretty well, with an R^2 of 0.99614. Although there is a relatively higher gap between the observed and predicted date in 2004, the gap has been closing over the years, and it generates almost exact values for the years 2008, 2009 and 2010.



Observed (Y1p)	635	906	832	1.165	2.002	3.806	7.408
Predicted (Y1)	240	505	949	1.340	1.921	3.833	7.404
Upper Bound (Y1pu)	786	1.051	1.494	1.886	2.466	4.379	7.950
Lower Bound (Y1pl)	0	0	403	794	1.375	3.288	6.858

Figure 4.11 : Validation results for Germany, Annual PV installations, MW.

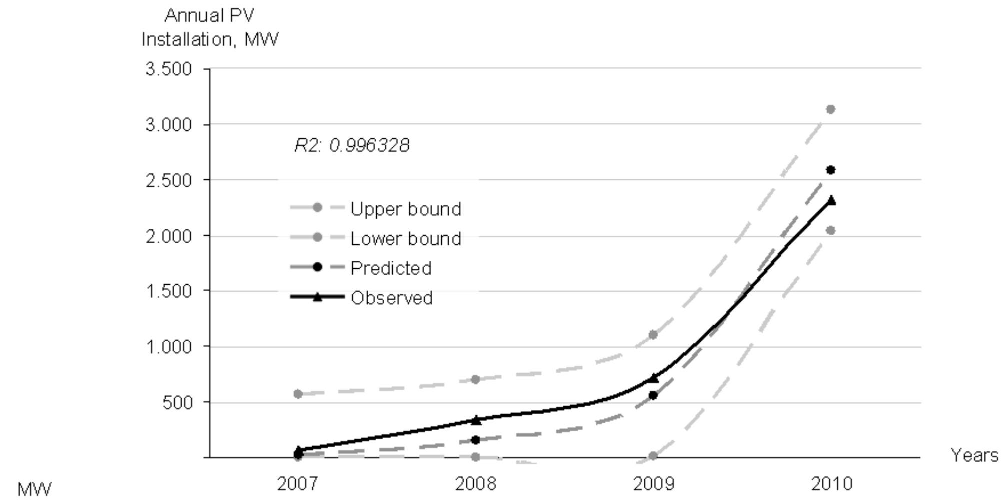
The Spanish market has fluctuated a lot over the years due to changes in FIT. This fluctuation has been reflected in the installed base as well. As referred to before, this up and down situation was named as a diffusion pattern of “unguided missiles”. Despite these gaps, the model has generated fluctuating results in parallel to observed PV diffusion. As seen in the figure below, for the years 2004, 2005 and 2006, observed data is in the range of model estimations. However, observed data in 2008 is beyond the predicted limits of the model, and the actual value is even higher than the upper bound of estimated values. In 2008, the PV market in Spain was booming and Spain reached 3.4GW of cumulative installed base, which is even higher than Japan (2.1GW) and the US (1.2GW), which already had several years of PV industry investment. It is a fact that predicting these kinds of jumps and slumps is quite difficult in statistical modeling. However, the developed model positively estimates a significant increase in installed base with only minor deviations. Following the PV boom in 2008, the PV market in Spain collapsed in 2009. Government commitment to PV was minimized and investors’ confidence in the Spanish PV market was destroyed. This means that trigger conditions had been damaged. Although the observed value is in the range of model estimations, no big installation is expected in 2009 due to the lack of trigger conditions.



MW							
Observed (Y1p)	12	23	102	542	2,708	17	369
Predicted (Y1)	24	25	51	588	1,681	234	651
Upper Bound (Y1pu)	570	571	597	1,134	2,226	780	1,197
Lower Bound (Y1pl)	0	0	0	42	1,135	0	106

Figure 4.12 : Validation results for Spain, Annual PV installations, MW.

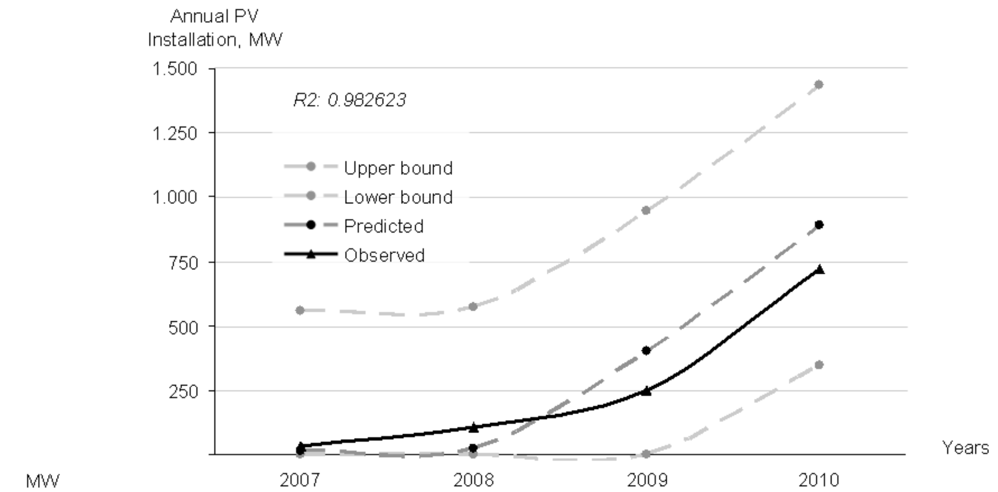
For Italy, the observed data are within the range of the model’s estimates, and the gap between predicted and observed values has been decreasing over the years, as seen in the figure below. For example, the gap reaches its smallest percentage in 2010.



MW	2007	2008	2009	2010
Observed (Y1p)	70	338	723	2,321
Predicted (Y1)	16	150	557	2,585
Upper Bound (Y1pu)	562	696	1,103	3,131
Lower Bound (Y1pl)	0	0	11	2,039

Figure 4.13 : Validation results for Italy, Annual PV installations, MW.

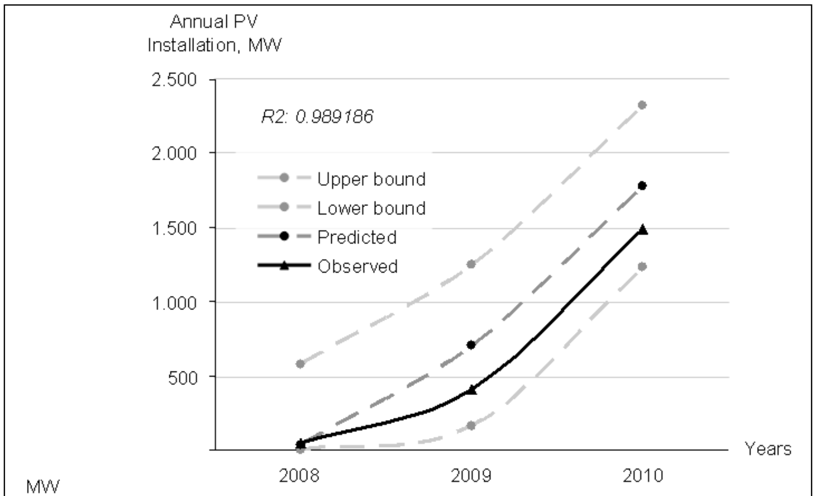
For France, the observed data are within the range of the model's estimates. While the observed data is higher than the predicted data in 2007 and 2008, the model estimates higher values compared to observed data in 2009 and 2010. The reason we get these results in 2007 and 2008 is that trigger conditions were not available for those years due to a long administrative process, and therefore the model was supposed to estimate lower figures. However, when trigger conditions are met in 2009 and 2010, the predicted values catch up to observed values and close the gap.



Observed (Y1p)	31	105	250	719
Predicted (Y1)	12	25	400	892
Upper Bound (Y1pu)	558	571	946	1,438
Lower Bound (Y1pl)	0	0	0	346

Figure 4.14 : Validation results for France, Annual PV installations, MW**.**

Like Spain, the Czech Republic is another generous country that provided one of the highest IRR values for PV investments. As seen in the chart below, the PV installed base in the Czech Republic ramped up very fast. However, observed data are in the range of model estimates. The reason for the gap between observed data and the mid-range of estimates might be that the build-up of industry knowledge takes a few years.

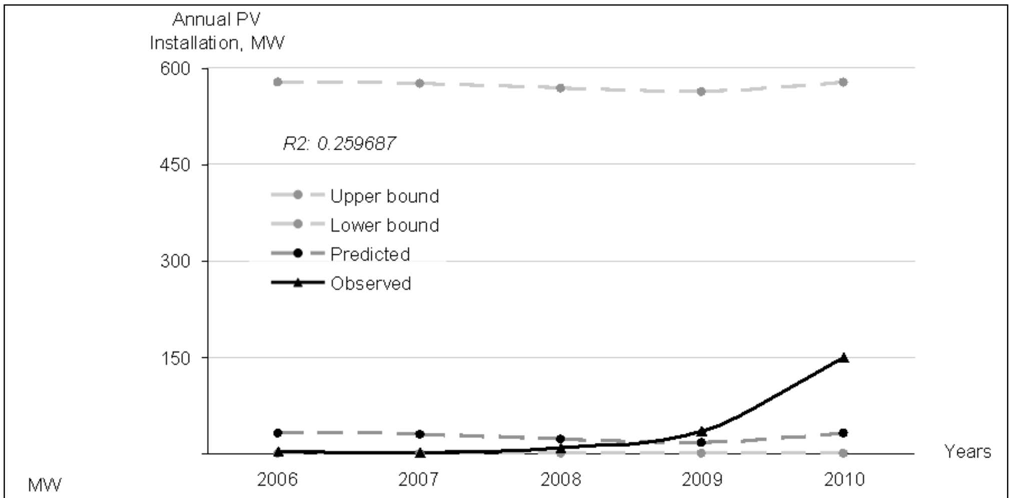


MW

	2008	2009	2010
Observed (Y1p)	50	411	1,490
Predicted (Y1)	33	705	1,782
Upper Bound (Y1pu)	579	1,250	2,328
Lower Bound (Y1pl)	0	159	1,236

Figure 4.15 : Validation results for Czech Republic, Annual PV installations, MW.

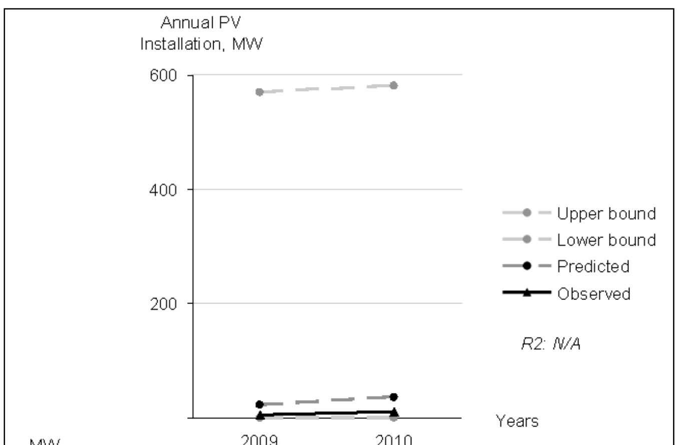
Greece has been supporting its PV industry for a long time, but trigger conditions for market pick-up were provided only in 2010. Due to the long and non-transparent FIT submission process, no market was expected to kick-off before 2010. As long as the trigger conditions are not met, the model estimates should be considered hypothetical values. Any gap between observed and predicted values is due to trigger conditions being met. As seen below, the biggest difference between predicted and observed data occurs in 2010. The reason is that in the model the PV market was assumed to have been triggered, however, significant delays in the administrative processes occurred, and thus the predicted data didn't take place. This was expected to occur in 2011.



MW	2006	2007	2008	2009	2010
Observed (Y1p)	3	2	10	35	150
Predicted (Y1)	32	30	23	17	32
Upper Bound (Y1pu)	577	576	569	563	578
Lower Bound (Y1pl)	0	0	0	0	0

Figure 4.16 : Validation results for Greece, Annual PV installations, MW.

The PV industry in Bulgaria has not met trigger conditions as of yet. As long as trigger conditions are not met, model estimates should only be considered hypothetical values. Although observed and predicted values are close to each other, the quality of estimation in the long run is not clear, due to the availability of only two years of data.



MW	2009	2010
Observed (Y1p)	6	11
Predicted (Y1)	23	36
Upper Bound (Y1pu)	569	582
Lower Bound (Y1pl)	0	0

Figure 4.17 : Validation results for Bulgaria, Annual PV installations, MW.

4.6.2 GBM estimates and validation

In a PV diffusion case, the following topics need to be considered:

Since the data are collected from different countries, each country should have their own upper limit, A, and diffusion speed, β.

Upper limit, A, and diffusion speed, β, should differ from country to country

There is no possibility to run GBM function / variables separately for each country as the number of observations is not sufficient.

GBM enables researchers to include exogenous variables in equation, but still does not enable the upper limit as a function of exogenous variables. In a PV diffusion case, variables influencing the upper limit still need to be investigated. For this reason, a regular GBM function should be improved in a way that the upper limit will be a function of exogenous variables. The improved function, called "improved GBM", is shown below:

$$\frac{f(t)}{1-F(t)} = \left[p + \frac{q}{M(t)} \left[A(t) \right] \right] x(t) \tag{4.6}$$

The difference from regular GBM is that M, the upper limit, is a function at time, t.

An add-in software for EViews has been developed for "improved GBM" for two following reasons:

There is a need to know the coefficients for t=0 (initial values), which is not available in our case. The default method is that EViews generates random values. Additionally, Guidolin and Mortarino (2010) suggested to use values of t=1 as the initial values in cases whereby initial values are unavailable. However, as simulated before, the model is highly sensitive to initial values. We want to avoid the definition of initial values, which might jeopardize the modeling results. For this reason, optimized initial values are generated by a developed add-in through MATLAB, using Lsqnonline.

This add-in enables researchers to make modeling trials faster and more efficient by only editing variables names in the boxes, rather than dealing with long equations. By simplifying data entry, it enables even researchers with no / limited statistical background to run GBM on their own.

In the figure below, one can see the interface developed for EViews' software below. The add-in was sent to Eviews Cooperation as a contribution from other researchers' work, and the add-in was well appreciated. Eventually, it was featured on the homepage of EViews Cooperation (www.eviews.com) and opened up for use by other researchers. A screen shot of the homepage of Eviews with the announcement can be found in appendix I.

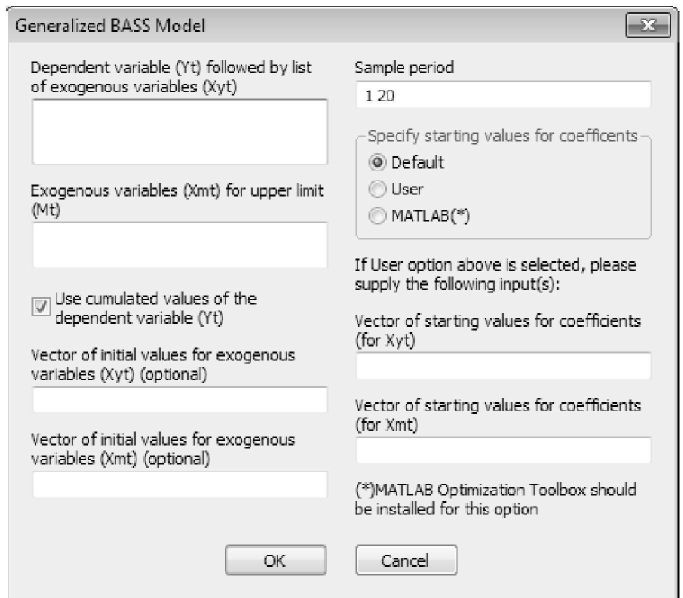


Figure 4.18 : Interface of developed add-in on EViews.

All countries' data are put into same dataset due to a lack of required historical data for each country, and the model considers the data as sequential even though the data belongs to different countries. Due to this reason, after dozens of modeling attempts, it was determined that sorting data in this manner highly influences the modeling results. Different ways of sorting, such as by country and year as well as by the size of annual installed base are examined. The most satisfactory results are performed when the data is sorted by annual installed base.

After including all of the potential variables related to upper limit and diffusion speed in modeling, the following result has been generated by EViews. In the output, it is important to note that C1, C2, C3 represent p (coefficient of innovation), q (coefficient of imitation) and m (limit) respectively.

Table 4.11: GBM result.

