ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

ASSESS AND EVALUATE RISKS OF RES INVESTMENT USING SYSTEM DYNAMICS APPROACH

M.Sc. THESIS

İzzet Alp GÜL

Energy Science and Technology Division
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JUNE 2019

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Thesis Advisor: Prof. Dr. Gülgün KAYAKUTLU

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

YENİLENEBİLİR ENERJİ SİSTEM YATIRIMININ SİSTEM DİNAMİĞİ YAKLAŞIMIYLA TESPİTİ VE DEĞERLENDİRİLMESİ

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HAZİRAN 2019

İzzet Alp Gül, a M.Sc. student of ITU Institute of Energy student ID 301161019, successfully defended the thesis entitled "ASSESS AND EVALUATE RISKS OF RES INVESTMENT USING SYSTEM DYNAMICS APPROACH" which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 3 May 2019
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To my family and beloved ones,

FOREWORD

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ABBREVIATIONS

AHP	**:** Analytical Hierarchy Process
CAPEX	**:** Capital Expenditure
FiT	**:** Feed in Tariff
FiP	**:** Feed in Premium
RE	**:** Renewable Energy
RES	**:** Renewable Energy System
OPEX	**:** Operational Expense
PV	**:** Photovoltaic
WPP	**:** Wind Power Plant

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ASSESS AND EVALUATE RISKS OF RES INVESTMENT USING SYSTEM DYNAMICS APPROACH

SUMMARY

Renewable energy has a critical role in improving energy security. The benefit is threefold: domestic demand is responded by domestic resources, sustainability is improved through diversified resources and environmental harm is reduced. Although the dependence on fossil fuels is still high, renewable energy usage rates are increasing gradually over the years. Expectations show that both government and private sector stakeholders will continue to invest in the renewable energy sector. However, impetuous development in the sector faces various risks due to the rapid growth. The investment risks of renewable energy sources over the years have caused unexpected issues in financial, technical, legal and other dimensions. The performance of new investments in terms of efficiency and profitability depends on the evaluation of these risks. Renewable energy investments will support the sustainability of growth rates in order to take appropriate measures against the risks with the aim of creating a better future.

Risk management is the key solution for renewable energy projects. Risk management in that sense is usually followed and complemented by a disciplined and coordinated application of resources to mitigate, monitor, and control the probability and the potential impact of the future events. The purpose of risk management is to organize uncertainty, that is, to make sure it does not avoid achieving financial business goals. In this thesis, risk factors in the renewable energy system investments are encountered and interactions among the risk factors are identified. The study is focused on factors prior to the project. Factors are selected based on Literature survey and expert reviews. Whereas, interactions are defined by using brainstorming and nominal group technique.

Furthermore, identified risk factors and interactions among them are analyzed with the Delphi method via applying survey in two rounds. In this survey, participants were evaluated by different sectors of the risks and the views of the participants is a process that can be achieved by considering the case of Turkey. The obtained survey results via Delphi method are used in the entropy method for further mathematical formulation of risk factors and interactions for assessment.

System Dynamics has been chosen as main assessment methodology because of its unique aspect of allowing and managing of representing the interactions and feedbacks even for non-linear links. During implementation of methodology, feedback model diagram is firstly established to illustrate the scheme behind the risk factors and interactions among them. In the feedback model diagram, risk categories are considered. Afterwards, mathematical modelling is constructed within the risk dynamics model which used the formulation obtained via entropy methodology. Model is defined with the time period considering the life cycle of similar renewable energy system investment. In this unique situation, the model is intended to make a

structure in which sustainable power source venture players can see the interaction between risk factors all through a particular project lifecycle. This research is unique in combining technical, political, social and environmental risk factors with interactions.

This thesis presents a model that can evaluate geothermal, solar, wind and hydroelectric power plant investments in a group. Investigation of investments in political, market, technical, environmental and social terms enlightens sector participants for their future investment evaluation. Monitoring the impact of a single risk factor on the entire system does not allow companies to make long-term and strategic investment planning in real life. Basic rules in business management emphasize the success of cautious risk taking and getting ready for the effects.

YENİLENEBİLİR ENERJİ SİSTEM YATIRIMININ SİSTEM DİNAMİĞİ YAKLAŞIMIYLA TESPİTİ VE DEĞERLENDİRİLMESİ

ÖZET

Yenilenebilir enerji, ülkelerin enerji ihtiyacını yerli kaynaklarla karşılayarak yabancı ülkelere olan bağımlılığını azaltmak, kaynaklarını çeşitlendirerek sürdürülebilir enerji kullanımını sağlamak ve enerji tüketimi sonucu çevreye verilen zararı azaltmak açısından önemli bir yere sahiptir. Fosil yakıtlara olan bağımlılık şu anda yüksek olmasına rağmen, yenilenebilir enerji sistem yatırımları ve kullanım oranları yıllar içinde giderek artmıştır. Hem hükümetlerin hem de özel sektör paydaşlarının yenilenebilir enerji sektörüne yatırım yapmaya devam etmesi ve önümüzdeki yıllarda bu yatırımların daha da artması beklenmektedir. Öte yandan, yatırımların artışı ve hızlı büyüme sektörde karşılaşılan risklerin belirginleşmesine sebep olmuştur. Bu risklerin ise kategoriler altına alındığında finansal, teknik, yasal ve çevresel kaynaklardan kaynaklandığı gözlemlenmiştir. Ancak, bu kategoriler arasındaki risk faktörleri arasındaki ilişki ise yapının daha karmaşık bir hal almasına yol açmıştır. Günümüzde ise yenilenebilir enerji yatırımlarının performansı, verimlilik ve karlılık açısından bu risklerin doğru değerlendirilmesine bağlıdır. Bu risklerin yönetilmesi için sigorta, destek politikaları ve teknolojik gelişmeler özelinde çözüm yöntemleri bulunmaktadır. Ancak, risklerin birbiriyle olan etkileşimi ve yatırımlarda gerçekleşen tetikleyici mekanizmalar bu risklerin ne zaman yatırımcının karşısına çıkacağı ve etkilerinin ne olacağı sorusunu karşımıza çıkarmaktadır. Bu amaçla, yenilenebilir enerji yatırımlarındaki riskleri inceleyecek ve bunlar arasındaki etkileşimi analiz edebilecek kapsayıcı bir yapıya ihtiyaç duyulmaktadır. Özellikle yeni teknolojilerin gelişmesiyle ortaya çıkan karmaşık yapılar iş geliştirme döneminde oluşan bir riskin santralin operasyon döneminde zarar görmesine yol açmaktadır. Bu sebeple, yenilenebilir enerji yatırımlarının risk analizinin yapılması ve karşılaşılacak sorunlar ve tehditler karşısında uygun önlemlerin alınmasını sağlamak, daha iyi bir gelecek yaratmak için yenilenebilir enerji yatırımlarındaki büyüme hızlarının sürdürülebilirliğini destekleyecektir.

Risk analizi ve bunlara ilgili çözümlerin geliştirilmesi, yenilenebilir enerji sistemi yatırımları için kilit çözüm noktasıdır. Bu anlamda risk analizi genellikle gelecekteki olayların olasılığını ve potansiyel etkisini en aza indirmek, azaltmak, izlemek ve kontrol etmek için disiplinli ve koordineli bir kaynak uygulaması ile takip edilir ve tamamlanır. Risk analizinin amacı, belirsizliği organize ederek yönetmek, yani işletmenin ekonomik hedeflerine ulaştığından emin olmaktır. Bu tezde, yenilenebilir enerji sistemi yatırımlarında karşılaşılan risk faktörleri ve riskler arasındaki etkileşimlerin değerlendirmesi yapılacaktır.

Değerlendirilecek olan riskler için ise güneş, rüzgar, jeotermal ve hidro enerji yatırımlarını kapsayan ve bu enerji yatırımlarında teknik risklere ek politik, piyasa, çevre ve sosyal riskleri kapsayan bir değerlendirme süreci gerçekleştirilecektir. Bu amaçla, risklerin tanımlanması sürecinin büyük önem arz ettiği düşünülerek çeşitli yöntemler araştırılmıştır. Yenilenebilir enerji sistemi yatırımlarının geniş kapsamı göz önünde bulundurularak, tez için en uygun olanları tercih edilmiştir. Yenilenebilir enerji yatırımlarında karşılaşılan risklerin belirlenerek analiz edilebilmesi amacıyla sektör raporları ve akademik kaynaklar taranmıştır. Daha sonra sektörde yer alan deneyimli uzmanlarla görüşülerek bu alanlarda kaynak taraması dışında kalan ve

ekleyebilecekleri diğer hususlar üzerine görüşmeler gerçekleştirilmiştir. Literatür kaynaklarından ve uzman görüşmeleri sonucunda belirlenen riskler ise birbiriyle etkileşimlerini görebilmek amacıyla beyin fırtınası ve nominal grup teknikleriyle taranarak ilgili etkileşimler kurulmuştur.

Yenilenebilir enerji sistemi yatırımlarına ait risk faktörlerinin belirlenmesi ve aralarındaki etkileşimin incelenmesinden sonra, modelin ana temelinde yer alan Sistem Dinamiği yaklaşımı için matematiksel modellemenin yapılması gerekmektedir. Matematiksel modelleme ise iki aşamada gerçekleştirilmiş olup risklerin matematiksel belirlendiği kısımda Delphi ve entropi yöntemleri kullanılmıştır. Sektör katılımcılarından oluşan on kişilik bir gruba hazırlanan anketler sunulmuş ve ilgili risk faktörlerini ve arasındaki etkileşimleri etki puanları üzerinden değerlemeleri istenmiştir. Bu ankete katılanların özelleştiği alanlar gereği riskleri sektörün farklı yönlerinden değerlendirmişlerdir ve katılımcıların görüşlerini anketler üzerinden belirtirken Türkiye örneği göz önüne alarak değerlendirmelerine devam etmişlerdir. Delphi anketi ise bu kapsamda iki tur olarak uygulanmış olup, ilk turun sonuçları istatistiki bir yöntem olan medyan yöntemiyle değerlendirilmiştir. Medyan yöntemiyle değerlendirilen sonuçlar ise ikinci turda uygulanan ankette katılımcılara sunulmuş ve katılımcılardan kendi sonuçları ve ilgili medyan sonuçları doğrultusunda anketi tekrar doldurmaları beklenmiştir. Entropi yönteminin kullanılması aşamasında ise ikinci Delphi anketinin sonucunda alınan değerler kullanılmıştır. Uygulanan metod sayesinde katılımcıların daha önce vermis olduğu sonuçlar belli bir skala içinde birbirleriyle uyumlu olacak şekilde çarpan olmak üzere bulunmuştur.

Yapılan çalışma sürecinde Sistem Dinamiği yaklaşımı tercihiyle birlikte risklerin değerlendirilmesi amacıyla çeşitli yöntemler incelenmiş ve doğrusal olmayan etkileşimler için geri bildirim analizine olanak sunması nedeniyle Sistem Dinamiği seçilmiştir. Ayrıca, Sistem dinamiğinin seçilmesinde geleneksel matematiksel ve istatistiksel modellerin sistem yapısındaki değişimleri görmezden gelerek dinamik bir çözüme ulaşamayışıyla birlikte sistem dinamiğinin tüm parametrelerin karmaşık yapılarının analizine izin vererek sistemdeki hızlı değişimlerin analizindeki başarısı, derinlemesine performans göstermesi etkili olmuştur. Bu sebeple, Sistem Dinamiği yöntemi karar verme sürecinde daha güvenilir sonuca ulaşılmasını sağlamaktadır. Bu sebeplerle Sistem Dinamiği yaklaşımı karmaşık yapıdaki işlemler için ideal ortamı sağladığı ve yenilenebilir enerji sistemi yatırımlarının uzun sürece yayılan yapısı ve içerdiği risklerin süreç boyunca etkileşimlerini analizindeki başarısı düşünülerek risk değerlendirilmesinin yapılması sürecinde kullanılmıştır.

Oluşturulan model jeotermal, güneş, rüzgar ve hidroelektrik santral yatırımlarını değerlendirebilmek amacıyla kullanılmaktadır. Yatırımların politik, piyasa, teknik, çevresel ve sosyal açıdan değerlendirme yapabiliyor oluşu yatırım katılımcılarını geleceğe dönük riskler konusunda farkındalık yaratması adına önem kazanmaktadır. Bunun önemi ise, tek bir risk faktörünün tüm sistem üzerindeki etkisinin izlenmesi sonucunda edinilen gerçek hayata uyumsuz bilgilerin, şirketlerin gerçek hayatta uzun vadeli ve stratejik yatırım planlaması yapmalarına yardımının dokunmayışıdır. Sistem Dinamiği ise bu alanda öne çıkarak yatırımcılara ve sektör katılımcılarına gerçeklere uygun analizler sunarak büyük faydalar sağlamaktadır.

Modelin kurulması sürecinde, yüksek kaliteli dinamik geribildirim modelinin geliştirilmesine, analizine ve oluşturulmasına katkı sağlayan Vensim arayüzü kullanılmıştır. Vensim üzerinden ilk etapta geri bildirim modeli oluşturulmuş ve risklerin biribiriyle etkileşimi görsel anlamda daha iyi anlaşılmıştır. Sonrasında ise risk analiz modeli oluşturularak asıl matematiksel modelleme gerçekleştirilmiştir. Risk analiz modelinin önemli özelliği ise stok ve akış değişkenlerini bünyesinde barındırması sebebiyle ileri analize izin veren yapısıdır.

Bu kapsamda yapılan modellemenin sonucunda ise yenilenebilir enerji sistem yatırımları risk faktörünün, inşaatın başlangıcına kadar hafifçe artmakta ve inşaatın bitiminde önemli bir şekilde azaldığı görülmüştür. Bununla birlikte, inşaatın başlangıcında tahakkuk eden risk, sektör katılımcıları için daha ileri değerlendirmelerde önemlidir. Bu kapsamda, teknik risk faktörlerinin etkisi, yatırımın ilk aşamasında diğer ana risk faktörü gruplarıyla karşılaştırıldığında yatırıma egemen olmuştur. Bir yandan, yatırım için tasarım ve teknoloji seçimi, teknik risklerin zirvesini ve sektörün uzmanlığını artıran yatırım üzerinde önemli bir etkiye sahip olup, teknik risk faktörlerinin teknoloji ve tasarım tarafında da önemli bir parametredir. İnşaat döneminden sonra, büyük çaplı yenilenebilir enerji sistem yatırımları üzerindeki muhtemel etkileri göz önünde bulundurarak, kanunda ani değişiklik olasılığı ve elektrik alım sözleşmesi karşı taraf risk faktörleri nedeniyle politika risk faktörleri artmaya başlamıştır. Zirveden sonra politika risk faktörleri bir miktar azalırken, projenin sonuna kadar en önemli risk unsuru olmayı koruyacaktır. Ayrıca, elektrik fiyatı ve kaynak oynaklığı, operasyonel süreçte piyasa risk faktörleri üzerindeki etkilerini model tarafından toplanan verilerde sunmaktadır. Ek olarak, çevresel riskler, yatırımlarda erken dönemde çok büyük öneme sahiptir. Bununla birlikte, görüşülen uzmanlara göre, çevresel etki yatırımın işletme dönemi boyunca diğer risk faktörlerine kıyasla göreceli olarak önemsizdir. Bu risk faktörleri, uygun politika tasarımı, piyasa yapısı, piyasadaki deneyim ve sigorta gibi diğer araçlarla belirli bir dereceye kadar azaltılabilir. Ayrıca yapılan çalışmada, senaryo analizleri yapılarak önemli bulunan risk faktörlerinin ana risk faktörlerine süreç içindeki etkileri incelenmiştir. Santralin dizaynı, politika dizaynı ve ülkenin ekonomik durumunun incelendiği bu senaryolarda yatırımcılara yatırımda gerçekleşebilecek risklerin proje özelindeki sonuçlarına yönelik bir öngörü sağlaması amaçlanmıştır.

Jeotermal, güneş, rüzgar ve hidroelektrik santral yatırımlarını farklı çerçevelerden inceleyerek tek bir havuzda toplayan bu model tezin ana çalışma unsuru olarak karşımıza çıkmıştır. Yatırımlar özelinde ilgili katılımcılarla birlikte çeşitli yatırım türlerine de uygulanabilecek bu yapıda yatırımların ömür sürelerinin de göz önüne alınması önem kazanmaktadır. Bu çalışma sadece Türkiye'deki yatırımcılar için değil, yenilenebilir enerji sistem yatırımları pazarının tüm katılımcıları için bir rehber niteliğinde olacaktır.

1. INTRODUCTION

Electricity demand continues to grow with the force of urbanization and digitization all over the world. The impact of this expeditious growth is most significant in the augmentation of CO2 emission caused by the power generation industry (Edenhofer et al., 2014). Thus, across the Globe, each government takes an action for a better future. In this process, a significant contribution to the development of renewable energy by developing appropriate incentive mechanisms under supportive policy schemes is made. Thus, share of renewable energy sector in power generation has gained momentum with technological developments, decreases in investment costs and public awareness (REN21, 2018). Investments in power generation using renewable resources reached approximately 300 billion USD per annum between 2005 and 2015 (IEA, 2016). Specifically in 2017 with the investment of 335 billion USD on renewable energy (Bloomberg, 2018), renewable power generation supplied approximately %25 of the total demand. This is a robust growth rate since 2010 averaging %8 per year (IRENA, 2018), and the projections show an increase up to %85 in 2050. On the other hand, expeditious development in the field faces various risks due to the rapid growth. Risks of investment in renewable energy resources through the years caused financial, technical, legal and other issues with different structures. Performance of new investments in terms of efficiency and profitability depend on the evaluation of these risks. Taking appropriate measures against the analyzed risks would support the sustainability for a better future.

Along with the increase in the renewable energy system (RES) shares, the power supply sector changes the structure, which also requires detailed analysis. Due to low operational expenditures and high capital expenditures of the RES, a substantial change occurs in the power markets "from an Operational Expenditures (OPEX) to a Capital Expenditures (CAPEX) world" (Auverlot et al., 2014). Because of the high CAPEX, the risks encountered during construction period become more critical. In the construction works where uncertainties are intense, and deviations are frequent in the anticipated time and budget, the profit gained mostly increases in line with risk awareness (Çaylıdemirci, 2010). However, interest shifting from the operation period to the construction period increases the complexity of risk management. Hence, identification of the related risks gain focus to maximize the profits and help more efficient use of limited resources. Furthermore, an increase in the number of non-energetic participants in the RES sector (Mazzucato & Semieniuk, 2016), due to the attractive nature of RES investments leads, to risk exposure for each participant (REN21, 2018).

Players of the energy industry, investors, policymakers and public stakeholders face the consequences of various risks in RES investments, outcomes of which are interactively linked to the project life cycle. Moreover, dynamic change of risks in each phase of the project creates a complex environment for evaluation. When risks are detected in a project, and their interactions are identified, measures can be taken against them with the appropriate methodology to prevent casualties in life cycle of energy investment.

1.1 Purpose and Scope of the Thesis

Objective of this thesis is to assess and evaluate the risks in RES investment projects by defining the dynamics in interactions run for different scenarios. Risk factors are determined based on a review of the existing academic and industrial literature. These risks are validated by industry experts through a survey. Identifying the critical links among the risk factors for further evaluation will be analyzed through the project life cycle. System Dynamics will be applied to evaluate the risks in a complex system. Risk classification is made to analyze different aspects of investments in solar, wind, geothermal and hydropower plants.

Many risk factors are examined in the literature focusing on particular issues; however, combining these risks for different renewable energy resources will bring the novelty to this study. Besides, studying the interactive of these risks impacts during the life cycle of investments will guide all sector participants for a better view on the project. In this aspect, the proposed model will be implemented for a case study to validate the model. Scenario analysis will be applied for the vital risk factors defined by the expert survey.

1.2 Structure of the Thesis

This thesis aims to be a guide for the decision-making process of RES investments and planning the project implementation through different stages. In the first stage, risk identification methodologies are reviewed for a feasible choice. The system dynamics method is preferred because of its unique aspect of allowing and managing of interactions and feedbacks even for non-linear links. In other words, system dynamic brings a dynamic perspective to forecasting. The basic structure is established after the dynamic analysis of interactions among the risk factors.

Following the construction of the basic structure, Literature on risk factors in a variety of categories is reviewed. The list of factors detected is shared with the experts make the critical choice. Brainstorming and nominal group techniques are used to determine interactions between risk factors. At the end of the Reviewing Risk Factors section, a survey was prepared to determine the importance of risk factors via Delphi method and to understand the relationship between them. Delphi method helped ranking with the weights based on preferences of decision makers. In the survey, participants in different technical and financial sides of the industry have expressed their opinions in two rounds, where, participants are asked to score the degree of impact of risk factors on the success of the project to one to five. Therefore, the data obtained is evaluated by using statistical methods to be used in the future model. The mathematical formulation of the outcomes of the Delphi analysis are evaluated by the Entropy methodology applied in the System Dynamics approach.

In the System Dynamics Evaluation section, a model is constructed to evaluate risk factors considering categories. Turkey is selected as the sample for the case study and is evaluated with the help of experts in survey who grade the domestic. Time period for the model is set up for 30 years, considering the similarities of development, construction and operational periods of different renewable energy technologies. Final application is the evaluation of the base model and different scenarios. Base model of system dynamics with relevant risk categories are evaluated with scenario analysis. Scenarios are designed with changes to guide the sector participants. Finally, in chapter four results achieved by applying the Base Model and Scenario analysis will be evaluated and discussed. A brief roadmap of the thesis is given in Figure 1.1.

