탄소중립 실현을 위한
재생에너지 전환정책 연구 :
EU 그린딜 사례를 중심으로

2024년 4월

환 경 부
원 혜 림

목 차

1. 국외훈련 개요

1. 훈련국 : 스웨덴 (Kingdom of Sweden)

2. 훈련기관명 : 스톡홀름 대학교
(Stockholm University / Stockholms Universitet)

3. 훈련분야 : 환경정책

4. 훈련기간 : 2022. 8 - 2024. 6

2. 훈련기관 개요

□ 스톡홀름 대학교

ㅇ 스톡홀름대학교는 세계 200대 대학 중 하나로, 유럽의 상위 100개 대학 중 하나[1)]

ㅇ 2022/2023 순위에서 스톡홀름 대학교 순위

- QS World University Rankings: 118
- ARWU (Shanghai): 98
- THE: 176

ㅇ QS World University Rankings 단과대별(과목별) 순위에서 아래 6개 학문 분야가 세계 상위 50위 안에 들고 있음

- 사회, 정치 및 행정 (11위)
- 환경과학 (25위)
- 지구물리학, 사회학, 지리학, 지질학 (38-40위)

□ 환경사회과학 (International Master’s Programme in Environmental Social Science)

ㅇ 스톡홀름대학교의 정치대학 단과대에서 환경 분야에 특화한 국제 석사과정

ㅇ 글로벌 거버넌스 및 경제, 정치 관련 과목을 포괄하고 있어 EU 및 글로벌 기후환경정책을 심화하여 공부할 수 있는 과정 제공

1) 출처: 스톡홀름대학교, University facts, Ranking Table. https://www.su.se/english/about-the-university/university-facts/stockholm-university-in-world-ranking-tables

3. 훈련결과 요약서

성　　명	원혜림	직　　급	행정사무관
훈 련 국	스웨덴	훈련기간	22.8~24.6
훈련기관	스톡홀름대학교	보고서 매수	104매 (요약 10매 제외)
훈련과제	탄소중립 실현을 위한 재생에너지 전환정책 연구 : EU 그린딜 사례를 중심으로		
보 고 서 제목	탄소중립 실현을 위한 재생에너지 전환정책 연구 : EU 그린딜 사례를 중심으로		
내용요약	1 국외훈련 개요 스웨덴 스톡홀름대학교, 2022.8-2024.6 2 훈련기관 개요 1. 단과대 : 스톡홀름대학교 정치대학 2. 전공 : 환경사회과학 3 본문 Which Policy Instruments Propel Renewable Energy Fast and Forward? Panel Data Analysis on Renewable Energy Policy Instruments (어떠한 정책 도구가 재생에너지를 빠르고 효과적으로 촉진할 수 있는가? 재생에너지 정책 도구에 대한 패널 데이터 연구) * 2024년 6월 최종제출 **1. 서론** 넷제로 달성을 이루기 위해 각 나라에서는 다양한 재생에너지 정책 수단을 마련하고 있다. 특히 유럽연합의 경우 그린딜 정책으로 본격적인 재생에너지 정책을 가시화하였으며, 이러한 그린딜 재생에		

너지 정책은 급작스럽게 마련되었다기 보다는 꾸준히 이어져 온 재생에너지 추진 정책을 한층 강화하는 차원이었다. 아울러, 그린딜 발표 이후 러시아-우크라이나 전쟁으로 인한 에너지 파동에 따라, 유럽연합은 에너지 안보 수단으로서 재생에너지 정책을 한층 강화하게 되는 계기가 되었다.

해당 연구의 경우 그린딜 추진 시점을 포함한 2000년대 이후 재생에너지 추이와 관련된 정책 변수를 시계열 분석을 통해 정책 효과성을 평가하였다.

2. 재생에너지를 위한 정책 도구

정책 도구에서는 여러 종류가 있으며 이에 대한 분류는 관련 학계와 논문마다 다양하게 이루어져 있다. 해당 연구에서는 크게 세 가지의 정책 도구를 분류하는데, 경제적 인센티브와 규제조치, 시장 기반 도구 세 가지로 크게 분류하기로 하였다.

시장 기반 도구의 경우 배출권거래제(ETS)가 국가들 간에 가장 폭넓게 쓰인다. 미국의 경우 환경청에서 국내 대기오염 배출 규제를 위해 처음 도입한 사례가 있으며, 국가 간 첫 배출권거래제의 경우 유럽연합에서 처음 도입하였다. 이러한 시장 기반 도구의 경우 재생에너지만을 타겟팅한 도구는 아니지만, 탄소 가격 부과를 통해 시장에서 자율적으로 재생에너지를 유도한다는 특징이 있다. 시장 기반 도구의 경우 다른 정책 도구와 병행하여 재생에너지 촉진에 사용된다.

한편, 한국을 포함해 여러 국가에서 도입중인 재생에너지 관련 규제조치로는 재생에너지 공급 의무화 제도(RPS)가 있으며, 미국, 한국 및 여러 나라에서 시행중에 있다. 이러한 규제조치의 경우 재생에

너지를 타겟팅하여 목표를 설정하게 된다. 마지막으로, 경제적 인센티브의 경우 여러 나라에서 가장 흔하게 쓰이는 재생에너지 정책 촉진 도구로, 발전량만큼의 차액을 보전해 주거나 관련 세액 면제를 하는 다양한 방식이 사용되고 있다.

3. 제도 이론

- 3.1 합리적 선택 제도주의(RCI)

합리적 선택 제도주의는 정치 기관, 정책 기관의 기능을 설명하기 위해 합리적 선택 이론의 가설을 적용한다. 합리적 선택 제도주의의 가설에 따르면, 시장 참여자(또는 정치 참여자)들은 주어진 선호를 가지고 있으며, 개인의 선호 충족을 최대화하기 위해 합리적으로 행동한다. 참여자들의 개인적 선호는 외부적 요인에 의해 영향받지 않으며, 개인은 이기적이고 전략적 선택을 한다.

합리적 선택 제도주의는 정치적 문제를 집단 행동 문제(collective action problem)으로 해석하고 있으며, 죄수의 딜레마나 공유 자원의 비극처럼 고전적인 예시도 이러한 집단 행동 문제에 포함된다.