Dependent Variable: Y2				
Method: Least Squares				
Date: 12/06/11 Time: 23:09				
Sample: 1 32				
Included observations: 32				
Estimation settings: tol= 1.0e-06				
Initial Values: C(3)=27275.3, C(4)=-0.10295, C(5)=0.01135, C(6)=-0.78762, C(1)=0.21964, C(2)=2.3e-14				
Convergence achieved after 9 iterations				
Y2=(C(3))*(1-EXP(-(@CUMSUM(1,"1 32")+C(4)*LOG(X12/0.082) +C(5)*LOG(X3/9785)+C(6)*LOG(Z7/67))*(C(1)+C(2))))/((C(2)/C(1)) *EXP(-(@CUMSUM(1,"1 32")+C(4)*LOG(X2/0.082)+C(5)*LOG(X3 /9785)+C(6)*LOG(Z7/67))*(C(1)+C(2)))+1)				
	Coefficient	Std. Error	t-Statistic	Probability
C(3)	27569.82	139.1836	198.0824	0.0000
C(4)	-0.112491	0.053095	-2.118676	0.0438
C(5)	0.145396	0.081972	1.773729	0.0878
C(6)	-0.660969	0.589823	-1.120622	0.2727
C(1)	0.305908	0.011471	26.66766	0.0000
C(2)	-0.171434	0.017995	-9.526985	0.0000
R-squared	0.997813	Mean dependent var		23786.41
Adjusted R-squared	0.997393	S.D. dependent var		5192.362
S.E. of regression	265.1193	Akaike info criterion		14.1656
Sum squared resid	1827494	Schwarz criterion		14.44042
Log likelihood	-220.6496	Hannan-Quinn criter.		14.25669
Durbin-Watson stat	1.213662			

The following key results are pointed out:

Considering 0.997 value of R^2, the predicted data match the observed data very well. R^2 is the statistical measure of how well the regression line approximates the real data points.

p, q and m are statistically significant at any acceptance level, 0.1 or 0.05.

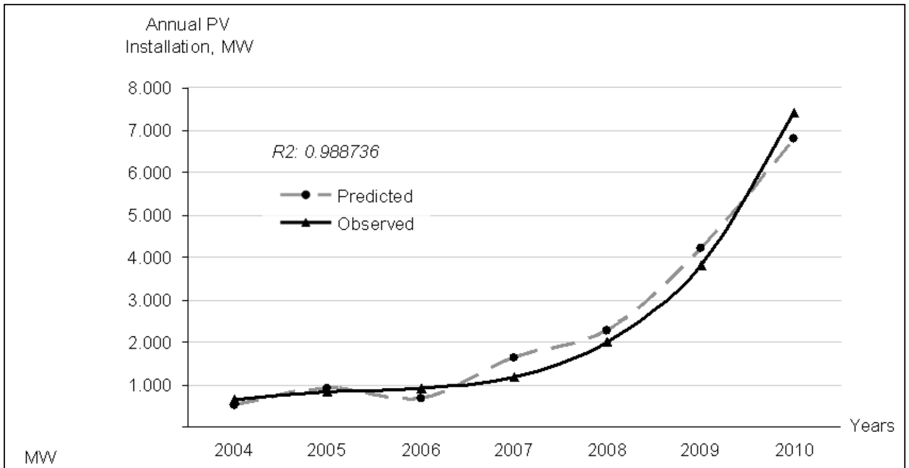
Variables of X12 (triggered IRR) and X3 (knowledge base) are statistically significant for determining diffusion speed at any acceptance level, 0.1 or 0.05.

Variable of Z7 (political stability) is not considered statistically significant for determining diffusion speed at any acceptance level, 0.1 or 0.05 due to a probability value of 0.2727.

In order to see how the predicted data correlates with observed data, validation work has been performed for each country separately, using confidence intervals (upper bound, Y1pu, and lower bound, Y1pl) at 95% confidence interval.

The figures below show country specific validation results for annual installed base in graphical and table form.

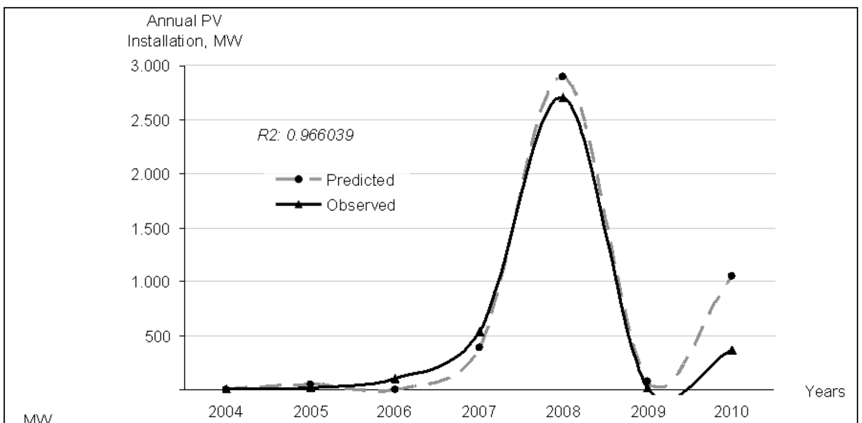
As seen in the chart below, the model predicts Germany's results pretty well, with R^2 of 0.988736. The yearly increase in predicted annual installations fluctuates more than the observed data, but predicted data is always in-line with observed data. All in all, the validation generates satisfactory results.



MW	2004	2005	2006	2007	2008	2009	2010
Observed (Y1p)	635	832	906	1,165	2,002	3,806	7,408
Predicted (Y1)	494	906	669	1,636	2,276	4,224	6,800

Figure 4.19 : Validation results for Germany, Annual PV installations, MW.

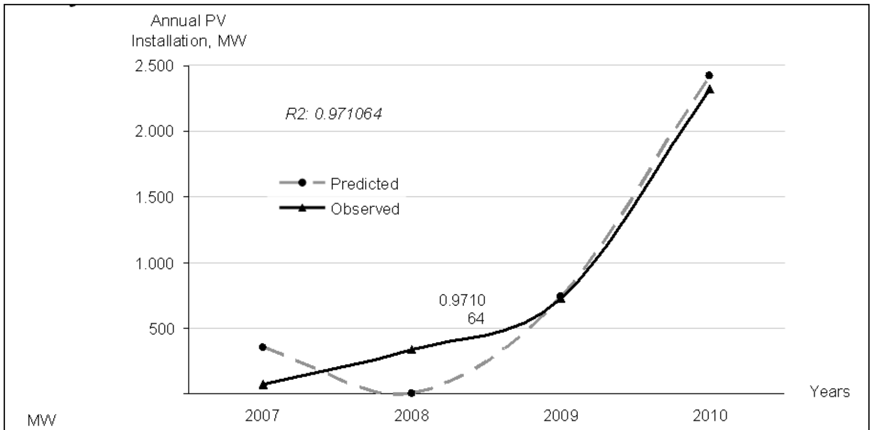
For Spain, the 'improved GBM" model predicts the jump in installations for the year 2008, but the prediction over-estimates the quantity of installations in 2010. This reason might be due to the expected impact of a built-up knowledge base.



MW	2004	2005	2006	2007	2008	2009	2010
Observed (Y1p)	12	23	102	542	2,708	17	369
Predicted (Y1)	2	47	0	386	2,899	78	1,050

Figure 4.20 : Validation results for Spain, Annual PV installations, MW.

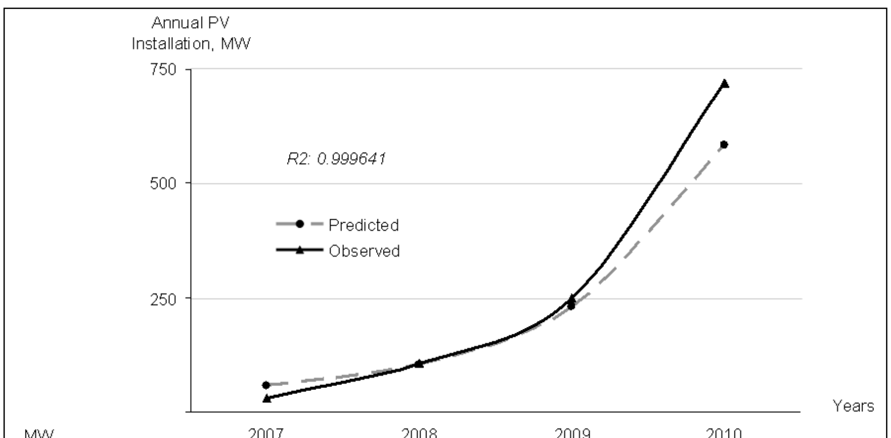
In the case of Italy, as seen in the figure below, the model generated satisfactory results only after two years. For 2007 and 2008, the model's predictions were either much higher or much lower than the observed data. However, the model predicts observed data very well in 2009 and 2010, parallel to the market kick-off.



MW	2007	2008	2009	2010
Observed (Y1p)	70	338	723	2,321
Predicted (Y1)	347	0	738	2,423

Figure 4.21 : Validation results for Italy, Annual PV installations, MW.

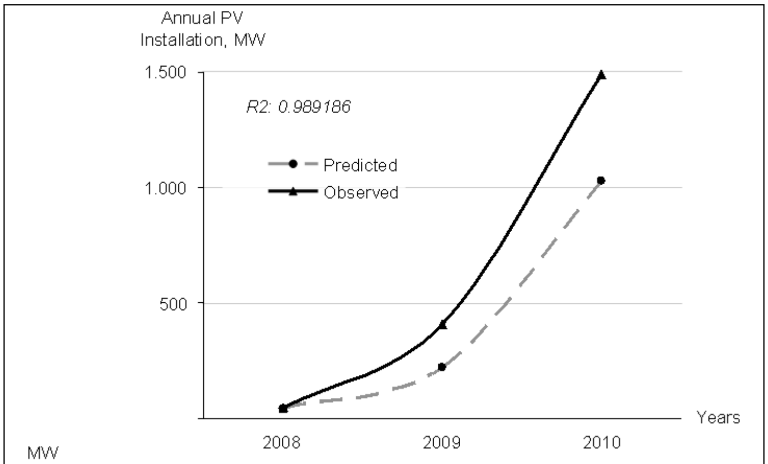
In regards to France as seen in Figure 4.22 below, beginning in year 1, the model started predicting the observed data very well. Only in 2010, after three years, does the predicted data fall behind. The reason might be related to the limited amount of data related to France.



MW	2007	2008	2009	2010
Observed (Y1p)	31	105	250	719
Predicted (Y1)	57	104	230	583

Figure 4.22 : Validation results for France, Annual PV installations, MW.

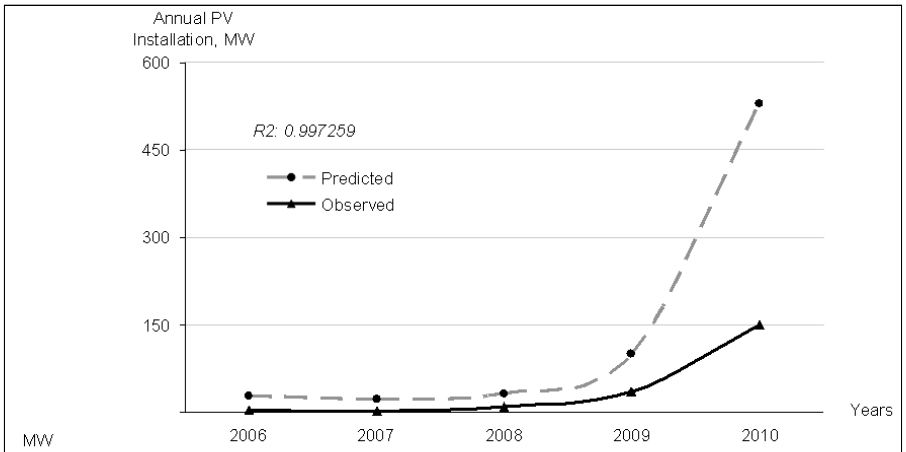
As discussed, PV diffusion in the Czech Republic has materialized much faster than expected. This is reflected in the chart, where predicted values are lower than observed values by up to 30%.



Observed (Y1p)	50	411	1,490
Predicted (Y1)	44	222	1,030

Figure 4.23 : Validation results for Czech Republic, Annual PV installations, MW.

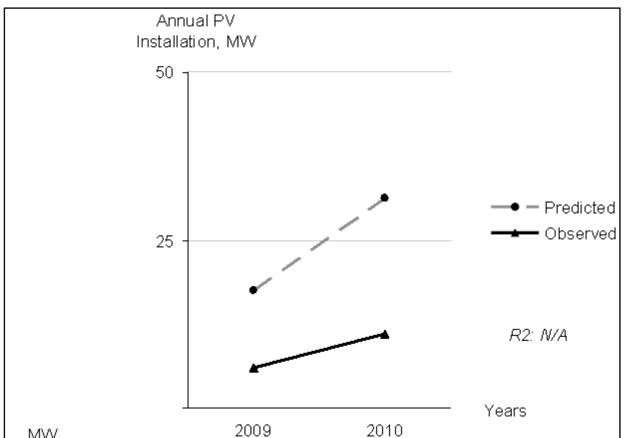
As seen in figure 4.24 below for Greece, the model generated satisfactory results for the years that Greece did not meet trigger conditions. In 2009 and 2010, the gap between observed and predicted data might be related to the cumbersome administrative hurdles in Greece. If in the future Greece should remove these hurdles, then observed data should increase so as to align better with the predicted data. The biggest difference between the predicted and the observed data occurs in 2010. The reason for this is that in the model, the PV market is assumed to be triggered, however, in reality, significant delays in the administrative processes occurred, pushing out the potential increase in installations until 2011.



	2006	2007	2008	2009	2010
Observed (Y1p)	3	2	10	35	150
Predicted (Y1)	27	22	32	99	530

Figure 4.24 : Validation results for Greece, Annual PV installations, MW.

Bulgaria is a recent entrant to the PV industry, and as such, the predicted data does not exaggerate the potential. The model predicts a relatively conservative installation due to the lack of trigger conditions.



	2009	2010
Observed (Y1p)	6	11
Predicted (Y1)	18	31

Figure 4.25 : Validation results for Bulgaria, Annual PV installations, MW.

4.6.3 Discussion on estimation and validation

"Improved GBM" and "improved logistic" are compared using R2 and RMSE (root mean square error), as seen at the table below. First of all, the results show that the two models provide satisfactory validation results. Moreover, "improved GBM" provides slightly better validation when compared to "improved logistic". However neither of them proves better than the other across all of the results.

Table 4.12: Comparison of forecast accuracy for both models.

	R2		RMSE	
	GBM	Logistics	GBM	Logistics
Germany	0.989249	**0.99614**	**3133**	3280
Spain	**0.966039**	0.96032	1433	**1145**
Italy	0.971064	**0.99633**	**1276**	1354
France	**0.999641**	0.98262	**338**	449
Czech Republic	**0.997387**	0.98919	**763**	955
Greece	**0.997259**	0.25969	216	**57**
Bulgaria	N/A	N/A	N/A	N/A
Entire dataset	0.997813	**0.972406**	**2071**	2087

4.7 Turkey PV Diffusion Model Forecasts and Discussion

Since there is no history of PV in Turkey, PV installation forecasts cannot be a continuation of available data. The future of PV installations depends on the policy decisions of the Turkish government. In order to avoid dependency on only one future installation forecast, forecasts are performed in defined scenarios below.

4.7.1 Diffusion scenarios

Future scenarios will be developed for 2020 for to two reasons. First, all EU country targets are designed for the year 2020. Although no official target has been communicated by the Turkish government, 2020 is the subject of PV studies by EPIA, Turkish National PV Platform, ICAT, EIE.

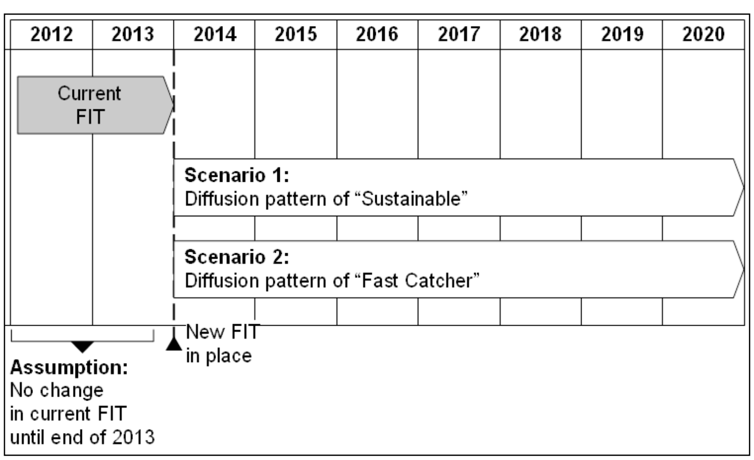
As discussed in detail before, the Turkish government published a new FIT in 2011. However, the announced FIT is not sufficient to trigger PV market diffusion. The following table shows the evaluation of the current FIT from trigger points' perspective. Two trigger points i.e. economic feasibility of PV investment and government commitment on PV are missed. No PV market is expected to trigger before the end of 2013. This pattern falls under the defined diffusion pattern of "lacking trigger".

Table 4.13: Evaluation of trigger conditions in the case of Turkey.

#	Identified Trigger conditions	Whether Turkey meets trigger conditions as of Dec. 2012 or not
1	PV investment is profitable for the investors *IRR is >6% for investors	No, negative IRR
2	Clear government commitment exists * Target of 1, 3 and 10 years exist * FIT of next 1 year communicated	No, no official PV installation target exists
3	Streamlined administrative process in place * Simple and documented process * Duration of permitting <8 months	Yes, process is similar to wind and industry has experienced it >2 years
4	Solar resources enables to generate reasonable level of output * Solar resources>800kWh/m2	Yes, average is 1724kWh/m2

Under the assumption that Turkey will still be in the “lacking trigger” diffusion pattern at the end of 2013, potential diffusion scenarios can only be developed beyond 2013. The four global diffusion patterns that have been developed (sustainable, unguided missiles, fast catchers, lacking trigger) will the basis for the scenario options. In our research, we will discuss only triggered options, which is why the pattern known as “lacking trigger” is left out of the discussion. Additionally, the pattern of “unguided missiles” was the consequence of uncontrolled diffusion due to the short-term policies of countries. Thus, the pattern of “unguided missiles” cannot be a targeted diffusion pattern as it is not the stated target of Spain and the Czech Republic upfront. Consequently, the implications of the scenarios based on the patterns of “sustainable” and “fast catchers” are to be investigated. The following table shows the development of the current FIT as well as future scenarios from a timing perspective.