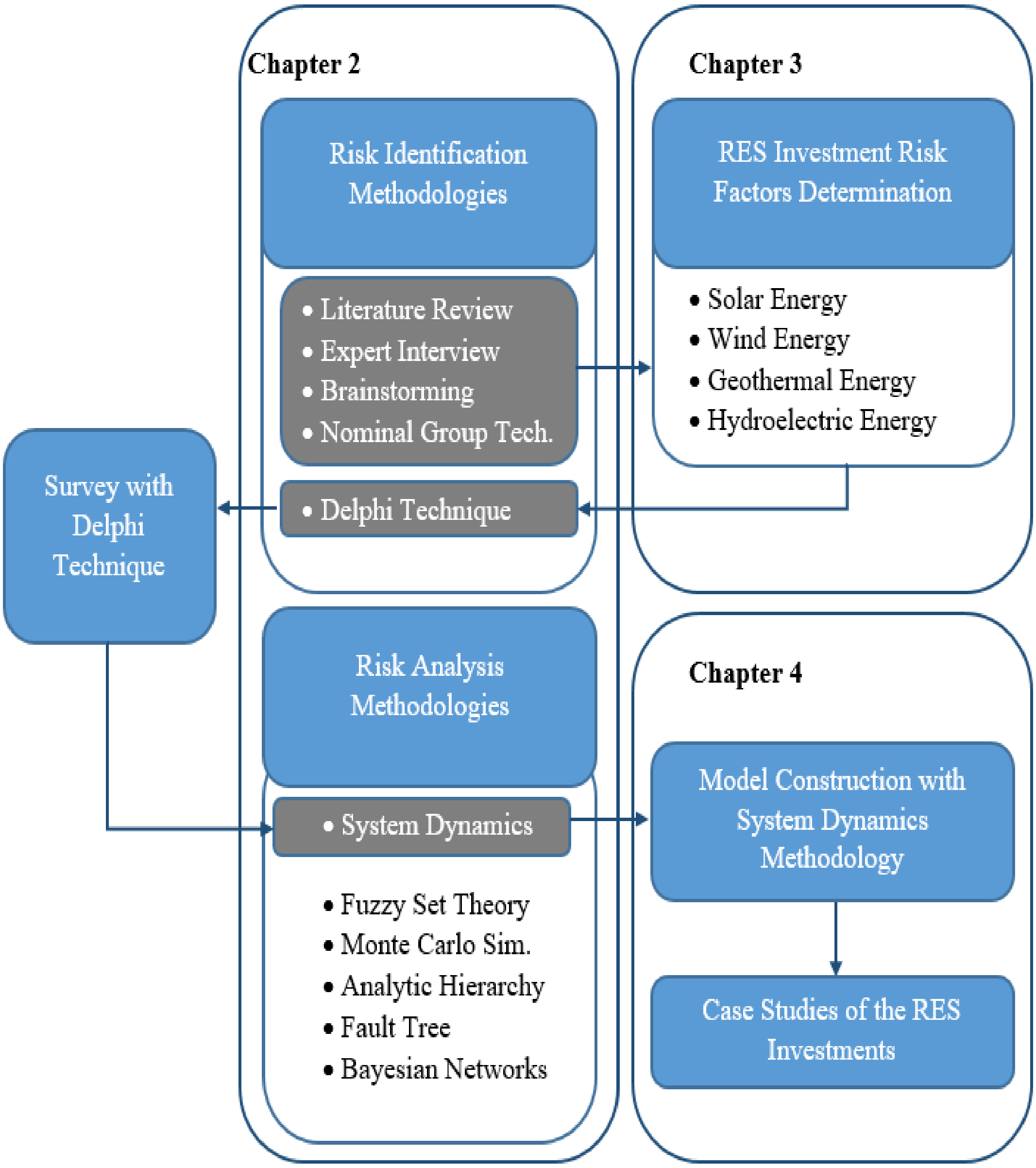

Figure 1.1 : Structure of the thesis

2. REVIEW OF RISK IDENTIFICATION AND ANALYSIS METHODOLOGIES

Risks are expressed as uncertainties that have impacts on the objective(s) of a project (Barber, 2005). Generally, risk factors can cause severe damages. Since the cost, time and quality are the components of a project objective, a risk can be defined as any event that causes uncertainty in the final cost, time, or quality of a project. For the project success, the effects of risks should be allocated or mitigated. However, it is essential to identify risk factors and to understand how risk factors can affect the project in order to eliminate them.

In this section, both risk identification and risk analysis methodologies will be reviewed. The detailed survey is performed to enable the choice of methodologies for the dynamical and complex behavior of the RES investment risks. The third part of this section is reserved for giving details and reasons for the choices in the thesis.

2.1 Risk Identification Methodologies

It is essential to ensure that risks factors are identified in the broadest scope during the risk identification process, because any risk factor excluded in this phase cannot be analyzed at a later stage. Therefore, different sources of information will be combined for the initial phase of identification. These resources will act as an input for the further process of analysis.

There are various techniques to identify risk factors in each type of project. However, there is no single method for defining risks, or no single combination with exact results. It is observed however that, the central pillar of success in all risk identification tools and techniques is the assistance of sector experts in definition (Anumba et al., 2005). In the literature, risk identification process with experts is separated to three different stages as presented below (Chapman, 1998):

- Sole risk expert approach
- Project team approach

- One or more working group approach to managing a risk process

In this study, the project team approach will be adopted. Considering the specific conditions of the RES Investments, integration of literature survey, interviews with experts, brainstorming, nominal group technique, and Delphi methods are used to reflect the experiences of various actors taking role in the RES market. Techniques and tools for risk identification in detail is given in this section.

2.1.1 Literature review

Previous studies on the subject are examined and information obtained is compiled and interpreted; if any, the missing sides are detected. Review requires a comprehensive investigation of documents and assumptions in the project draft to identify unclear or inconsistent areas. That is why, describing the key concepts and boundaries of the research gains importance (Webster & Watson, 2002). This search fulfills the afore skipped information and hidden risks.

The point that should not be overlooked when using this method is to be selective and not to lose the critical objective in order to identify the risk factors and interest when making use of the available data. Literature Review Methodology is commonly used by the authors in order to identify the risks in renewable energy investment (Boqiang & Chuanwen 2009, Yang et al 2010, Lorca & Prina 2014).

Hence, previous studies are reviewed within the framework of renewable energy investments. Reference studies are either risk analysis on investment activities of RES. Review is performed on geothermal, solar, wind and hydroelectric power plant types. Due to the diversity and size of the business issues, it has been observed that the authors focus on specific areas like economic, policy and technical sides of renewable energy investments for specified periods. Thus, few studies are covering the whole life-cycle of the investments and all the investment types in a single pool.

2.1.2 Interviews with experts

Interview with experts is an effective way to identify risk factors. Interviews can be done one-on-one or can be done with a group working together. If the interview intends to obtain an expert’s information and experience about the issue, one-to-one interviews are more applicable. However, group discussions are advised when information about companies and association activities are required (Kozlowski &

Ilgen, 2006). Examples of the interview with a group of employees in various departments of a company dealing with the subject of interest are questions and answers, information exchange and data sharing. Interviews with experienced sector participants, shareholders and experts can help identify the characteristics and functions of the desired renewable energy system investments (PMI, 2008). In order to cover every aspect of the topic, the one-to-one interview is held with the experts of different renewable energy investment companies. The group includes experts with the foci of finance, environment, construction, operation, business development and policy side of the renewable energy sector.

Interviews can help to outline the risk factors of renewable energy investments. Yet, it is limited to the effectiveness of the interviewer and the questions asked. In Literature (PMI, 2008), Brainstorming is described as a group creativity technique used to generate and collect various ideas related to project and product requirements. Application of both techniques will establish the required environment for the stable and reliable risk identification process and understanding interactions among the factors. The interview can be held either before or after a brainstorming session. However, if the interviews with the experts are done after the brainstorming session, interview results should be shared with the participants (Kunifuji et al, 2007). During this study, interviews with experts were conducted before the brainstorming session and the above procedure is applied for the participants. The outcome of the interviews is gathered and shared in the following sections.

2.1.3 Brainstorming

Brainstorming Technique is originated by Alex Osborn in the year of 1939 to solve problems with creative thinking (Parker & Begnaud, 2004). This technique has the goal to obtain a comprehensive list of project risks, and project team usually performing brainstorming with a multidisciplinary group of experts (PMI, 2008). Brainstorming is a useful technique in the beginning of the definition of comprehensive risks. The success of brainstorming, an interactive approach developed within the framework of specific rules, depends on the skills of the brainstorming group and skills of the practitioner. The brainstorming session aims to identify all potential risks in the beginning, regardless of the order or importance of risks. When an unconstrained and unstructured approach is adopted, the most successful results are achieved. The group members contribute to the creation of other ideas by identifying the risks through words. Achieving the desired results depends on the members of the group who are familiar with the topic discussed, the relevant document compiled, and a practitioner who knows the process of group management.

Brainstorming is based on the fact that the members of the group express their thoughts freely and that the ideas that emerged at this time trigger the emergence of new ideas through the association in other members. In this regard, group members express their ideas freely. From time to time, some members play a dominant role in the group and may restrict their ability to express their thoughts on other members. Here, the group should be mindful of applying brainstorming to maintain such balances within the group. As stated in the literature (Khalafallah, 2002), monitoring is necessary for the brainstorming methodology for active parties not to dominate the process. In the thesis, the brainstorming technique is used to determine the relationship between defined risk factors for RES investment with the Nominal Group Technique.

2.1.4 Nominal group technique

Nominal Group Technique is a focus group research method that can be used in risk studies to obtain information from a group on a specific subject. The general purpose of the use is in conformity with the management sciences (Delbecq et al., 1986). It is designed to increase creativity among the participants for better decision making. Nominal group technique was defined as an interview technique in which the participants expressed their ideas independently by writing their ideas individually (Macphail, 2001). Also, the applicability of the Nominal Group Technique for the renewable energy risk analysis proved that it is beneficial and practical to assign corrective actions for reducing potential problems (Feili et al., 2013).

In the process of application of the Nominal Group Technique, using simple sentences to express the ideas is the main force behind the technique. Therefore, the usage of the technique in this type of industry cases will be well suited due to the smooth implementation of the methodology and minimizing the nature of the other experts’ prejudices. In this study, the simple structure of the nominal group technique will be used in order to include the additional opinions of the sector experts under the session of a brainstorming activity to determine interactions. As stated in the literature (PMI, 2008), Nominal Group Technique has the characteristic of prioritization via enhancing brainstorming session with a voting process used to rank the most useful ideas.

2.1.5 Delphi technique

Under the Cold War Period, Delphi is developed by US Rand Corporation to identify the possible risk of attack by the Soviet Union (Dalkey & Helmer, 1962). It is used to forecast the possible outcomes of the risk factors while consulting with related experts. After that, the Delphi Technique has been widely used in technical and scientific research for almost half a century in the field of the management of various projects. The unique aspect of the technique is explained as structured, systematic identification and the collective assessment of rare or even hardly possible and inexperienced events (Markmann et al., 2013). Besides, the Delphi Technique is well suited to analyze the complex structures, which required different views by sector experts, like RES Investments.

Delphi technique is a systematic and interactive research technique designed to reveal the opinion of the survey participant, which is composed of independent experts on a specific subject (Yıldırım & Büyüköztürk, 2018). In the structure of the Delphi Technique under the risk identification process, questionnaires are prepared to confer on selected experts for identifying risk factors and estimation of the impact and probability of the previously defined risk factors. With this content, this technique is the preferred method of research in cases where the problem is not solved possibly using analytical techniques (Rowe & Wright, 1999), but where personal opinion can be replaced with precise measurements in answering the questions.

In the implementation of this method, experts of the renewable energy industry are asked to participate in some rounds of surveys (Fusfeld & Foster, 1971). At the end of each round, the surveyor depicts the results based on what the participants have predominantly marked in the questionnaire according to the chosen statistical method and adds them to the following questionnaire. In this process, each participant gives his opinion anonymously which allows to proceed remotely (Hirschhorn, 2019). In each subsequent round, participants continue to review the responses of the other participants to the previous questionnaire anonymously and proceed by revising their responses. In this process, the aim is to reduce the diversity in the results and to ensure the participants focus on the most critical risk factors. In the final round, the process is completed by achieving a predefined criterion and by concluding the results in statistical terms. Under this process, outcomes of the technique will be evaluated to form mathematical expression for the prospective study to see the interactions of the risk factors among themselves.

Figure 2.1 : Delphi technique application structure.

The survey needs to include two other parts for the expert opinion: the case country evaluation and the relation between the risk factors. Evaluation of the case country can be handled with further scenario analysis. Besides, a panel of expert selection is a critical phase of the Delphi Technique (Kuusi, 1999). Therefore, the technique should take into account different roles in the industry to choose the participants and interest groups both globally and locally. It should also ensure that the decisions regarding the size, characteristics, and composition of the expert panel are in line with the research interests represented in the panel (Donohoe & Needham, 2008). During the implementation of the technique, a minimum of eight participants is recommended, as the number of participants in the majority of studies varies between eight and sixteen (Hallowell & Gambatese, 2010). In this study, experts of panels will include ten participants who have comprehensive knowledge of global and local markets. Also, their expertise is enough to cover the construction, operation, financial, design and environmental side of RES investments. In figure 2.1, the application structure of methodology is shown.

Risks encountered in renewable energy investments and the relationship between them were determined and summarized in a table as a result of the literature review, interviews with experts brainstorming study and nominal group technique. The questionnaire was prepared based on this table prepared in the next section of the study. This questionnaire was applied by using the Delphi method in order to test the work done up to this stage and to evaluate the risks determined for use with risk analysis methodology. The process of preparing the questionnaire was accepted as the first round of implementation of the questionnaire. Afterward, two rounds are applied to the selected ten experts.

2.1.6 Other techniques

Main techniques used in the literature are described, and their characteristics and applicability to this study are discussed in detail. However, risk identification techniques used in project management and renewable energy systems are a lot more than described. These are Checklist, Flowcharts, Pondering, Influence Diagram, Root Cause Identification, Cause, and Effect Diagrams and SWOT Analysis (Garrido, 2011). Some of the techniques could be used within the main structure of the other techniques. For example, Checklist Technique is designed to give yes or no answers to proposed list items under the process of the interview with experts or brainstorming session. However, the application of the checklist technique is not suitable for this thesis due to the aim of mathematical modeling at the end.

On the other hand, flowcharts are an excellent example of process analysis to show stages with graphical methodology. Influence Diagram, Pondering and Root Cause Identification are effective methodologies to understand the causes of the risks. However, the cause of the risk factors is not examined in this study, and relationships between risk factors will be examined with a different structure. Thus, these methodologies are not included in the study. During the identification of renewable energy systems investment risk factors, methodologies which are explained in details, are chosen to conduct the study.

Under the process of the risk factors identification, Literature Review will be made to cover the broad scope of the risks from academic and sector resources. Then, Interviews with experts take place to cover the related risk factors in the investment. Nominal Group and Brainstorming Techniques will be applied to group participants for creative thinking on renewable energy investment risks relationships. In conclusion, the Delphi Technique will be applied to ten participants for the mathematical analysis of the thesis. In this structure, the mathematical formulation of the risk factors will be established to use in the risk analysis methodology.

2.2 Risk Analysis Methodologies and Modeling

Risk analysis is the process of evaluating the risks according to the available data. The process of risk analysis is the use of collected data as an input in the selected method and the evaluation of the risks. In the traditional analysis, the decision maker attempts to express specific parameters with the anticipated change mathematically. In the risk analysis, uncertain parameters are defined by a possible distribution with applied methodology. In the analysis of renewable energy investments and other types of investments, various methodologies are used to interpret risks and explain their relationship with each other. On the other hand, the traditional methods used in the analysis are not suitable for renewable energy systems investment due to its complex nature. There is a need for valid methodologies to understand the dynamic nature of the investments through their life cycle. Some risk analysis techniques that are compatible in project management studies and also applicable for renewable energy systems investments are reviewed below (Nasirzadeh et al, 2019).

- Fuzzy Set Theory
- Monte Carlo Simulation
- Analytic Hierarchy Process
- Fault Tree Analysis
- Bayesian Networks
- System Dynamics

2.2.1 Fuzzy Set Theory

Theory of Fuzzy Set is originated in the year of 1965 by Zadeh, and is used in a variety of disciplines like management science, artificial intelligence and computer science (Zimmermann, 2010). The Fuzzy Set is a generalization of the degree of the cluster that constitutes a variation of the theory of sets. In fuzzy data, it is possible to assign a degree for each element of the cluster. Fuzzy Set Theory can be used to evaluate factors in qualitative terms and sets out ways to investigate possible consequences. In the literature (Dernoncourt, 2013), the main characteristic of the fuzzy set theory is defined by creating flexibility for reason-cause relations and environment for subjectivity and imprecisions. Besides, the methodology is suitable for qualitative linguistic variables (Zadeh, 1975), and considering the qualitative approach in policy risks under RES investments, the methodology is also applicable for the investment risk analysis. The logic behind the fuzzy set theory is presented with the steps in Figure 2.2.

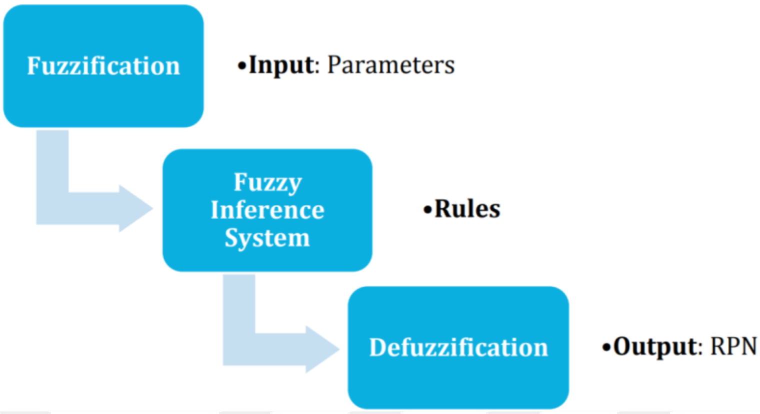

Figure 2.2 : Fuzzy set theory diagram (Gallab et al., 2019).

Fuzzy Set Theory is used for the RES Investments Risk Analysis by many authors. China's Belt and Road Initiative's Energy Investment Risk analysis is studied by a fuzzy integrated evaluation model with the entropy weight (Duan et al., 2018). Another critical study involved Hesitant Fuzzy Linguistic Term Sets, Fuzzy Synthetic Evaluation and Triangular Fuzzy Number concepts for risk evaluation of photovoltaic power plants in China (Wu et al., 2019). Improved Fuzzy Analytic Hierarchy Process used as a hybrid methodology to assess the risks in wind power project investments (Yang S. , 2014). These studies are the robust implementation of the fuzzy set theory in RES investment risk analysis; however, methodology does not cover the related relationship between the risk factors to understand the complex nature of reasons and causes among them. Thus, Fuzzy Set Theory as traditional risk analysis methodology lacks to evaluate the dynamical change of risks in the project life cycle.

2.2.2 Monte Carlo Simulation

Monte Carlo Simulation is used in risk analysis as a state-of-the-art methodology (Arnold & Yıldız, 2015). It is used in various areas of project management, strategic planning, and financial management (Rout et al., 2018). In the application side, the Monte Carlo method is to obtain random variables from the uniform distribution and move them appropriately to the distribution of interest. A uniform distribution is available if the variable values are limited to a particular area and have equal chances or have the same possibilities. It is often referred to as random numbers from these smooth random variables. Under the risk analysis process, Monte Carlo Simulation is used in project management cycle that generates a large number of random samples of a process or condition, depending on a large number of repeated and/or specific variables (Rout et al., 2018). With this structure, the use of the method in renewable energy investments and other investments for risk analysis is becoming increasingly widespread. However, Monte Carlo is a method used in combination with probability simulation models rather than being a simulation itself. Simulation Scheme of the Monte Carlo Methodology is presented in Figure 2.3 to illustrate the repetitive evaluation and random numbers generation in its nature.

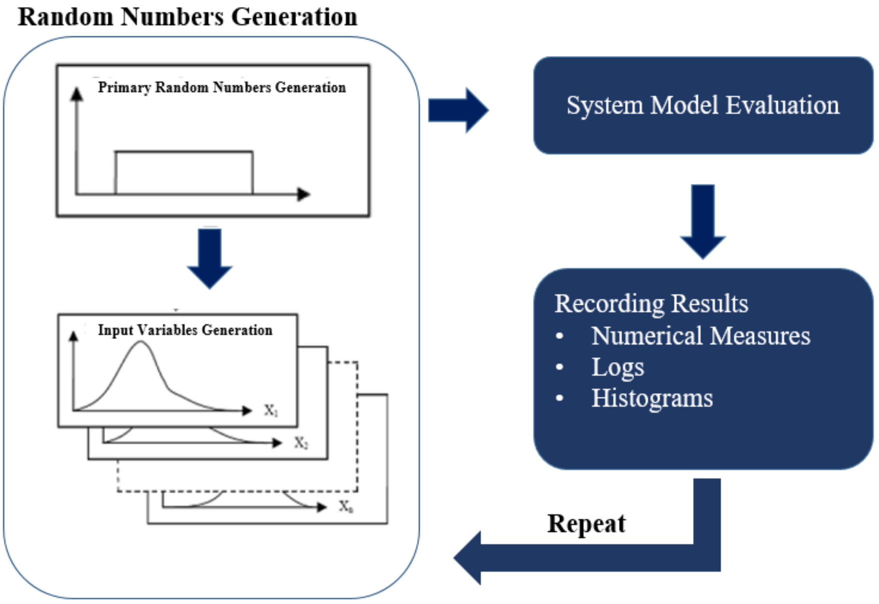

Figure 2.3 : Monte carlo simulation process (Marek et al., 2003).

The applications of Monte Carlo Simulation method in risk analysis of renewable energy systems is frequently encountered in the literature within different sides of the sector. Literature, proposed using Monte Carlo Simulation to the decentralized renewable energy infrastructures for their economic risk analysis based on the project life cycle of investment of those projects (Arnold & Yıldız, 2015). It is shown that the author creates a more advantageous modeling compared with traditional approaches of Net Present Value Estimation and Sensitivity Analysis. Net Present Value method is integrated with the application of Monte Carlo Simulation with the benefit of a stochastic approach to the issue (Zaroni et al., 2019). In this study, Brazilian Energy Market is examined considering university campus as an investor.

On the other hand, Monte Carlo Simulation depends on the data collected by experiments and its reliability. Then, it is stated that the methodology cannot be suitable to solve complex structures like renewable energy investments (Gyllenskog, 2010). Besides, uncertainties for the structure under risk analysis should be controlled for the Monte Carlo Simulation Methodology.

2.2.3 Analytical Hierarchy Process (AHP)

In 1970, Thomas L. Saaty developed the Analytical Hierarchy Process, a multi-criteria decision-making method. The author defines the method as a theory or a technique that enables the modeling of the problems that cannot be modeled under social and management issues (Saaty, 1990). Also, the method is defined as a reliable and easily understandable methodology that could combine qualitative and quantitative factors that were assessed in the decision-making process. At the same time, the AHP is used in the risk analysis process mainly for ranking the risks (Gohar et al., 2009). In the literature (Lidong et al., 2009), AHP is commonly used with Fuzzy Theory especially for risk analysis due to prioritization characteristic of the methodology. The prioritization process performed by AHP shown graphically in Figure 2.4.