- 3.2 환경정책의 RCI 적용: 장점과 한계

합리적 선택 제도주의를 환경분야 또는 환경정책에 적용하는 것은 여러 학자들에 의해 이루어져 왔다. 특히 1970년대 전 비교적 환경정책 구조가 비교적 단순했을 때에는 정부를 통한 top-down 규제가 환경정책의 주류를 차지했으나, 이후 환경문제 및 기후문제, 탄소 배출 관련 규제 필요성이 점점 커지면서 다양

		한 이해관계자들의 복잡한 상호작용을 환경정책에 적용하기 위해 RCI가 대두되게 되었다. 다만 RCI에 대한 여러 가지 비판도 유효하며, 특히 완벽한 RCI 적용을 위해서는 정보비대칭성 문제가 해결되어야 한다는 사실이 실제로는 실현 불가능하다는 점이 많이 지적되어 왔다. 또한, 정책 집행자를 이기적 개인으로 가정할 경우 환경정책이 환경 개선과는 상관없이 정치적 이합집산에 의한 결과물로 해석될 수 있다는 비판이 많이 있어 왔다. 이 경우 환경문제 해결과는 별개로 정치적 시장이 형성되어 그 결과로 정책이 생겨나게 되는데, 실제 환경문제 해결과는 동떨어진 결과가 나올 수 있다는 문제점이 있다. • 3.3 합리적 선택 이론과 재생에너지 • 3.3.1 집단 행동 문제와 재생에너지 RCI에 따르면 재생에너지는 집단 행동 이론 문제 중 하나로 해석할 수 있다. 재생에너지 생산은 여러 긍정적인 외부효과를 생산하는데, 첫째는 재생에너지 생산으로 인한 탄소 배출 감소이다. 두 번째는 재생에너지 기반 확대를 통한 기술 진보 및 혁신활동 증대다. 이러한 외부 효과를 고려할 때, 외부 효과를 내재화하는 정부의 추가적인 개입의 없을 경우 일반적인 상황에서 재생에너지는 과소 생산되기 쉽다. 이러한 재생에너지 과소 생산의 경우 전형적인 집단 행동 딜레마 중에 하나로, 특히 RCI 이론에서는 환경 문제를 집단

		행동 딜레마로 해석하는 접근이 많이 있어 왔다. 해당 집단 행동 딜레마를 해결하기 위해서 RCI는 제도에 초점을 맞춘다. RCI는 제도를 공식적 또는 비공식적인 수단으로, 개입을 통해 시장 및 정치 참여자의 예상을 바꾸게 한다. 이 때 개입은 직접 시장 및 정치 참여자를 강제하는 것이 아니며, 정책이나 규제 관련 정보 등 정보 제공을 통해 참여자의 미래 예측을 바꾸게 해 합리적인 개인이 바뀌어진 미래 예측에 따라 행동할 수 있도록 유도한다. • 3.3.2 거래 비용 이론과 ETS 탄소배출권 거래의 경우 적절한 제도 설계를 통해 국가의 직접 개입보다 거래 비용을 절감하고 기업 및 시장에 대한 압력을 높여 재생에너지 생산을 촉진할 수 있다. 다만, 거래 비용을 낮추기 위한 적절한 설계가 필수적이다. 예를 들어 EU ETS의 경우 중앙화된 시장이 존재하며 부가적으로 시장을 통하지 않고 브로커나 기업이 배출권을 거래할 수 있도록 허용하며, 이러한 설계는 거래 비용을 효과적으로 낮출 수 있다. 특히 기존 환경 규제와 비교할 때 정책입안자 입장에서 시장 기반 도구의 가장 큰 장점은 모든 정보를 획득할 필요가 없다는 것이다. 규제의 경우 규제 목표를 설정하기 위해 해당 재생에너지(또는 환경오염)이 유발하는 긍정적 또는 부정적

		외부효과와 이에 드는 사회적 비용을 계산하여 이상적인 규제 목표를 설정하여야 한다. 그러나 시장 기반 규제의 경우 주로 쿼터(배출권 거래제의 경우 총 배출권)만 설정하고 나머지 세부적인 정보를 획득할 필요는 없기 때문에 규제 입안자 입장에서 정보 비용(거래 비용의 일종)을 효과적으로 줄일 수 있다. • 3.3.3 주인-대리인 문제 재생에너지에 대한 경제적 인센티브의 경우 생산자에게 안정성과 예측 가능성을 제공하여 보다 재생에너지 투자를 쉽게 결정하고 미래를 계획할 수 있도록 한다. 그러나, 주인-대리인 문제로 인해 생산자는 재생에너지 혁신에 대한 인센티브를 충분히 가지지 못할 수 있으며, 이는 재생에너지 생산에 대한 장기적인 경쟁력을 저해할 수 있다. 주인-대리인 문제는 대리인이 주인과 똑같은 인센티브 구조를 가지지 않으며 정보의 비대칭성이 부각될 때 주로 발생한다. 정부 계약 또는 정부 지원에서 주인-대리인 문제는 많이 연구되어 왔으며, 여러 연구에서 주인(정부기관)-대리인(대리기관 혹은 사기업)의 정보 비대칭성으로 인한 문제들이 발견되고 있으며 이를 보완하기 위한 추가 정책도구(모니터링, 목표 동기화 등)이 같이 시행되고 있다.

4. 연구방법론

- 4.1 RE 정책 도구의 효과성 측정

정책 도구의 효과성 측정에 여러 가지 방법이 존재하며, 해당 연구에서는 Young (2005)이 정의한 효과성 측정 방법 중에서 outcome을 통한 측정 방법을 사용하기로 하였다. 해당 측정 방법의 경우 직관적으로 정책의 시행과 그 효과성을 비교할 수 있다는 장점이 있다. 그러나 해당 결과의 인과관계를 단순 결과만으로는 입증하기 힘들다는 단점이 있으며, 본 연구는 이를 보완하기 위해 적정한 데이터셋 및 회귀 모델을 선택하였다.

- 4.2 데이터셋

해당 연구에서는 2000년부터 2021년까지 OECD 국가(대부분의 유럽 국가들을 포함)들을 대상으로 다양한 재생 에너지 정책 수단의 효과를 조사한다.

- 4.3 회귀 모델

4.3.1 패널 수정 표준 오차(PCSE) 모델

재생에너지의 경우 정책 변수 뿐만 아니라 다양한 요소의 영향을 받으며, 특히 유럽 국가들의 경우 유럽 집행위원회의 영향으로 비슷한 정책을 비슷한 시기에 집행하여 correlation이 발생할 확률이 높다. 이에 따라 해당 위험을 효과적으로 낮출 수 있는 PCSE 모델을 사용한다.

4.3.2 Random Effect 모델

해당 연구는 데이터 결과의 robustness를 높이기 위해 random effect 모델을 추가적으로 실시한다. 해당 연구에서 적용하는 데이터가 여러 국가 간 시계열 데이터이며, 국가 간 차이가 크기 때문에 fixed effect 모델에 비해 안정적인 결과를 제공해 준다. 또한 Hausman test 결과 random effect 모델을 사용하는 것이 더 이상적인 결과값을 출력할 수 있는 것으로 나타났다.

4.4 변수

4.4.1 종속 변수

재생에너지 생산을 대표하는 다양한 변수들이 존재하지만 본 연구에서는 재생에너지 발전 원에서 생산된 전기 에너지를 지표로 사용한다. 해당 연구에서 언급한 정책들이 주로 전기 생산자 및 소비자를 대상으로 하기 때문에 이에 초점을 맞추는 것이 주요한 선택 이유이다.