Table 4.14: Timing of new diffusion scenarios.



Market kick-off in any country is only possible after it achieves trigger conditions. In discussion of the current situation in Turkey, the Turkish government needs to address two topics i.e. level of FIT to enable economically feasible PV plant investment and its commitment to the future of the PV industry. A prerequisite for both scenarios is that the Turkish government meets trigger conditions by 2014. The only / critical difference between the two scenarios is the attractiveness of PV investment. While a "Sustainable" scenario provides ~8% IRR value to the investors, the "Fast Catcher" scenario enables ~12% IRR values. This difference will be reflected in the modeling.

4.7.2 Data

In the proprietarily developed Logistic models, the variables of X12 (triggered IRR), X3 (knowledge base), Z6 (PV target 2020) and Z4 (GDP per capita) are found to be statistically significant, while Z5 (GDP growth) was on the cusp of being significant. In the GBM model, X12 (triggered IRR) and X3 (knowledge base) are found to be statistically significant. A short description on Turkey's specific variables can be found below:

X12 (triggered IRR): This is the main design variable for diffusion speed. The values for this variable are given based on defined global diffusion patterns. We will be using the "Sustainable" and "Fast Catcher" diffusion scenarios, which require ~8% and ~12% values respectively.

X3 (knowledge base): This is primary data that was defined based on the development of PV diffusion in the modeling phase. It is assumed that knowledge base builds up when the cumulative installed base reaches 100MW, and increases one point by each year. Assuming this, market kick-off will be realized in 2014, and knowledge base will start counting from 2014.

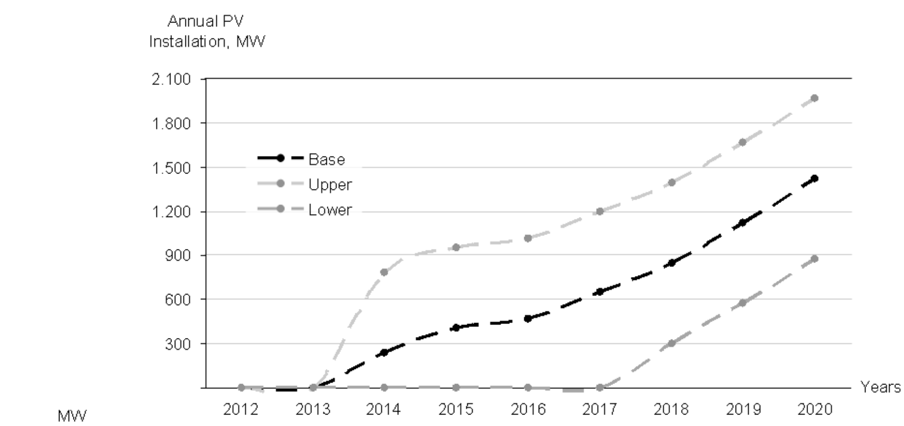
Z4, Z5 (GDP per capita; GDP Growth): This value will be gathered from external sources. The database of Global Insight (www.globalinsight.com) will be used for forecasting the GDP per capita of Turkey.

Z6 (PV target 2020): There is no officially communicated target, and thus currently available targets will be used as the basis. As discussed before, EPIA provides forecasts of 1.7GW, 2.9GW and 5.7GW, depending on the different diffusion scenarios. The Turkish National PV Platform projects 4GW, ICAT expects 4.8GW by 2020; EIE expects 5GW by 2023. The average of all these future oriented expectations is in the range of 4GW.

As the current FIT, which does not meet the minimum requirements of trigger conditions, will be in place through 2013, a modeling effort is expected to forecast for 2013 and beyond.

4.7.3 Forecasts with "improved logistic"

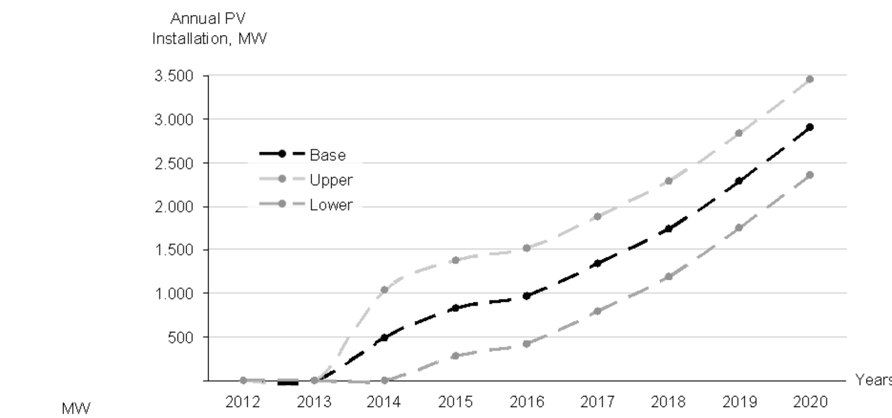
Based on our developed model, the dataset gathered and the scenarios identified, "improved logistic" modeling is run on EViews. The following results are performed using "Sustainable" and "Fast Catcher" diffusion patterns.



Base (Y1p)	0	0	240	405	472	653	849	1,121	1,420
Upper Bound (Y1pu)	0	0	786	951	1,018	1,199	1,395	1,666	1,966
Lower Bound (Y1pl)	0	0	0	0	0	0	303	575	874

Figure 4.26 : "Improved logistic" forecasts for "sustainable" scenario, Turkey.

Based on the "Sustainable" diffusion pattern, the diffusion of PV in Turkey starts with 240MW installed base in 2014. In the initial three years after diffusion starts, the increase in annual installations is expected to be more gradual than the increase beyond 2016.This could be related to the period of knowledge base build-up within the country. Once local knowledge is sufficient, market kick-off accelerates. By 2020, cumulative installed base is expected to be almost 1.5GW. From the shape of the curve, reaching maturity level is not forecast within the next decade.



Base (Y1p)	0	0	493	830	967	1,338	1,738	2,292	2,903
Upper Bound (Y1pu)	0	0	1,039	1,375	1,513	1,884	2,283	2,838	3,448
Lower Bound (Y1pl)	0	0	0	284	422	792	1,192	1,747	2,357

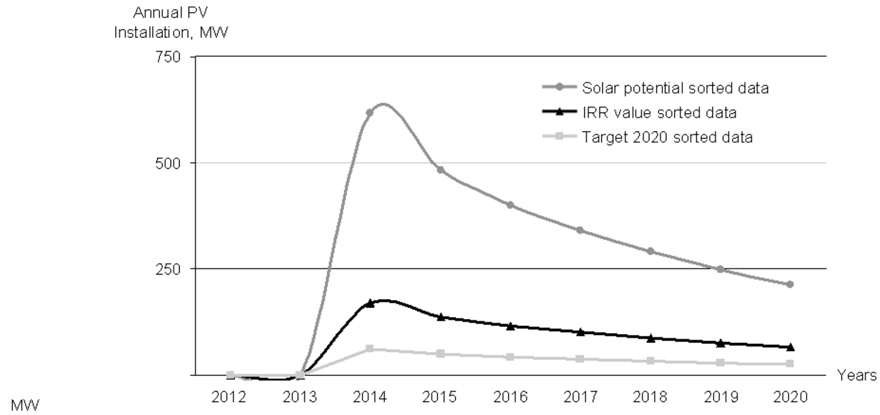
Figure 4.27 : "Improved logistic" forecasts for "fast catcher" scenario, Turkey.

Based on the "Fast Catcher" diffusion pattern, the diffusion of PV in Turkey starts with 493MW installed base in 2014. By the year 2020, the annual installed base is expected to be almost 1.5GW. From the shape of the curve, reaching the maturity level is not yet seen in the forecast.

As a result, it is observed that changing the IRR from 8% to 12% will double the PV installation figures. For example, the cumulative installed base in 2020 is 5.161MW in the "Sustainable" scenario, whereas it is 10.560MW in the "fast catcher" scenario.

4.7.4 Forecasts with "improved GBM"

Since annual installations (sorted by annual installations in countries) is used as the dependent value in the "improved GBM" modeling, it is required to identify where to include the "to be forecasted" exogenous variables of Turkey. For example, adding exogenous variables to the end of the dataset forces the model to consider that PV diffusion of Turkey is in the maturity stage of diffusion. For this reason, three different scenarios i.e. sorting by solar potential, IRR values, target 2020 are considered for use in the data of Turkey.

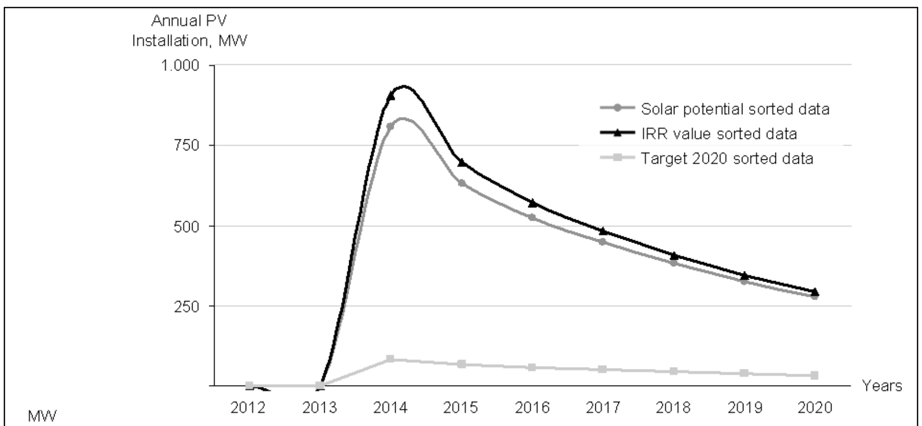


MW	2012	2013	2014	2015	2016	2017	2018	2019	2020
Sorted by solar potential	0	0	617	482	399	342	291	248	213
Sorted by IRR values	0	0	170	137	116	102	88	77	66
Sorted by Target 2020	0	0	62	51	43	38	33	29	25

Figure 4.28 : “Improved GBM” forecasts for “sustainable” scenario, Turkey.

As seen in the figure above, each scenario generates a different result for PV diffusion in Turkey, based on the “Sustainable” diffusion scenario. While solar potential sorted data forecasts 617MW installation in 2014, the dataset sorted by target 2020 generates only 62MW installation.

The model with this dataset generates a diffusion pattern showing a declining rate of diffusion. Combining a constant IRR value of 8% with an increasing knowledge base in the diffusion pattern, it is unrealistic to expect a declining installed base at such an early stage of diffusion.



MW	2012	2013	2014	2015	2016	2017	2018	2019	2020
Sorted by solar potential	0	0	808	631	523	447	381	325	279
Sorted by IRR values	0	0	907	696	569	482	406	344	293
Sorted by Target 2020	0	0	82	66	57	50	43	38	33

Figure 4.29 : “Improved GBM” forecasts for “sustainable” scenario, Turkey.

The same data sorting methodologies are also run for the "Fast Catcher" scenario, as seen in figure 4.29 above. The estimations vary with a wide range of values. For example, while IRR sorted data forecasts 907MW installation in 2014, the dataset sorted by target 2020 generates only 82MW installation.

Combining a constant IRR value of 12% with an increasing knowledge base in the diffusion pattern, again, it is also unrealistic to expect a declining installed base at such an early stage of diffusion.

4.7.5 Discussion on forecasts

In the following two charts, the estimates for each scenario are combined.

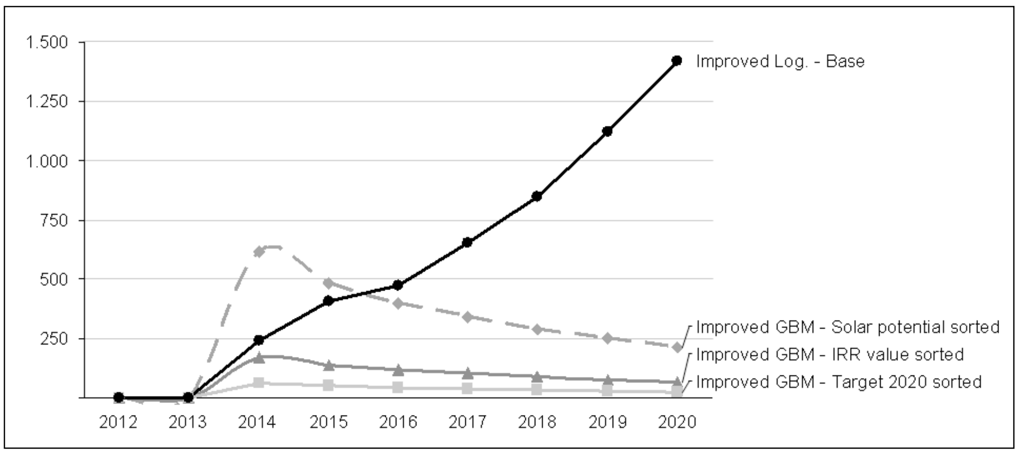


Figure 4.30 : Comparison of forecasts of "improved logistic" and "improved GBM" for "sustainable" diffusion scenario.

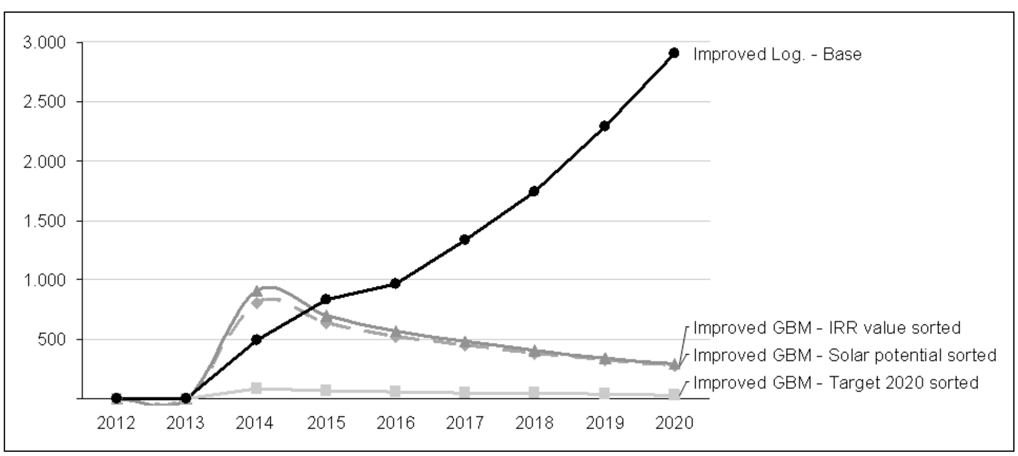


Figure 4.31 : Comparison of forecasts of "improved logistic" and "improved GBM" for "Fast Catcher" diffusion scenario.

As different models predict significantly different values, the question is which one of these models is more realistic. For this analysis, in table 4.16 below, diffusion speed and cumulative installed base are analyzed using different methods, based on defined criteria.

Table 4.15: Comparison of speed and upper limit for each scenario by "improved GBM" and "improved logistic".

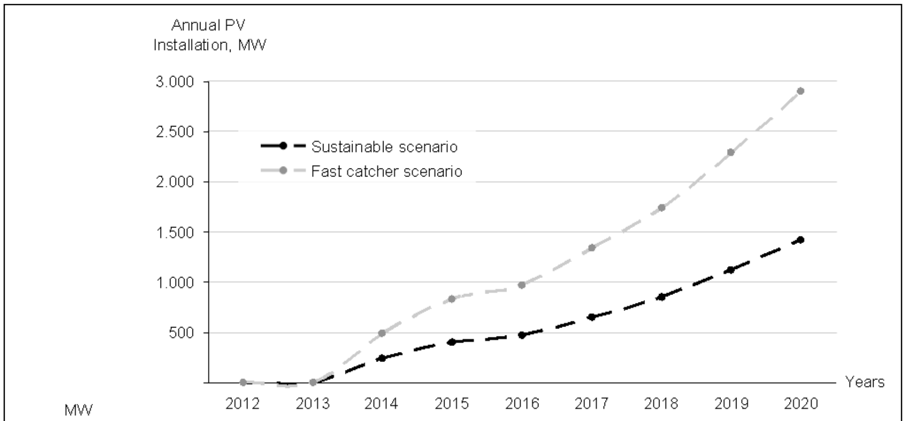
"Sustainable" scenario	MW	Installed base (MW) in first year	Year of 1GW annual installation	Year of 1GW cumulative installation	Annual installed base in 2020 (MW)	Cumulative installed base in 2020 (MW)
	Improved Log. - Base	240	2019	2016	1,420	5,161
	Improved GBM - Solar potential sorted	617	Never	2015	213	2,591
	Improved GBM - IRR value sorted	170	Never	Never	66	757
	Improved GBM - Target 2020 sorted	62	Never	Never	25	282
"Fast catcher" scenario	MW	Installed base (MW) in first year	Year of 1GW annual installation	Year of 1GW cumulative installation	Annual installed base in 2020 (MW)	Cumulative installed base in 2020 (MW)
	Improved Log. - Base	493	2017	2015	2,903	10,560
	Improved GBM - Solar potential sorted	808	Never	2015	279	3,395
	Improved GBM - IRR value sorted	907	Never	2015	293	3,697
	Improved GBM - Target 2020 sorted	82	Never	Never	33	369

In both diffusion scenarios, the shape of the diffusion curve is the main difference among the methods. The "Improved GBM" model predicts reaching maturity at a very early stage i.e. in 2014, and annual installed base decreases every year. On the other hand, the "Improved Logistic" model predicts a gradual increase in the annual installed base. Reaching the maturity level is not predicted until 2020.