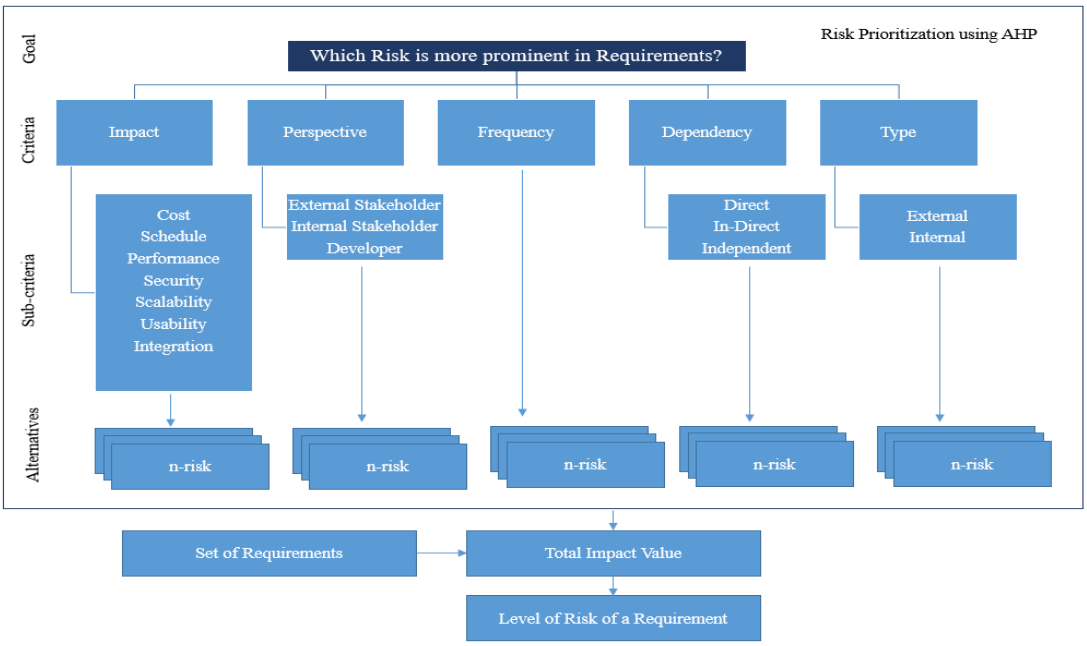

Figure 2.4 : Analytical hierarchy process (Chandani & Gupta, 2018).

In the renewable energy investment risk analysis, Analytical Hierarchy Process is generally used for the decision-making process of power plant investment. In the literature (Kahraman et al., 2009), the methodology consists of evaluation scores from experts with linguistic inputs to decide the best selection among alternatives of energy investments also considering the risks, however fuzzy set theory is also suggested for the study. Then, authors used fuzzy axiomatic design approach for the selection and fuzzy analytical hierarchy process for comparison of the alternatives. It is also possible that AHP is applied for case studies are another essential side of the methodology, and technique is used to evaluate the electricity generation potential of hydropower, solar, wind and biomass with multi-perspective approach (Ahmad & Tahar, 2014). Defined criteria within the article will also be used in the risk identification part of the thesis. Akash et al. (1999) used the Analytical Hierarchy Process to execute comparative analysis between different types of power plant investments in Jordan. In the literature, AHP methodology is used to evaluate the renewable energy system investments; however, the technique is frequently used for selection or ranking.

2.2.4 Fault Tree Analysis

Fault Tree Analysis is originated in 1961 by Watson within the US Air Force Contract for Launch Control Systems (Hill, 1961). Fault Tree Analysis transforms a physical system into a logic diagram under established fault tree which will lead to the most significant event of interest (Lee et al., 1986). Fault Tree Analysis is a systematic and graphical analysis technique based on deductive logic as a quantitative risk analysis process. This method is used to calculate the probability of root events and certain risk factors. In the Fault Tree Analysis, the causes and critical counter-measures of critical risks are shown schematically. Besides, Event Tree Analysis could be combined with the Fault Tree Analysis to analyze the related risk factors on hazard identification (Rosyid et al., 2007).

This methodology is commonly used for the investment processes of renewable energy during construction and operation periods. Literature (Wenyi et al., 2013), shows the use of this methodology on the vibration signals in rotating parts of the wind turbines, proposing diagonal spectrum and binary tree support approaches. For the purpose of technical risk assessment, authors used Fault Three Analysis to understand the small-sized biogas systems (Cheng, et al., 2014). However, both studies focus on the technical risks of the process systems, and they do not cover the risks from a broad perspective.

2.2.5 Bayesian Network

Bayesian Network is originated by the Judea Pearl to analyze the in-depth casual knowledge of an expert (Pearl, 1985). Bayesian Network is a directed graphical model used to reflect the conditional probabilities between variables. Bayesian Networks, built as a Directed Acyclic Graph, are used to demonstrate interrelated relationships between decision variables. The nodes, which are the first of the two part of the Directed Acyclic Graph, represent the uncertain decision variables, the second part as the directional arrows represent the relationship between these variables (Hui, 2003). Thus, nodes contain conditional probability tables depending on the conditions of the variables they represent. Their representation could be seen in Figure 2.5.

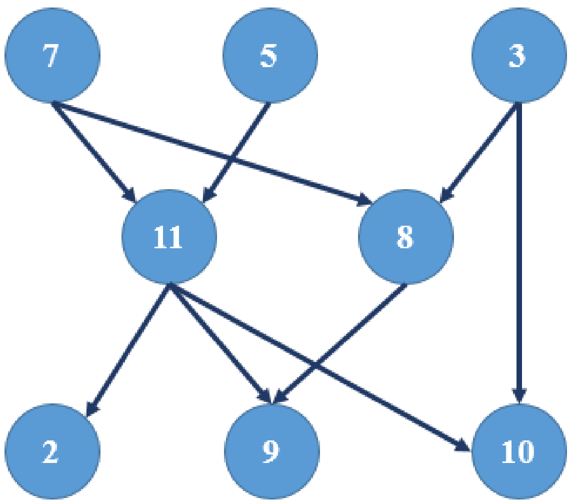

Figure 2.5 : Directed acyclic graph (Dereli, 2014).

In renewable energy research, Bayesian Network methodology is generally used for the decision-making processes. In the literature, Authors proposed a Methodology to decide Wave Energy Converter’s site while considering economic risks via optimizing energy extraction (Abaei et al., 2017). In the application of the Bayesian Network, probabilistic influencing parameters are modeled for influence diagram to estimate the utility of selected site for Wave Energy Converters. Cinar and Kayakutlu

(2010) used Bayesian Network models to create scenarios for energy policies which is described as another crucial main risk factor in the other studies (Gatzert & Vogl, 2016). Majority of the use of this technique seems to be for decision model with scenario analysis rather than just risk analysis methodology. Borunda et al. (2016) presented the applicability of Bayesian Network methodology to the complex renewable energy implementation problems rather than Genetic Algorithms and Fuzzy Logic. It is also used for risk analysis approach for the estimation of the probability and consequences of the events (Cornalba & Giudici, 2004).

2.2.6 System Dynamics

Jay W. Forrester first originated the System Dynamics approach in 1961 as a modeling approach that explains the functioning of the complex systems within dynamical changes (Forrester, 1968). The main feature of the system dynamics approach that makes it suitable for use in complex fields is that it can manage nonlinear relationships and feedback structures. In this regard, System Dynamics Approach is used in aerospace, defense, construction, power plants, and project management industries (Sterman, 2014). With the fact that traditional mathematical and statistical models ignore the dynamic nature of the systems, the use of System Dynamics has become widespread. Other features that distinguish System Dynamics from other methods are the inclusion of all parameters in the analysis of complex structures, the success of analyzing the rapid changes in the system, the ability to perform in-depth cause result analysis with increasing interaction of decision-making mechanisms and the ability to work together with uncertainties (Rodrigues & Bowers, 1996). Although the mathematical model can be accessed via analytical techniques, sometimes the complex structure of the dynamics in terms of projects or industry requires the use of the balance in a large number of systems. Thus, System Dynamics models provide the ideal environment for such processes.

In the literature of RES investment, System Dynamics Approach is used to analyze of the risk factors and other types of concepts due to the dynamic life cycle of renewable energy investment. A dynamic, stochastic model is preferred rather than a deterministic standard one. Dong et al., (2016) mentioned about the rapidly growing renewable energy industry in China and many uncertain factors occurring during the investments. The article aims to maximize the efficiency of investment decisions and also predicting the future of market establish investment risk evaluation index system and performance evaluation of the index system for the renewable energy power generation. Aslani et al., (2014), proposes a system dynamics model to evaluate policies on renewable energy investments in Finland. The security side of the energy supply in the article is discussed with the diversification in the aspect of a portfolio analysis considering the risk factors. Liu et al., (2017) pointed out the importance of developing a model to imply renewable resource utilization by considering the constraints of enabling sustainable energy and developing a low-carbon economy. In this process, authors believe that renewable energy investment is capital and technology intensive and it includes a lot of uncertainties. Investment risk and risk assessment models are put into casual loop diagrams. At the end of the study, a numerical example is studied to understand which risks are more effective and more cautious for the early stage, mid-stage and later stage of investment. Also, consideration of the dynamical change is essential for the change of risk in the whole project cycle and the influence on the system risk affected by feedback loops which are not considered in traditional risk analysis methods. Lopez et al. (2014), proposed system dynamics modeling for the CO2 emission analysis in Ecuador using scenario analysis studies. Gross Domestic Product of Ecuador is selected as a variable in the study and its interaction with CO2 emission analyzed within the renewable energy and fossil energy investments.

Other articles are examined in the different sectors. One of them applies the system dynamic methodology in the financial system of one company (Nair & Rodrigues, 2013). Applied methodology in this article gives new considerations for the current project which improve the model of the study and establishes a detailed insight for the financial character of RES investments. Boateng et al., (2012) gave more comprehensive approach to investment process development with system dynamics methodology and focused on megaprojects. This article very well explained the lack of systematic approaches to describing the interaction among technical, political, economic and environmental risks in complex structures with thinking the inefficiency of risk management standards. Their feedback structures and the logic behind the construction of reinforcing loop, balancing loop and loops with delay is unique in literature. Also, He et al., (2018) presents a detailed analysis of the optimization of Chinese power grid investment based on transmission and distribution tariff policy. To construct the model, authors studied the revenue stream of Chinese grid companies and divided them into sub-modules. Each module investigated for its equations and model structure of each module is constructed. Research on investment risk management of prefabricated construction projects is a detailed analysis of model construction (Li et al., 2017). Feedback chart and risk flow chart are modeled by identifying the related risks in the country according based on the research objectives. Because of the complexity in construction projects, step by step explanation will be the most efficient way to visualize the whole system. Factors chosen are an economic risk, company internal risk, technical risk, policy and legal risk and market risk. After the establishment of a feedback model for system dynamics, the target of a risk control layer and risk factor layers are bonded to each other for further modeling. Later, authors identified the primary risk paths which are vital to understand the modeling action and reactions with respect to each element.

From the literature review of risk analysis methodologies, traditional risk analysis methodologies like Fuzzy Set Theory, Monte Carlo Simulation, AHP, FTA would not be suitable in the application of the thesis. Reasons behind this consideration are that traditional risk methodologies do not enable to analyze the dynamic change of risks in the project life cycle and influence of the risks with cause and effect relationship. Besides, the interaction between risk factors are not analyzed with traditional methodologies. Then, System Dynamics Approach will be used to analyze the renewable energy investment risk analysis in this thesis. In this section, Literature will be reviewed based on the application of System Dynamics Approach for RES and other types of investments, and the application of the System Dynamics will be presented in the next section.

2.3 Application of System Dynamics Approach

Modeling, an engineering design for the analysis can be performed two ways; physical models and symbolic models (Barlas, 2009). System Dynamics models are considered as symbolic models with diagrams, mathematical equations, and graphs. In the dynamic structure of the methodology, changes of variables are examined with the descriptive characteristic of how variables interact with each other. Feedback loops, stocks and flows, and nonlinearities are the main components of the System

Dynamics Structure (Sterman, 2014). These components of the structures establish the behavior of the systems and these behavioral modes of the are presented in Figure 2.6.

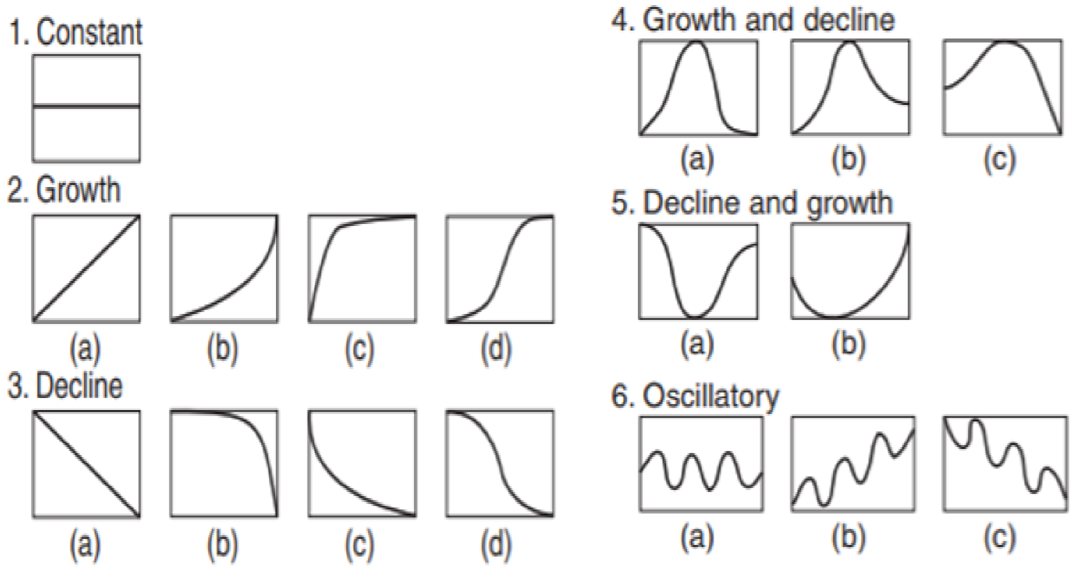

Figure 2.6 : Basic dynamic behavior patterns (Barlas, 2009).

In the components of the System Dynamics, feedback characteristic is unavoidable. Feedback characteristics are represented with the Casual Loop Diagrams in the structure. They are useful for analyzing the causes of dynamics and creating communication among the variables. As could be seen in the classical casual loop diagram notation in Figure 2.7, variables are linked with the arrow denotation to present the relationships between variables. In this structure, variables are connected with the casual links and negative (o) and positive (s) signs in the structure describe the cause and effect relationship in the system. In the casual loop diagrams, positive and negative signs are described respectively as reinforcing and balancing. Reinforcing loops means the increase in the effect variable when the source variable increase and balancing loops lead to a decrease in the effect variable when the source variable increase. Despite Casual Loop Diagrams are one part of the system dynamics approach, they are valuable tool to present and show the feedback structure of complex systems with their components and behavioral patterns.

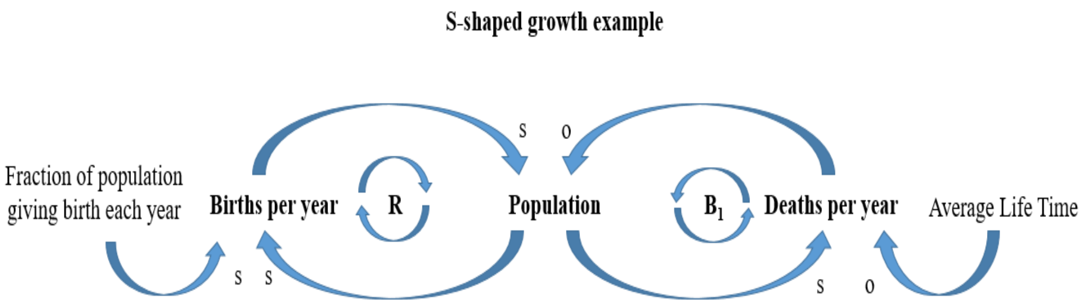

Figure 2.7 : Casual loop diagram notation (Higgins, 2013).

Casual Loop Diagrams could not proceed required analysis within its structure, even they are well suited to show interdependencies and feedbacks. Their limitation on the analysis side requires additional tools to analyze the stock and flow of the systems. In this regard, Stocks and flows are other main pillars of System Dynamics Approach. The explanation of these pillars is that Stock Variables consist of delays between the input and output variables and the accumulations resulting by the flow. Internal and external flow is the value arising from the accumulated differences of variables. Stock variables determine the system state and are the basis of actions in the system. Stock Variables serve as an accounting reserve for simulation, and Stock Variables are the source of delays in the system. Examples of such variables could be considered as warehouses and bank accounts. The way to understand whether a variable is a stock variable or a flow variable is to bring the system to a static state. When the system is set to a static position, observation on the system is conducted. If the variable maintained its accumulation, then it is stated as stock, on the other case, it is defined as flow. In Figure 2.8, stock and flow nomination is presented with other notations in the Stock-Flow Diagram. The mathematical expression of Figure 2.8 is presented below with the stock and flow variables.

$$Stock\ (x) = \int_0^t \big(Inflow\ (x) - Outflow\ (x)\big)dx + Stock\ (x_0) \tag{2.1}$$

In the mathematical expression, the stock variable is measured as the unit, and the flow variable is measured as unit/time. As seen in this formulation, they are influenced by the change of in and outflow variables and the initial state of the system.

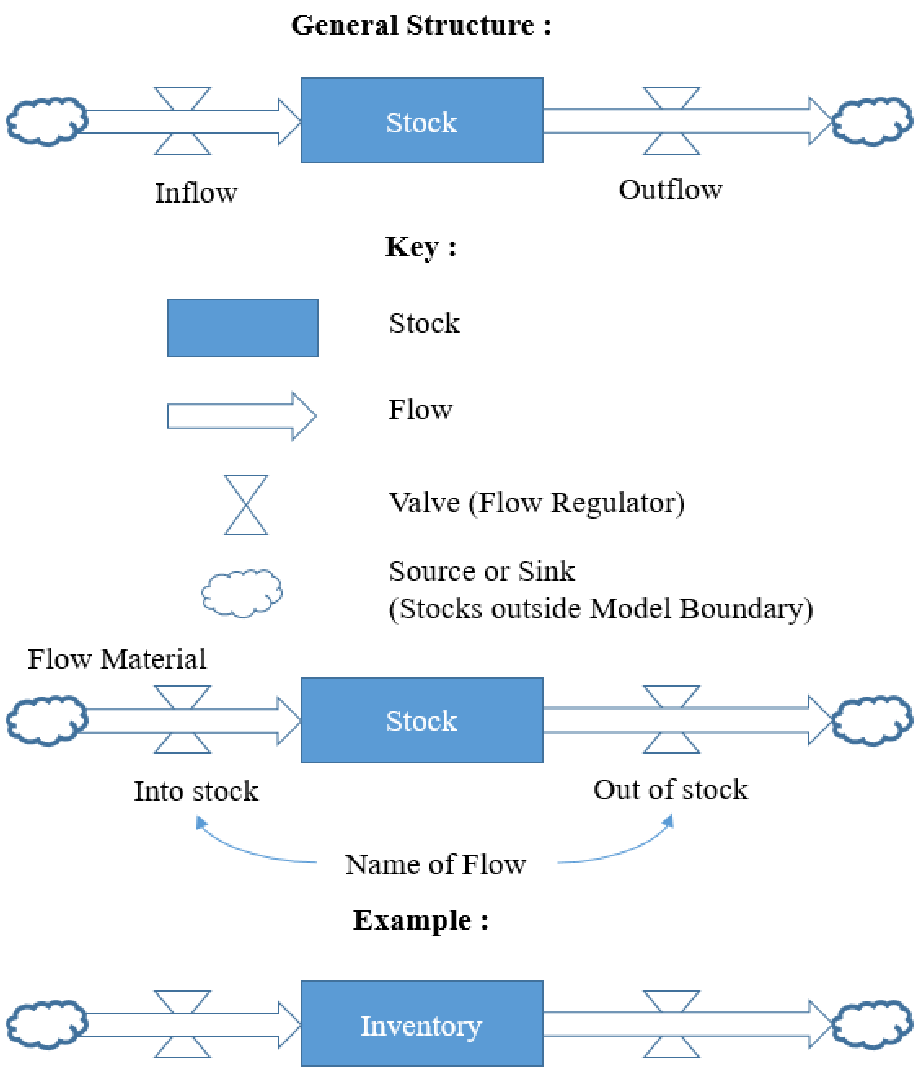

Figure 2.8 : Stock and flow diagram notation (Sterman, 2014).

In the system dynamics model, the decision functions determine how the information is accumulated in the stock variables and will be converted into the decision(s) to produce specific actions. The elements of this set of threads affect another variable, and the system enters a new state. The flow of information in the system starts from the stock or flow variable and ends in the decision-flow variable of the other network. It leads the flow in other networks to stock in the other network by following a chained path. In this way, the system operation is dynamically modeled. The interaction between the variables in the system can be observed as an auxiliary variable in the information flow continues by affecting other auxiliary variables.

3. DETERMINATION OF RISK FACTORS IN RENEWABLE ENERGY SYSTEMS INVESTMENTS

Within the scope of this thesis, it is planned to determine the risks that may be encountered in Renewable Energy Systems Investments in order to perform the analyses of the risks factors and to provide a guide for the industry stakeholders. During the determination of the risks, two methods were used: Literature Review and Expert Opinions. In order to determine the interaction between the risk factors, brainstorming and nominal group techniques are preferred. Selected investment types of renewable energy systems are hydropower, solar, wind and geothermal energy. Literature review and other risk identification methodologies will focus on four types of investment in general, bio-energy is not included.

Review process includes the research in scientific journals and industrial reports documents published by the sectoral organizations. Classification studies were performed from academic literature, and each classification was examined separately under the relevant section. At the end of each section of risk identification methodology, investigated risk factors are presented with a table.

Experts interviewed are the private sector workers taking role in renewable energy projects actively. Due to the diversity of risk factors covered, attention has been given to ensure knowledge on different processes of investment project life cycle, experts are selected different phases and different departments.

The methods to be used in establishing the relationship between the risks were obtained by using brainstorming and nominal group technique methods performed by experts in renewable energy investments. Finally, risks obtained as a result of the first two methods are combined, and two other methods examine the interactions. The risk factors resulting from the combination of all the methods used and their interaction with each other were presented to the participants by the Delphi Method via questionnaire. After, System Dynamics Approach is used to evaluate the results of the Delphi method for mathematical modeling.

3.1 Risk Factors Determined from Literature Review

In this section, the risks encountered in the investments of renewable energy systems are compiled for the hydropower, solar, wind and geothermal energy resources by scientific article and industrial report reviews.