4.4.2 독립 변수

재생에너지 정책을 경제적 인센티브, 시장 기반 도구 및 정부 규제 세 가지로 나누었으며, 세 가지 카테고리에 따른 프록시 및 더미 변수를 지정하였다. 예를 들어 시장 기반 도구의 경우 배출권거래제의 시행 여부가 더미 변수이며, 배출권거래제 제도가 총 탄소배출 중 몇 퍼센트를 차지하는지를 주요한 프록시 변수로 활용하였다.

4.4.3 통제 변수

기존 연구에 따라 재생에너지 생산 및 확장에 영향을 크게 미치는 네 가지 변수를 추가했다. 탄소 배출량, 토지 면적, 장기 이자율, 국내총생산이 통제 변수로 들어가게 되었다. 탄소 배출량의 경우 고체, 액체, 기체연료 및 소각으로 인한 이산화탄소 총 배출량을 기준으로 하며, 해당 지표는 국가의 에너지 의존도를 나타내는 지표로 사용한다. 토지 면적은 재생에너지 시설 용량 크기에 영향을 미칠 수 있는 통제 변수이며 장기 이자율은 재생에너지 장기 사업의 자금 조달 비용 및 사업 결정에 영향을 미친다.

5. 데이터

OECD, 국제에너지기구, 세계은행 등에서 제공하는 데이터가 사용되었으며, OECD 회원국을 대상으로 분석을 진행하였다. OECD 국가 및 그들의 주요 무역국가들은 전 세계 에너지 배출량의 과반수를 차지하고 있기 때문에, 이들 국가의 정책 효과성을 분석하는 것이 중요하다.

다만 전체 38개 회원국 중 최근에 가입한 코스타리카 및 주요 정책 데이터가 충분하지 않은 국가들은 제외되어 30개 회원국에 대해서 분석을 진행하였다.

기간의 경우 2000년부터 2021년까지의 기간에 대한 데이터를 분석하였다. 이 기간은 유럽연합의 그린딜 출범이 포함될 뿐만 아니라, 21세기 초부터 확대되기 시작한 글로벌 에너지 환경 변화, 파리협정과 같은 중요한 분기점을 담고 있다.

6. 분석

패널 수정 표준 오차(PCSE) 모델 분석 결과, 배출권거래제의 커버 퍼센티지가 재생에너지 확대와 유의미한 연관성을 보였으며, 이 외에 규제 도구의 시행도 유의미한 연관성을 보였다. 다만 배출권거래제의 경우 더미 변수만으로는 부정적인 연관성이 나타내었는데, 배출권거래제 커버리지가 일정 레벨 이상이며 적절하게 디자인되어 시행되었을 경우 긍정적인 연관성을 나타내었다.

규제도구, 그리고 시장기반도구가 재생에너지 확대에 유의미한 연관성이 있는 것으로 나타났으며 시행 유무보다는 해당 정책 목표에 따른 적절한 제도 설계와 시행이 재생에너지 확대에 긍정적인 영향을 끼칠 수 있다고 유추할 수 있다.

7. 결론

④정책적 시사점

유럽의 경우 그린딜의 출범과 함께 배출권거래제 달성 목표를 강화하고, 관련 산업에 대한 지원을 강화하는 등 탄소중립 실현을 위한 재생에너지 정책 지원을 지속적으로 이어 오고 있다. 유럽 집행위원회는 확대된 배출권거래제 타겟과 커버리지에 따라 탄소 가격은 2030년까지 톤당 129유로까지 상승하는 것을 목표로 삼고 있다. 이는 화석연료 배출 비중이 높은 산업에 대한 압력으로 작용하여 재생에너지 생산을 더욱 가속화할 것으로 예상된다.

또한, 스웨덴의 경우 그린딜 출범 이전부터 환경산업 및 재생에너지 정책을 성장동력으로 삼고 있다. 스웨덴 정부에서는 Ecological modernization이라는 슬로건을 필두로 환경정책 강화와 경제 성장을 동시에

	달성하려는 노력을 진행해 왔으며, 이러한 정책 방향은 대국민적으로 일정 레벨 이상의 지지를 얻어 왔다. 스웨덴은 이러한 정책 추진을 바탕으로 그린 철강(green steel)과 같이 기존 탄소배출 산업을 신산업으로 전환하여 경제성장 및 탄소중립 실현 동력으로 삼고 있다. 스웨덴 이외에도 덴마크, 독일과 같은 유럽 국가들은 이러한 방향의 환경 정책을 산업 정책과 연계하여 지속적으로 추진하여 왔다. 결론적으로, 한정된 정부 자원과 예산을 고려할 때 재생에너지 관련한 정책을 시장기반도구를 통해 정책 집행 예산을 절감하고, 아울러 관련 업계와 피규제자 소통 및 정보 제공을 통해 시장 참여자들이 향후 재생에너지 시장에 대한 적절한 예상 및 투자 선택을 할 수 있도록 유도하는 것이 장기적인 재생에너지 확대에 효과적이다. 다만, 재생에너지 확대의 경우 다양한 변수가 연관되어 있으며 정책의 세부적인 설계에 따라 효과성이 상당히 변동될 수 있으므로 향후 연구에서는 정책 관련 추가적인 프록시를 추가하여 보다 세부적인 연구를 진행하는 것이 바람직하다.

4. 본 문 (학위논문, 참고문헌 포함)

Stockholm University

Department of Political Science

Which Policy Instruments Propel Renewable Energy Fast and Forward?

Panel Data Analysis on Renewable Energy Policy Instruments

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Independent Research Project in Political Science, 30 credits
International Master's Program in Environmental Social Science with a focus in Political Science
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Contents

Abbreviations

CO_2: Carbon Dioxide
ETS: Emission Trading System
EU: European Union
FITs: Feed-in Tariffs
GDP: Gross Domestic Product
GHG: Greenhouse Gas
GWh: Gigawatt-hour
IEA: International Energy Agency
IPCC: Intergovernmental Panel on Climate Change
IRENA: International Renewable Energy Agency
MWh: Megawatt-hour
NDC: Nationally Determined Contribution
OECD: Organization for Economic Co-operation and Development
PCSE: Panel-Corrected Standard Error
RE: Renewable Energy
RCI: Rational Choice Institutionalism
RPS: Renewable Portfolio Standards
UNFCCC: United Nations Framework Convention on Climate Change

1. Introduction

"Today, the world takes an important step to limit global warming to 1.5 degrees. Reaching this goal starts with transforming the energy sector. As you all know, energy accounts for 75% of the global greenhouse gas emissions. This has to go down. We must roll out more renewables."[2)]

\- **Ursula von der Leyen at COP 28**

Renewable Energy (RE) plays a important role in realizing global net-zero emissions, especially when it comes to RE expansion. In 2015, nearly all nations worldwide consented to the Paris Agreement, which was the enormous global effort to constrain the escalation of global temperatures. Following with the Paris Agreement, numerous countries established, their Nationally Determined Contributions (NDCs), incorporating ambitious renewable energy targets. Over 90% of countries submitted NDCs referenced renewables, and most of them include quantified renewable energy goals (IRENA, 2019). As net-zero emerged as a global imperative, the demand for renewable energy witnessed a surge, averaging an annual increment of 4.7% from 2010 to 2020 (REN21, 2023). Renewable energy can contribute as a useful tool for climate change mitigation, adaptation, reinforcing global climate action in worldwide (IRENA, 2019).