According to global benchmark from other focus countries, no country has observed to reach maturity level in a year and performed declining installed base starting from second year of diffusion. Even the Czech Republic, one of the "fast catcher" countries in the diffusion patterns, saw an annual installed base increase in two sequential years. Considering the controlled diffusion behavior of the Turkish Government, diffusion will not be pushed in a year and thereafter left aside for years.

Although the "improved GBM" model performed better than the "Improved Logistic" model in validation results, it shows a relatively poor forecast quality which does not match the realities of PV diffusion. For this reason, "improved Logistic" forecasts are to be communicated as the reference model and forecasts as a thesis result and lessons learnt on "improved GBM" are expected to shed some light on future works.

The "Improved Logistic" model predicts continuously increasing annual installations. Roughly, the installed base of the "fast catcher" diffusion scenario has double the installed base of the "sustainable" scenario. For example, annual installed base in 2014 is 240MW based on the “sustainable” scenario, whereas it is 493MW in the “fast catcher” scenario; cumulative installed base is expected to reach approximately 5GW in the “sustainable” diffusion scenario, meanwhile, cumulative installed base is approximately 10GW in the “fast catcher” scenario.



MW	2012	2013	2014	2015	2016	2017	2018	2019	2020
Sustainable scenario	0	0	240	405	472	653	849	1,121	1,420
Fast catcher scenario	0	0	493	830	967	1,338	1,738	2,292	2,903

Figure 4.32 : Comparison of forecasts for both scenarios, Turkey.

The question is whether or not predictions using the “improved logistic” model are realistic and whether or not these predictions fit the reality of Turkey. In order to make this judgment based on facts, the following three cross-checks are performed:

Comparison with other forecasts: Forecasts by EPIA done in 2011, Turkish National PV Platform done in 2009, ICAT done in February 2010 and EIE (date does not exist) exist and they are compared to the modeling results in the figure below.

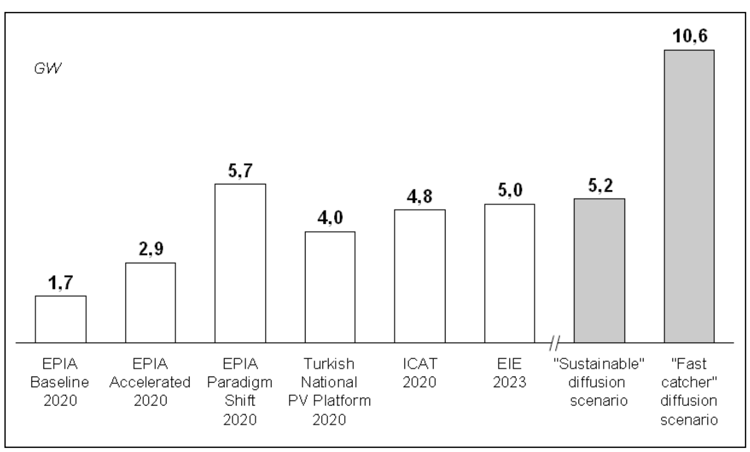


Figure 4.33 : Comparison of “improved logistic” forecasts with external forecasts.

As seen in the analysis with the external forecasts, the model's results for a "sustainable" diffusion scenario are within the range of the others, however, the "fast catcher" scenario offers a relatively ambitious forecast. The "fast catcher" method is a high growth scenario. The reason why EPIA has relatively lower estimates might be related to the timing of the trigger conditions being met in their model. For example, if trigger conditions are met in 2015 rather than 2014, which was assumed in their model, the result is that by 2015, 3.740MW of installed base will materialize rather than 5.161MW in the "sustainable" diffusion scenario.

At the end of the day, the modeling result passes the cross-check and is inline with the other forecasts.

Comparison with other countries: A comparison with other countries' installation targets by 2020 can be obtained in the figure below.

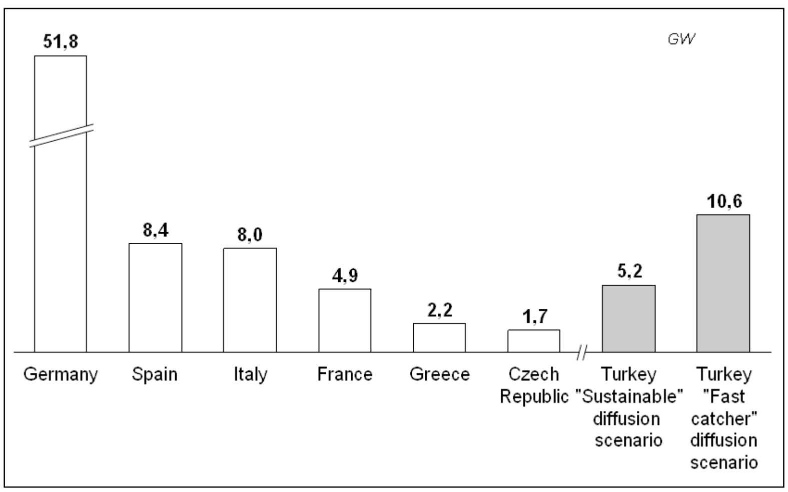


Figure 4.34 : Comparison of forecasts with countries' PV targets by 2020.

The forecast for Turkey is significantly below the 2020 target of Germany, but this result is inline with expectations, as Germany already has 17GW of PV installations and has defined solar energy as one of its national priorities. The forecasts for Turkey are pretty much inline with the PV targets of Spain and Italy. The average PV installation target of Spain and Italy is approximately 8.2GW, compared with a 7.9GW average for Turkey. The similarity might come from the similar solar potential of those three countries (Spain: 1,819kWh/m2; Turkey: 1.724kWh/m2; Italy: 1.664kWh/m2). However Spain and Italy are expected to reach its 2020 targets well in advance and is expected to exceed them before 2020. For this comparison, the final group of countries includes France, Greece and the Czech Republic. A relatively low utilization rate of solar technology in France is due to the country's current and future interest in nuclear power. Greece and the Czech Republic are relatively smaller energy markets compared to Turkey. For example, the total installed base (including all technologies) in Greece is 14GW (NREAP Greece, 2010); the Czech Republic was 18GW (NREAP Czech Rep., 2010) in 2008, meanwhile Turkey has a total of 50GW at the end of 2010 (URL-2, 2011).

Consequently, the comparison shows that the model forecasts are similar to the 2020 PV targets of Spain and Italy, which have similar solar potentials; the differences with the other countries can be reasonably explained due to national interests and size of the energy market.

Comparison with installed base development in Turkey: The idea is that the model's results for PV diffusion should be inline with the development of the total installed base (including all technologies). For example, 5GW of installation cannot take place if a country plans only a 1GW capacity increase for the respective years. In this case, the model results are to be compared with the development of the total installed base in Turkey. As of the end of 2010, Turkey has 50GW of an installed base of power generation (URL-2, 2011). The Turkish government announced the targets of 2023, during the 100 year anniversary of the establishment of the Republic of Turkey. Those targets include energy sector related topics e.g. installed base. According to the announced targets, the Turkish government expects that the installed base will reach 100GW by 2023, with wind accounting for a 20GW share; no target has been communicated for solar. The Turkish government has a relatively higher commitment towards the wind industry and offers greater support for its development. In figure 4.35 below, one can see the current installed base, the 2023 target, and calculated 2020 targets based on the 2023 figures. Penetration rates are also added to show the share in percentage terms of each technology in the entire installed base fleet.

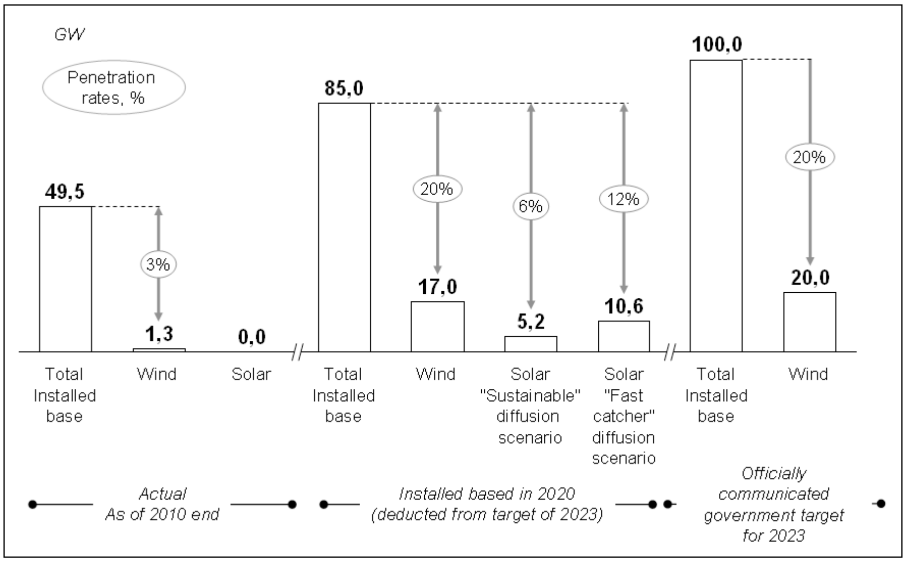


Figure 4.35 : Comparison of forecasts with projected installed base of Turkey.

The analysis shows that the "fast catcher" diffusion scenario generates more than half the market share of wind penetration by 2020. Whereas the "Sustainable" diffusion scenario achieves nearly 6% of penetration of the total installed base. Considering the exponential jump in wind technology penetration from a 3% rate in 2010 to a 20% rate in 2020, both solar diffusion scenarios can be considered reasonable.

This comparison shows that the model forecasts are in the range of a reasonable diffusion scenario, considering the growth potential of the installed base and the diffusion speed of new energy generation technologies e.g. wind.

As a result, the evaluation above indicates that diffusion forecasts by "improved logistic" are reasonable considering solar's potential, the additional capacity plans in Turkey and are inline with other forecasts. It also confirms why the "improved logistic" model is the preferred forecasting model in this thesis.

4.7.6 Boundary conditions

Forecasts for Turkey are done for the two diffusion scenarios, which were developed based on observed global diffusion patterns. There are certain boundary conditions (so called prerequisites) that are needed to be in place in order to kick-off the diffusion and maintain the speed of diffusion as modeled. Any delay and / or change in implementation might impact date of trigger conditions and / or speed of diffusion.

Additionally, IRR, core of modeling, should be translated into FIT terminologies in order to provide a basis to policy makers.

The boundary condition for Turkey is defined as "new FIT meets identified trigger conditions for 2014". The most important dimensions are timing and the scope of the new FIT law.

Regarding the timing perspective, current FIT sets the FIT until the end of 2013. The Turkish government needs to make a decision on how to continue beyond 2013. In the modeling, it is assumed that the current level of FIT will be in place until end of 2013 without any change, and a new FIT will be announced for 2014 in due course.

Regarding scope in the case of Turkey, the level of FIT and government commitment are the most important elements to meet trigger conditions. The current FIT does not provide a reasonable investment return to the investors. According to the global benchmark, the level of IRR is the main input for the pace of diffusion. For future diffusion scenarios, different levels of IRR values are considered as an assumption that was developed based on the diffusion patterns of other countries. However, it was required to calculate the level of FIT in order to enlighten better policy makers. Basically, the IRR for a PV plant investment is the discount rate that makes the present value of a PV plant investment's income stream equal to zero. The formula is as follows:

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0 \qquad \textbf{(4.7)}$$

in which,

NPV: Net present value

N: Total number of periods

C: Cash flow

n: period

r: IRR

Considering the thesis' scope on PV technology and its relationship to economics, an analysis on how to calculate income for power generation deepens here and the rest of the cash flow calculation uses a financial engineering discipline. The assumptions used in financial planning for IRR calculation will also be elaborated here:

$$I = S * SI * CF * F \tag{4.8}$$

in which

I: Income from power generation, monetary term, € or USD

S: Plant size, MW

SI: Solar irradiation, kWh/m2/year

CF: Capacity factor (performance ratio), %

F: FIT, € or USD/kWh

The most important input for IRR calculation is capital cost. Capital cost is the cost of commissioning a PV plant. As discussed, the costs of PV have decreased significantly over the years, but it is still more expensive than fossil-fuel power generation technologies. As the capital cost diminishes it gradually approaches the prices of fossil-fuels. As there is no benchmark for the capital cost of a PV plant in Turkey, global benchmark figures are to be used in the calculation. Although dozens of forecasts exist in studies done by academicians and association, using the most up-to-date forecast is important to calculate the most accurate IRR and FIT values, especially after the slump in module prices in late 2011 due to over-capacity. For this reason, the following forecasts done by Chase and Kim (2011) in October 2011 will be used.

Table 4.16: Capital cost assumptions over the years.

Million USD	2012	2013	2014	2015	2016	2017	2018	2019	2020
Capital cost per MW	2.36	2.19	2.08	2.00	1.81	1.68	1.57	1.47	1.38

For an FIT calculation from a given IRR value, assumptions for other supportive variables in the following table are considered:

Table 4.17: List of assumptions in FIT calculation from given IRR values.

Assumptions	Values	Source / Reasoning
Plant size for IRR calculation scenario	20MW	Average size of PV plants in near future is in the range of 20MW (Saliger, 2011)
Lifetime of PV plant	20 years	Most of the FIT provides support for 20 years and module suppliers provides guarantee for 20 years.
Performance ratio	76%	Performance ratio changes based on efficiency and quality of PV plant. 76% is the average ratio calculated based on dozens of references (Saliger, 2011) will be kept constant over the years for the simplicity purpose
Solar irradiation in Turkey	1894kWh/m²/year	In the first years, relatively more attractive sites to be selected by the investors. 1894kWh/m²/year is the upper quartile of solar irradiation in Turkey
Yearly yield losses	1st year: 2% 2nd year: 1% 3rd year+: 0.5%	This is the efficiency losses of modules based on module suppliers' guarantee (Saliger, 2011)
Equity-loan share	20%-80%	Typical ratio in plant investments (Saliger, 2011)
Land investment per donum	€ 10,000	Typical land investment figure in wind investments in Turkey (Saliger, 2011)
Required land per MW	1.6 dunam	Average of dozens of reference projects (Saliger, 2011)
Operational cost (incl.service and maintenance) / MW / year	€ 300,000	Average of dozens of reference projects (Saliger, 2011)
Depreciation duration	10 years	Given in Turkish accounting system
Depreciation type	linear	Given in Turkish accounting system
Income tax rate	20%	Given in Turkish accounting system
Euro / USD parity	1.33	Current parity in financial markets
Interest rate for foreign currency	4%	Current rate in the Turkish market according to Central Bank of Turkey
Inflation rate over the years	10%	Current expected inflation in the Turkish market

Two scenarios ("sustainable" and "fast catcher") are modeled for PV diffusion, and each scenario has different IRR values contained within, thus it is required to calculate different FIT values for each scenario. FIT values (calculated based on the assumptions above) in the table above are calculated on a yearly basis to so as to avoid potential speculation in the PV market by preventing extraordinary profit margins for the investors:

Table 4.18: Calculated FIT values for different diffusion scenarios.

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Given IRR in "sustainable" scenario (%)	8%	8%	8%	8%	8%	8%	8%	8%	8%
Required FIT (USD/kWh)	0.201	0.189	0.182	0.177	0.165	0.156	0.149	0.144	0.137
Purchase guarantee for years	20	20	20	20	20	20	20	20	20
Given IRR in "fast catcher" scenario (%)	12%	12%	12%	12%	12%	12%	12%	12%	12%
Required FIT (USD/kWh)	0.215	0.205	0.196	0.190	0.177	0.166	0.160	0.153	0.145
Purchase guarantee for years	20	20	20	20	20	20	20	20	20

Another dimension to trigger the PV market is government commitment. With the announcement of a new FIT, the Turkish government also needs to give a commitment on the future development of PV market. One way can be to state an installed base target for the short, mid and long term for PV installations. This commitment is crucial to attract local and foreign investors to invest not only in PV plants, but also expanding manufacturing capacity for key components e.g. modules, cells. For example, the 20GW wind target in 2023 was communicated, and this commitment by the Turkish government has already attracted several large international component manufacturers e.g. GE, Nordex to invest in Turkey.

According to the forecasted annual installed PV capacities until 2020, the required investment volume (a simple calculation of system cost per annual MW installed) is roughly calculated based on the diffusion scenarios. In the figure below, one can see the development of yearly investment over the years.