Liu and Zeng (2017), made a classification for renewable energy investment risk factors by separating risks as technical, policy and market. Gatzert and Kosub, (2016), examined the risk factors associated with onshore and offshore wind parks. In their classification, risk factors are divided as business, transport/construction/completion, operation/maintenance, legal, market/sales, counterparty and policy risks. Whereas, Lee and Zhong (2015) is focused on the finance side of risks in renewable energy projects focusing on hybrid bonds. Goh et al. (2014), investigates various essential factors using System Dynamics Methodology using a classification as financing, policy, technological and technical sides of an investment. Another research, Steckel and Jakob, (2018) classified risk factors as policy, finance and technology. Another study suggests three main areas of risks which are price, technical and financial risks (Guerrero et al., 2016). In the sight of literature surveys on renewable energy investments, the thesis classified the risk factors under technical, policy, market and environment/social subgroups for the defined energy types. During the literature review, the technical sides of each energy types require special consideration due to their unique characteristics. However, other subgroups will be investigated without separation of the different types of energy resource.

3.1.1 Technical risk factors

Survey on technical risk factors, hydropower, solar, wind and geothermal energy will be examined separately. However, identified risk factors will be collected at the end of the section. Besides, it is preferred to use a general expression for the repeated risk factors in different sources to make identified risks clearer and more comprehensible. The same process will be applied to different energy types to examine the wide aspect of energy sector. It will also focus on the different kind of technologies under the same group of energy type. For illustration, thesis will examine both PV technology and concentrated solar technology.

3.1.1.1 Wind energy technical risk factors

Studies on wind power plants are generally focused on project design, technical characteristics of equipment, construction, technology and operational risks. In this regard, different approaches presented in the below tables with respect to each study.

Gatzert and Kosub (2016), pointed out the crucial role of the renewable energy investments in European Energy mix. They presented the risk factors in onshore and offshore wind parks with the risk management proposing solutions. In this article, risk factors associated with wind power plant investment covers many sides of investments and project life cycle. Life cycle perspective is useful for the further implementation of the System Dynamics methodology, so, time-specific occurrence of risk factors will be determined. In table 3.1, technical risk factors of onshore and offshore wind power plant investments are represented.

Table 3.1 : Wind energy investment technical risks (Gatzert & Kosub, 2016).

Risk Type	Description
Technology and Innovation Risk	Risk lead to uncertainties within the resource assessment of investment at the early planning of the investment and arise the lower than expected revenues.
Transport/Construction/Completion Risk	This risk includes the commercial operation period delays and damages due to logistic and construction side of the project, which will lead to lower revenues in every stakeholder of the project.
General Operation and Maintenance Risks	Main factors behind this risk group which will damage the physical asset, - Unavailable Spare Parts or replacement during the maintenance period - Efficiency and reliability of selected technology - Negligence, accident, wear and tear within the equipment

Table 3.1 (cont.) : Wind energy investment technical risks (Gatzert & Kosub, 2016).

Risk Type	Description
Damage due to serial losses	This risk factor is caused by the Supplier due to the equipment's defectiveness.
Revenue loss due to business interruption	It may seem related to the legal side of the risks. However, EPC and O&M Contractor's liability within the project life cycle cause severe damages to project
Resource risk	The technical side of this risk factor lay within the proper resource assessment of the wind power plant investment. Project Design (Resource, Siting of wind turbines and feasibility study) at the business development period gains importance.
Grid Availability and Curtailment Risk	Grid Management of the operator and aging of the grid infrastructure is leading causes of these kinds of risks. Besides, excessive investment in the same substation will lead to curtailment issues.
Contractor Risks	In the credibility side of the O&M and EPC contractors, poor credit quality will result in revenue losses.

Yeter (2011), examined the path to be followed during project development and installation phases of wind power plant investment in his thesis. The study examined the issues to be considered during the installation of wind power plants and stated the importance of them. In table 3.2, considered risk factors are explained with their details.

Table 3.2 : Technical risks in wind power plants (Yeter, 2011).

Risk Type	Description
Selection of Technology Risk	The price of the wind turbine is between 70% and 80% of the Wind Power Plant cost. Due to this ratio, it can be problematic for return of investment by not optimizing energy production values while selecting a turbine.

Table 3.2 (cont.) : Technical risks in wind power plants (Yeter, 2011).

Risk Type	Description
Construction Risks	Risks could arise within the insufficient project management side of the investment due to simultaneous works in the construction period of the wind power plants.
Transportation Risks	In the conditions of mountainous and rough terrain, transportation is one of the most critical works of project implementation which could end up in severe damage to wind turbine equipment.
Assembly Risks	Although the installation works carried out in RES projects do not cost a considerable amount in total investment amount, it is a risk factor in terms of the effect of engineering and environmental factors.
Electricity Connection Risks	Nature of the Wind Power Plant Investment requires serious consideration about the engineering side of Balance of Plant. In the cabling and construction of substation lead to severe damage without required topographic and geological studies.

In the article of Montes and Martin (2007), the barrier against the profitability of wind power plant investments is examined in Spain to satisfy the goals of Plan de Fomento of 2010. In this regard, the study gives its main focus on the short term probability of the power plants. In table 3.3, the technical sides of these obstacles which have an impact on the profitability of investments are examined.

Table 3.3 : Technical barriers in profitability of WPP investments (Montes & Martin, 2007).

Risk Type	Description
Resource Supply	Inadequate wind resources in the project site lead to controversy to revenues. This proves the importance of measurements that have been spread over many years.
Property Damage Risk	Property Damage Risks are defined within the terms of fire, theft or weather damage. However, malfunction of equipment in investment leads to severe damage.

Table 3.3 (cont.) : Technical barriers in profitability of WPP investments (Montes & Martin, 2007).

Risk Type	Description
Machinery Breakdown Risk	The low quality of the products provided by the supplier is the risks encountered.
Technology Risk	The choice of technology poses risks due to problems in the power generation stage and the lack of track record of the selected technology.
Third Party Liabilities	In this regard, O&M costs of the wind power plants are increasing in those years. Then, contractors could not offer stable prices for long term period which lead to unstable revenues as a significant risk factor.

Another report (EWEA, 2013), considered the legally binding target of the European Union. In this regard, the authors investigated the major obstacles in the operation and construction phase of the offshore wind power plant investment. Besides, offshore wind tender is intended to implement by the Turkish Energy Ministry (2018), then, the article will be useful to investigate the offshore wind investment. In table 3.4, construction and operation risks are presented.

Table 3.4 : Key construction and operation phase risk factors (EWEA, 2013).

Risk Type	Description
Grid Availability	Risk causes a mismatch between the supply-demand side of the electricity at the time of delivery.
Supplier Risks	These risks are examined in three sections, Credit Strength: Supplier credibility gains importance to accomplish its liability against the contract. In the offshore wind power plants, supplier side bankruptcy is a serious issue in this regard. Contracting: Multi Contracting and fewer multi contracting create essential issues with respect to project management of offshore wind power plant construction due to miscommunication between the contractors . Installation and Logistic: Service Providers are pointed out the importance and damages caused by the items.

Table 3.4 (cont.) : Key construction and operation phase risk factors (EWEA, 2013).

Risk Type	Description
Component Risk	Wind Turbines include many components like gearbox and bearings. The unproven components could cause reliability problems with their productivity.
Technology Risk	Non-evolutionary technology selection could cause in the late phase of project operation period.

3.1.1.2 Solar energy technical risk factors

Solar Power Plant investments are increasing due to decreases in module prices and system prices in previous years. In this context, researches on solar energy investments are diversified. Although it has a simpler infrastructure compared to other types of investment in technical terms, the risks faced by the sector participants are also increasing due to high investment size. In this section, Solar Power Plant investments will be examined considering both concentrated and photovoltaic technologies.

Turner et al. (2013), indicate the driving factors behind renewable energy investments and emphasize the importance of management of the risks for the sake of the future. With the investments made within the force of recent trends, the solar energy sector has evolved and became complex that needs an analysis with care. Risks faced in solar power investments are shared through the author's perspective in table 3.5.

Table 3.5 : Risks faced in solar energy projects (Turner, et al., 2013).

Risk Type	Description
Damage Risks	The construction period of the investment is stated as the most crucial part of the investment. Then, damage to assets of the power plant occurs as a significant risk factor.
Start-up Delay	Delay in commercial operation date causes revenue losses, the main reasons behind this risk are careless contracting, non-effective project management and due diligence.

Table 3.5 (cont.) : Risks faced in solar energy projects (Turner, et al., 2013).

Risk Type	Description
Loss, Damage and Failure	In the article, risks behind the loss, damage, and failure defined as material risks. It could occur due to design flaws, natural catastrophe during operation. Downtime due to failure of equipment causes a decrease in revenues
Warranty	Project Developer needs a proper warranty with respect to equipment from the Supplier; otherwise, credit risk of the project and continuous operation could end up with severe damage.
Contracting	In the last years, Lenders requested financially stable O&M and EPC contractors, and contracts should cover the related risks with respect to contractors' liabilities. On the other hand, credit risks and the project would be under risk.

Komendantova et al. (2009), focuses on the concentrated solar power systems to produce electricity in North African countries. In this regard, the excess amount could be supplied to European Countries within Transmission Lines. Then, the article pointed out the obstacles to investing in Northern African countries for renewable energy development. In the study, risk factors are evaluated with respect to risks perceived as being most serious by investors without a definition of the risk factors. In Figure 3.1, investor's decision about the ranking of the risks are given.

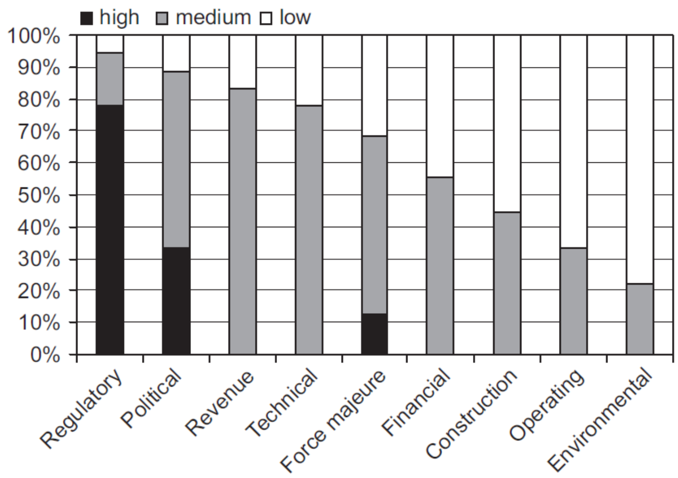

Figure 3.1 : Risks perceived by ranking (Komendantova et al., 2009).

Şimşek (2014), focused on identifying and analyzing risks in tower type condensed solar projects. According to the stages of the project, conceptual design, system components design, production, and purchasing of system components, assembly, hardware and software integration, commissioning and system tests have been evaluated. The identified risks are also divided into categories according to technical, social, economic and political conditions. Then, the qualitative analysis of the risks falling into the technical category within the scope of the project risk assessment and analysis is carried out. In the qualitative risk analysis section of the study, examined risks are given in Table 3.6.

Table 3.6 : Risk analysis of solar tower thermal projects (Şimşek., 2014).

Risk Type	Description
Conceptual Design Risk	Three items are defined under this risk group. They are mainly related to the site design of the project - Field Settlement Plant - Process Flow Diagrams - System Modeling and Simulation
System Component Design Risk	Careful Design of the gain importance with respect to CSP projects due to the complex nature of the system. Thus, defined components have a crucial role. - Heliostat Design, Tower Design, Receiver & Thermal Equipment Design, Software Design
Production and Supply of System Components	Supply Chain and Logistics are essential factors in the success of the project. Then, presented components of the solar tower thermal projects are carefully produced and transport to the project site.
Assembly Risks	In the assembly side of the plant, below items are causes severe damages under improper assembly. - Heliostat Erection - Tower Erection - Receiver & Thermal Equipment Replacement

Table 3.6 (cont.) : Risk analysis of solar tower thermal projects (Şimşek., 2014).

Risk Type	Description
Hardware and Software Integration Risks	In the solar tower thermal power plants, design of the software with respect to each project directly affect the generation of electricity. Then, it causes severe damages to the revenues of the project.
Commissioning and System Test Risks	In the thesis, Commissioning and System Test Risks are evaluated. Their useful application could prevent the risks under the project like deformation, measurement problems, lower yield, erosion, and problem in signaling devices.

Tjengdrawira et al. (2017) presented a study on the risk identification assessment and mitigation process of the bankability of photovoltaic power plant investment. In this study, each stakeholder's perspective is included with respect to potential legal, technical and economic risks through the project lifecycle considering the possible losses on the revenue stream of the project. In table 3.7, the risk factors faced in the photovoltaic power plants are presented.

Table 3.7 : Arising risks under technical inputs of PV plants (Tiengdrawira, et al., 2017).

Risk Type	Description
Procurement/Technology Selection Risks	PV Technology selection gains importance considering the environment of the site. Then, Selected Design's technical specifications lead to lower yield in the production.
Procurement/Technology Selection Risks	Deviations due to improper testing lead to a loss in revenue. Independent product delivery acceptance tests are required to evaluate the sustainability of the equipment.
Planning and Resource Assessment	Inadequate long term measurement of the solar data leads to loss on revenue. Improper degradation of the power plant will result in lower yield in the project lifecycle. Availability assumptions are essential to guarantee the expected production.

Table 3.7 (cont.) : Arising risks under technical inputs of PV plants (Tiengdrawira, et al., 2017).

Risk Type	Description
Planning and Resource Assessment	Main factors could end up with severe damage on the yield are an improper assumption on soiling losses, modules mismatch, shadowing of the tables, sizing of the inverters and improper ventilation systems. Site Selection in the business development period is also important parameter affecting the grounding costs and yield of power plants.
Logistic	Transportation and Handling plans have a crucial impact on the start-up delays in the project.
Construction and Installation	Insufficient project management plan and procedures could lead to serious health and safety issues and incorrect installation of the power plant. Within the management structure, monitoring and scheduling of the construction works are other important factors which could end up as risk factors under the inadequate application.
Operation	Inadequate Fault Detection and Determination on Power Plant Equipment will create problems on below items, - Hotspot Detection of PV Panels, Breakage on Glasses, Improper mounting structure, Overheating on inverters, Grounding and Firmware issues in Inverters Definition of the performance indicators on contracting sider could lead to a loss on yield and revenue.
Maintenance	Cleaning of the modules and frequency of the activity could lead to lower yield and revenue losses. Then, water management and cleaning schedules are important factors for a stable generation.

Furthermore, failure data collection on the components of the PV power plants are conducted, and failures on panels and inverters are frequently occurring on the investments. The risk matrix is adequately constructed to enlighten the sector participants regarding modules and inverters failures on specific periods.

3.1.1.3 Geothermal energy technical risk factors

Geothermal energy is a renewable, sustainable, inexpensive and reliable source of energy. Although continuous power generation is a unique advantage of the geothermal energy with respect to other types of renewable energy sources, the technical design of the investment needs careful attention to establish a bankable project. In this regard, various studies conducted to examine the investment risks of geothermal energy projects.

Ngugi (2014) noted the various risks of varying degrees in geothermal energy development. The article pointed out the importance of resource risk of geothermal energy compared with other types of renewable energy projects. Besides, considering the market, financing, commercial and macro-economic risks is distinguished the study from other studies on the topic. In table 3.8, technical risk factors of the geothermal energy projects are illustrated.

Table 3.8 : Technical risk factors in geothermal energy (Ngugi, 2014).

Risk Type	Description
Land Access Risks	Wells and Road Infrastructure of the geothermal energy power plants spread wide area beyond the plant site. Then, land acquisition for the project could end up with a delay in the development and construction phase of the project.
Resource Risks	Authors stated the resource risk of the geothermal energy project is the most significant factor in investment. Then, separation with respect to resource risk is examined - Existence Risk – Drilling of the wells to prove the profitability of the reservoir is a necessary application for the development, however, the drilling process is costly and unsuccessful drilling could lead to severe damage on the bankability of the project.

Table 3.8 (cont.) : Technical risk factors in geothermal energy (Ngugi, 2014).

Risk Type	Description
Resource Risks	- Suitability – Authors defined the suitability of a resource with the four main factors. These are temperature, enthalpy, pressure, and permeability of the resource. Then, the selection of the technology gains importance with respect to well's characteristics. - Size - Resistivity measurements used to make initial resource size estimates are known to deviate from reality (Hadi et al., 2010). This could result in uncertainties on the yield. - Sustainability – Degeneration of the reservoir is important topic for the geothermal energy. The risk behind this concept could end up with the shorten life-term of the reservoir and failure in the investment. - Development of the Source - The source discovered by drilling method in geothermal energy projects may cause problems in electricity generation due to low performance in the some of production wells.
Technology Selection	Reliability of the geothermal energy systems are stated in the study; however, selection of these systems should match with the characteristic of the reservoir characteristic.

Kahraman et al. (2009), conducted a comparative analysis on the renewable energy selection. In this regard, the article used fuzzy axiomatic design and fuzzy analytic hierarchy process to evaluate the best option for the portfolio considering the uncertainties under the investment. Under this structure, authors evaluated the geothermal energy as an alternative source of energy, and defined technical criteria, which have evaluated as risks factors, for the decision-making process are presented below,

- Technology as the main criteria
    - Feasibility of the Project
    - Reliability of the Sources
    - Duration of the development phase
    - Duration of the implementation phase
- Environmental as the main criteria
    - Land Requirements
    - The need for waste disposal (This sub-risk could be determined as management of re-injection of the reservoir steam under geothermal energy)

Ungemach et al. (2005) examined the importance of geothermal reservoir management and production engineering in the study. In this study, the Paris Basin Geothermal District Heating Scheme is selected for the case study approach. Then, their approach with respect to risk assessment of the reservoir management presented below.

- Exploration Risk

In the exploration side of the resource, authors pointed out the importance of the hot water aquifer and regional studies conducted for the basin which creates a reliable environment for the exploration risk of the drilling.

- Exploitation Risk

Uncertainty of the exploitation reservoir continues its existence through the life cycle of the reservoir. In this regard, thermochemistry of the fluid could end up with severe damage to the equipment with corrosion and scaling damage.

McVeigh et al. (2007), proposed a management tool for the risk analysis for geothermal energy technologies. Under the risk factors, technical risk factors are examined to conduct the study. In this regard, their risk factors with respect to the technological development of geothermal energy systems are enlightened the crucial factors for the technical side of the study in table 3.9.

Table 3.9 : Preliminary technical risk factors under new technologies (McVeigh et al., 2007).

Risk Type	Description
Temperature Prediction	Inaccuracies in the temperature prediction could lead to inefficiencies under operation period
Fracture Prediction	Permeability Development and Fracture Growth are important technological consideration for geothermal energy.
Resource Assessment	This risk factor is related to the success of the exploration and completion of the power plant.
Drilling Period Time	It will lead to an increase in the production and injection well costs increase which will directly affect the bankability of the project
Reservoir Performance Modelling	Inadequate modeling will lead to incorrect results with respect to reservoir temperature decline rate, and the required precautions could be delayed with respect to it.
Geophysics	Seismic and magnetotellurics modeling of the reservoir is important factor geothermal energy development

In the identification of the risk factors of geothermal energy, the main focus is given to the development phase and reservoir related issues due to its unique features. However, construction side and operation side of the risks faced in the geothermal energy are very similar with other types of power plants. On the other hand, geothermal power plants could great impact on the environment and public due to inadequate design parameters which leads to pollution in the soil and air in the region. However, the whole system should be carefully designed and constructed due to complexity in the geothermal power plants.

3.1.1.4 Hydro energy technical risk factors

Hydroelectric Power Plants are plants, where electricity is produced by using water power. In principle, it is based on generating electricity using the potential energy of water. Comparing the hydropower plants with other types of power plant investments, it has high capital expenditure, however, return on investment and operational expenditures are respectively very short and minimum (Bakır, 2009). In this regard, technical risks lay in the hydropower investment should be carefully considered due to high investment cost and size of land occupation. To determine the technical risk factors, many studies are conducted and surveyed literature presented below.

In the literature, river-type hydropower plants are investigated based on the risk factors with using fuzzy logic approach. Expert opinions and the risk assessment is used rather than using the probabilistic approach (Kucukali, 2011). Using the expert views, field studies and literature reviews, risk factors are defined, and site geology and environmental issues are considered as the most important at the end of the evaluation. In table 3.10, technical risk factors of river-type hydropower plants are presented.

Table 3.10 : Technical risk factors of river-type hydropower plants (Kucukali, 2011).

Risk Type	Description
Site Geology	This risk factor is originated by the geotechnical properties of the project site which could result with the overheads due to the investment scale of the hydropower plants
Land Use	It is considered as the right to use the land for the construction of a power plant. It is also related to the regulatory side of the project development period.
Grid Connection	It is related to the low capacity on the substations and demand-supply mismatch on the project region.
Access to Infrastructure	Due to geographical characteristics of the many hydropower plant sites, inadequate transportation infrastructure is common in these types of project.

The literature stated that the generation of electricity by hydropower plants are increasing on a global scale (Yucesan & Kahraman, 2019). In this regard, Efficiency for the operation side of the hydropower plants gains importance, and authors examined and evaluated the hazards in the operation side of the plant considering as risk factors. The defined risk factors with respect to investment are illustrated below.

- Measurement of isolated oils of transformers and chemical oil exposure during the regeneration process
- Asbestos exposure when generator shoes are replaced
- Risk of isolator explosion in the switchyard
- Due to electrical impulse in the interconnected system is a risk at the turbines
- With crane transportation of heavy materials during breakdowns and maintenance
- Risk of falling cavitation damage during repair in a draft tube
- Water flow failure in bearing cooling system and increase of bearing temperatures
- Leakage failure in bearing cooling
- Employees should not remove heavy goods properly in a manner that harms the resulting skeletal system
- Employees working without protective materials such as masks and ear plugs
- Risk of falling over penstock in penstock seal changes
- Risk of falling slippery floors with oil and water
- The danger posed by the chemicals used to clean oily surfaces
- Both malfunction of the switches and safety valves of compressed air and oil tanks risk of explosion resulting in excessive pressure increase
- Due to governor failures, the turbine goes to excessive speed, and the bearings are damaged
- High-speed braking causes lining smoke and the carbon dioxide system works
- When the units were disabled, failure of the power plant's internal requirement system risks occurring due to the inability to feed the places where the electricity should be fed due to the generator not entering the circuit
- Rise of turbine pit water due to turbine pit seal failure
- Entering the generator cell without informing the control operator

- Employees working with psychological disorders

Caylıdemirci (2010) examined the risks on the construction of river-type of hydroelectric power plants. During the process of the study, risk factors in hydropower plants are given with details considering the technical, environmental, policy, management, economic, legal sides of the investment. In table 3.11, technical risks of the hydropower plant investment will be shared including the development, construction and operation side of the projects.

Table 3.11 : Technical risk factors of hydropower plants (Caylıdemirci, 2011).