In recent years, countries in worldwide have implemented more than 80 kinds of RE policies, surprisingly, predominantly in the form of financial incentives (REN21, 2023). In addition, regulatory or market-based policy measures have been also

2) Speech by President von der Leyen at COP28 on tripling renewable energy and doubling energy efficiency by 2030, 2 December 2023, European Commission Press corner, https://ec.europa.eu/commission/presscorner/detail/en/speech_23_6258 implemented. Supportive national policies have proven to be indispensable for the successful deployment of renewable energy technologies and innovation (Marques et al., 2010).

The EU Commission formulated a general implementation package under the Green Deal to accelerate RE expansion, building upon the consistent RE policies implementation in preceding years. In 2019, the European Union set up the European Green Deal, instituting a core target to attain net-zero emissions, with a strong emphasis on RE development. This initiative did not emerge abruptly; rather, it was a continuation and intensification of previously implemented strategies aimed at expanding RE (Miłek et al., 2022). The European Green Deal explicitly acknowledges the important and pivotal role of renewable energy expansion in the transition towards a net-zero society that promotes sustainable growth . This plan covers the EU's commitment to environmental sustainability and economic resilience. The EU has been signaling a strategic shift towards cleaner energy sources as foundational elements of Europe's future (Miłek et al., 2022).

Moreover, RE represents a crucial tool for diversifying energy sources and enhancing energy security. The recent surge in fossil fuel prices has prompted numerous nations to explore alternative sources, leading to the adoption of diverse renewable energy policies. For instance, the European Union has significantly augmented its renewable energy capacity through the REPower EU plan, alongside import bans on Russian natural gas (WEF, 2023). For countries who do not have enough fossil fuel resources within their territory area, RE provides a important and sustainable solution to reducing dependence on fossil fuel energy imports.

Comprehending the relationship, between RE policies and RE expansion, is critical for several reasons. A country is a main actor in RE expansion, and policy is country's primary tool for implementation. Nation-states leverage RE policies as key instruments to go forward to a net-zero society (OECD, 2015). Under the United Nations Framework Convention on Climate Change (UNFCCC) framework, countries announce their Nationally Determined Contribution (NDC) targets to the world, including their RE policies.

The effectiveness of RE policies would influence global energy markets and the geopolitical landscape. The REPower plan was established not only for environmental reasons but also for energy security reasons (WEF, 2023). Whether RE policies are effective or not would have a significant impact on the dynamics of the global energy trend, and effective RE policies might diminish the negotiation power of traditional fossil fuel countries.

RE policies also play a crucial role in arranging social equity in the energy sector. Compared to fossil fuels with concentrated stores, RE provides more widely distributed forms of sources (Burke & Stephens, 2018). RE cannot be viewed as a simple technological substitution for fossil fuels, and the transition to RE should be perceived as a political struggle reflecting and rearranging society (Burke & Stephens, 2018). Effective policy frameworks can promote social justice by decentralizing energy sources within a country.

The aim of this paper is to examine the empirical impact of RE policy. Specifically, this paper categoried RE policies into roughly three categories; financial incentives, market-based measures, and regulation, as referred to in previous research (Polzin et al., 2015). These three categories, which have been broadly utilized worldwide countries in recent decades, is the main types of this paper research. While there are other types of RE policies, these three are widely used in many countries and are easy to compare with each other by using a longitudinal research design. It is important to conclude results and outcomes from recent datasets to determine which policy has been effective so far. This paper employs quantitative measurement, with time-series panel data from the year 2000 to 2021. To measure the effectiveness of policies, a cross-country comparison is applied to the research.

The paper adopts Rational Choice Institutionalism (RCI), one of the political science theory tool, as a theoretical lens. This paper applies collective action problems, transaction cost theory, and principal-agent theory to explain RE issues and RE policy structures. Since the Organization for Economic Co-operation and Development (OECD) countries emit almost 40% of global carbon emissions around the world (OECD, 2015), the paper will focus on variables from these countries. Regarding methodology and data, this paper conducted a panel data regression which covers RE capacity from 2000 to 2021 in 30 of the 38 OECD countries.

The main question of this paper is, what kinds of policy instruments are most effective in expanding RE. Effectiveness can be measured by several criteria. Young (2011) mentioned basic variables for effectiveness: output and outcome. Output measures direct changes in governmental regulations and law, while outcome measures following behavior changes in specific target groups by policies. In the case of RE policy effectiveness, many scholars have chosen the outcome as a RE policy effectiveness measurement. There have been numerous quantitative research studies about the effectiveness of RE policy after year 2000 (Dong, 2012; Polzin et al., 2015; Liu et al., 2019; Kersey et al., 2021), by applying several categories of RE policies, such as financial aids or regulations, and comparing them with quantitative expansion of RE.

One contribution that this paper would offer is that it provides distinct theoretical approach using RCI. Most of the quantitative previous research about RE expansion (Dong, 2012; Polzin et al., 2015; Liu et al., 2019; Kersey et al., 2021) relies on public policy theory or financial/economics theories. This paper expands the RE policy debate by applying RCI. RCI is a prevalent political science tool that can effectively explain certain government policies and stakeholder's choices based on those policies and subsequent expectation changes. Some research employs RCI to explain environmental organizations or establishment of international negotiations (Vijge, 2013), but so far, it has not been studied specifically for RE policies in each country. Therefore, this paper can contribute by using RCI to describe RE policies and their effectiveness, which has not been fully explored before.

2. Policy Instruments for Renewable Energy

2.1 Three Categories of RE policy instruments

When it comes to categorizing of RE policies, this paper adopts the previous framework of Polzin et al. (2015). Polzin et al. (2015) broadly classifies RE policy instruments into mainly three categories: financial incentives, market-based mechanisms, and regulatory instruments. These three categories have significantly influenced the stakeholders, especially investment choices by RE producers (Polzin et al., 2015).

Additionally, this paper does not cover the direct investment category as a indicator, which Polzin et al. (2015) included in their research about RE investment expansion. Direct investment refers to the direct allocation money from federal or regional governments related to RE projects (Polzin et al., 2015). This paper decides to exclude the direct investment category in the data. The primary reason is that direct government investments in RE projects cause a set of dynamics and outcomes that is very differ from those generated by policy mechanisms like Feed-in Tariffs (FITs), Renewable Portfolio Standards (RPS), and Emission Trading Systems (ETS).