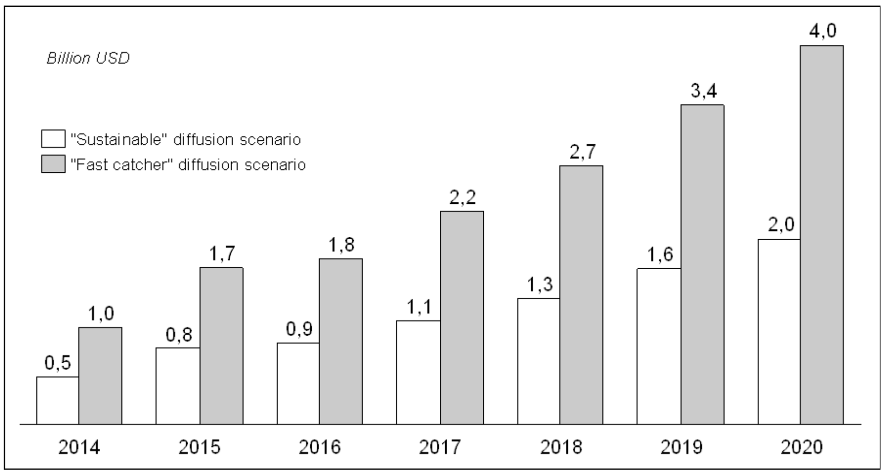
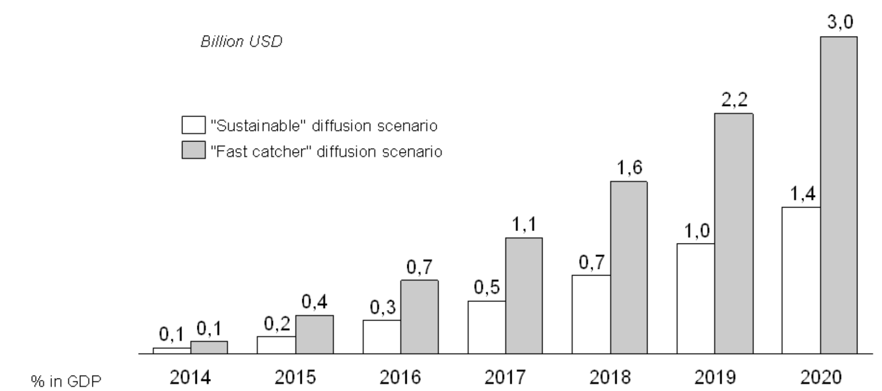


Figure 4.36 : Yearly required amount of investment in PV.

As was discussed in the section on the variables that influence the upper limit, the FIT liabilities of a government as a % of GDP is an important indicator to determine if the size of an economy is big enough to continuously support the PV industry. For example, the Czech Republic has overly burden some FIT liabilities equal to 0.5% of its GDP, whereas Germany's liabilities are equal to only 0.2% of GDP, despite its 17GW installation. The FIT liabilities of the Turkish government for the two diffusion scenarios are calculated below. Based on the "sustainable" diffusion scenario, in 2020, Turkey will have a liability of ~1.4 billion USD i.e. 0.12% of GDP, while according to the "fast catcher" diffusion scenario, Turkey's liability in 2020 will be ~3 billion USD i.e. 0.27% of GDP. The evolvement of the payments is shown below.



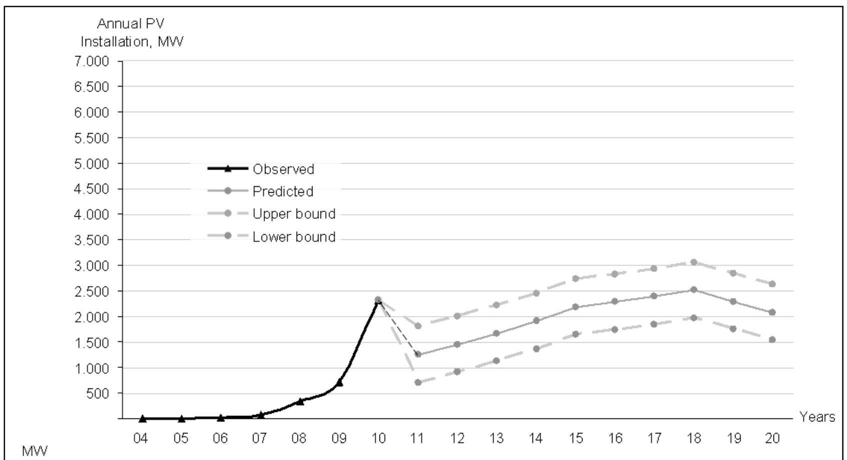
% in GDP	2014	2015	2016	2017	2018	2019	2020
"Sustainable"	0.01%	0.02%	0.03%	0.05%	0.07%	0.10%	0.12%
"Fast catcher"	0.01%	0.04%	0.07%	0.11%	0.16%	0.21%	0.27%

Figure 4.37 : Forecasted annual PV FIT liabilities of Turkish government.

4.8 Improved Logistic Diffusion Forecasts for Selected Countries

Our developed statistical diffusion model is able to generate forecasts for other countries as well, although it was not originally intended for this purpose. In order to leverage this possibility, forecasts are performed for other two countries, Italy and Greece, which have a similar range of solar potential compared to Turkey.

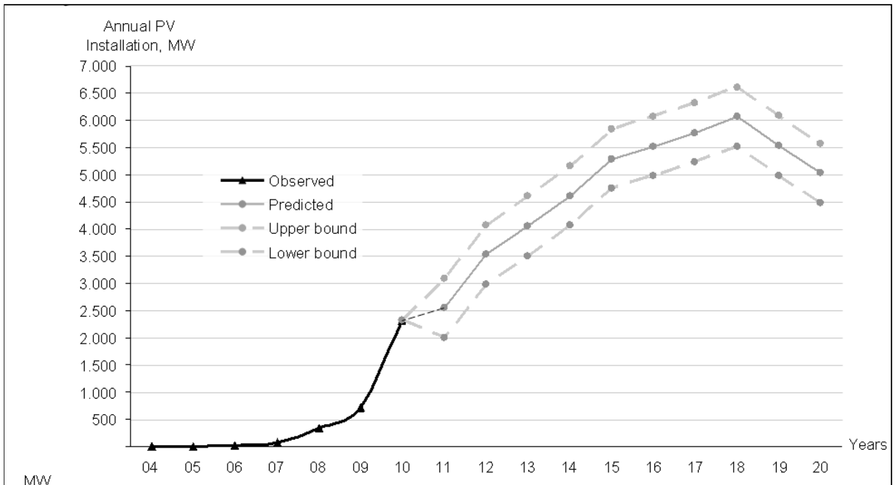
For these countries, the same scenarios i.e. “sustainable”, “fast catcher” are used. In the figure below, we can see the results for Italy based on the “sustainable” diffusion case.



MW	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Observed	5	7	13	70	338	723	2321										
Predicted								1251	1451	1669	1903	2185	2283	2389	2513	2291	2079
Upper Bound								1797	1996	2215	2449	2730	2829	2935	3058	2837	2625
Lower Bound								705	905	1123	1357	1639	1738	1844	1967	1745	1533

Figure 4.38 : Forecast for Italy in “sustainable” diffusion scenario.

Three main patterns are observed. First, a drop is expected beyond 2010 according to the “sustainable” scenario. Second, the annual installed base is not expected to regain today’s level until 2014. Lastly, the PV market is expected to reach a stagnation level beyond 2018, as seen in the reduction in annual installations. When we consider Italy’s cumulative 8GW PV installation target of 2020, we can see that Italy is expected to almost reach this target by the end of 2013. This is one year later than the EPIA (2011a) estimation. The delay in the modeling might be due to a lowered IRR value compared to Italy’s current market. For this reason, another forecast is done using the 12% of IRR value in the “fast catcher” scenario, which is the diffusion pattern of Italy today.

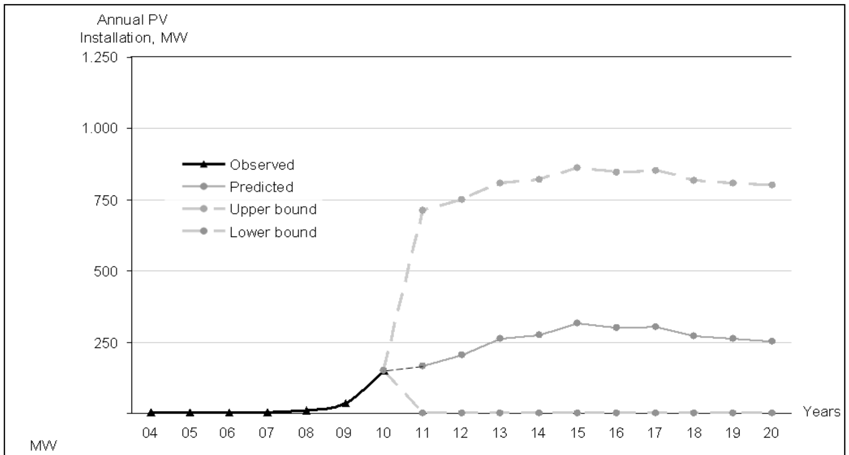


Observed	5	7	13	70	338	723	2321										
Predicted								2552	3529	4055	4615	5287	5521	5772	6063	5535	5029
Upper Bound								3097	4074	4600	5161	5832	6067	6318	6609	6081	5575
Lower Bound								2006	2983	3508	4069	4741	4975	5226	5517	4989	4483

Figure 4.39 : Forecast for Italy in “fast catcher” diffusion scenario.

In the “fast catcher” scenario, Italy is expected to maintain its increase in the installed base annually until 2018, at which point the market is expected to reach stagnation. In this scenario, Italy actually reaches its 2020 target of cumulative 8GW of PV installation by 2011 – 2012, which is inline with the EPIA forecast for Italy.

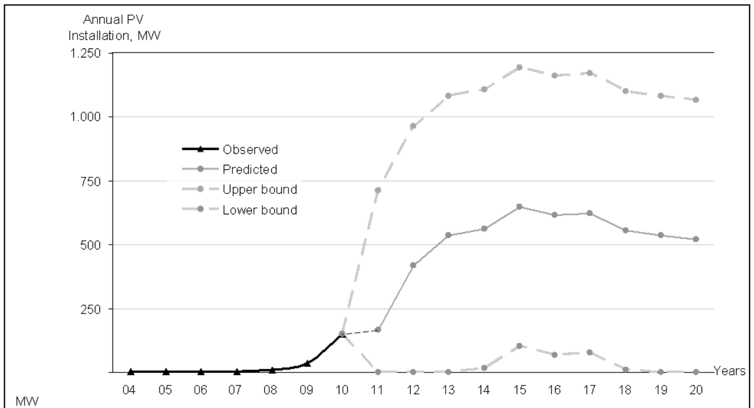
Although Greece’s regulations provide one of the most attractive FITs for investors, the market has not developed as expected. This is due to high hurdles in the administrative process and a lack of confidence in the government’s commitment, due to the difficult economic conditions in the country. Once the market has confidence in the investing environment, Greece might have a chance to limit the profit to PV investors in order to avoid speculation and the high level of liabilities to the government. In the figure below, a forecast for Greece under the "sustainable" diffusion scenario is performed.



Observed	2	2	3	2	10	35	150										
Predicted								167	203	261	274	315	300	304	271	261	253
Upper Bound								712	749	807	820	861	845	850	817	807	799
Lower Bound								0	0	0	0	0	0	0	0	0	0

Figure 4.40 : Forecast for Greece using the "sustainable" diffusion scenario.

As seen in the figure above, "sustainable" market conditions are able kick the market up to 300MW annual installation. We can see that the market reaches stagnation by 2015. Greece's 2020 cumulative PV installation target is 2.2GW, and using the "sustainable" scenario, it is expected to reach this target by 2018, which is in the range of EPIA's forecast of 2017 – 2020. However, if Greece keeps providing a relatively higher IRR to the investors, as in the "fast catcher" scenario, another much different diffusion path is forecast as follows.



MW	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Observed	2	2	3	2	10	35	150										
Predicted								167	417	535	562	646	614	623	555	535	519
Upper Bound								712	962	1081	1108	1192	1160	1169	1101	1081	1064
Lower Bound								0	0	0	16	101	68	77	9	0	0

Figure 4.41 : Forecast for Greece using the “fast catcher” diffusion scenario.

According to the “fast catcher” diffusion pattern, the market reaches stagnation by 2015, the same as with the “sustainable” diffusion scenario. However, Greece is expected to reach its 2020 installation target of 2.2GW by 2014 – 2015, which are several years ahead of the EPIA’s forecast of 2017 – 2020.

As seen in the forecasts for Italy and Greece, the developed logistic model provides reasonable results. It also provides a high level of confidence in the results of the developed model.

4.9 Recommendations For Policy Setting in Turkey

As Germany’s experience shows, setting proper legislation can greatly contribute to the success of the PV industry, while if flawed and ineffective, government legislation it can destroy the confidence of investors, as seen in Spain and the Czech Republic. For this reason, in this chapter, policy recommendations to the Turkish government for proper PV legislation will be based on the knowledge gained from the thesis and also inputs from EPIA (2011b), EPIA (2010) and BMU (2007).

Adequate financial incentives: First of all, the FIT should enable investors to generate a reasonable profit from their investment. While generous FIT schemas create speculative markets like in Spain and the Czech Republic, conservative FIT schemas do not trigger investments and stall industry progress. For this reason, the level of FIT should be defined in a way that it will cover the minimum level of IRR as required by investors. Additionally, since the capital cost of PV has been decreasing rapidly over the years, today's FIT might be too generous in near future. Thus, the level of FIT should be harmonized and designed to reflect the true value of an investment thesis over the years, until PV reaches grid parity. It means that the reduced costs in PV should be closely monitored and FIT should be reviewed periodically to reflect the changes in these costs. In order to avoid a spike in the installed base, several countries, such as Turkey, have started to implement a cap in annual MW installation. Using a global benchmark, an average of ~8% IRR provides a reasonable return rate to investors in a "sustainable" diffusion pattern, while ~12% IRR might create an overzealous ramp-up with the subsequent drop-off, emblematic of for the "fast catcher" diffusion pattern. These IRR values are the result of international comparisons; however they can be adjusted according to the appetite of Turkish investors.

Clear government commitment: An installation target for PV should be set with the consideration of national installed base development, energy mix and energy dependency on imported sources. In Turkey's case, 100GW total installed base in 2023 is projected by the government, yet no PV share has been quantified. The first thing the Turkish government must do is set a PV target for 2023. In addition to creating binding long-term targets, it is also important to set interim milestones in the short and mid-term in order to provide confidence to the investors and to be able to monitor diffusion progress by the government. In Turkey case's, setting interim targets for 2015 and 2020 could be beneficial for PV investors, who will recognize the commitment and understand the pace of industry growth.

Transparent and lean regulatory procedures: Although the FIT in Greece provides an adequate level of return to investors, and government commitment is in place, the PV industry has not been developing as expected due to overly complicated regulatory procedures. It is critical that the utmost attention is paid to these procedures. The rationale behind this comes from the distributed power generation structure of PV. Just as corporations can create large megawatt power plants, PV modules can be built by individuals. Therefore, an individual who has no / limited knowledge on energy procedures should have the ability to make the submission alone. The best case might be one-stop shopping (for small systems at least), meaning that an investor starts and completes the process by visiting only one location or making only one submission. Unnecessary steps in the process should be avoided, thus keeping the paperwork process lean and efficient. On the other hand, legal penalties against investors should be in place so as to avoid any delays on investors' side. Another mitigation action might be to develop standard solutions for certain project sizes in order to limit the technical complexity and to ease the application process.

Keep eye on grid capacity: As soon as PV installations expand beyond negligible quantities, the fluctuation of energy produced by PV might challenge the capacity of the grid. Therefore, there is a need for a detailed grid analysis to be combined with specific allowable grid limits in each region.

Promote PV to build up PV awareness: The promotion of PV is a must, especially to attract individual investors. Addressing the environmental concerns and the potential return for investors can be useful. Additionally, associations such as GENSED (Turkish Photovoltaic Industry Association), ICAT (International Centre For Applied Thermodynamics and UFTP (the National PV Technology Platform in Turkey) should be supported.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Key Findings

The thesis reaches key findings that had not been addressed before in the literature. They are listed below:

A gap has been identified globally at the intersection of technology diffusion, forecasting and the solar industry. Diffusion models have been mainly used for commercial products, especially in B2C markets. According to the literature review, government policy linked markets e.g. PV is not yet addressed in diffusion models enough. Most of the studies on diffusion are found in the areas of accelerators and inhibitors. Additionally, most of the studies done on Turkey are found in the areas of calculating its solar potential and / or analyzing an application of solar energy. Only a limited quantity of detailed analyses was found regarding diffusion models in the PV industry.