Risk Type	Description
Design of the Project	Inadequate design of the project.
Geology	The missing parts and errors in the soil study and geological study.
Project Site Conditions	Insufficient site environment for the labor, and delays in field permissions.
Unqualified Labor and Project Management Team	Absence of qualified personnel
Application of New Techniques	Arising risks due to the applicability of the new techniques, and losses on the property and revenue stream
Business Interruption	Risk arising from problems among the stakeholders
Insufficient Resources	- Inadequacy of labor force, laboratory, and equipment due to overload - Equipment failure / maintenance shortage - Reduction of the project team
Reliability of estimated cost of exploration	Overheads on the budget could end up with the interruption or cancelation of the investment
Project Site Excavation Material	Inadequate management of excavated material on the project site.
Miscommunication within the EPC team	Risks arising from communication between senior management and field team

Table 3.11 (cont.) : Technical risk factors of hydropower plants (Caylıdemirci, 2011).

Risk Type	Description
Access to Project Site	Difficulties in transportation to the site due to lack of access roads, rough terrain, ownership of other people land

3.1.2 Policy risk factors

In the recent development of renewable energy infrastructures, a variety of institutions and private sector parties play an essential role. In this context, regulations and policies of the regulating institutions or government entities have a significant impact on the investment return and evaluation. Then, risk factors under the policy side of RES investment should be considered very carefully to prevent possible failures or not to block the RES investment. Gatzert and Kosub, (2016), regulatory and policy risks factors are a significant obstacle for RES investment with the limited insurance coverage to these issues. In the literature, regulatory, policy and political risks are different in their definition (Smith, 1997); however, they will be identified under the Policy Risk Factors section for the purpose of this study.

Gatzert and Vogl (2016) proposed a stochastic model framework in order to evaluate policy risk factors in RES investments. For quantifying risk factors, expert measures and fuzzy set theory is adopted for the modeling. They considered the reduction of Feed-in Tariff as well as the price, resource, and inflation risks in the systems. In this regard, Feed-in Tariff reduction is the main risk factor of the study with related subfactors. In table 3.11, the identified policy risk factors and their descriptions are illustrated.

Table 3.12 : Policy risk factors based on FiT reduction (Gatzert & Vogl, 2016).

Risk Type	Description
Economic Stress Situations	It is caused by the budget constraints on the application of government policies.
National Targets Definition	Arising risks, government, and entities could remain under the moral hazard due to reaching RES target of the country

Table 3.12 (cont.) : Policy risk factors based on FiT reduction (Gatzert & Vogl, 2016).

Risk Type	Description
Subsidy Payment	Large subsidy payments could establish uncontrolled growth of the RES investments. On the other side, low subsidy payments could prevent the development of RES investment
Political Uncertainty	Arising risk due to political change or changing priorities

Angelopoulos et al. (2017), noted the required investment for achieving European Union's 2020 targets for Renewable Energy. In this context, authors provide an assessment of risk factors in RES investments in Greece with relation to policies. The objective of the study is defined as the impact of risk factors on the weighted average cost of capital (WACC), and factors are evaluated considering the value of the WACC. Evaluated policy risk factors are shown in table 3.13.

Table 3.13 : Policy risk factors in Greece RES investment (Angelopoulos et al., 2017).

Risk Type	Description
Administrative	Risks arising due to administrative process are mainly related to the uncertainties on the permits which lead to delays on the project and damages on the implementation of the project.
Policy Design	Policy Support Schemes are the main driver and barrier of the RE Investments, and their poor implementation could prevent the development of the RE projects.
Market Design and Regulation	Transformation of the traditional FiT mechanism to market-based support schemes like Feed in Premium (FiP) in the RE market. It could cause a low return on investment in projects due to the unstable framework.
Sudden Policy Change	The reduction of the FiT levels and additional taxes on the RE Generators is occurred in the European Market (Spain and Greece). This could lead to the default of the investment.

Gatzert and Kosub (2016), made a comprehensive survey of risk factors in the literature for onshore and offshore wind parks. In that study, defined liability/legal, policy/political and one side of the counterparty risks will be used under policy risk factors. In table 3.14, identified policy risk factors are shared.

Table 3.14 : Policy risk associated with wind parks (Gatzert & Kosub, 2016).

Risk Type	Description
Complex Approval Processes	Public Sector Administrator's inadequate application could lead to intransparent and inefficient licensing and permit procedures. Loss in the revenues and delays are the outcomes of these risk factors. expected payments
Counterparty Risk Power Purchase Agreement (PPA)	Unstable financials of the off-taker in PPA could lead to revenue losses with delay in payments and bankruptcy.
Political, Policy, Regulatory Risks	Adverse changes in the government policy schemes or regulations could result in the lower revenues or obstacles on the further development of RES investments.
Liability and Legal Risks	Risk arising from liabilities to third parties due to potential environmental damages, uncertainty regarding resulting legal disputes and contracting risks due to complex legislation or processes.

Noothout et al. (2016), proposed an environment for the future policy needs which will provide the continuous evaluation of current policy schemes of renewable energy projects under DiaCore project that is established due to the European Union's targets. In this context, the project facilitates the RES support across the European continent and create a platform for the development of further investments. In figure 3.2, proposed RES investment risk factors are presented with their occurring period on the investment life cycle.

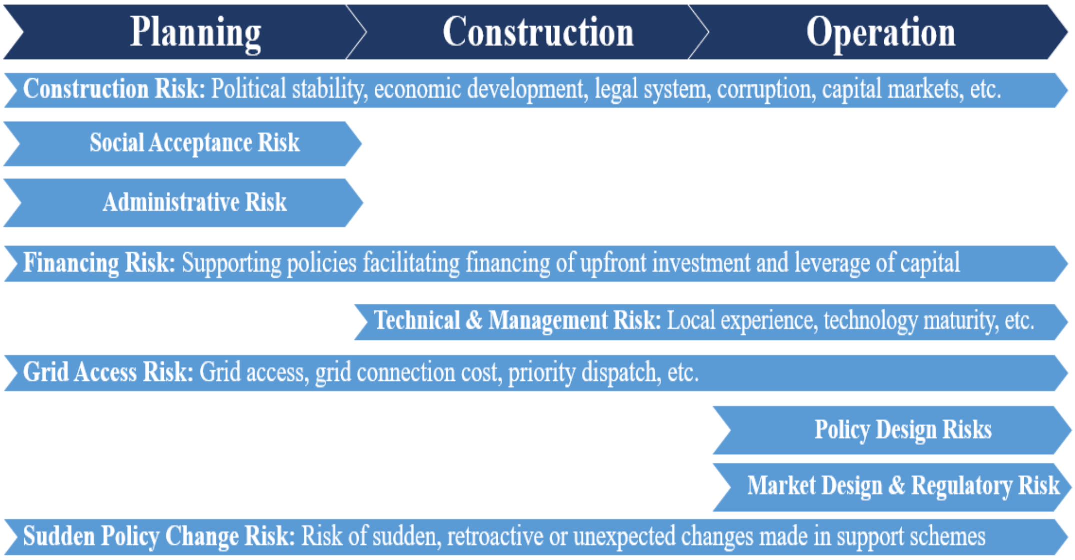

Figure 3.2 : RES investment risk factors (Noothout et al., 2016).

Liu and Zeng (2017) proposed a system dynamics modeling for the risk analysis for renewable energy investment where, policy risk factors are analyzed as the leading risk group of the evaluation. In this context, political risks are defined as the uncertainties regarding access policy, industry regulation and price policies. Besides, promoting the development of renewable energy is an essential consideration which will be affected by the establishment of R&D Funding, Tax Incentives, Subsidy Payments, Quota System and Feed in Premium or Feed in Tariff mechanisms. As of industrial policies, Private Sector decision making is affected by those policies, and inadequate application of the policy could prevent the sector participants to invest in RES. Also, inefficient subsidy schemes could lead to adjustment on the policies which will result in the risks on the revenue stream of the investors and other stakeholders which causes material losses.

3.1.3 Market risk factors

Studies on market risks are highly valuable in order to reflect the investor and other stakeholders' perspectives. Before analyzing market risk perceptions for RES investments, it is necessary to define the market type of risks covered in the literature. Market risks will include the financial, economic and sectoral risk factors faced in the RES investment.

- The financial risk of the company
- Marketing capabilities and service quality

- Fund utilization and the profitability of the company
- The experienced team on financing proposals and fund operation

On the external side of the market risks, authors defined the below factors:

- Market access barriers (License, approval and industry standards)
- Market competitiveness
- Market growth potential
- International Market Volatility
- Incomplete Equipment Industry Chain

Caylıdemirci (2010) examined the risks on the construction of river-type of hydroelectric power, and his findings are presented at table 3.15.

Table 3.15 : Market risk factors in hydro power plants (Caylidemirci, 2010).

Risk Type	Description
Insufficient Management Team	Inadequate management source could lead to severe damage to the return of investment. Scheduling, equity management and miscommunication are causes of this risk.
Economic Crisis	Effects of the economic crisis have a significant impact on the investments due to volatility in the exchange rates, inflation, interest.
Financing Risks	The existence of finance, increase in interest costs, a valuation from credit rating agencies are the risk factors that affect investment and investor.
Import and Export Restrictions	Closed economy applications could bring limitations on the market and the access to finance and equipment.
Payments	Payments risk of the off-taker is important for the revenue stream, and payment made by the investor to its contractors is another important side for the progress.

Gatzert and Kosub (2016) also investigated the market risk factors for onshore and offshore wind power plants, and their achievements are presented at table 3.16.

Table 3.16 : Market risk factors in wind power plants (Gatzert & Kosub, 2016).

Risk Type	Description
Financing Risks	Risk of insufficient access to financial markets in the country. These could prevent the development of the whole renewable energy types
Insufficient Expertize on Market	Market development brings the benefits of experienced consultants and other types of stakeholders. Inadequate expertize could lead to major problems in the market
Insufficient Management Know-how in market	This risk is considered as business management risks in the private sector company. Track records of renewable energy companies will have important role in the development of further investments.
Revenue Loss due to business Interruption	It is both considered in the technical and market risk factors, relations between contractors and any stakeholder in the structure of investment could lead to interruption of business, and material adverse effects (Delay and Exiting of contractors) are the major outcome of this risk.
Variability of Revenue due to price volatility	Risk arising from uncertainty regarding volatile energy prices resulting in lower revenues

Ozbugday (2016), gave a brief description of the market risk factors in his report to analyze the risk perception of RES Investments in Turkey. In this context, the author examined the policies and subsidy mechanism of RES in Turkey to present the relationship between risk factors and investments. In table 3.17, market risk factors of the report are illustrated.

Table 3.17 : Market risk factors in Turkey (Ozbugday, 2016).

Risk Type	Description
Electricity Price Risks	Risk arising from the volatility of the cash flow of electricity producers as a result of the fluctuations in electricity prices.
Demand Risk	Risk arising due to insufficient levels of electricity demand.

Table 3.17 (cont.) : Market risk factors in Turkey (Ozbugday, 2016).

Risk Type	Description
Fuel Price Risk	the risk of not generating electricity due to the increase in the prices of the resources used for electricity generation or the interruption of supply. However, considering the geothermal, hydro, wind and solar resources, this risk will not be examined in the study. On the other hand, biomass power plants are affected by the risk of fuel price fluctuations.
Financial Risk	Risk arising from adverse changes in financial and economic parameters such as exchange rate, interest rate, and inflation, which disrupt the cash flow of electricity producers
Balancing Risk	Risks arising from the financial responsibility of the market participants for the settlement of energy imbalances and imbalances on the settlement period basis.

3.1.4 Environmental and social risk factors

Social and Environmental risk factors are encountered due to problems related to geothermal and hydroelectricity power plant investments. However, wind and solar energy have their own impact on the environment, and they should be examined very carefully. In this context, the literature review of the sector reports and academic sources will be examined to illustrate the risk factors within the RES investments. However, the effects of global climate change have not been investigated in the scope of thesis.

In the literature (Yuksel, 2010), the importance of hydropower site construction is considered with the technical, economic and environmental sides. In this regard, the disadvantages and advantages of hydropower development are studied to show the sustainable development of the source. Comparison study presented in the article includes important risk factors faced in the Hydro Power Projects which will be presented in table 3.18.

Table 3.18 : Environmental and social risk factors of hydro power plants (Yuksel, 2010).

Risk Type	Description
Resettlement Risks	Hydro projects require considerable land acquisition for the investment which will result in the disturbance in public. In this regard, some of the projects are interrupted due to expropriation side of the investment.
Habitat Risks	Investment of the hydropower influence the habitat in the region. Destruction of the vegetation could lead to severe damage to the future phases of the operation.
Social Acceptance Risk	Risk arising from the social acceptance of the public for the investment.

Caylıdemirci (2010) examined the risks on the social and environmental side of hydroelectric power investment, and its findings as below,

- Natural Disasters – Risk arising from earthquakes and floods
- Weather Conditions – It creates risk on the business interruption in the construction progress and loss on revenue stream during the operation phase
- Environmental Effects – Project’s adverse effects on the regional environment could lead to severe issues with regard to public
- Health and Safety – It is caused by fatigue, safety and inefficiency issues.
- Ecological Risks – it is caused by the ecocide of the environment.
- Cultural Heritage on the project site – it causes the start-up delays on the construction of the project

In the report of Turkish Development and Investment Bank (2016), geothermal energy environmental and social risk factors are defined. In table 3.18, these factors are illustrated.

Table 3.19 : Environmental and social risk factors of geothermal power plants (TDIB, 2016).

Risk Type	Description
Waste Water Discharge	Discharge of drilling fluids, including water from exploration and operation wells during testing

Table 3.19 (cont.) : Environmental and social risk factors of geothermal power plants (TDIB, 2016).

Risk Type	Description
Groundwater	Contamination of underground freshwater resources by leakage of thermal groundwater during drilling and testing.
Air Emissions	Possible toxic gas emissions during drilling and well testing (hydrogen sulfate, mercury, etc.). In the case of absence reinjection wells, toxic gases could mix with the air and create natural hazards for the public
Well Explosions	Borehole burst during drilling
Social Acceptance	Concerns and complaints of affected communities in the project region due to soil and air pollution
Noise	Noises caused by Seismic surveys, drilling rig, generators, traffic on the project site.

In the literature review section, many risks have been identified, and It also enlightens the time periods of the risk factors when they will show their effect on the investment life cycle. In the second phase of the risk identification process, interviews with experts will be held. At the end of both processes, general risk factor table will be established.

3.2 Risk Factors Validated by Expert Interviews

Interviews with experts are an effective way to identify risk areas. The experts to be interviewed are selected from those who involved in construction, operations, business development, finance, law and environmental sides of the sector. The team has made significant contributions to the study with comments and opinions because they looked at these investments from different windows.

The information obtained as a result of these interviews confirms the information obtained by the literature survey used in the risk identification process. As a result of the interviews, some of the previously identified risks were not taken into consideration, and the negative results on the return of investments are determined. For example, in times of limited access to finance, investments that have reached a certain level of development period are at higher risk. Additionally, it is stated that the problems due to the design of the power plants could lead to losses on revenue. The inadequate siting of wind power plants are problematic, and it a significant amount of additional investment to solve the problems is required, which will result in credibility issues in investment. On the other hand, it was observed that there was a time loss during the acquisition of a number of bureaucratic permits and documents. For example, it is stated that the changes to be made in production or other licenses take place on average three and six months and affect the investment of RES. In conclusion, defined risks by the experts are presented in the tables of 3.20, 3.21, 3.22, 3.23, 3.24 and 3.25.

Table 3.20 : Technical risk factors validated by experts.

Risk Type	Description
Grid Related	Responsible stakeholder for grid connection construction
	Right of way of the grid, expropriation of land for the grid
	Aged infrastructure and curtailment issues
	Matching of grid regulation with industry standards
	Capacity limitations on the substation
	Excessive electricity supplier on the same substation
	Feasibility of the distance between site and substation
Land Related	Restrictions on land acquisition
	Obtaining rights of way to project site
	The residential and agricultural area in the project site
	Ecologically and environmentally sensitive area
Resource and Project Site	Seismic zone, weather-related risks in the project site
	Historical resource data for forecasts
	Consistency of the resource data (gaps in the data)
	A logistic study considering the construction and operation phases
Technology	Restrictions on the selected equipment
	Track records of the selected technology
Budget	Availability of local equipment manufacturers
	Minimum wages' suitability for implementation
	Additional sub-charges and fees
	Skilled labor in the country

Table 3.21 : Financial risk factors validated by experts.

Risk Type	Description
Taxation	Custom taxes in the country Availability of the tax exemptions
Financial	Sufficient market structure for electricity transaction Availability of electricity spot market Inflation risks (Indexation mechanism, frequency of indexation, interest and currency rate coverage) Currency Risk (Available Hedging Instruments, Central Bank Limitations, Devaluations) Country Fiscal Risks (Current Account Deficit, Budgetary deficit, Foreign Reserves, Country Risk Premium, Stable Central Bank Interest Rates
Off-taker	Available purchase support mechanism (FiT, FiP, Green Certificate etc.) Bankability of the off-taker to make related payments Security provided by off-taker (Sovereign Guarantee, Letter of Credits) Availability of Take-or-Pay mechanism

Table 3.22 : Legal risk factors validated by experts.

Risk Type	Description
General	Availability of purchase agreements which creates security Expropriation risks on assets Availability of contractual agreements
Agreements	Effective dispute resolution mechanisms in the country Sufficient items in government side contractors (Force Majeure, Default Risks, Carrying Cost Mechanism) Risk of change-in-law Availability of delayed payment mechanism Termination procedures with respect to PPA

Table 3.23 : Regulatory risk factors validated by experts.

Risk Type	Description
Development Stage	Availability of Project Obtaining Mechanism (Tender, Bilateral Discussion) The requirement of the feasibility, grid and environmental studies The transparent structure on the permitting and obtaining mechanisms
Construction Stage	Requirement on the permits and licensing procedures Security of the construction area (terror zone) Environmental conditions
Operation Stage	Additional fees on tariff or transmission/distribution electricity (possibility of change of laws) Unavailability of a compensation mechanism for curtailment

Table 3.24 : Country risk factors validated by experts.

Risk Type	Description
Country Risks	Demand/Supply side inconsistencies in the region Political Risks (Corruption, Fraud, Stability) Unavailability of independent market regulation Availability of local or regional financial institutions Restrictions on the financial instruments Limitation on Step-in rights in the country National targets of the country

Table 3.25 : Environmental and social risk factors validated by experts.

Risk Type	Description
Country Risks	Availability of carbon markets for further development of social and environmental projects Social Acceptance Risk by the local community Cultural or Historical Heritage in the region Health and Safety Issues Implementation of Environmental and Social Regulations of International Lenders

Considering the defined risks in the literature reviews and expert interviews, risk factors that will be evaluated under the System Dynamics Approach are presented in table 3.26. The definitions of all these risks were shared in previous sections.

Table 3.26 : Final risk factors on RES investments.

Risk Type		Description
Technical Risks	1	Design of the Power Plant
	2	Geology of the site
	3	Available Resource Data
	4	Technology Selection
	5	Aged Grid Infrastructure and Capacity
	6	Unqualified Labor and Application Mistakes
	7	Curtailment
	8	Business Interruption
	9	Land Access
	10	Planning Risk
	11	Property and Asset Damage
	12	Warranty
	13	Logistic
	14	Budget Overruns
Policy Risks	15	National Targets
	16	Permitting and Licensing Procedures
	17	Market Design and Regulation
	18	PPA Counterparty
	19	Expropriation of asset
	20	Available Legal Mechanism
	21	Sudden change in law
	22	Subsidy Payment Scheme
	23	Policy Design Risk
Market Risks	24	Financing Resources
	25	Electricity Price Volatility
	26	Resource Volatility
	27	Financial Instruments
	28	Economic Status of Country
	29	Indexation Mechanism
	30	Inflation
	31	Exchange and Interest Rate
	32	Credit Risk of Suppliers
	33	Management Team
	34	Expertise of the sector
Environmental and Social Risks	35	Weather Conditions
	36	Environmental and Social Regulations
	37	Social Acceptance
	38	Land Acquisition
	39	Natural Hazards
	40	Health and Safety

3.3 Interaction among the Chosen Risk Factors

The employees of one private energy company investing in the renewable energy sector were interviewed for brainstorming and Nominal Group Technique study. It was decided that a team of six people would be suitable for the communication, sharing of information and free expression of the participants. The selected team of six people comes from different fields of the sector. Infrastructure for the System Dynamics Approach will be prepared by conducting studies in order to evaluate the relationship between the determined risk factors. Brainstorming and nominal group technique studies were conducted with a team of six. Brainstorming and nominal group technique studies and the purpose of techniques were explained to the participants. Hence, the results of the previous stage and the detailed description of the risk factors are shared with the participants. As a result, participants interpreted the relationships between the related risk factors and revealed the relevant links. During this study, the relationship between the sub-risk factors and effects on main risk groups were interpreted in table 3.27, and S.R means effect of sub-risk factor on other sub-risk factor.

Table 3.27 : Interaction of risk factors on RES investments.

Risk Type	S.No*	Description	S.R*
Technical Risks	1	Design of the Power Plant	7,10,11,14,24
	2	Geology of the site	39, 26
	3	Available Resource Data	-
	4	Technology Selection	1, 32
	5	Aged Grid Infrastructure and Capacity	25
	6	Unqualified Labor&Application Mistakes	34,40
	7	Curtailment	18
	8	Business Interruption	20,24
	9	Land Access	-
	10	Planning Risk	14
	11	Property and Asset Damage	-
	12	Warranty	1
	13	Logistic	8, 14
	14	Budget Overruns	33
Policy Risks	15	National Targets	28
	16	Permitting and Licensing Procedures	-
	17	Market Design and Regulation	25
	18	PPA Counterparty	24
	19	Expropriation of asset	-
	20	Available Legal Mechanism	-
	21	Sudden change in law	25
	22	Subsidy Payment Scheme	28

Table 3.27 (cont.) : Interaction of risk factors on RES investments.