This paper focuses on indirect policy mechanisms for several reasons. Firstly, FITs, RPS, and ETS are designed to create incentives and market signals that promote private sector to decide their own investments towards the RE sector, leveraging market mechanisms to achieve policy goals. In contrast, direct investments represent a more direct way of government intervention. The governments play a primary role in direct investment. In contrast, indirect investment assumes that private investors are main player. Therefore, while acknowledging the critical role that direct investments play in advancing the RE sector, the analysis framework of this paper is specifically aiming to investigate the mechanisms through which policy can indirectly shape the market environment to foster sustainable growth in the RE sector.

Firstly, financial subsidies are widely used as an accelerating tool for RE. Especially, these measures provide financial benefits to private actors for long-term commitments in RE sector. FITs set the price that RE producers receive for supplying electricity to the power grid over a determined period. This mechanism often involves contracts offering higher price than market situation, which ensures the long-term profits for renewable energy investments. In the end, FITs can motivate producers to increase their renewable electricity output. FITs are a prevalent tool that has been applied in many different regions as a financial subsidy method. By offering price certainty and predictability, FITs promote ongoing investment and production, fostering a conducive environment for the growth of RE (Kersey et al., 2021). For example, when Japan initially launched their preliminary FITs projects for solar panels, the FIT program mandated that the government purchase excess solar power at a fixed price of JPY48 (USD 0.60) per kWh over 10 years. This rate nearly doubleed the electricity market price at that time (Chen et al., 2014). This pilot program, launched in 2009, was very effective in promoting RE in Japan and has significantly propelled the expansion of solar power in the country at short time. RE producers seeking profit-maximization would likely expand their facilities to obtain more profits in the future. FITs are effective in promoting RE investments since guaranteed prices can drastically decrease market risk for producers, but they might have a negative impact on competitiveness in the long run, as guaranteed prices may cause a negative effect on RE competitiveness (Kwon, 2015). It could occur that producers of renewable energy may lack the incentive to channel funds into emerging renewable energy advancements to cut costs. Different forms of financial support might include investment grants or tax benefits (Kersey et al., 2021), but FITs are one of the usual standardized forms of financial subsidies. Many scholars categorize FITs not as a strict regulatory measure but more as a financial incentive (Polzin et al., 2015; Kersey et al., 2021; Dong, 2012), since FITs typically take the form of subsidies. Although this paper also uses FITs as a proxy for financial incentives, it is noteworthy that some scholars view FITs as a price regulation (Kwon, 2015).

Second, regulations are also a common tool utilized by nations to promote RE production. Countries can impose quotas or other regulatory standards on energy producers, which can lead to the expansion of RE facilities. Renewable Portfolio Standards (RPS) are a major type of RE regulation. While FITs impact pricing, RPS regulates quantity. RPS mandates that large-scale electricity suppliers generate a fixed percentage of their electricity from RE sources. For example, in the case of South Korea, the government has set an RPS target of 13% for 2023, which means that an electricity supplier generating 100MWh must acquire at least 13MWh of electricity from RE sources (Korea Energy Times, 2023). Even if electricity suppliers primarily produce their electricity from fossil fuel sources, this regulation imposes a required amount of RE production on every supplier, which would lead to an expansion of RE power production. Electricity suppliers can generate RE themselves or purchase certificates from other RE generators to meet the requirement. The government gradually increases the RPS ratio to expand RE, for example, South Korea has announced plans to increase the requirement to 25% by 2030. RPS provides strong incentives for cost reduction in RE generation, which can promote competitive improvement (Kwon, 2015). Since the government does not provide financial benefits for RE production, electricity suppliers would seek ways to produce RE at the lowest possible cost. On the other hand, RPS can hinder RE expansion by imposing more market risk on investors (Kwon, 2015). Electricity suppliers might want to spend the minimum cost for RE production and might not want to invest more, as the market risk for producers is much larger than in the FIT scenario. RPS is clearly seen as a strong regulatory policy in much research (Polzin et al., 2015; Kersey et al., 2021).

Lastly, many economic scholars have argued that market-based instruments are the best solutions for expanding RE (Gawel et al., 2015; del Río, 2017). Market-based policies do not directly compel renewable energy production but rather incentivize stakeholders to produce or invest in renewable energy by creating favorable market conditions. The most prominent example of this market-based policy is emission trading schemes (ETS). ETS, also known as a 'cap and trade' system, involves setting a maximum level of emissions, and prices of emission permits are determined by an emission-trading system (Ritchie et al., 2023). For example, in the case of the European Union (EU), ETS sets an overall cap on GHG emissions in the EU and provides a trading mechanism in a cost-effective manner. The EU gradually decreases emission allowances over time, driving up prices and incentivizing a cleaner power sector by enforcing scarcity in emission permits. ETS is known to effectively cover the general climate and energy policy area, and some scholars argue that ETS can provide optimal energy outcomes without additional policy instruments (Gawel et al., 2015). Based on ETS, actors in the market can freely sell and buy emission permits, which can naturally promote RE in the energy market since RE does not require any emission permits for additional energy generation. GHG ETS have been noted for attracting institutional investors, who favor these instruments over FITs due to their lower susceptibility to governmental policy shifts (Polzin et al., 2015). In 2022, 32 out of 38 OECD member countries have adopted ETS on carbon emissions (Ritchie et al., 2023).

To recap, there are largely three categories for RE policies: financial incentives, regulations, and market-based instruments. This paper will focus on one primary policy for each category: FITs as a proxy for financial incentives, RPS as a proxy for regulation, and ETS as a proxy for market-based instruments. The main reason for choosing these policies is that they are most prevalent worldwide and have been examined by several previous studies (Gawel et al., 2015; Polzin et al., 2015; Zhao et al., 2018).

2.2 What has been done with FITs, RPS, ETS

Several research conducted empirical studies of RE policy instrument effectiveness. For example, Polzin et al. (2015) tested the effectiveness of policies such as FITs on renewable energy investment in OECD countries. In the research, it is noted that RE policies plays a important role in promoting RE, especially investment, by providing guaranteed returns for investors and setting up laws and regulations for market stakeholders. Dong (2012) also compared the effectiveness of FITs and RPS in promoting wind capacity in Germany over recent decades. The findings of this study emphasized that how different policy mechanisms can differently influence the development of specific renewable energy sectors. For instance, FITs have lead the way in terms of direct encouragement for wind energy expansion in that research. Kersey et al. (2021) also used panel data to test the effectiveness of diverse policies around small-scale RE producers in Caribbean islands.

During the beginning area of RE expansion, FITs have been broadly applied as a main RE policy around the world. Many European countries such as Spain and Germany (Zhao et al., 2018) have practiced the FITs before 2000 year. FITs provide a favorable pricing mechanism for RE, offering higher prices compared to fossil fuel energy, which makes power producers to increase RE output (De Jager et al., 2011). Many scholars have already noticed that FITs could be powerful policy tool, especially in the early development stages of RE (De Jager et al., 2011; Zhao et al., 2018). According to the empirical data research, it has been noted that, at the early beginning of RE, some researchers proved that FITs could be an effective tool to promote RE producers for more RE production. In some cases, those policies have been effective in the initial stages, and in other cases it has been even effective in all kinds of stages. By guaranteeing RE producers a relatively higher market price (over certain period) for the renewable energy they generate, FITs directly incentivize the production of renewable energy. Producers of renewable energy receive a stable and predictable income, and furthermore, they could significantly reduce the financial risks regarding RE projects.