Seven countries are analyzed and four diffusion patterns are found, called "sustainable", "fast catchers", "unguided missiles" and "lacking trigger". A "Sustainable" diffusion pattern was executed by Germany, and it is observed that the main characteristics are providing reasonable IRR to investors in conjunction with a transparent, structured administrative process. Italy and France are the countries that fall under the "Fast catchers" diffusion pattern. Both countries provide a relatively higher IRR (~12%) to investors, with existing hurdles in the beginning removed thanks to new legislation. In addition to these two diffusion patterns, we have identified two additional diffusion patterns that are associated with wrong, cumbersome and/or uncontrolled legislation. "Uncontrolled missiles" are deemed to be a success story in the beginning of the diffusion process due to a quick ramp up in PV industry. However, it becomes almost a nightmare to governments due to the high level of FIT liabilities over the following decades. Spain and the Czech Republic are the two countries that best represent this pattern. Both countries placed retroactive cuts in their FIT commitment and thus investors' enthusiasm and confidence waned dramatically. The final diffusion pattern we identified is known as "Lacking trigger"; Bulgaria, Greece and Turkey fall into this diffusion pattern. These countries announced legislation for the PV industry, but the industry has not yet kicked-off. Although Greece and Bulgaria provide one of the most attractive FITs globally, the market has stalled due to an unclear and long administrative process.

Under the light of the four diffusion patterns, three dimensions (trigger conditions, diffusion speed and upper limit) that differentiate the patterns are identified. Determined trigger conditions are the profitability of a PV investment that meets the minimum market expected IRR, a clear government commitment exists, a lean administrative process is in place and solar resources are higher than >800kWh/m^2. Until these entire trigger conditions are met, market pick-up is not expected. After achieving these aforementioned trigger conditions, PV diffusion speed is then affected by the IRR level, knowledge base, FIT, duration of administrative process, GDP growth and per capita and political stability of the country. For the diffusion to reach its upper limit, it will depend on the respective country's PV installation target, solar potential, grid allowance and weight of FIT liability on GDP.

For the purpose of developing statistical modeling, among the four growth curves we analyzed, the logistic and GBM models are considered the most relevant modeling techniques. This is due to the possibility of adding exogenous variables inside. However, typical logistic and GBM functions couldn't address our needs due to missing flexibility in the upper limit definition. Thus, the functions of "improved GBM" and "improved logistic", in which the upper limit is a function of exogenous variables, are developed. For "improved GBM", an add-on for EViews software was developed. The EViews Corporation recognized this add-on and posted it on their homepage.

Both modeling methodologies reached satisfactory results in validation. The "Improved logistic" model reached 0.972 value of R^2. The variables of X12 (triggered IRR) and X3 (knowledge base) are found to be statistically significant for determining diffusion speed considering acceptance level, 0.1

or 0.05. The variables of Z6 (PV target 2020) and Z4 (GDP per capita) are statistically significant for determining the upper limit considering an acceptance level of 0.1. The "Improved GBM" model reached 0.997 value of R^2. The variables of X12 (triggered IRR) and X3 (knowledge base) are statistically significant for determining diffusion speed at acceptance level, 0.1 or 0.05.

Turkey's PV market has not yet achieved its trigger conditions. The current FIT, which is valid until the end of 2013, is not expected to trigger the PV market, even in consideration of the drop in global costs. The reason is that two trigger points i.e. economic feasibility of PV investment and government commitment on PV are missing.

"Improved GBM" performs slightly better in validation compared to "improved logistic", however "improved logistic" generates more reasonable forecasts for Turkey through 2020. As discussed, GBM generates a pick-up in the first year of diffusion, 2014, but from that point going forward, the annual installed base is forecasted to decline. This diffusion pattern is not logical from the perspective of the development of installed base. Therefore, forecasts done by "improved logistic" are taken as the reference for the thesis.

"Sustainable" and "fast catcher" scenarios are developed beyond 2013 for Turkey. Based on the "improved logistic" forecasts, a "sustainable" scenario starts with 240MW PV installations in 2014; it reaches 1.4GW annual PV installations by 2020 and 5.2GW cumulatively by 2020; this scenario might bring USD 2 billion in yearly investment and cause USD 1.4 billion (0.12% of GDP) FIT liabilities to the Turkish government in 2020. The "Fast catcher" scenario starts with 493MW in 2014; it reaches 2.9GW annual PV installations and 10.6GW cumulatively by 2020; this scenario might bring USD 4 billion in yearly investment and create an FIT liability of USD 3 billion (0.27% of GDP) to the Turkish government by 2020. The forecasts are cross-checked with local and international forecasts, other countries' 2020 installation targets and the installed base development of Turkey. All cross-checks provide satisfactory results.

Turkey should address the topic of economic attractiveness and government commitment for PV in order to trigger the PV market. Turkey should pay attention to the following topics when designing a policy for PV. The FIT should provide adequate financial incentives (not more not less; the international benchmark required for market kick-off is a minimum IRR of 6%); clear government commitment should be shown by communicating short, mid and long term installation targets, as it did in the case of wind energy; transparent and lean regulatory procedures should be in place to avoid over-bureaucracy; grid capacity for PV should be followed carefully, and finally, promotion of PV should be done to build up public awareness.

As a global diffusion statistical model is developed, it is used for Italy and Greece under "sustainable" and "fast catcher" diffusion scenarios. In both scenarios, PV installations are expected to reach a stagnation level beyond 2018. In a "sustainable" scenario, Italy is supposed to reach its 8GW installation target of 2020 much earlier i.e. end of 2013 while Italy achieves this target by 2011 – 2012 in the "fast catcher" scenario. Pertaining to Greece, the "sustainable" diffusion scenario is able to kick the market up to 300MW in annual installation. The market reaches a stagnation level by 2015. Considering the cumulative 2.2GW of Greece's PV installation target in 2020, it is expected to reach this target by 2018. In the "fast catcher" scenario, the market reaches a stagnation level by 2015, the same timeframe as in the "sustainable" diffusion scenario. However, it is expected to reach its 2020 installation target of 2.2GW by 2014 – 2015, as opposed to 2018.

5.2 Limitations and risks

Two main limitations / risks of this study are identified as follows:

- *Data availability and accessibility:* Solar energy is a developing technology and there is no historical data in Turkey. Therefore, a cross-border comparison needs to be performed. Nonetheless, even a cross-border comparison increased the number of observed values to only 32.
- *No validation possibility for Turkey:* There is a need to have at least a short history of development in order to make valid forecasts for Turkey, but a lack

of historical data limits this. The risk is that the modeled results will not be accurate. Several years out due to the lack of historical data. In order to limit this risk, a comparison of results is done with other forecasts.

5.3 Suggestions For Further Research

As we are analyzing a relatively immature industry, data availability is limited. Thus, modeling is done based on data that is considered to be of a high level. For example, only total installed base of PV is used as variable because it is not possible to find an installed base split for different sizes of applications (small vs. large applications), as can be found when analyzing FIT. As the industry matures and more data becomes available, the modeling can be re-performed with sub-segments.

The PV industry has been forming quite fast, but in our modeling, yearly data e.g. installed base, FIT is used. However, going forward, using quarterly or semi-annual data might increase the quality of validation and forecast.

Developing a system dynamics' modeling was intended in the beginning of the thesis, but the direction of modeling moved to growth curves due to the lack of adequate data. As more data becomes available, it might be a subject of another Ph.D. thesis.

The IRR calculations for focus countries are based on other researchers' calculations. Though the utmost effort was performed to find IRR values calculated using similar assumptions, the best way would be to calculate historical IRR values based on our own IRR calculation. It might be a subject for future researchers.

Turkey has very high solar potential, and this fact combined with expensive electricity relative to the EU could lead Turkey to reach grid parity before any other European country. An LCOE perspective has not been analyzed in the thesis, but reaching grid parity could trigger a boom in market diffusion. Additional research might be done on grid parity and its possible implications on solar energy development in Turkey.

The modeling and all analyses were conducted for the entire PV market as a package. However, there might be some niche markets e.g. high solar irradiation area or decentralized solutions for a village in the Southeastern part of Turkey that could be triggered much earlier than any other market segment due to the comparable cost of today.

5.4 Lesson Learned on Writing a Ph.D. Thesis

All Ph.D. candidates have their own recipe for completing the thesis, but I would like to summarize my personal lessons learned. I hope that the topics below will shed some light on the process to make future Ph.D. candidates' lives as smooth as possible. The topics are classified / sorted under the steps of completing a Ph.D. thesis.

Before investing 1 day in a Ph.D.: A Ph.D. is a marathon, it might take much longer than you expect. Although some examples of completing a Ph.D. in 2 years exists in other countries, it takes 5 years on average in Turkey (I assume it is same in all universities in Turkey), due to the required 8 lectures to take in addition to the 2 written and 1 verbal proficiency exams. Last but not least of course is the Ph.D. thesis to complete. Thus, it is a commitment for 5-7 years, which means 20-25% of your lifetime so far (assuming the Ph.D. candidate's age of 25 – 35). In the case that a Ph.D. candidate has even 1% doubt about her / his commitment, (s)he shouldn't continue, because there will be many happenings in life that will challenge the decision to continue. Basically, doing a Ph.D. requires the candidate's 100% commitment. "It is a Ph.D. thesis", is a famous phrase that you will get used to hearing from academicians.

In addition to personal commitment, it is also required to have 100% commitment from your spouse and family. If a candidate tries to do a Ph.D. thesis in parallel to a marriage with a child (like my case), the candidate is stealing time from the family. While a supportive family might be the only reason to be successful (like my case), other examples exist reflecting that family is the reason to hold or even stop the Ph.D.

Selecting a Ph.D. topic: Selection of a Ph.D. topic is an early decisions but one of the most important decisions in the Ph.D. process. While a Ph.D. candidate might select a topic from today's agenda of which you are more knowledgeable, the Ph.D. candidate might also select a topic which has future potential but on which (s)he has limited knowledge. In my case, I selected a topic that I believed is where the future will be, and I had very little knowledge of it. The Ph.D. thesis helped me to develop my knowledge on the dynamics of solar energy. Taking on a challenge in an area that is new to the candidate might help to improve one's knowledge base, but that decision can also jeopardize the success of the Ph.D. thesis.

Writing Ph.D. thesis: Doing a Ph.D. requires a continuous focus, rather than the stop & go approach. Accelerated studying on the Ph.D. thesis before the progress report will impact the progress and quality of result significantly. Once the candidate is interrupted for weeks or even months, warming up takes a long time. In the case there are other life functions to perform such as in the professional arena and being a husband and father (as in my case), arranging 100% dedicated time in an isolated environment will expedite the progress immensely. From my experience, dedicated time means a minimum of two sequential days for incremental progress and a minimum of two sequential weeks for substantial progress. In the figure below, one can see the progress of the Ph.D. thesis from the perspective of the number of pages completed (excluding chapter of references and appendices). As can be seen, especially during the past two months when I was able to be 100% dedicated (meaning no work, minimal personal interaction), I completed the same amount of pages as I had since the beginning of 2011.

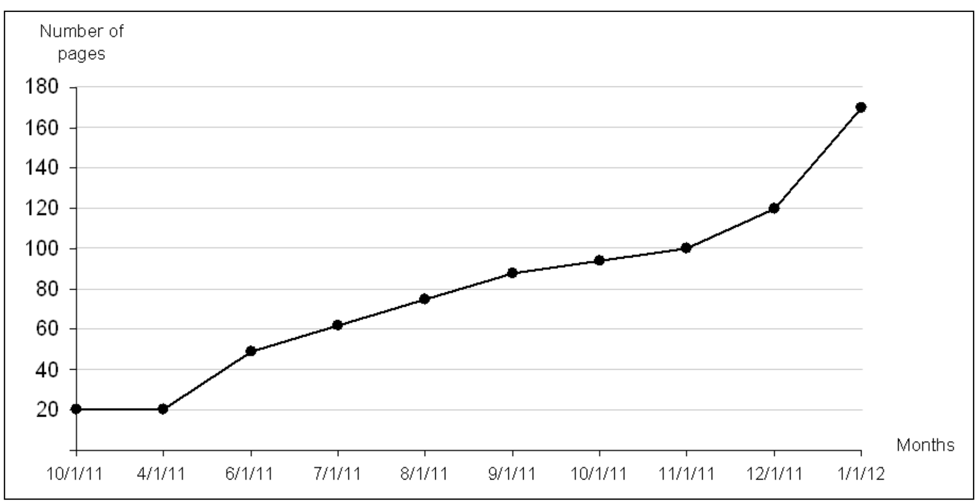


Figure 5.1 : Development of the number of pages written in Ph.D. thesis over the year.

For the stereotypical perfectionist, a Ph.D. can be quite the miserable process. However, the candidate will be able to complete the Ph.D. thesis only when (s)he understands the balance of "perfection" and "the biggest enemy of good is better". It was the case in my situation.

In addition to the Ph.D. advisor, jury members help to set a direction to the thesis. Gaining jury members' confidence in a methodology to be followed will support the progress very much. Of course, it is not always as easy as written, but at least earlier is better.

Technological advancements on IT side also support the progress of Ph.D. thesis:

> Identifying RSS feeds (Really Simple Syndication) for the keywords, relevant to the topic on academic databases e.g. Science Direct will keep the Ph.D. candidate up to date on posted articles. It will enable you to do only several massive searches on the literature in the beginning, and the researcher will be posted on newly published articles via an RSS reader later on.
>
> Simultaneous backup for documents on the internet might avoid any shocking and bad surprises e.g. losing data during Ph.D. writing. I used Dropbox software (www.dropbox.com), which allows 2GB free simultaneous backup for users.
>
> The Ph.D. folder in my computer has more than 1.600 files within ~130 folders. A Ph.D. candidate has access to an enormous amount of resources, but somehow all these documents must be kept in an organized structure in a way that the Ph.D. candidate will be able to find them easily. My own recipe to keep it structured is to store all documents under the one main folder, name the articles with their own title, and prioritize articles by adding 1, 2 and 3 to the beginning of their name based on their relevance and storing the relevant part of the articles in a Microsoft Word document for each chapter.
>
> Keeping three parallel Microsoft Word document i.e. one for body text, one for references and one for appendices might limit the time spent while the Ph.D. candidate is surfing through the pages.
>
> I found the Outline layout of Microsoft Word quite beneficial. In the version of Microsoft Word 2003, it is possible to select it using view >> outline. It enables the Ph.D. candidate to see different levels of depth of the Ph.D. thesis and it is easy to get an entire picture of the Ph.D. thesis.

REFERENCES

Alagappan, L., Orans, R. and Wooa, C.K. (2011). What drives renewable energy development?. *Energy Policy*, in press.

Arrow, K. (1962). The economic implications of learning-by-doing. *Review of Economic Studies*, **29**, 155 – 173.

Avack, F. (2010). *Italy: hottest PV market in Europe in 2011*. Bloomberg New Energy Finance, London. UK.

Ayres, R. U. (1969). *Technological Forecasting and Long-Range Planning*, McGraw-Hill, USA.

Bass, F. M. (1969). A new product growth model for consumer durables. *Management Science*, **15**, 215–227.

Bass, F. M., Krishnan, T. and Jain, D. (1994). Why the Bass model fits without decision variables. *Marketing Science*, **13**, 203 – 223.

BMU. (2007)**.** *EEG – The Renewable Energy Sources Act: The Success Story of Sustainable Policies for Germany*. Berlin, Germany.

Boust, M., Mühlenbach, M. and Berg, J. (2011). *No Turkish delight following new renewable law*. EER IHS, Cambridge, US.

Boyle, G. (1998). *Renewable energy: Power for a sustainable future*. Oxford University Press, Oxford, UK, 1 – 40.

Bulte, C. V. (2002). Want to know how diffusion speed varies across countries and products? Try using a Bass model. *PDMA Visions*, **4**, 12 – 15.

Bulut, H. and Büyükalaca, O. (2007). Simple model for the generation of daily global solar-radiation data in Turkey. *Applied Energy*, 84, 477 – 491.

Byrnea, J., Kurdgelashvilia, L., Poponia, D. and Barnettb, A. (2004). The potential of solar electric power for meeting future US energy needs: a comparison of projections of solar electric energy generation and Arctic National Wildlife Refuge oil production. *Energy Policy*, **32**, 289 – 297.

Campoccia, A. Dusonchet, L. and Telaretti, E. (2009). Comparative analysis of different supporting measures for the production of electrical energy by solar PV and Wind systems: Four representative European cases. *Solar Energy*. **83**, 287 – 297.

CEC. (2008a)**.** *0019 Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources*. European Commission, Brussels, Belgium.

CEC. (2008b). *The support of electricity from renewable energy sources.* Commission Staff Working Document, Brussels, Belgium.

Celiktas, M. S. and Kocar, G. (2010). From potential forecast to foresight of Turkey's renewable energy with Delphi approach. *Energy*, **35**, 1973 – 1980.

Celiktas, M. S., Sevgili, T. and Kocar, G. (2009). A snapshot of renewable energy research in Turkey. *Renewable Energy,* **34**, 1479 – 1486.

Cetin, M. and Egrican, M. (2011). Employment impacts of solar energy in Turkey. *Energy Policy*, **39**, 7184 – 7191.

Chabot, B. (1993). *Analyse e´conomique des filie`res d'e´nergie solaire*. Sommet Solaire Mondial, UNESCO, Paris.

Chase, J. and Kim, A. (2011). *Solar Energy Q4 2011 conference call*. Bloomberg new Energy Finance, London, UK.