Risk Type	S.No*	Description	S.R*
Policy Risks	23	Policy Design Risk	36, 16
Market Risks	24	Financing Resources	4
	25	Electricity Price Volatility	18
	26	Resource Volatility	7
	27	Financial Instruments	-
	28	Economic Status of Country	15, 23
	29	Indexation Mechanism	-
	30	Inflation	-
	31	Exchange and Interest Rate	24
	32	Credit Risk of Suppliers	1
	33	Management Team	-
	34	Expertise of the sector	1, 4
Environmental and Social Risks	35	Weather Conditions	25, 26
	36	Environmental and Social Regulations	24, 17
	37	Social Acceptance	8
	38	Land Acquisition	9
	39	Natural Hazards	-
	40	Health and Safety	11

3.4 Application of Delphi Methodology

In this section, the identified risks will be analyzed and graded considering the case country of Turkey for use in the next section. The two methods used to identify the risk factors and other two methods are used to establish the relations between the two tables and combine them. Following this study, a questionnaire is prepared. The questionnaire form is shared in Appendix A. In the application of the Delphi methodology, tables, where the risks are identified and sorted, consist of category, risk and impact columns. At the bottom of the same survey, there is a separate table to evaluate the interactions among the risks. During the application of the questionnaire, the participants filled in the effect column. In the Impact column, the participant is asked to respond to the impact of the project on the risk factor mentioned in Turkey case considering the YEKDEM mechanism which is a support mechanism established by Republic of Turkey Ministry of Energy and Natural Resources. The participant will express opinion by filling the boxes with numbers from one to five, respectively low to high impact.

In the evaluation of the first Delphi Questionnaire, median approach is used as statistical approach. The median method is based on finding the middle value while separating 50% of the values to the left and 50% to the right in the data. Accordingly, when calculating the median of the results obtained from ten questionnaires, the impact scores of each risk are listed from small to large. The median value was obtained by dividing the sums of the fifth value and the sixth value by two. In mathematical terms,

$$Median\ (x_{1,10}) = \frac{(Fifth\ Value + Sixth\ Value)}{2} \quad (3.1)$$

It is evaluated with the above formula using the participants' impact scoring values. Average calculation of the values could be done with different methods, and mean, median and mode are the most common ones. In this thesis, median is chosen considering data obtained as scores between 1 and 5. In such a set of data, where both very small and very big numbers are absent, median gives a more robust measure excluding the contradiction among the participants. Hence, median is selected with its robustness compared to mode and average.

The questionnaire is applied for two rounds by using the Delphi method. In the application side, participants are asked to score the related risk factors considering the renewable energy investments in Turkey. The values obtained as a result of the first round were evaluated with statistical methods and the participants were asked again to weigh, in the second round. The results obtained in the second round were left to include the ratings of all participants to further evaluation. There statistical result of the first Delphi survey is presented in the table 3.28.

Table 3.28 : Statistical results of the first Delphi survey on risk factors.

Category	Risk	Impact
Technical	Design of the Power Plant	4
	Geology of the site	2
	Available Resource Data	4
	Technology Selection	4
	Aged Grid Infrastructure and Capacity	3
	Unqualified Labor and Application Mistakes	3
	Curtailment	3
	Business Interruption	3.5
	Land Access	2
	Planning Risk	4
	Property and Asset Damage	2
	Warranty	3
	Logistic	2.5
	Budget Overruns	4.5

Table 3.28 (cont.) : Statistical results of the first Delphi survey on risk factors.

Category	Risk	Impact
Policy	National Targets	2.5
	Permitting and Licensing Procedures	4
	Market Design and Regulation	3.5
	PPA Counterparty	4
	Expropriation of asset	2
	Available Legal Mechanism	2.5
	Sudden change in law	4
	Subsidy Payment Scheme	4
	Policy Design Risk	3
Market	Financing Resources	4
	Electricity Price Volatility	3.5
	Resource Volatility	4
	Financial Instruments	2.5
	Economic Status of Country	5
	Indexation Mechanism	2.5
	Inflation	3
	Exchange and Interest Rate	4
	Credit Risk of Suppliers	3
	Management Team	4
	Expertise of the sector	2.5
Environmental and Social	Weather Conditions	3
	Environmental and Social Regulations	3
	Social Acceptance	3
	Land Acquisition	2.5
	Natural Hazards	2
	Health and Safety	3.5

In the result of first survey, participants are mainly focuses on the design of power plant, available resource data, technology selection, planning risk and budget overruns on the technical side. In the policy side, permitting, power purchase agreement counterparty, subsidies and sudden change in law are decided as more prevalent. Participants scored the impact of financing resources, resource volatility, exchange and interest rate and management team in high values compared to other factors. Furthermore, economic status of the country is the most important one among all other risk factors. In the table 3.29, interaction impact scores are presented.

Table 3.29 : Statistical results of the first Delphi survey on interactions among risk factors.

No	Sub-Risk		Affected Risk	Median
1	Design of the Power Plant	→	Curtailment	4
2	Design of the Power Plant	→	Planning Risk	2
3	Design of the Power Plant	→	Property and Asset Damage	4
4	Design of the Power Plant	→	Budget Overruns	3.5
5	Design of the Power Plant	→	Financing Resources	2
6	Geology of the site	→	Resource Volatility	3
7	Geology of the site	→	Natural Hazards	2.5
8	Technology Selection	→	Design of the Power Plant	2
9	Technology Selection	→	Credit Risk of Suppliers	3
10	Aged Grid Infrastructure and Capacity	→	Electricity Price Volatility	4
11	Unqualified Labor and Application Mistakes	→	Expertise of the sector	1.5
12	Unqualified Labor and Application Mistakes	→	Health and Safety	3.5
13	Curtailment	→	PPA Counterparty	2.5
14	Business Interruption	→	Available Legal Mechanism	3
15	Business Interruption	→	Financing Resources	3
16	Planning Risk	→	Budget Overruns	3
17	Warranty	→	Design of the Power Plant	3.5
18	Logistic	→	Business Interruption	3
19	Logistic	→	Budget Overruns	3.5
20	Budget Overruns	→	Management Team	3.5
21	National Targets	→	Economic Status of Country	3
22	Market Design and Regulation	→	Electricity Price Volatility	4
23	PPA Counterparty	→	Financing Resources	3
24	Sudden change in law	→	Electricity Price Volatility	1
25	Subsidy Payment Scheme	→	Economic Status of Country	3
26	Policy Design Risk	→	Environmental and Social Regulations	2
27	Policy Design Risk	→	Permitting and Licensing Procedures	4
28	Financing Resources	→	Technology Selection	2
29	Electricity Price Volatility	→	PPA Counterparty	3
30	Resource Volatility	→	Curtailment	2.5
31	Economic Status of Country	→	National Targets	4
32	Economic Status of Country	→	Policy Design Risk	2.5
33	Exchange and Interest Rate	→	Financing Resources	4.5
34	Credit Risk of Suppliers	→	Design of the Power Plant	4
35	Expertise of the sector	→	Design of the Power Plant	2

Table 3.29 (cont.) : Statistical results of the first Delphi survey on interactions among risk factors.

No	Sub-Risk		Affected Risk	Median
36	Expertise of the sector	→	Technology Selection	3
37	Weather Conditions	→	Electricity Price Volatility	3
38	Weather Conditions	→	Resource Volatility	2
39	Environmental and Social Regulations	→	Financing Resources	4
40	Environmental and Social Regulations	→	Market Design and Regulation	3
41	Social Acceptance	→	Business Interruption	3
42	Land Acquisition	→	Land Access	3.5
43	Health and Safety	→	Property and Asset Damage	3

The second Delphi Survey is the same as the first survey. Example of the second Delphi survey is given below; the whole questionnaire is given in Appendix B. The second Delphi questionnaire was delivered to the participants with median results. Participants are required to review their decision to compare the answers to the first survey with the median values of the group in the second survey. The questionnaires were applied within this framework. The responses will be used in the system dynamics model construction. In the Appendix C, scores of survey participants on the risk factors are shared for each participant. Also, application results of the interaction among the risk factors are shared in the Appendix C.

4. SYSTEM DYNAMICS EVALUATION OF RISK FACTORS

Research on evaluation of RES risk factors are either limited to one resource (wind, hydro etc.) or to one group of functions (Finance, Economic, Politics or Market etc.) there are a limited number of resources for examining these risks over the project life cycle. The thesis aims to examine possible risk factors that may occur during the entire investment life-cycle by grouping risk factors, and the dynamic interactions of these risks with each other. The critical point for the system dynamics model to be created is to reveal the system limits of the system to be examined. For this purpose, risk factors that scored with the Delphi Method which will represent the limits of the system dynamics model.

In the mathematical model, the entropy method is applied on the results of the second Delphi Questionnaire. Then, mathematical expressions are entered to Vensim software to construct the System Dynamics model. Vensim is a simulation software which is developed by Ventana Systems. Models can be done with the help of graphical or text editor by it using stock and flow, and casual loop diagrams.

4.1 Mathematical Modeling of the Risk Factors

Entropy is a noteworthy concept applied in physics, knowledge theory and mathematics. Rudolph developed the beginning of entropy in 1865 in the field of thermodynamics, and in 1948 Claude E. Shannon developed the concept of knowledge entropy. In information theory, entropy is a measure of uncertainty associated with a random variable (Zhang et al., 2011). Entropy method is an objective evaluation method because it calculates the criteria weight by considering the data without revealing the subjective judgments of decision makers such as Delphi techniques in determining the importance level of the criteria without creating a hierarchical structure (Cakır & Percin, 2013).

In the application of the entropy method, binary logarithm is also used methodology with the natural logarithm as alternative notations. In the application for the below methodology, entropy of the factor does not create difference among factors using both natural logarithm and binary logarithm. Then, natural logarithm is selected due to wide usage.

When applied using the equation 4.1, f_{in} means the i_{th} expert scored n_{th} factor, q_i the ratio of the score to the sum of scores which is used for the next step evaluation. Formulation is given below,

$$q_i = \frac{f_{in}}{\sum_{n=1}^{10} f_{in}} \tag{4.1}$$

Entropy of the factor n is k_n:

$$k_n = -\left(\frac{1}{\ln(i)}\right) * \sum_{i=1}^{10} q_i * lnq_i \tag{4.2}$$

x_n is the coefficient of difference of factor f_{in}, and g_n is the weight of factor:

$$x_n = |1 - k_n| \tag{4.3}$$

$$g_n = \frac{x_n}{\sum_{n=1}^{43} x_n} \tag{4.4}$$

After applying entropy on second Delphi questionnaire, the results are achieved as in Table 4.1 for the weight of risk factors in RES Investments.

Table 4.1 : Entropy method to determine the weight of risk factors.

No	Risk	x_n	g_n
1	Design of the Power Plant	0.004	0.013
2	Geology of the site	0.027	0.077
3	Available Resource Data	0.003	0.008
4	Technology Selection	0.007	0.020
5	Aged Grid Infrastructure and Capacity	0.008	0.022
6	Unqualified Labor and Application Mistakes	0.016	0.046
7	Curtailment	0.010	0.028
8	Business Interruption	0.007	0.020
9	Land Access	0.030	0.085
10	Planning Risk	0.004	0.012
11	Property and Asset Damage	0.011	0.032
12	Warranty	0.003	0.009
13	Logistic	0.009	0.025
14	Budget Overruns	0.003	0.007
15	National Targets	0.009	0.025
16	Permitting and Licensing Procedures	0.004	0.011
17	Market Design and Regulation	0.004	0.013

Table 4.1 (cont.) : Entropy method to determine the weight of risk factors.

No	Risk	x_n	g_n
18	PPA Counterparty	0.002	0.007
19	Expropriation of asset	0.018	0.052
20	Available Legal Mechanism	0.014	0.038
21	Sudden change in law	0.005	0.015
22	Subsidy Payment Scheme	0.004	0.012
23	Policy Design Risk	0.003	0.007
24	Financing Resources	0.002	0.005
25	Electricity Price Volatility	0.004	0.012
26	Resource Volatility	0.007	0.020
27	Financial Instruments	0.009	0.025
28	Economic Status of Country	0.003	0.007
29	Indexation Mechanism	0.009	0.025
30	Inflation	0.007	0.019
31	Exchange and Interest Rate	0.004	0.012
32	Credit Risk of Suppliers	0.004	0.012
33	Management Team	0.003	0.010
34	Expertise of the sector	0.009	0.025
35	Weather Conditions	0.008	0.022
36	Environmental and Social Regulations	0.018	0.052
37	Social Acceptance	0.010	0.028
38	Land Acquisition	0.018	0.049
39	Natural Hazards	0.026	0.072
40	Health and Safety	0.009	0.025

In Table 4.2, weights of risk factors, and interactions are presented. y_n and t_n are coefficients of difference and weight factors, respectively.

Table 4.2 : Entropy method to determine the weight of risk factors.

No	Sub-Risk		Affected Risk	y_n	t_n
1	Design of the Power Plant	→	Curtailment	0.012	0.023
2	Design of the Power Plant	→	Planning Risk	0.015	0.027
3	Design of the Power Plant	→	Property and Asset Damage	0.017	0.032
4	Design of the Power Plant	→	Budget Overruns	0.015	0.027
5	Design of the Power Plant	→	Financing Resources	0.004	0.007
6	Geology of the site	→	Resource Volatility	0.013	0.024
7	Geology of the site	→	Natural Hazards	0.018	0.033
8	Technology Selection	→	Design of the Power Plant	0.000	0.000
9	Technology Selection	→	Credit Risk of Suppliers	0.010	0.018
10	Aged Grid Infrastructure and Capacity	→	Electricity Price Volatility	0.007	0.014
11	Unqualified Labor and Application Mistakes	→	Expertise of the sector	0.030	0.055
12	Unqualified Labor and Application Mistakes	→	Health and Safety	0.016	0.030

Table 4.2 (cont.) : Entropy method to determine the weight of risk factors.

No	Sub-Risk		Affected Risk	y_n	t_n
13	Curtailment	→	PPA Counterparty	0.015	0.027
14	Business Interruption	→	Available Legal Mechanism	0.007	0.012
15	Business Interruption	→	Financing Resources	0.011	0.021
16	Planning Risk	→	Budget Overruns	0.003	0.006
17	Warranty	→	Design of the Power Plant	0.004	0.008
18	Logistic	→	Business Interruption	0.010	0.018
19	Logistic	→	Budget Overruns	0.009	0.016
20	Budget Overruns	→	Management Team	0.017	0.032
21	National Targets	→	Economic Status of Country	0.003	0.005
22	Market Design and Regulation	→	Electricity Price Volatility	0.008	0.015
23	PPA Counterparty	→	Financing Resources	0.010	0.018
24	Sudden change in law	→	Electricity Price Volatility	0.090	0.167
25	Subsidy Payment Scheme	→	Economic Status of Country	0.008	0.014
26	Policy Design Risk	→	Environmental and Social Regulations	0.015	0.028
27	Policy Design Risk	→	Permitting and Licensing Procedures	0.007	0.014
28	Financing Resources	→	Technology Selection	0.008	0.015
29	Electricity Price Volatility	→	PPA Counterparty	0.007	0.012
30	Resource Volatility	→	Curtailment	0.015	0.029
31	Economic Status of Country	→	National Targets	0.007	0.014
32	Economic Status of Country	→	Policy Design Risk	0.008	0.015
33	Exchange and Interest Rate	→	Financing Resources	0.010	0.019
34	Credit Risk of Suppliers	→	Design of the Power Plant	0.001	0.003
35	Expertise of the sector	→	Design of the Power Plant	0.015	0.027
36	Expertise of the sector	→	Technology Selection	0.007	0.012
37	Weather Conditions	→	Electricity Price Volatility	0.013	0.024
38	Weather Conditions	→	Resource Volatility	0.021	0.038
39	Environmental and Social Regulations	→	Financing Resources	0.003	0.005
40	Environmental and Social Regulations	→	Market Design and Regulation	0.008	0.015
41	Social Acceptance	→	Business Interruption	0.011	0.021
42	Land Acquisition	→	Land Access	0.018	0.033
43	Health and Safety	→	Property and Asset Damage	0.013	0.024

In mathematical analysis of the model, risk in RES investment will consist of the technical, policy, market and environmental/social factors. In the below formulation, this main risk is presented as sum of risk factors with their weights.

$$R_r = R_t * f_t + R_p * f_p + R_m * f_m + R_e * f_e \tag{4.5}$$

Where, R_t, R_p, R_m, R_e and R_r represents technical, policy, market, environmental/social and renewable risks; f_t, f_p, f_m, f_e are the influence weight of technical, policy, market and environmental/social risks. Technical side of the formulation is presented below.

$$R_t = S_1 * g_1 + S_2 * g_2 + S_3 * g_3 + S_4 * g_4 + S_5 * g_5 + S_6 * g_7 + S_8 * g_8 + S_9 * g_9 + S_{10} * g_{10} + S_{11} * g_{11} + S_{12} * g_{12} + S_{13} * g_{13} + S_{14} * g_{14} \tag{4.6}$$

S_1 to S_{14} denote the impact of technical risk factors with respect to main risk table in 4.1. On the other hand, g_1 to g_{14} denote the weight of for the risk factors which is obtained via entropy methodology. Policy side of the formulation is illustrated below.

$$R_p = S_{15} * g_{15} + S_{16} * g_{16} + S_{17} * g_{17} + S_{18} * g_{18} + S_{19} * g_{19} + S_{20} * g_{20} + S_{21} * g_{21} + S_{22} * g_{22} + S_{23} * g_{23} \tag{4.7}$$

S_{15} to S_{23} denote the impact of policy risk factors with respect to main risk table in 4.1. On the other hand, g_{15} to g_{23} denotes the weight of the risk factors. Market side,

$$R_m = S_{24} * g_{24} + S_{25} * g_{25} + S_{26} * g_{26} + S_{27} * g_{27} + S_{28} * g_{28} + S_{29} * g_{29} + S_{30} * g_{30} + S_{31} * g_{31} + S_{32} * g_{32} + S_{33} * g_{33} + S_{34} * g_{34} \tag{4.8}$$

S_{24} to S_{34} denote the impact of market risk factors with respect to main risk table in 4.1. On the other hand, g_{24} to g_{34} denotes the weight of the risk factors. Environmental and social side represented by R_e is again defined as a weighted sum as below:

$$R_e = S_{35} * g_{35} + S_{36} * g_{36} + S_{37} * g_{38} + S_{39} * g_{39} + S_{40} * g_{40} \tag{4.9}$$

Are presented with above formulation with denotation of S_{35} to S_{40} for risk factors and t_1 to t_{43} for weight of the risk factors. In the below formulations, relationship between risk factors will be defined with respect to entropy results of the Table 4.2.

$$P_7 = S_1 * t_1 + S_{26} * t_{30} \tag{4.9}$$

$$P_{10} = S_1 * t_2 \tag{4.10}$$

$$P_{11} = S_1 * t_3 + S_{40} * t_{43} \tag{4.11}$$

$$P_{14} = S_1 * t_4 + S_{10} * t_{16} + S_{13} * t_{19} \tag{4.12}$$

$$P_{24} = S_1 * t_5 + S_8 * t_{15} + S_{18} * t_{23} + S_{31} * t_{33} + S_{36} * t_{39} \tag{4.13}$$

$$P_{26} = S_2 * t_6 + S_{35} * t_{38} \tag{4.14}$$

$$P_{39} = S_2 * t_7 \tag{4.15}$$

$$P_1 = S_4 * t_8 + S_{12} * t_{17} + S_{32} * t_{34} + S_{34} * t_{35} \tag{4.16}$$

$$P_{32} = S_4 * t_9 \tag{4.17}$$

$$P_{25} = S_5 * t_{10} + S_{17} * t_{22} + S_{21} * t_{24} + S_{35} * t_{37} \tag{4.18}$$

$$P_{34} = S_6 * t_{11} \tag{4.19}$$

$$P_{40} = S_6 * t_{12} \tag{4.20}$$

$$P_{18} = S_7 * t_{13} + S_{25} * t_{29} \tag{4.21}$$

$$P_{20} = S_8 * t_{14} \tag{4.22}$$

$$P_8 = S_{13} * t_{18} + S_{37} * t_{41} \tag{4.23}$$

$$P_{33} = S_{14} * t_{20} \tag{4.24}$$

$$P_{28} = S_{15} * t_{21} + S_{22} * t_{25} \tag{4.25}$$

$$P_{36} = S_{23} * t_{26} \tag{4.26}$$

$$P_{16} = S_{23} * t_{27} \tag{4.27}$$

$$P_4 = S_{24} * t_{28} + S_{34} * t_{36} \tag{4.28}$$

$$P_{15} = S_{28} * t_{31} \tag{4.29}$$

$$P_{23} = S_{28} * t_{32} \tag{4.30}$$

$$P_{17} = S_{36} * t_{40} \tag{4.31}$$

$$P_{9} = S_{38} * t_{42} \tag{4.32}$$

In above formulation P denotes to the sub-risk factor effect for the main risk factor. On the other hand, risk is not countable measure in the mathematical terms. Therefore, there is no unit defined for mathematical evaluation. In the model establishment phase, main risk formulation and relationship formulation will be used in the equation side of the System Dynamics Approach.

4.2 Construction of a Feedback Model for System Dynamics

Throughout the RES investment and decision-making period, risk factors identification and analysis of renewable energy investments are performed.

Renewable energy industry is a complex system with dynamic interrelations which requires detailed risk analysis. Besides, RES risk factors have cause and effect relation which can be seen as a closed and complex self-adaptation system. In this context, feedback model will include the technical, policy, market and environmental/social risk factors as main risk categories. Therefore, other sub-group relations will be established to show cause-effect relation in the system. After determining the limits of the system with Delphi Analysis, a systematic feedback model of the RES investment risk factors is established based on the feedback principle of system dynamics theory.

Therefore, other sub-group relations will be established to show cause-effect relation in the system. After determining the limits of the system with Delphi Analysis, a systematic feedback model of the RES investment risk factors is established based on the feedback principle of system dynamics theory.