On the other hand, RPS serves as a stronger regulatory mechanism, mandating that electricity generators include a certain percentage of renewable energy in their production portfolio (Schelly, 2014). In contrast to the direct financial incentives provided by FITs, RPS policies impose a regulatory requirement that electricity suppliers produce a minimum fraction of their electricity from renewable sources. This creates a mandated demand for RE, pushing utilities and other electricity producers to either invest in renewable energy production capacities or purchase renewable energy credits to meet the requirement. The United States first started RPS at the state level in 1983, and currently, 37 states have RPS requirements (IEA, 2019). Today, countries such as Australia and South Korea have also implemented RPS as their main RE policy (Zhao et al., 2018).

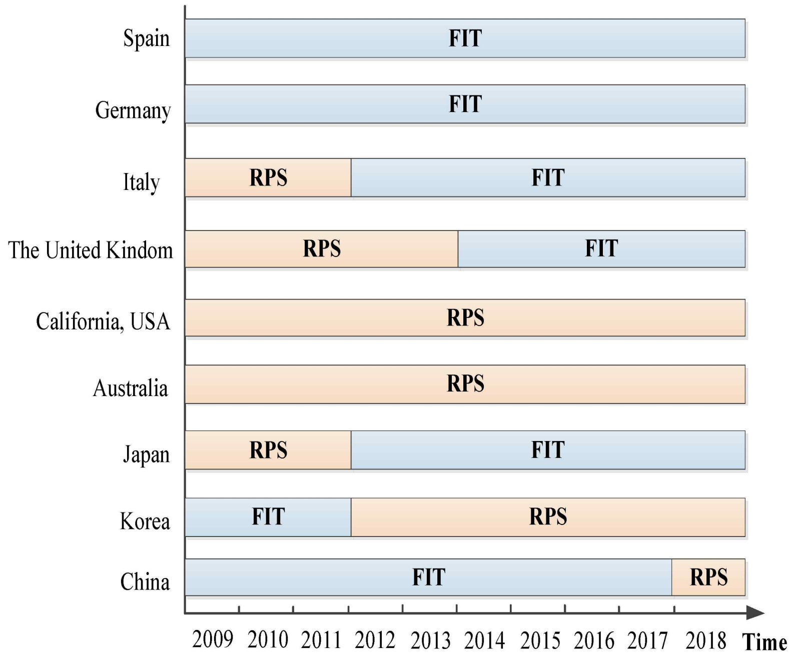

Figure 1. The selection of policy instruments between FITs and RPS in typical countries and regions. Zhao et al. (2018)

RPS and FITs have their distinct policy structures. Nonetheless, many countries uses RPS and FITs as substitutable tools (see Figure 1). South Korea and China converted from FITs to RPS, while Italy, the United Kingdom, and Japan shifted from RPS to FITs. It is noteworthy that South Korea changed their policy from RPS to FITs, while Japan simultaneously had the opposite switch. In South Korea's case, FITs had been successfully implemented for a while, but the financial burden on the government was noted as a primary reason for the transition from FITs to RPS in 2012 (Chen et al., 2014). On the other hand, Japan had adopted RPS since 2003, and a new national energy strategy was established after the nuclear disaster in 2011, with including FITs and excluding RPS to promote rapid RE growth (Chen et al., 2014).

Scholars have compared the policy effectiveness of FITs and RPS on RE expansion. Some argued that FITs have a greater impact on deployment (Dong, 2012), while others suggested that RPS could be more effective during high technological phases (Polzin et al., 2015). Polzin et al. (2015) conclude that financial incentives prove to be effective for the less mature technologies phases, while market-instruments were more effective for high technologies period. However, some researchers also highlight that FITs and RPS themselves do not have a statistically significant correlation with RE expansion. Other factors, such as governance, national wealth, and business environments, would affect the RE expansion deeply (Kim, 2011).

Lastly, ETS (also called as cap-and-trade systems especially in European region), expands another dimension to the policy tool for supporting renewable energy. ETS set a maximum cap on the national level of greenhouse gas emissions and allow the stakeholders to determine the price of emitting carbon. While most ETS policies are not directly aiming a renewable energy expansion, ETS indirectly supports RE expansion by making fossil fuel-based energy production more costly. It leads to the improvement of competitiveness of renewable energy.

Regarding the relationship between ETS and other policies, many countries viewed ETS as a complement tool with other RE policies and have applied ETS altogether with RPS or FITs. Several scholars have already noted that appropriate policy package between ETS and RE can enhance the overall efficiency of climate policy (Gawel et al., 2014; del Río, 2017; Lindberg, 2019). It has been suggested that market-based systems and other regulatory measures become more effective for mature RE technologies that are cost-competitive

(Polzin et al., 2015).

Nevertheless, some scholars point out that implementing ETS and RPS could be double-regulative tool for RE producers. Some conclude that the country might need to go through the detail effect before applying these two instruments together, to reduce regulatory pressure and create more synergy between policies (Ahn et al., 2011).

To recap, scholars have argued that the relevant integration of ETS with FITs or RPS policies can enhance the effectiveness of climate policy by aligning market signals with regulatory requirements. However, the implementation of ETS with other RE policies requires careful coordination and delicate design to avoid regulatory overlap, reduce compliance costs, and maximize the synergies between market-based and regulatory instruments.

3. Theoretical framework

3.1 Rational Choice Institutionalism

This paper uses Rational Choice Institutionalism (RCI) as a theoretical lens. RCI borrows economic models and assumptions, specifically from rational choice theory, to analyze the behaviors regarding functioning of political institutions (Lowndes et al., 2018). It is crucial to begin with the definition of an institution, as RCI is one of several new institutionalisms that bring a broader definition of the term (Hall and Taylor, 1996). According to March & Olsen (1983), institutions cover a wide range of formal and informal rules, norms, governance structures, and practices. Therefore, the concept of an institution encompasses not only official governmental organization but also their overall political practices and implementation.

There are several assumptions of RCI regarding political actors (Hall and Taylor, 1996). Firstly, actors have exogenous preferences. They behave rationally to maximize the attainment of their individual preference sets. In other words, the actors are self-interested and strategic, and their individual preferences are not influenced by other kinds of external factors. This basic assumption aligns with rational choice theory. It has also been known that RCI adopts a calculus approach for individual action (Vijge, 2013). Secondly, RCI views politics as a collective action problem, This collective action problem has several classic examples: prisoner's dilemma or the tragedy of the commons. The collective action problem occurs when every single actor tries to maximize their preference, but their actions would not lead to overall welfare in the group (or each individual fails to achieve ideal attainments for their preferences). RCI sees institutions as a solution for this kind of collective action problem. This leads to the third assumption; The development of specific institutions can be explained by the outcome of efforts to solve specific collective action problems or reduce transaction costs. RCI views that institutions are established by actors' expectations about others' behavior, for instance, focusing on minimizing transaction costs and resolving collective action dilemmas. Actors decide their actions based on their expectations of other actors' behaviors in specific situations, and institutions can affect those expectations by setting rules and structure, which ultimately change each individual's behavior. Therefore, specific reasons always underlie the establishment of institutions (Hall and Taylor, 1996).