Dalla Valle, A., and Furlan, C. (2011). Forecasting accuracy of wind power technology diffusion models across countries. *International Journal of Forecasting*, **27**, 592 – 601.

DeLine, C. (2010)**.** *Europe PV System Cost Trends and Analysis: 2010,* IHS Emerging Energy Research, Cambridge, Massachusetts, US.

Desiraju, R., Nair, H. and Chintagunta, P. (2004). Diffusion of new pharmaceutical drugs in developing and developed nations. *International Journal of Research in Marketing*, **21**, 341 – 357.

Diez-Mediavilla, M., Alonso-Trista´n, C., Rodriguez-Amigo, M.C. and Garcia-Calderon, T. (2010). Implementation of PV plants in Spain: a case study. *Renewable and Sustainable Energy Reviews*, **14**, pp. 1342 – 1346.

Durand, Y. and Jacquin, P. (2009). *Solar Photovoltaic Electricity Applications in France National Survey Report 2008*, Paris, France.

Dusonchet, L. and Telaretti, E. (2010)**.** Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European Union countries. *Energy Policy*, **38**, 3297 – 3308.

EC. (1997). *Energy for Future: Renewable Energy Sources –European Union Action Plan.* Communication from the Commission, Brussels, Belgium.

EC. (2005). *The support of electricity from renewable energy sources.* Communication from the Commission, Brussels, Belgium.

EC. (2009). *Directive 2009/of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.* European Commission, Brussels, Belgium.

EER. (2009). *Southern Europe Solar PV Markets and Strategies: 2009–2020*, IHS, Cambridge, US.

EER. (2010a), *EER Europe Solar Power Markets National Action Plans and Country Profiles,* IHS, Cambridge, US.

EER. (2010b). *Europe PV System Cost Trends and Analysis: 2010.* IHS, Massachusetts, US.

EER. (2011), *Europe Solar PV Markets and Strategies: 2011–2025,* IHS, Cambridge, US.

Ekins, P. (2004). Step changes for decarbonising the energy system: research needs for renewables, energy efficiency and nuclear power. *Energy Policy*, **32**, 1891 – 1904.

EP. (2009). *Directive2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.* European Commission, Brussels, Belgium.

Eris, A. (2002). Enerji politikalari ile yerli, yeni ve yenilenebilir enerji kaynaklari. *TMMOB Turkiye VI. Enerji sempozyumu bildiriler kitabi*, Ankara, Turkey.

Focacci, A. (2009). Residential plants investment appraisal subsequent to the new supporting photovoltaic economic mechanism in Italy. *Renewable and Sustainable Energy Reviews,* **13**, 2710 – 2715.

Frank, L.D. (2002). An analysis of the effect of the economic situation on modeling and forecasting the diffusion of wireless communications in Finland. *Technological Forecasting and Social Change*, **71**, 391 – 403.

Gamboa, L.F. and Otero, J. (2009). An estimation of the pattern of diffusion of mobile phones: the case of Colombia. *Telecommunications Policy,* **33**, 610 – 620.

Gatignon, H., Eliashaberg, A. J. and Robertson, T. S. (1998). Modelling multinational diffusion patterns: an efficient methodology. *Marketing Science,* **8**, 231 – 247.

Gellings, R. (2006). Boom Stopped: The Outlook for Spain's Photovoltaic Sector Seemed Rosy – But Now Politics is Obstructing. *PHOTON*, **September 2006**, 132 – 140.

Gonzalez, P. R. (2008). Ten years of renewable electricity policies in Spain: An analysis of successive feed-in tariff reforms. *Energy Policy,* **36**, 2917 – 2929.

Gouchoe, S., Everette, V. and Haynes, R. (2002). Case Studies on the Effectiveness of State Financial Incentives for Renewable Energy. *Working paper,* North Carolina State University Raleigh, Colorado.

Guidolin, M., and Mortarino, C. (2010). Cross-country diffusion of photovoltaic systems: Modeling choices and forecasts for national adoption patterns. *Technological Forecasting & Social Change*, **77**, 279 – 296.

Haas, R., Meyer, N.I., Held, A., Finon, D., Lorenzoni, A., Wiser, R. and Nishio, K. (2008). *Promoting Electricity from Renewable Energy Sources—Lessons Learned from the EU, US and Japan.* Lawrence Berkeley

National Laboratory. <www.escholar ship.org/uc/item/17k9d82pS> date retrieved 15.04.2011.

Havstad, J.W. and Ehlers, C.L. (1989). Attractor dimension of nonstationary dynamical systems from small data sets. *Physical Review*, **39**, 845 – 853.

Hoffert, M.I., Caldeira, K., Benford, G., Criswell, D.R., Green, C., Herzog, H., Jain, A.K., Kheshgi, H.S., Lackner,K.S., Lewis, J.S., Lightfoot,H.D., Manheimer,W., Mankins, J.C., Mauel,M.E., Perkins, L.J., Schlesinger, M.E., Volk, T. and Wigley, T.M.L. (2002). Advanced technology paths to global climate stability: energy for a greenhouse planet. *Science*, **298**, 981 – 987.

Hubbert, M.K. (1962). *Energy Resources: Report to the Committee on Natural Resources' Publication 1000-D*. National Academy of Sciences and National Research Council, Washington, USA.

Hvelplund, F. (2001). Political prices or political quantities?. *New Energy*, **5**, 18 – 23.

Ibenholt, K. (2002). Explaining learning curves for wind power. *Energy Policy,* **30**, 1181 – 1189.

IEA. (1993). *World Energy Outlook to the Year 2010*, International Energy Agency, OECD, Paris, France.

IEA. (2000). *Experience Curves for Energy Technology Policy,* IEA Publications, OECD, Paris, France.

IEA. (2004). *Renewable energy: market and policy trends in IEA countries*. IEA, OECD, Paris, France.

Islam, T. and Fiebig, D. B. (2001). Modelling the development of supply-restricted telecommunications markets. *Journal of Forecasting*, **20**, 249– 264.

Isoard, S. and Soria, A. (2001). Technical change dynamics: evidence from the emerging renewable energy technologies. *Energy Economics*, **23**, 619 – 636.

ISPRE (International Science Panel on Renewable Energies). (2009). Research and Development on Renewable Energies, *ISPRE*, Germany.

Jäger-Waldau, A., Szabó, M., Scarlat, N. and Monforti-Ferrario, F. (2011). Renewable Electricity in Europe. *Renewable and Sustainable Energy Reviews,* **15**, 3703 – 3716.

Kalish, S. and Lilien, G. L. (1983). Optimal price subsidy policy for accelerating the diffusion of innovation. *Marketing Science*, **2**, 407 – 420.

Kececioglu, T. (1990). Türkiye'de stratejik enerji planlamasında güneş enerjisinin yeri, *Ph.D. Thesis*, Ege University, Izmir, Turkey.

Kelly, H. and Weinberg, C.J. (1993). *Utility strategies for using renewables.* In: Johansson, T.B., Kelly, H., Reddy, A.K.N., Williams, R.H. and Burnham, L. (Eds.), Renewable Energy. Island Press, Washington DC, USA.

Khan, FI., Hawboldt, K., and Iqbal, M. T. (2005). Life cycle analysis of wind–fuel cell integrated system. *Renewable Energy*, **30**, 57 – 77.

Kotler, P. (2003). *Marketing Management, 11th ed.*, Prentice Hall, New Jersey, USA.

Kumbaroglu, G., Madlener, R., and Demirel, M. (2008). A real options evaluation model for the diffusion prospects of new renewable power generation technologies, *Energy Economics*, **30**, 1882 – 1908.

Kurosawa, K., Takashima, T., Hirasawa, T., Kichimi, T., Imura, T., Nishioka, T., Iitsuka, H. and Tashiro, N. (1997). Case studies of largescale PV systems in desert areas of the world. *Solar Energy Materials and Solar Cells*, **47**, 189 – 196.

Laurens, D. (2010). *Solar Photovoltaic Sector Review*, Societe Generale, Paris, France.

Lesourd, J.B. (2001). Solar photovoltaic systems: the economics of a renewable energy resource. *Environmental Modelling & Software,* **16**, 147 – 156.

Levary, R. R. and Han, D. (1995). Choosing a technological forecasting method. *Industrial Management*, **37**, 14 – 20.

Lipp, J. (2007). Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy,* **35**, 5481 – 5495.

Lorenz, P., Pinner, D. and Seitz, T. (2008). The Economics of Solar Power, *The McKinsey Quarterly*, **June 2008**.

Lund, P. (2006). Market penetration rates of new energy technologies. *Energy Policy*, **34**, 3317 – 3326.

Lüthi, S. (2010). Effective deployment of photovoltaics in the Mediterranean countries: Balancing policy risk and return. *Solar Energy*, **84**, 1059 – 1071.

Madlani, R., Basu, A. and Roques, J. (2010). *European renewables & clean technology: global wind and solar demand forecast 2010-2014*, Barclays Capital, London, UK.

Mahaian, V., Muller, E. and Bass, F.M. (1990). New product diffusion models in marketing: a review and directions for research. *Journal of Marketing,* **54**, 1 – 26.

Makridakis, S. and Wheelwright, S.C. (1978). *Forecasting Methods and Applications*. Wiley, New York.

Mark, M. and Nick-Leptin, J. (2010). *Short and long-term impacts of the expansion of renewable energy on the German labour market*. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin, Germany.

Martino, J.P. (1993). *Technological forecasting for decision making*, McGraw-Hill, New York, USA.

Masini, A. and Frankl, P. (2002). Forecasting the diffusion of photovoltaic systems in southern Europe: A learning curve approach. *Technological Forecasting & Social Change*, **70**, 39 – 65.

Mccrone, A. (2011). *Greece Approves 1,793 Megawatts of Photovoltaics in 2010,* Bloomberg new Energy Finance, London, UK.

McKinsey. (2008). The economics of solar energy. *McKinsey Quarterly,* **June 2008 edition**, 1 – 11.

Meade, N. and Islam, T. (1998). Technological forecasting – model selection, model stability, and combining models. *Management Science*, **44**, 1115 –1130.

Meade, N. and Islam, T. (2006). Modelling and forecasting the diffusion of innovation – A 25 years review. *International Journal of Forecasting,* **22**, 519 – 545.

Metcalfe, J. S. (1988). *The diffusion of innovations: an interpretative survey.* In: Dosi G, Freeman C, Nelson R, Silverberg G, Soete L, editors. Technical change and economic theory. Printer Publishers, London, UK.

Meyers, R.A. (1983). *Handbook of Energy Technology and Economics.* Wiley, New York, US.

Michalakelis, C., Varoutas, D. and Sphicopoulos T. (2008). Diffusion models of mobile telephony in Greece. *Telecommunications Policy,* **32**, 234 – 245.

Mishra, S., Deshmukh, S.G. and Vrat, P. (2002). Matching of technological forecasting technique to a technology, *Technological Forecasting & Social Change*, **69**, 1 – 27.

Montalvo, C. and Kemp, R. (2008). Cleaner technology diffusion: case studies, modeling and policy. *Journal of Cleaner Production*, **16**, 1–6.

Neidlein, B. (2011). Too little, too late?, *PV Magazine*, 02/2011, 40 – 41.

Neij, L. (1997). Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology. *Energy Policy*, **23**, 1099 – 1107.

Nitsch, J. (2007). *Pilot Study 2007: Expansion Strategy for Renewable Energy. Update and reevaluation up to the years 2020 and 2030 with an outlook to 2050.* BMU, Stuttgart, Germany.

NREAP Czech Republic. (2010). *Italy's National Renewable Energy Action Plan 2011-2020,* European Commission, Brussels, Belgium.

NREAP France. (2011). *France's National Renewable Energy Action Plan 2011-2020: Response from the French authorities to requests for information on the Renewable Energy Action Plan,* European Commission, Brussels, Belgium.

NREAP Greece. (2011). *Greece's National Renewable Energy Action Plan 2011-2020,* European Commission, Brussels, Belgium.

NREAP Italy. (2010). *Italy's National Renewable Energy Action Plan 2011-2020,* European Commission, Brussels, Belgium.

NREAP Spain. (2010). *Spain's National Renewable Energy Action Plan 2011-2020,* European Commission, Brussels, Belgium.

Park, S. Y., Kim, J. W. and Lee, D. H. (2011). Development of a market penetration forecasting model for Hydrogen Fuel Cell Vehicles considering infrastructure and cost reduction effects. *Energy Policy*, **39**, 3307 – 3315.

Perez, R., Seals, R. and Stewart, R. (1993). Assigning the load matching capability of photovoltaics for US utilities based upon satellite derived isolation data. *Proceedings of the 23rd IEEE Photovoltaic Specialists Conference*, 1146–1151.

Peter, R., Ramaseshan, B. and Nayar, C.V. (2002). Conceptual model for marketing solar based technology to developing countries. *Renewable Energy*, **25**, 511 – 524.

Pulfrey, D.L. (1978). *Photovoltaic Power Generation.* Van Nostrand, New York.

Rao, K. U. and Kishore, V. V. N. (2008). Wind power technology diffusion analysis in selected states of India. *Renewable Energy,* **34**, 983 – 988.

Rao, K. U. and Kishore, V. V. N. (2010). A review of technology diffusion models with special reference to renewable energy technologies. *Renewable and Sustainable Energy Reviews*, **14**, 1070 – 1078.

REN21, (2010). *Global Market Outlook for Photovoltaics until 2015*. Renewable Energy Policy Network for 21st Century, France.

REN21. (2011). *Renewables 2010 Global Status Report*. Renewable Energy Policy Network for 21st Century, France.

Rio, P. and Unruh, G. (2006). Overcoming the lock-out of renewable energy technologies in Spain: the cases of wind and solar electricity. *Renewable and Sustainable Energy Reviews*, **11**, 1498 – 1513.

Robinson, B. and Lakhani, C. (1975). Dynamic pricing models for new product planning. *Management Science*, **10**, 1113 – 1122.

Roca, M. (2011). *Bulgaria Government Cuts Solar Feed-In Incentives By Up to 31%.* Bloomberg new Energy Finance, London, UK.

Rogers, E.M. (1962). *Diffusion of Innovations*, The Free Press, New York, USA.

Sadeghi, M., Seddigh, S. and Bidgoli, S. E. (2007). System Dynamic Modeling for Technology Forecasting, *Working Paper*.

Salas, V. and Olias, E. (2009). Overview of the photovoltaic technology status and perspective in Spain. *Renewable and Sustainable Energy Reviews,* **13**, 1049 – 1057.

Saliger, R. (2011). Personal Interview.

Saylan, L., Sen, O., Toros, H. and Arisoy, A. (2002). Solar energy potential for heating and cooling systems in big cities of Turkey. *Conversion and Management*, **43**, 1829 – 1837.

Shah, V. and Greenblatt, J. (2010)**.** *Solar Energy Handbook: The Third Growth Phase of the Solar Era*, Barclays Capital, New York, US.

Sieber, J. (2007). A Hot Market: Investments in Solar Parks in Spain. *PHOTON*, **July 2007**, 34–36.

Simonek, M. (2011). *Czech PV market: the end of a Bohemian rhapsody.* Bloomberg new Energy Finance, London, UK.

Singh, S.K. (2008). The diffusion of mobile phones in India. *Telecommunications Policy,* **32**, 642–651.

Speed, P.A. (2009)**.** China's ongoing energy efficiency drive: origins, progress and prospects. *Energy Policy,* **37**, pp. 1331 – 1344.

Sozen, A., Arcaklioglu, E., Ozalp, M. and Kanit, E. G. (2005). Solar-energy potential in Turkey. *Applied Energy*, **80**, 367 – 381.

Söderholm, P. and Klaassen, G. (2007). Wind power in Europe: a simultaneous innovation diffusion model. *Environmental and Resource Economics*, **36**, 163 – 190.

Sözen, A., Arcaklioglu, E., Ozalp, M. and Caglar, N. (2005). Forecasting based on neural network approach of solar potential in Turkey. *Renewable Energy,* **30**, 1075 – 1090.

Sultan, F., Farley, J. U. and Lehman, D. R. (1990). A meta-analysis of applications of diffusion models. *Journal of Marketing Research*, **27**, 70 – 77.

Syndicat des Energies Renouvelables. (2011). *Second appel d'offres photovoltaique : La filiere reste confrontee a des mesures inadaptees*, Paris, France.

The IPCC. (1995). *Climate Change 1995: The Science of Climate Change, Summary for Policy Makers and Technical Summary and IPCC Second Assessment Report: Climate Change.* United Nations Environment Program and World Meteorological Organization, New York.

The IPCC. (2001). *Summary for Policymakers, Climate Change 2001: Impacts, Adaptation, and Vulnerability.* United Nations Environment Program and World Meteorological Organization, New York, NY,

Thirugnanasambandam, M., Iniyan, S. and Goic, R. (2009). A review of solar thermal technologies, Renewable and Sustainable Energy Reviews. **13**, 318 – 345.

Timilsina, G.R. Kurdgelashvili, L. and Narbel, P. A. (2011). Solar energy: Markets, economics and policies. *World Bank Policy Research Working Paper*, No. WPS 5845.

Trappey, C. V. and Wu, H.Y. (2008). An evaluation of the time-varying extended logistic, simple logistic, and Gompertz models for forecasting short product lifecycles. *Advanced Engineering Informatics,* **22**, pp. 421 – 430.