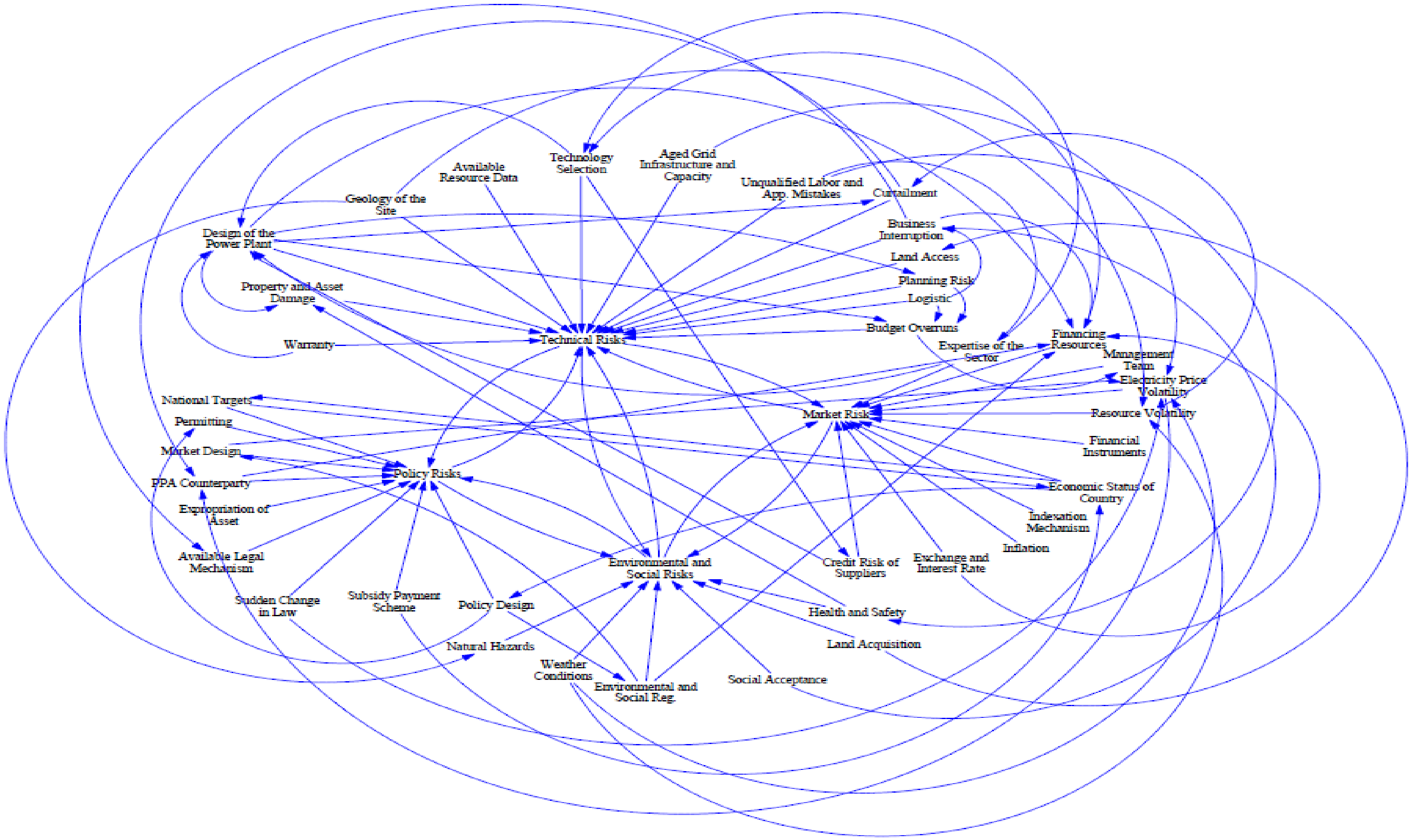

Figure 4.1 : System Dynamics feedback model diagram.

4.3 Risk Dynamics Model for TURKEY

Risk factors are required to estimate and evaluate the identified project's main risk factors for the project risks. The feedback diagram only carries out the application of the risk identification and a flowchart for risk estimation, furthermore risk dynamics model for the evaluation of RES of project risk factors should be established. Therefore, stock-flow model is set up with respect to feedback diagram to integrate the flows, modifying and complicating the dynamics involved. In this regard, model's time frame is set up to 30 years considering the life-cycles of the RES investments. Although hydropower projects have 50 years of operation period, geothermal, wind and solar projects are relatively shorter period of life cycle as 25 years. Also, addition of the project development period to the project life cycle makes 30-year time frame for the risk dynamics model. In the time line, first 6 years are defined for the development and construction period of the RES Investments. Then, remaining period is defined for the operation period of the RES Investment. In the figure 4.2, proposed risk dynamics model is presented.

4.4 Baseline Scenario Simulation

Simulation is run on the system dynamics model for 30 years with the current conditions. In order to validate the results of the simulation, outputs are shared with survey participants for discussion. In return, they approved the achievements of our model for RES investments in Turkey. In the figures, blue section presents the development and construction period, and red section presents the operation period. As mentioned before, the simulation consists of four major risk factors as technical, policy, market and environmental/social, and simulation results are shared in figures of 4.3 and 4.4. After ten-year period, RES Investment risk continue in stable characteristic, then, it is shared for first ten years.

In Figure 4.3, RES Investment risk factors are slightly increasing until the beginning of construction period, and significant decrease occurs with the finalization of the construction. However, accrued risk at the start of the construction period is important for the sector participants for further evaluation. It is also observed that the radical changes on all four groups are getting smoother after the tenth year.

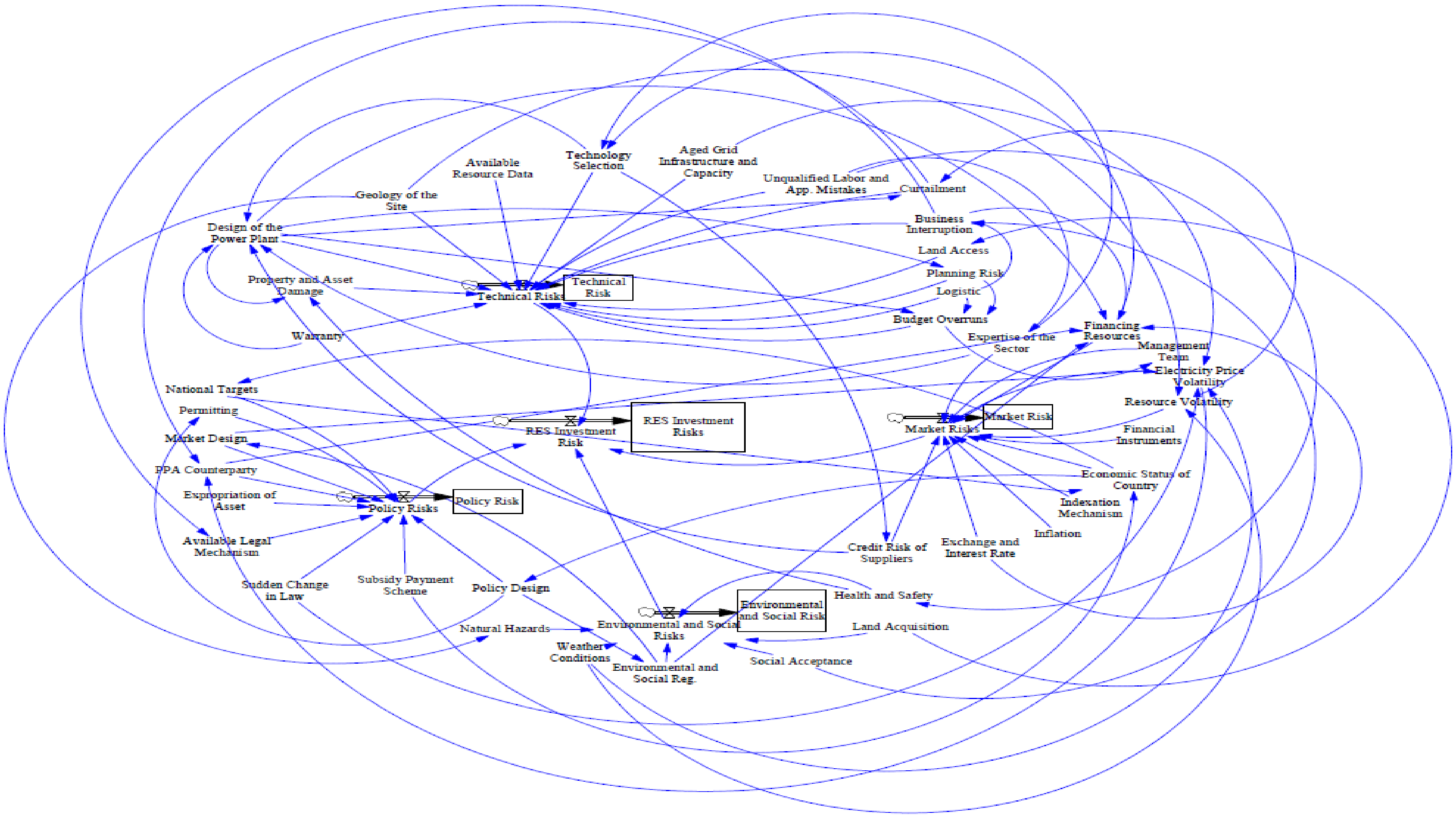

Figure 4.2 : Risk dynamics model.

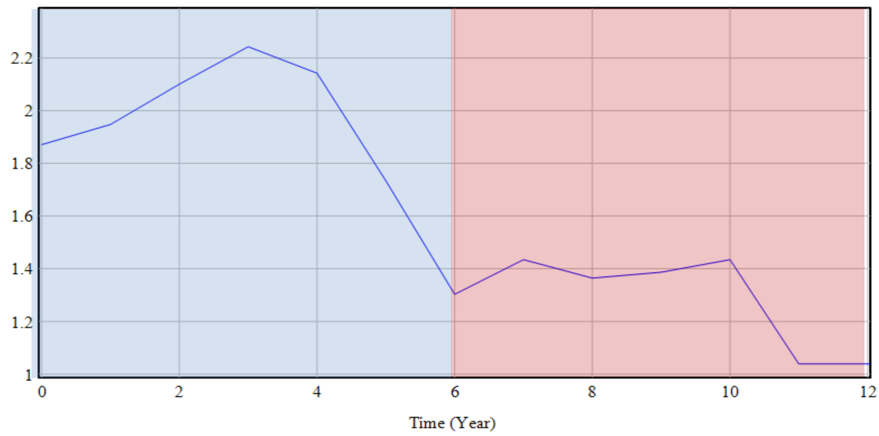

Figure 4.3 : RES investments risk – baseline scenario.

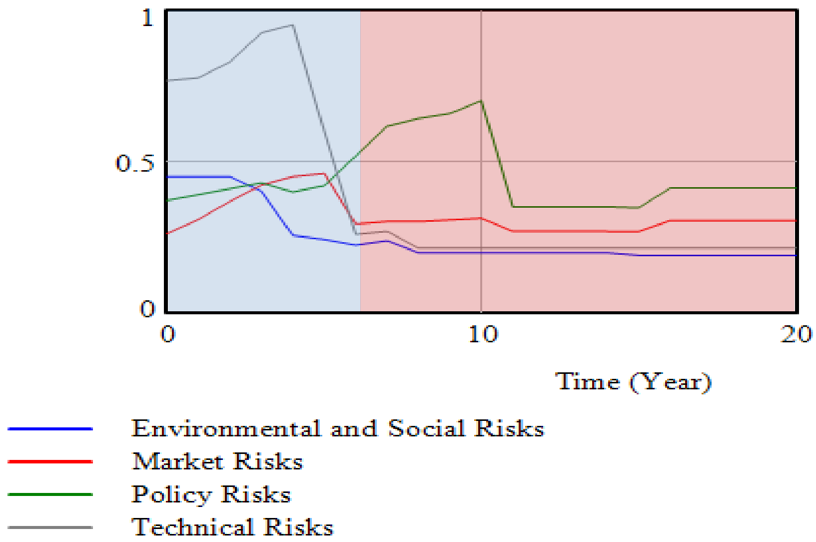

Figure 4.4 : Main risk factors - baseline scenario.

In the fig 4.4, impact of the technical risk factors dominated the investment when compared with other main risk factor groups in the early stage of the investment. Main risk factors on the figure show stable characteristic after 15 years, however, graph is presented for 20 years considering the possible effects of bathtub curve of wind turbines and solar panels which are related with the failure of the technologies with aging. On the one hand, design and technology selection for investment has significant effect on the investment which cause the peak of technical risks, on the other hand, expertise of the sector is another important parameter for technical risk factors. After the construction period, policy risk factors start to increase due to possibility of the sudden change in law and power purchase agreement (PPA) counterparty risk factors considering the possible effects on the large scale of RES investments. After the peak, policy risk factors slightly decrease, still maintains its importance until the end of the period. For the financing side of the project, market risk factors are slightly increasing. Besides, electricity price and resource volatility present their impact on the market risk factors during the operation period inside the data collected by model. In addition, environmental risks have crucial importance on the very early side of the investment as it can be seen in the figure. However, according to the experts interviewed, environmental impact is relatively insignificant compared with the other risk factors during the operation period of the investment. These risk factors can be reduced to a certain degree with the proper policy design, market structure, experience in the market and other type of instruments like insurance.

4.5 Scenario Analysis

In this section important sub-risk factors will be evaluated in correspondence with the main risk factors based on different scenarios. Besides, their relation with other affected main risk factor will be presented to show the effect of the related sub-risk factor. In this regard, comprehensive evaluation of the important RES investment risk factors will be analyzed. Design of the Power Plant, Economic Status of the Country and Policy Design sub-risk factors are selected for further scenario analysis. Because, effects of those sub-risk factors on the RES investments and their relation among other risk factors become prominent in the Delphi questionnaires among the participants compared with others.

In the consideration of the base scenario analysis, technical risk factor is observed to have the biggest impact in the construction phase. Therefore, Design of the Power Plant as sub-risk is selected for further scenario analysis. Additional analysis is held for the Market Risk based on design. In the figures of 4.5 and 4.6, scenario analysis for technical and market risks are presented respectively.

Best and worst case scenarios are defined for the sub-risk values analyzed. In the rapid development of RES investment, new technologies and applications are presented in the market which requires adequate design parameters for this kind of complex structures. In view of the figure 4.5, design of the power plant proves the significance for the RES investment with the difference in the peak point and how technical risk affected in the change of design parameter. After the development and construction period, design of power plant shows small effect in the first years of operation, then it converges till end of operation.

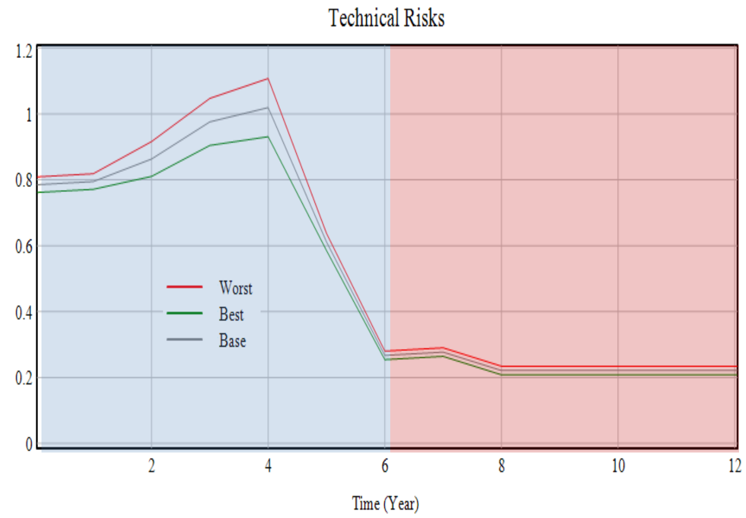

Figure 4.5 : Technical risks scenario - design of power plant.

On the other hand, design of the power plant creates pressure for the market risk of RES investment especially in the construction period and early stages of operation period. However, Design of the power plant does not have effect on the late phases of the investment. Both in technical and market side, it converges after first years of operation period as the probability of failure occurrence is commonly in the first years. After that, it does not have great importance with the track record it caught during the first years of the operation; however, it should also be considered that bathtub effects of solar and wind energy plants are excluded in this analysis.

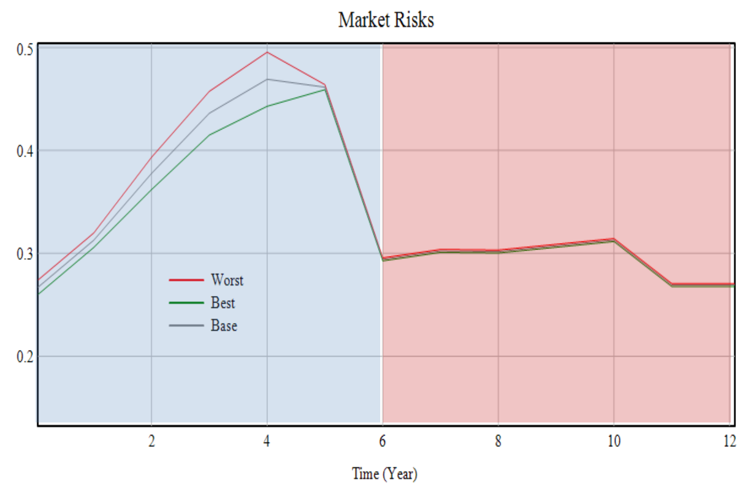

Figure 4.6 : Market risks scenario - design of power plant.

In the second scenario, Economic Status of the Country is evaluated within the Market Risks. Its relation with policy sub-factors brings the necessity of the evaluation of the Policy Risks. Results are presented in the figures of 4.7 and 4.8 for Market and Policy Risks respectively.

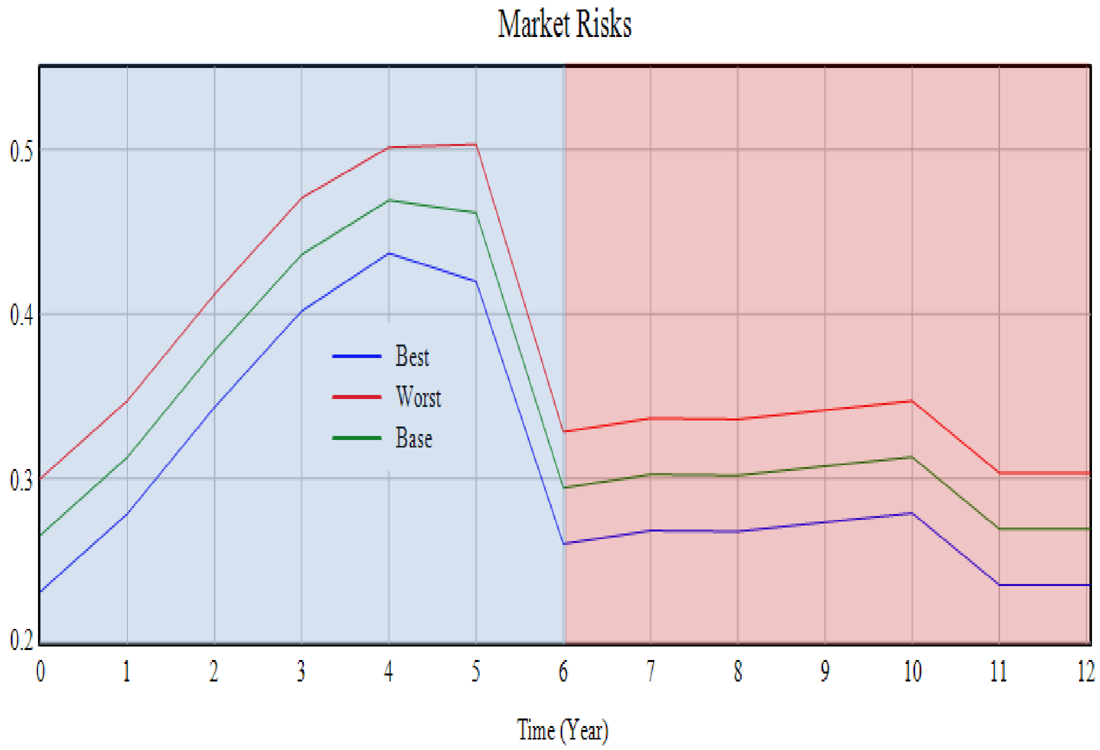

Figure 4.7 : Market risks scenario - economic status.

Within the market risks, economic status of the country shows its effect on the development, construction and operation sides of the investment. During the operation period, investment presents the same pattern, however risk range between the scenarios illustrate the importance of the Economic status of the country. Thus, difference between the best and worst case scenarios show its impact during the whole life cycle. In the baseline scenario, it is known that policy risk is major factor during the operation period. In the analysis side of the economic status, policy risks are affected mostly during the development and construction side, however it converges after maturity in the operation. On the other hand, it shows the strong relation between the economic status of the country and policy risks till the tenth year of the whole life cycle. Based on this background, it modeled that national target and policy design will be highly affected by the increase in the economic status of the country sub-risk. In the fig 4.8, results of the simulation are presented.

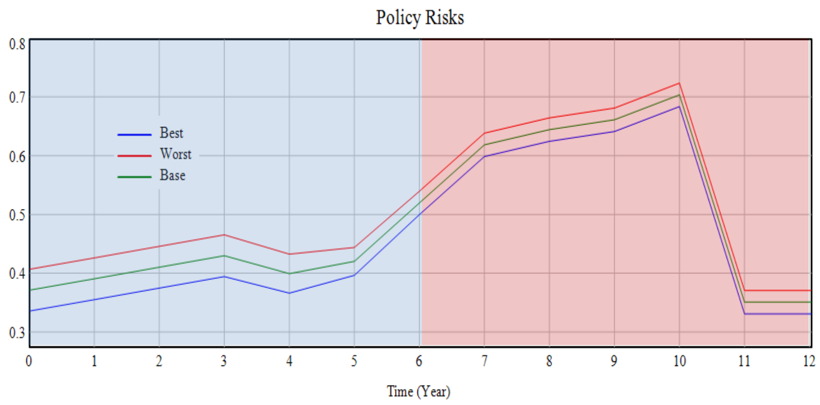

Figure 4.8 : Policy risks scenario - economic status of country.

In the policy risk scenario, policy design is selected amongst the other variable sub-risk factors due to its relation with other main risk factors and its effect on the policy risk side. Then, policy, market and environmental/social main risk factors is evaluated with respect to policy design.

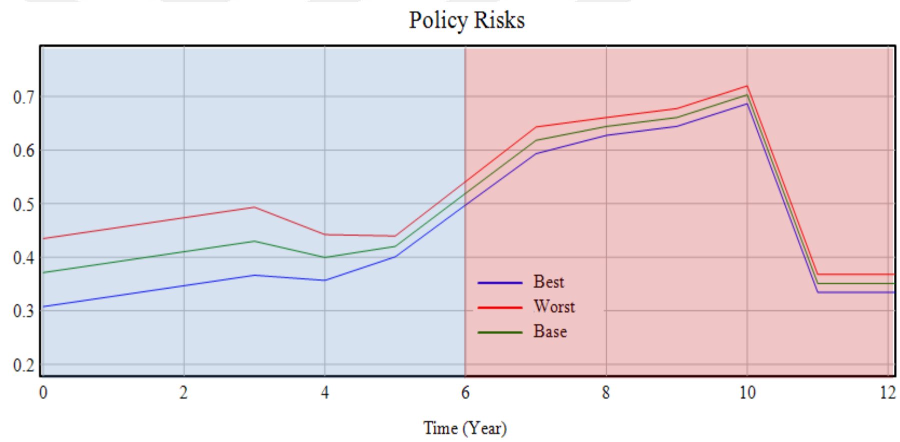

Figure 4.9 : Policy risks scenario - policy design.