Institutions establish the context within which actors function, shaping their conduct and choices (see Figure 2). It depitcs the political decision making process through RCI lens. The inherent nature of the problem shapes how actors collect their interests and the issue at hand. Individuals or organizations, acting in accordance with their interests, make strategic decisions guided by their preferences and expectations of others' actions. The selection of policy instruments to address the problem emerges as a consequence of the interplay between actors, institutions, and their comprehension of the issue. This process is interactive, with institutions evolving from endeavors to resolve collective challenges, followed by influencing actors' expectations and choices, thereby finalizing the selection of policy tools (Böcher, 2012).

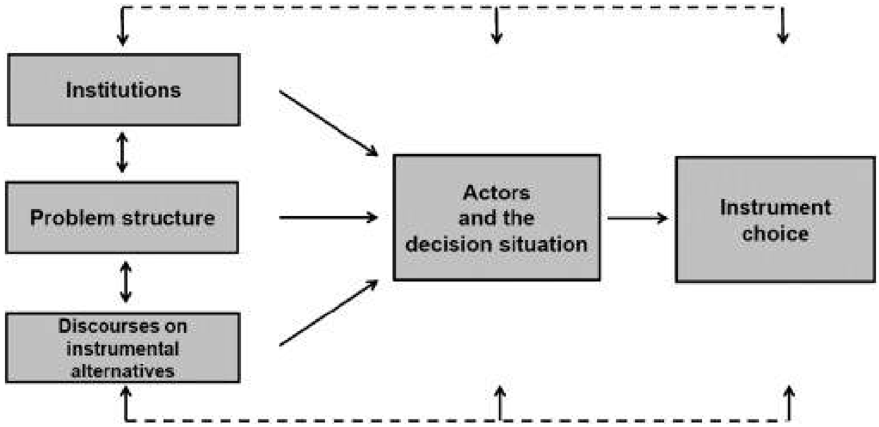

Figure 2. An analytical framework of instrument choice. Böcher (2012).

Principal-agent theory is another pivotal concept of RCI. It mainly concerns the relationship between two parties: the principal (who assigns a task/delegation) and the agent (who is allocated with carrying out the assignment). A principal-agent problem can evoke when principals delegate tasks and enforce compliance on agents (Hall and Taylor, 1996). For instance, a government (principal) might hire a contractor (agent) to construct renewable energy infrastructure (e.g. solar panel). If the contractor prioritizes their own preference (e.g. profit maximization) over contract requirement, the accomplishment level of the contract might be compromised. This problem may arise when an agent has to act on behalf of a principal but originally have different motivations. The principal imposes the agent to achieve certain goals or tasks, but uncertainty and information asymmetry arises when the agent tries to not act under the principal's best interests. This theory elucidates why institutions can be inefficient or dysfunctional despite actors' rational choices. RCI assumes institutions have specific functions or reasons of establishment, but the principal-agent problem may cause institutions to not function as it meant to. Agents often possess more detailed knowledge about the task at hand than principals do. This disparity can lead to situations where agents act in ways not fully visible or understandable to principals, resulting in information asymmetry (Hall and Taylor, 1996).

3.2 Applying RCI to Environmental Policy: Strengths and Limitations

Young (2002) highlights the critical role of institutions in environmental governance, underscoring their ability to effectively address or, conversely, exacerbate collective action problems inherent in managing environmental issues. According to Young (2002), the collective action model serves as an explanatory framework for environmental dilemmas. For institutions to effectively tackle environmental challenges, strategic design tailored to the collective action problems is crucial.

Prior to 1980, environmental challenges often prompted swift, top-down regulatory responses with limited stakeholder engagement. Only a few producers were stakeholders in environmental issues (such as large-scale chemical manufacturers). Governments typically directly affect the industry through top-down regulations. As complex, long-term nature of climate change became the core issue in environmental area, more flexible, market-based, or cooperative instruments have been needed. Nowadays, as numerous stakeholders have become engaged in environmental issues, RCI can play a significant role in this context (Vijge, 2013).

Environmental policy choices is mainly about the management of common goods (Vatn, 2005). Based on RCI assumptions, which defines market participants as calculative and self-interested individuals, it is crucial for institutions to promote these rational actors to behave cooperatively for common interests, given perceived external constraints. A classic example of negative externality is an lead pollution: when a factory produces harmful goods, it might also release pollutants into the air or water, harming public health and the environment. The factory may not count in these costs to society when making production decisions since it does not impose them directly.

To address this issue, institutions can play a pivotal role by creating rules or mechanisms that incorporate these external costs into the decision-making process for individuals and companies, such as regulation, taxes, or emission trading. This process is known as internalizing externalities. In this case, institutions can be defined as "constraints on individual behavior" (Vatn, 2005, p.205), and many authors have noted that institutions can function as structures to reduce uncertainty or lower transaction costs, which in turn influence actors' behavior concerning their actions related to the environment. For example, Young (2002) discusses the importance of relevant institutional design in addressing environmental problems that cause externalities and also mentions collective action theory as an explanatory tool. According to RCI, environmental policies can be viewed as institutions, which adjust actors' behavior by providing more information or reducing costs (Vatn, 2005).

Conversely, applying RCI to environmental policies also has significant limitations. Firstly, RCI assumes that there is an ideal optimum existing for the whole society. To define this optimum point, information needs to be complete, or information costs need to be almost zero. If information about environmental issues is not fully collected, it is impossible for institutions(or governments) to determine the ideal intervention. For example, to effectively address pollution problems in a particular river, it is essential to gather comprehensive information. This includes identifying every source of pollution along the river, quantifying how much pollution each source is responsible for, and understanding the preferences and priorities of every stakeholders affected by the river's condition. Only with this complete picture, the country can bring up the best strategy for cleaning up the river. We all know that, in reality, it is impossible for nations to collect perfect information about all environmental problems. Moreover, because it is so complex and the involves a bunch of stakeholders, it might be inconsistent to maintain the assumption of optimization and rationality given the limited information on environmental issues (Vatn, 2005).

Another limitation is its assumption of an ideal policy planner. If policy planners were free from selfishness, or if social structures were perfectly designed for planners to choose optimal environmental policies for the whole society, then the ideal social optimum could be achieved through desirable environmental policies. However, policymaking itself can be influenced by self-interested behaviors. In this case, policy planning could become a policy market, serving the interests of administrators or policymakers. Policy planners might not make the ideal decision not only because of the lack of perfect information but also due to their self-interested behaviors (Moore et al., 1979).