Tükenmez, M. and Demireli, E. (2012). Renewable energy policy in Turkey with the new legal regulations. *Renewable Energy*, **39**, 1 – 9.

Ulgen, K. and Hepbasli, A. (2009). Diffuse solar radiation estimation models for Turkey's big cities. *Energy Conversion and Management*, **50**, 149 – 156.

United Nations, (1997). *Convention on Climate Change. Kyoto Protocol to the United Nations Framework Convention on Climate Change*, UN, US.

Villiger, A., Wüstenhagen, R. and Meyer, A. (2000). *Beyond the Eco-Niche*, Birkhauser, Basel/Boston/Berlin.

Yilmaz, Z. and Kundakci, A. B. (2008). An approach for energy conscious renovation of residential buildings in Istanbul by Trombe wall system. *Building and Environment*, **43**, 508 – 517.

Wand, R. and Leuthold, F. (2011). Feed-in tariffs for photovoltaics: Learning by doing in Germany?. *Applied Energy*, in press.

Wilson, J. H. and Keating B. (2007). *Business Forecasting,* McGraw-Hill International Edition, New York.

Winnerlein, A. (2009). Influence of political support mechanisms on the market attractiveness in the PV energy sector, *Diploma Thesis*, University of Applied Sciences, USA.

Wissing L. (2010). *National Survey Report of PV Power Applications in Germany 2009. International Energy Agency Co-Operative Programme On Photovoltaic Power Systems*, Jülich, Germany.

Wissing, L. (2011). *National Survey Report of PV Power Applications in Germany 2010*, Jülich, Germany.

Wu, H. (2007). An Evaluation of the Time-Varying Extended Logistic, Simple Logistic, and Gompertz Models for Forecasting Short Lifecycle Products and Services, *Ph.D. Thesis*, National Chiao Tung University, Hsinchu, Taiwan.

Diaz-Rainey, I. (2005). Modelling international wind energy adoption: Are the patterns of induced diffusion s-shaped?, *working paper*. <http://www.tu-dresden.de/wwbwleeg/events/enerday/2009/Paper/Daiz.Rainey.pdf> date retrieved 12.08.2011

EIA. (2009). *International Energy Outlook*. <http://www.eia.doe.gov/oiaf/ieo/index.html> date retrieved 10.09.09.

EPIA. (2009). *SET for 2020.* <http://www.epia.org/publications/epia-publications.html> date retrieved 15.03.2011.

EPIA. (2010). *Unlocking sunbelt potential of photovoltaics*. [http://www.epia.org/publications/epia-publications.html] date retrieved 15.04.2011.

EPIA. (2011a). *Global Market Outlook for Photovoltaics until 2015*. <http://www.epia.org/publications/epia-publications.html> date retrieved 15.04.2011.

EPIA. (2011b). *Photovoltaic observatory and policy recommendations 2011*. <http://www.epia.org/publications/epia-publications.html> date retrieved 08.03.2011.

GSE, (2011). *Fotovoltaico: L'italia Supera I 10 Mila Mw Di Potenza Installata*, http://www.gse.it/GSE%20Informa/pagine/FOTOVOLTAICOL'ITAL

IASUPERAI10MILAMWDIPOTENZAINSTALLATA.aspx, date retrieved 13.09.2011.

IEA PVPS. (2010). *Trends in photovoltaic applications: Survey report of selected IEA countries between 1992 and 2009*, <http://www.iea-pvps.org/publications>, retrieved on 10.02.2011.

IEA PVPS. (2011). *National reports of 2009, 2008, 2007.* <http://www.iea-pvps.org/index.php?id=93> date retrieved 02.10.2011.

Müller, S. (2010). *Photovoltaik-Markt in den Europäischen "Emerging Markets"*, <http://www.enerparc.de/>, date retrieved 15.01.2011.

Solar Plaza. (2011). *For How Long will Germany Remain the World's Largest PV Market?*. <http://www.solarplaza.com/article/for-how-long-will-germany-remain-the-worlds-large>, date retrieved 29.08.2011.

URL-1, <http://www.erneuerbare-energien.de/inhalt/46291/20026/> date retrieved 02.07.2011.

URL-2. <http://www.eru.cz/>, date retrieved 10.08.2011.

URL-3. <http://www.eie.gov.tr/turkce/YEK/gunes/tgunes.html>, date retrieved 10.08.2011.

URL-4. <http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices>, data retrieved 03.07.2011.

WBGU. (2003). *World in Transition—Towards Sustainable Energy Systems: Summary for Policy Makers*. <www.wbgu.de> date retrieved 02.09.2011.

APPENDICES

APPENDIX A: Table A.1 : Trigger conditions for countries.

APPENDIX B: Table B.1 : Trigger Conditions for countries.

APPENDIX C: Table C.1 : Data for knowledge base options.

APPENDIX D: Table D.1 : GDP per capita over the years.

APPENDIX E: Table E.1 : Real GDP growth.

APPENDIX F: Table F.1 : "Political stability no violence" index.

APPENDIX G: Table G.1 : Solar potential (Global yearly irradiation) (kWh/m^2).

APPENDIX H: Figure H.1 : Announcement of E-views on homepage, developed GBM add-in.

APPENDIX A

Table A.1 : Trigger conditions for countries.

			Elements for trigger condition			
Country	**Year**	**Yes / No for trigger conditions met** (1: Yes; 0:No)	**IRR >6%** (1:yes; 0: No)	**Clear gov't commitment exists** (1:yes; 0: No)	**Streamlined admin. processes in place** (1:yes; 0: No)	**Solar resources > 800kwh/m2** (1:yes; 0: No)
Germany	2004	1	1	1	1	1
Germany	2005	1	1	1	1	1
Germany	2006	1	1	1	1	1
Germany	2007	1	1	1	1	1
Germany	2008	1	1	1	1	1
Germany	2009	1	1	1	1	1
Germany	2010	1	1	1	1	1
Spain	2004	0	0	0	1	1
Spain	2005	0	0	0	1	1
Spain	2006	0	0	1	1	1
Spain	2007	1	1	1	1	1
Spain	2008	1	1	1	1	1
Spain	2009	0	1	0	1	1
Spain	2010	1	1	1	1	1
Italy	2007	0	1	1	0	1
Italy	2008	1	1	1	1	1
Italy	2009	1	1	1	1	1
Italy	2010	1	1	1	1	1
France	2007	0	1	0	0	1
France	2008	0	1	0	0	1
France	2009	1	1	1	1	1
France	2010	1	1	1	1	1
Czech Rep.	2008	0	1	0	1	1
Czech Rep.	2009	1	1	1	1	1
Czech Rep.	2010	1	1	1	1	1
Greece	2006	0	0	0	0	1
Greece	2007	0	1	0	0	1
Greece	2008	0	1	1	0	1
Greece	2009	0	1	1	0	1
Greece	2010	1	1	1	1	1
Bulgaria	2009	0	1	0	0	1
Bulgaria	2010	0	1	0	0	1

APPENDIX B

Table B.1 : Trigger IRR values for countries.

Country	Year	IRR (x1, %)	Trigger conditions met (x4, 1/0)	x12 (x12, %)
Germany	2004	7.5%	1	7.5%
Germany	2005	8.2%	1	8.2%
Germany	2006	8.3%	1	8.3%
Germany	2007	8.7%	1	8.7%
Germany	2008	8.9%	1	8.9%
Germany	2009	8.1%	1	8.1%
Germany	2010	8.2%	1	8.2%
Spain	2004	6.1%	0	0.0%
Spain	2005	6.4%	0	0.0%
Spain	2006	7.1%	0	0.0%
Spain	2007	10.0%	1	10.0%
Spain	2008	13.1%	1	13.1%
Spain	2009	9.0%	0	0.0%
Spain	2010	12.6%	1	12.6%
Italy	2007	10.3%	0	0.0%
Italy	2008	9.5%	1	9.5%
Italy	2009	14.2%	1	14.2%
Italy	2010	16.0%	1	16.0%
France	2007	10.4%	0	0.0%
France	2008	11.0%	0	0.0%
France	2009	11.5%	1	11.5%
France	2010	12.0%	1	12.0%
Czech Rep.	2008	16.3%	0	0.0%
Czech Rep.	2009	16.0%	1	16.0%
Czech Rep.	2010	14.2%	1	14.2%
Greece	2006	6.0%	0	0.0%
Greece	2007	10.2%	0	0.0%
Greece	2008	11.3%	0	0.0%
Greece	2009	13.3%	0	0.0%
Greece	2010	14.1%	1	14.1%
Bulgaria	2009	19.0%	0	0.0%
Bulgaria	2010	20.0%	0	0.0%

APPRENDIX C

Table C.1 : Data for knowledge base options.

		Alternative 1	Alternative 2	Alternative 3
Country	Year	Number of years >100MW PV installation	Cumulative installed base	Installed base of previous year
Germany	2004	4	1074	143
Germany	2005	5	1980	635
Germany	2006	6	2812	906
Germany	2007	7	3977	832
Germany	2008	8	5979	1165
Germany	2009	9	9785	2002
Germany	2010	10	17193	3806
Spain	2004	0	24	5
Spain	2005	0	47	12
Spain	2006	1	149	23
Spain	2007	2	691	102
Spain	2008	3	3399	542
Spain	2009	4	3416	2708
Spain	2010	5	3785	17
Italy	2007	0	120.2	4
Italy	2008	1	458.3	70
Italy	2009	2	1181.3	338
Italy	2010	3	3502.3	723
France	2007	0	75.3	4
France	2008	1	179.8	31
France	2009	2	430.1	105
France	2010	3	1149.1	250
Czech Rep.	2008	0	54	1
Czech Rep.	2009	1	465	50
Czech Rep.	2010	2	1955	411
Greece	2006	0	7	1
Greece	2007	0	9	3
Greece	2008	0	19	2
Greece	2009	0	54	10
Greece	2010	1	204	35
Bulgaria	2009	0	7	1
Bulgaria	2010	0	18	1

APPENDIX D

Table D.1 : GDP per capita over the years.

USD	2004	2005	2006	2007	2008	2009	2010
Germany	37,561	37,860	39,183	40,275	40,743	38,937	40,462
Spain	30,083	30,527	31,326	32,092	31,698	30,127	29,782
Italy	35,704	35,773	36,317	36,615	35,950	33,980	34,175
France	40,220	40,701	41,388	42,079	41,890	40,602	40,982
Czech Republic	15,597	16,543	17,637	18,549	18,819	17,995	18,393
Greece	25,960	26,500	27,631	28,742	29,036	28,311	27,145
Bulgaria	4,989	5,341	5,725	6,133	6,554	6,269	6,335

APPENDIX E

Table E.1 : Real GDP growth.

%	2004	2005	2006	2007	2008	2009	2010
Germany	1.2%	0.8%	3.4%	2.7%	1.0%	-4.7%	3.6%
Spain	3.3%	3.6%	4.0%	3.6%	0.9%	-3.7%	-0.2%
Italy	1.4%	0.8%	2.1%	1.4%	-1.3%	-5.1%	1.0%
France	2.3%	2.0%	2.4%	2.3%	0.1%	-2.5%	1.5%
Czech Republic	4.3%	6.4%	7.0%	6.1%	2.3%	-4.0%	2.4%
Greece	4.4%	2.3%	4.5%	4.3%	1.3%	-2.3%	-3.9%
Bulgaria	6.7%	6.4%	6.5%	6.4%	6.2%	-4.9%	0.4%

APPENDIX F

Table F.1 : "Political stability no violence" index.

COUNTRY	YEAR	Political stability no violence Index
Germany	2004	64
Germany	2005	65
Germany	2006	68
Germany	2007	70
Germany	2008	70
Germany	2009	69
Germany	2010	67
Spain	2004	58
Spain	2005	60
Spain	2006	60
Spain	2007	52
Spain	2008	50
Spain	2009	48
Spain	2010	46
Italy	2007	60
Italy	2008	62
Italy	2009	61
Italy	2010	61
France	2007	61
France	2008	62
France	2009	61
France	2010	61
Czech Rep.	2008	68
Czech Rep.	2009	68
Czech Rep.	2010	68
Greece	2006	63
Greece	2007	61
Greece	2008	57
Greece	2009	49
Greece	2010	49
Bulgaria	2009	59
Bulgaria	2010	59

APPENDIX G

Table G.1 : Solar potential (Global yearly irradiation) (kWh/m^2).

kWh/m2	Minimum	Average	Maximum
Germany	984	1157	1795
Spain	1179	1819	2094
Italy	931	1664	2057
France	1004	1437	1986
Czech Republic	1083	1172	1286
Greece	1349	1671	2009
Bulgaria	1264	1484	1778
Turkey	1172	1724	2051

APPENDIX H

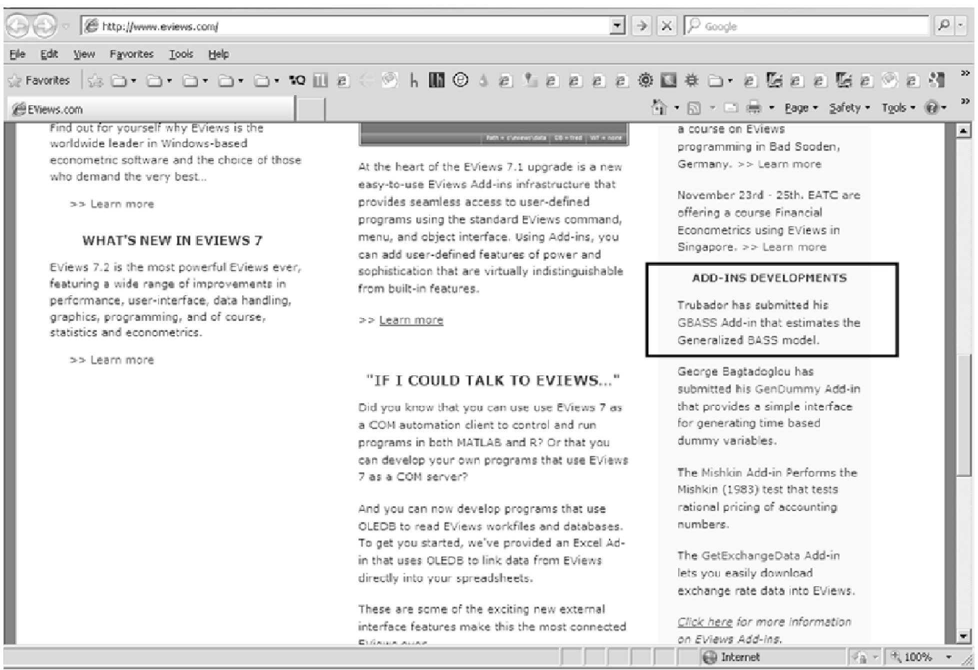


Figure H.1 : Announcement of E-views on homepage, developed GBM add-in.

CURRICULUM VITAE

Name Surname: Alper ÇELEBİ

Place and date of birth: Istanbul, Turkey, June 19, 1980

E-mail: alpercelebi@gmail.com

B.Sc.: Management Eng., Istanbul Technical University

M.Sc.: Management Eng., Istanbul Technical University

Professional Experience:

2012 – present: Sales and Bid Manager, Middle East Region, Solar Energy, Siemens UAE, Dubai.

2010 – 2012: Regional Business Developer, Business Development, Solar & Hydro Division, Siemens Germany, Nürnberg.

2008 – 2010: Head of Corporate Development Strategies, Siemens Israel, Rosh A'yin.

2002 – 2008: Senior Management Consultant at Corporate Strategies and Consulting, Siemens Turkey, Istanbul.

List of Publications:

In proceedings of international conferences:

- **Çelebi, A.** (2008). Decision Making Typologies in Strategic Planning, *PICMET 2008*, 27 – 31 July, 2008 Cape Town, South Africa.
- **Çelebi, A.** and Gözlü, S. (2008). Technology Strategy for a Strategic Planning Tool in a Multinational Company: Case of Dynamic Strategic Planning System, *PICMET 2008*, 27 – 31 July, 2008 Cape Town, South Africa.
- **Çelebi, A.** and Alsan, A. (2007). Technology Performance Criteria in Strategic Planning: Case of Dynamic Strategic Planning System, *PICMET 2007*, 5 – 9 August, 2007 Portland, Oregon, USA.
- Alsan, A., **Çelebi, A.** and Kalan, Ö. (2006). The Role of Technology for Strategic Planning Systems: The Case of Dynamic Strategic Planning System, *PICMET 2006*, July 8 – 13, 2006 Istanbul, Turkey.

In proceedings of national conferences:

- Alsan, A. and **Çelebi, A.** (2003). Kaliteli Üniversite-Sanayi İşbirliği için Kurumsal Organizasyon ve Entegre Yönetim Modeli. *I. Elektrik Elektronik Bilgisayar Mühendislikleri Eğitimi Sempozyumu Bildirileri*, 30 April – 5 May 2003 Ankara, Turkey.

Working papers:

- Öner, A., Soydan, A. I. and **Çelebi, A**. (2003). Dinamik Sistem Modelleme ile Makroekonomik Analiz: Türkiye Için Bir Oyun Denemesi, *working paper*.