In the policy design scenario analysis in figure 4.9, difference between the scenarios could be seen in the early phases of the project life cycle due to its significance in the project development period, and its affect show its presence in the construction period too. On the other hand, policy design of the RES investments could not create greater impact in the late phases of the operation period. Main increase of the policy risks during the early operation period could be caused by the sub-risk factors of sudden change in law and issues with regard to PPA counterparty. Considering the maturity phases of the operation which have stable characteristics, it starts to converge after the eleventh year of the life cycle.

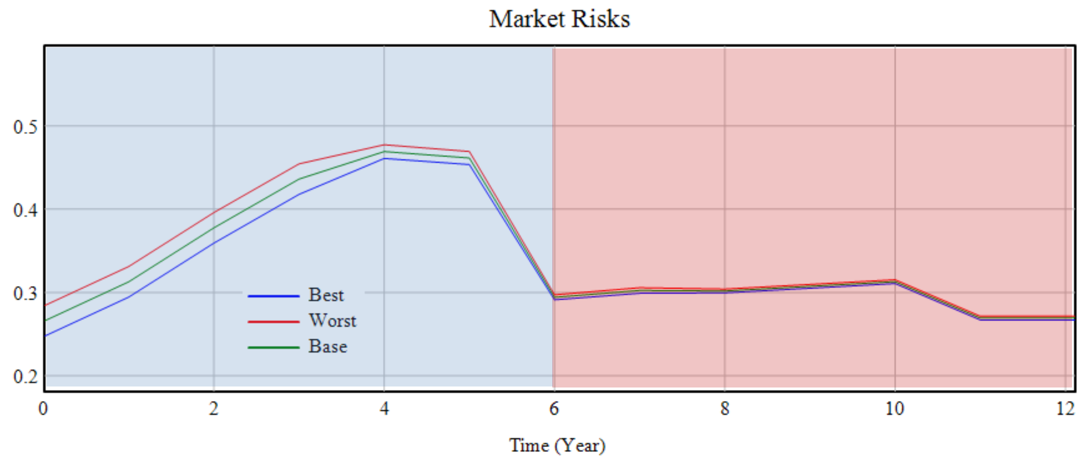

Figure 4.10 : Market risks scenario - policy design.

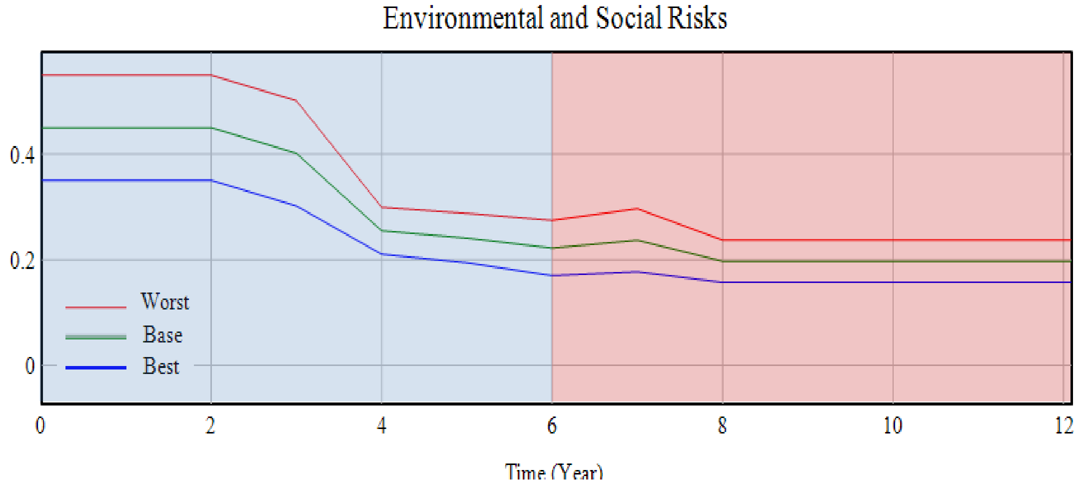

Figure 4.11 : Environmental and social risks scenario - policy design.

In the figure 4.10, markets risks are evaluated under the change of the policy design sub-risk factor. Besides, policy design affects the market side of the RES investment in the business development and construction period. It is caused by early implementation of the RES investment directly impacted by the policy design due to response of financing resources against inadequate policies. On the environmental social side, effects of the policy design show its presence in the implementation period, however it preserves its effects during the whole period, and difference is not considered a lot. In this context, risks in policy design could lead to severe damage on the environmental and social side of the RES investment. In this scenario analyses, selected sub-risk factors have impact on the development and construction period or first years of the operation period. After some period, all of the risk factors start to converges while losing their effects on the RES investment.

5. CONCLUSION

Risk management is an important issue in RES investments, while renewable energy investments are complex in nature because of covering many processes, and because of considerable amount of inter-linked parameters. Any neglected risk during the evaluation phase leads to unexpected losses and delays. Hence, risk evaluation aims to control the possible effects of risks and to prevent the negative effects as much as possible. Initial step in any risk assessment study is to identify risk factors. After that, it is necessary to rank them and to carry out risk behavior activities in line with the determined objectives. The risk assessment process is a continuous process, where risk monitoring is to be realized throughout the project life cycle, and interactions are to be evaluated during different stages.

In this thesis, all the afore studied risk factors are encountered for renewable energy system investments and interactions of the risk factors were identified before the project risk assessment process was started. Assessment uses a System Dynamics after having analyzed several mathematical modeling methods. Delphi and entropy methods were used in risk identification and interaction processes in parallel with the literature survey. Subsequent to the determination of risk factors, the framework for mathematical model was prepared. The location based survey allowed the evaluation of risks by different sector participants, with a case study in Turkey. The data obtained is used in setting up the mathematical background for the system dynamics approach using entropy method. In this context, model is designed to create a structure in which renewable energy investment players see the interaction between risk factors through a specific period of project life-cycle. This research is original in combining technical, political, social and environmental risk factors with interactions for all renewable resources.

Results achieved by using the system dynamics model in simulation, the interaction of the risks in the renewable energy system investments occur extensively. This approves the idea of combining them in a single analysis. The results also show that technical risk factors would be more effective in business development and construction periods of the project, but political risks were in the foreground during the operation period. The sub-risk factors such as design of power plant, policy design and the economic status of the country were analyzed by applying three scenarios. Case study for Turkey shows that economic status and policy design have crucial impact on the further development of the renewable energy investments.

This thesis provides a model that could evaluate the geothermal, solar, wind and hydroelectric power plant investments in one group. The fact that investments are examined in terms of political, market, technical, environmental and social terms, empower the investment participants. Monitoring the impact of a single risk factor on the whole system does not allow companies to make long-term and strategic investment planning in real-life.

In the future studies, sub-categories can be selected and implemented as a combined model. It is recommended to compare the results of combined project approach with the single energy type investments. Other methods like Fuzzy Inference sets can also be investigated and compared with the results achieved in this thesis. It is recommended to create a model for 50 years, lifecycle of Hydro-plant investments but considering the renewals of wind, solar and geo-thermal energy with reinvestments. As a further analysis for the thesis, consideration of established YEKA support mechanism could be examined with the YEKDEM mechanism or separately.

This study will be a guide not only for investors in Turkey, but for all participants of the RES market.

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APPENDICES

APPENDIX A

First Delphi Survey

08.03.2019

Dear Participant,

The attached questionnaire was established within the scope of the thesis study named "ASSESS AND EVALUATE RISKS OF RES INVESTMENT USING SYSTEM DYNAMICS APPROACH" in the Master Program of Energy Science and Technology Programme of Istanbul Technical University.

This questionnaire is applied to experts who have knowledge and experience on the subject and will be used during the analysis of the risks identified in renewable energy systems investments and their relationship with each other. The personal information given in this context will be used within the scope of the mentioned academic study and will be evaluated by observing the privacy principles.

The contribution you make to this survey is very important for the success of the study. Thank you in advance for your time.

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Survey Information

The risks are listed according to the categories in the questionnaire. During the filling of the questionnaire, the participants are asked to score the impact each risk and their relationship in the tables with regard to RES investment considering the case country of Turkey.

During scoring in the Impact column,
(1) Very Light
(2) Lightweight
(3) Moderate
(4) Serious
(5) Very serious
Above points will have the meaning as described.

Please evaluate the impact of the risks and their relationships by using the scoring system above given on the next page tables.

Table A.1 : Risk impact survey.

Category	Risk	Impact
Technical	Design of the Power Plant	
	Geology of the site	
	Available Resource Data	
	Technology Selection	
	Aged Grid Infrastructure and Capacity	
	Unqualified Labor and Application Mistakes	
	Curtailment	
	Business Interruption	
	Land Access	
	Planning Risk	
	Property and Asset Damage	
	Warranty	
	Logistic	
	Budget Overruns	
Policy	National Targets	
	Permitting and Licensing Procedures	
	Market Design and Regulation	
	PPA Counterparty	
	Expropriation of asset	
	Available Legal Mechanism	
	Sudden change in law	
	Subsidy Payment Scheme	
	Policy Design Risk	
Market	Financing Resources	
	Electricity Price Volatility	
	Resource Volatility	
	Financial Instruments	
	Economic Status of Country	
	Indexation Mechanism	
	Inflation	
	Exchange and Interest Rate	
	Credit Risk of Suppliers	
	Management Team	
	Expertise of the sector	
Environmental and Social	Weather Conditions	
	Environmental and Social Regulations	
	Social Acceptance	
	Land Acquisition	
	Natural Hazards	
	Health and Safety	

Table A.2 : Risk interaction impact survey.

No	Sub-Risk		Affected Risk	Median
1	Design of the Power Plant	→	Curtailment	
2	Design of the Power Plant	→	Planning Risk	
3	Design of the Power Plant	→	Property and Asset Damage	
4	Design of the Power Plant	→	Budget Overruns	
5	Design of the Power Plant	→	Financing Resources	
6	Geology of the site	→	Resource Volatility	
7	Geology of the site	→	Natural Hazards	
8	Technology Selection	→	Design of the Power Plant	
9	Technology Selection	→	Credit Risk of Suppliers	
10	Aged Grid Infra. and Cap.	→	Electricity Price Volatility	
11	Unqualified Labor and Application Mistakes	→	Expertise of the sector	
12	Unqualified Labor and Application Mistakes	→	Health and Safety	
13	Curtailment	→	PPA Counterparty	
14	Business Interruption	→	Available Legal Mechanism	
15	Business Interruption	→	Financing Resources	
16	Planning Risk	→	Budget Overruns	
17	Warranty	→	Design of the Power Plant	
18	Logistic	→	Business Interruption	
19	Logistic	→	Budget Overruns	
20	Budget Overruns	→	Management Team	
21	National Targets	→	Economic Status of Country	
22	Market Design and Regulation	→	Electricity Price Volatility	
23	PPA Counterparty	→	Financing Resources	
24	Sudden change in law	→	Electricity Price Volatility	
25	Subsidy Payment Scheme	→	Economic Status of Country	
26	Policy Design Risk	→	Env. and Social Reg.	
27	Policy Design Risk	→	Permitting and Licensing	
28	Financing Resources	→	Technology Selection	
29	Electricity Price Volatility	→	PPA Counterparty	
30	Resource Volatility	→	Curtailment	
31	Economic Status of Country	→	National Targets	
32	Economic Status of Country	→	Policy Design Risk	
33	Exchange and Interest Rate	→	Financing Resources	
34	Credit Risk of Suppliers	→	Design of the Power Plant	
35	Expertise of the sector	→	Design of the Power Plant	
36	Expertise of the sector	→	Technology Selection	
37	Weather Conditions	→	Electricity Price Volatility	
38	Weather Conditions	→	Resource Volatility	
39	Env. and Social Reg.	→	Financing Resources	
40	Env. and Social Reg.	→	Market Design and Regulation	
41	Social Acceptance	→	Business Interruption	
42	Land Acquisition	→	Land Access	
43	Health and Safety	→	Property and Asset Damage	

APPENDIX B

Second Delphi Survey Form

17.03.2019

Dear Participant,

The attached questionnaire was the second part of the applied questionnaire within the scope of the thesis study named “ASSESS AND EVALUATE RISKS OF RES INVESTMENT USING SYSTEM DYNAMICS APPROACH” in the Master Program of Energy Science and Technology Programme of Istanbul Technical University. In the second Delphi survey you are expected to review your answers to the first survey.

The personal information given in this context will be used within the scope of the mentioned academic study and will be evaluated by observing the privacy principles. The contribution you make to this survey is very important for the success of the study. Thank you in advance for your time.

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Table B.1 : Risk impact second survey.

Category	Risk	Median	Impact
Technical	Design of the Power Plant	4	
	Geology of the site	2	
	Available Resource Data	4	
	Technology Selection	4	
	Aged Grid Infrastructure and Capacity	3	
	Unqualified Labor and Application Mistakes	3	
	Curtailment	3	
	Business Interruption	3.5	
	Land Access	2	
	Planning Risk	4	
	Property and Asset Damage	2	
	Warranty	3	
	Logistic	2.5	
	Budget Overruns	4.5	
Policy	National Targets	2.5	
	Permitting and Licensing Procedures	4	
	Market Design and Regulation	3.5	
	PPA Counterparty	4	
	Expropriation of asset	2	
	Available Legal Mechanism	2.5	
	Sudden change in law	4	
	Subsidy Payment Scheme	4	
	Policy Design Risk	3	
Market	Financing Resources	4	
	Electricity Price Volatility	3.5	
	Resource Volatility	4	
	Financial Instruments	2.5	
	Economic Status of Country	5	
	Indexation Mechanism	2.5	
	Inflation	3	
	Exchange and Interest Rate	4	
	Credit Risk of Suppliers	3	
	Management Team	4	
	Expertise of the sector	2.5	
Environmental and Social	Weather Conditions	3	
	Environmental and Social Regulations	3	
	Social Acceptance	3	
	Land Acquisition	2.5	
	Natural Hazards	2	
	Health and Safety	3.5	

Table B.2 : Risk interaction impact second survey.

No	Sub-Risk		Affected Risk	Median Impact
1	Design of the Power Plant	→	Curtailment	4
2	Design of the Power Plant	→	Planning Risk	2
3	Design of the Power Plant	→	Property and Asset Damage	4
4	Design of the Power Plant	→	Budget Overruns	3.5
5	Design of the Power Plant	→	Financing Resources	2
6	Geology of the site	→	Resource Volatility	3
7	Geology of the site	→	Natural Hazards	2.5
8	Technology Selection	→	Design of the Power Plant	2
9	Technology Selection	→	Credit Risk of Suppliers	3
10	Aged Grid Infra. and Cap.	→	Electricity Price Volatility	4
11	Unq. Labor and App. Mist.	→	Expertise of the sector	1.5
12	Unq. Labor and App. Mist.	→	Health and Safety	3.5
13	Curtailment	→	PPA Counterparty	2.5
14	Business Interruption	→	Available Legal Mechanism	3
15	Business Interruption	→	Financing Resources	3
16	Planning Risk	→	Budget Overruns	3
17	Warranty	→	Design of the Power Plant	3.5
18	Logistic	→	Business Interruption	3
19	Logistic	→	Budget Overruns	3.5
20	Budget Overruns	→	Management Team	3.5
21	National Targets	→	Economic Status of Country	3
22	Market Design and Regulation	→	Electricity Price Volatility	4
23	PPA Counterparty	→	Financing Resources	3
24	Sudden change in law	→	Electricity Price Volatility	1
25	Subsidy Payment Scheme	→	Economic Status of Country	3
26	Policy Design Risk	→	Env. and Social Reg.	2
27	Policy Design Risk	→	Permitting and Licensing	4
28	Financing Resources	→	Technology Selection	2
29	Electricity Price Volatility	→	PPA Counterparty	3
30	Resource Volatility	→	Curtailment	2.5
31	Economic Status of Country	→	National Targets	4
32	Economic Status of Country	→	Policy Design Risk	2.5
33	Exchange and Interest Rate	→	Financing Resources	4.5
34	Credit Risk of Suppliers	→	Design of the Power Plant	4
35	Expertise of the sector	→	Design of the Power Plant	2
36	Expertise of the sector	→	Technology Selection	3
37	Weather Conditions	→	Electricity Price Volatility	3
38	Weather Conditions	→	Resource Volatility	2

Table B.2 (cont.) : Risk interaction impact second survey.

No	Sub-Risk		Affected Risk	Median	Impact
39	Env. and Social Reg.	→	Financing Resources	4	
40	Env. and Social Reg.	→	Market Design and Reg.	3	
41	Social Acceptance	→	Business Interruption	3	
42	Land Acquisition	→	Land Access	3.5	
43	Health and Safety	→	Property and Asset Damage	3	

APPENDIX C

Table C.1 : Risk impact second survey results.

Risk	1	2	3	4	5
Design of the Power Plant	5	4	5	4	5
Geology of the site	2	3	3	2	3
Available Resource Data	4	4	4	5	4
Technology Selection	4	3	4	4	4
Aged Grid Infrastructure and Capacity	3	3	4	3	3
Unqualified Labor and Application Mistakes	4	2	4	2	4
Curtailment	2	3	3	3	2
Business Interruption	3	3	3	4	3
Land Access	2	2	4	2	2
Planning Risk	4	4	5	4	3
Property and Asset Damage	2	2	3	2	2
Warranty	3	3	3	3	4
Logistic	2	3	3	2	3
Budget Overruns	5	4	5	5	5
National Targets	3	2	2	2	3
Permitting and Licensing Procedures	4	4	3	4	5
Market Design and Regulation	4	3	3	3	4
PPA Counterparty	4	4	4	5	5
Expropriation of asset	2	2	2	1	2
Available Legal Mechanism	3	2	2	2	3
Sudden change in law	4	4	3	4	4
Subsidy Payment Scheme	4	5	4	4	4
Policy Design Risk	3	3	3	2	3
Financing Resources	4	4	4	4	4
Electricity Price Volatility	3	4	4	3	4
Resource Volatility	3	4	4	5	5
Financial Instruments	2	2	2	2	2
Economic Status of Country	4	5	4	4	5
Indexation Mechanism	3	3	2	3	2
Inflation	3	2	3	3	3
Exchange and Interest Rate	3	4	4	3	4
Credit Risk of Suppliers	3	4	4	3	4
Management Team	3	4	4	4	4
Expertise of the sector	3	3	2	2	3
Weather Conditions	4	3	4	3	3
Environmental and Social Regulations	2	2	2	3	3
Social Acceptance	3	2	4	3	2
Land Acquisition	3	3	4	2	3
Natural Hazards	2	2	3	3	2
Health and Safety	3	3	4	3	4

TABLE C.1. (cont.) : Risk impact second survey results.

Risk	6	7	8	9	10
Design of the Power Plant	4	4	3	4	4
Geology of the site	1	2	1	2	3
Available Resource Data	4	4	4	4	3
Technology Selection	3	4	5	5	3
Aged Grid Infrastructure and Capacity	2	2	3	3	3
Unqualified Labor and Application Mistakes	3	3	2	4	3
Curtailment	3	3	3	2	4
Business Interruption	3	4	4	4	5
Land Access	1	1	2	2	2
Planning Risk	3	4	4	4	4
Property and Asset Damage	2	2	2	1	2
Warranty	3	3	3	4	3
Logistic	2	3	2	2	3
Budget Overruns	5	4	5	4	4
National Targets	3	3	2	2	3
Permitting and Licensing Procedures	5	4	4	4	4
Market Design and Regulation	4	4	3	4	3
PPA Counterparty	4	4	5	4	4
Expropriation of asset	3	2	2	1	2
Available Legal Mechanism	2	4	3	2	3
Sudden change in law	5	4	5	3	4
Subsidy Payment Scheme	4	3	4	4	3
Policy Design Risk	3	3	3	3	3
Financing Resources	4	5	4	4	5
Electricity Price Volatility	3	4	4	3	4
Resource Volatility	4	3	4	4	3
Financial Instruments	3	3	3	3	3
Economic Status of Country	5	5	5	4	5
Indexation Mechanism	3	2	3	2	2
Inflation	4	3	4	3	3
Exchange and Interest Rate	4	4	5	4	4
Credit Risk of Suppliers	3	3	3	4	3
Management Team	4	3	4	4	3
Expertise of the sector	2	3	2	2	3
Weather Conditions	3	2	3	3	4
Environmental and Social Regulations	4	3	3	3	5
Social Acceptance	3	3	3	2	3
Land Acquisition	2	2	2	2	4
Natural Hazards	1	1	2	2	3
Health and Safety	2	4	3	4	4

Table C.2 : Risk interaction impact second survey results.

No	1	2	3	4	5	6	7	8	9	10
1	4	4	4	4	4	4	4	2	2	4
2	2	3	2	2	2	2	2	2	4	2
3	4	2	4	4	2	4	2	3	4	4
4	3	4	3	4	2	3	4	3	2	2
5	3	2	2	2	2	2	2	2	2	2
6	4	2	3	2	3	3	3	4	3	2
7	2	3	2	2	3	2	4	2	4	3
8	2	2	2	2	2	2	2	2	2	2
9	3	3	4	3	2	3	3	2	4	3
10	2	3	4	4	4	4	4	4	4	4
11	2	2	1	2	3	3	2	4	4	2
12	4	2	4	3	2	3	2	3	4	4
13	2	2	2	2	3	2	2	2	4	2
14	3	3	4	2	4	3	3	3	3	3
15	2	3	3	2	4	3	4	3	3	4
16	3	4	3	3	3	3	3	3	4	3
17	3	3	4	4	4	3	4	3	3	3
18	3	4	4	3	3	2	3	3	3	2
19	3	4	3	4	3	4	4	2	4	4
20	4	2	3	4	4	3	2	2	4	4
21	3	3	3	3	2	3	3	3	3	3
22	4	4	4	4	3	4	3	4	2	4
23	4	4	3	3	2	3	3	3	2	3
24	1	1	4	3	1	1	4	4	1	1
25	3	4	3	3	3	2	2	3	3	3
26	3	2	3	2	2	4	2	2	2	2
27	4	2	4	4	3	4	4	4	4	4
28	2	2	3	2	3	2	2	2	3	2
29	3	4	4	3	3	3	3	2	3	3
30	2	2	3	3	2	3	2	3	4	4
31	4	3	4	4	4	2	4	4	4	4
32	3	2	3	2	3	3	3	3	2	2
33	4	3	5	4	2	4	3	4	4	4
34	4	3	4	4	4	4	4	4	4	4
35	4	2	2	2	2	2	2	3	2	2
36	4	2	3	3	3	3	3	3	3	4
37	3	3	2	3	4	2	4	3	2	3
38	2	4	2	4	2	2	3	2	2	2
39	4	4	3	4	4	4	4	4	4	3
40	4	3	3	2	3	4	3	4	3	3
41	3	4	3	3	4	3	3	2	2	4
42	2	4	3	4	2	2	2	3	3	4
43	3	4	2	2	2	3	4	3	3	3

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