Lastly, RCI borrows basic assumptions from rational choice theory and those assumption alread received many criticisms due to its clear limitations. Actors cannot always behave 'rationally and selfishly' in actual life, and their decisions are also deeply affected by other factors, such as social norms or historical pressures (Vatn, 2005).

This paper looks in strengths and limitations of RCI. Regarding environmental policies, there can be similar issues about the RE policies. As many stakeholders are engaged in the RE market and related environmental issues, RCI can provide an practical lens to explain their behaviors and governments' choices of RE policies. On the other hand, the RCI approach also has clear limitations on the reality of RE expansions because of the information asymmetry and policy planners' self-interested situations,

3.3.1 Collective Action Problem and RE

This paper uses collective action theory as a theoritical tool for environmental and climate problems. Especially, this paper emphasizes the importance of well-designed institutions in addressing collective action dilemmas regarding the societal benefits of renewable energy (RE). Young (2005) argues that institutions that are well-fitted to the specific characteristics of environmental problems are more likely to effectively address collective action problems. In this context, RE policies can be considered as institutions implemented by governments to tackle the collective action dilemmas related to the societal benefits of RE.

RE offers large amount of positive externalities that benefit society overall (Kwon, 2015). These externalities include the reduction of carbon emissions, of course, by transitioning away from fossil fuels and the creation of a positive feedback loop between technological advancement and market growth within the green economy. Furthermore, RE policies play a crucial role in promoting technological innovation (Johnstone et al., 2010). However, goods which have positive externalities are likely to be produced in lesser amounts than the ideal, unless external interventions from governments or other structures occur to internalize their positive externalities. As a result, the ideal amount of production level of RE often cannot be achieved naturally, a scenario that Rational Choice Institutionalism (RCI) defines as a collective action problem. In this case, Political institutions or governments aim to deal with this underproduction by changing stakeholder behavior through informational and structural adjustments, guiding society towards optimal outcomes.

Vijge (2013) explores the lack of robust environmental governance in global communities through the RCI lens, offering two explanations. The first suggests that the situation itself could be a collective action dilemma, where the current structure of environmental politics fails to provide sufficient information to stakeholders, leading to a suboptimal outcome for all nations due to the absence of optimal governance and action. The second explanation posits that nations rationally and strategically chose to maintain the current lax governance because most countries prioritize national interests or security issues over collectively solving international environmental challenges such as climate change.

Building on Vijge's (2013) analysis, this paper seeks to explore the realm of RE policies and their outcomes. The underproduction of RE can be seen as a collective action problem, as the current societal structure provides insufficient information or optimal conditions for stakeholders to make decisions that would produce the optimal outcome of RE for the whole society. Alternatively, if the second explanation is adopted, the underproduction situation could be the result of each actor's strategic rational choice, with countries or other stakeholders deliberately choosing not to produce an adequate amount of RE due to their interest in other issues or profits.

As the focus of the paper is on the effectiveness of RE policies rather than the hidden intentions of policymakers or nations, the author adopts the first viewpoint of Vijge (2013) as the main perspective, assuming that the underproduction of RE itself is a collective action problem. RE problem could be exacerbated by existing structures that fail to provide sufficient information or incentives for stakeholders to invest in RE production. To overcome these challenges, there is a need for adequate institution—or in other words, policies—that can provide enough information and therefore facilitate more RE production and consumption. In conclusion, by adopting Vijge's (2013) first perspective, the foundational assumption for this research is:

Assumption 1.1: The underproduction of RE is a collective action problem.

To overcome these challenges, there is a need for adequate institutions, or policies, that can provide sufficient information and facilitate more RE production and consumption. This includes not only simple regulation of RE policies but also ensuring the expectation that the benefits of such RE investments and productions will be realized.

This paper views RE policies as fundamental institutions for RE expansion. RE policies are acting as adjustment tools by providing relevant information about RE (e.g. regulations implementation, sanctioning or monitoring) and imposing constraints on stakeholders' (e.g. RE producers') behavior. RCI provides another crucial assumption the research, which could be a ground rule in this paper:

Assumption 1.2: RE policies, as institutions, effect on RE production by modifying stakeholders' expectations and behaviors.

While it may seem obvious that national RE policies affect RE expansion, the underlying reasons for their influences can vary across different analytical frameworks. By adopting RCI as its analytical lens, the paper uses a distinct approach to understand the mechanisms through which RE policies are expected to affect RE expansion. This approach provides a straightforward rationale: by adjusting the expectations and behaviors of stakeholders through institutional mechanisms, RE policies can effectively carry the production and adoption of renewable energy.

3.3.2 Transaction Cost Theory and ETS

According to Rational Choice Institutionalism (RCI), one of the primary reasons for the establishment of institutions is to reduce transaction costs among actors (Hall and Taylor, 1996). Transaction costs refer to the expenses incurred in finding and communicating with partners, arising from the discrepancy between the buying and selling price of a product in a market (Woerdman, 2001).

Specifically, transaction costs in markets can be classified into three categories (see Figure 3): as depicted, the cost of using the market, the cost of establishing the rights and orders within the system, and the cost of maintaining the political system (Crals & Vereeck, 2005). These categories cover transaction costs borne by market stakeholders, and policy-related transaction costs, such as those brought by governments (Crals & Vereeck, 2005).

Moreover, the concept of transaction cost is closely linked to information cost, which refers to the uncertainty surrounding market conditions, such as the quality and quantity of products, and the expenses incurred by actors in acquiring sufficient information to facilitate a transaction (Vijge, 2013). From this standpoint, institutions can effectively reduce transaction costs by establishing clear rules and providing accurate information for transactions.

Transaction costs	Fixed (ex ante)	Variable (ex post)
– Market	– Information costs	– Insurance costs
	– Search costs	
	– Signaling costs	
	– Negotiation costs	
	– Contract costs	
– Managerial	– Set-up costs	– Monitoring costs
		– Enforcement costs
		– Bonding costs
– Political	– Lobbying costs	– Operational costs
	– Public support costs	– Compliance costs
	– Enacting costs	– Delay costs

Figure 3. Taxonomy of transaction costs. Crals & Vereeck (2005)

The establishment of ETS can also be explained by the transaction cost theory, as many scholars suggest that ETS provides a more effective and less costly alternative to environmental taxes or regulatory measures (Crals & Vereeck, 2005). The concept of tradable permits, such as ETS, originated from the idea of information and transaction costs. Coase (1960) initially argued that if transaction costs were low and property rights were well-defined, externality problems could be resolved through free negotiations among actors. Following the emergence of the Coase theorem, other scholars, such as Crocker (1966), noted that the Coase theorem could be applied to environmental pollution by establishing a trad?ble permit system (Nentjes, 2016). In the 1980s, the United States Environmental Protection Agency began using tradable permits for air pollution control on a domestic scale, and more countries implemented trading systems for greenhouse gases after the Kyoto Protocol, such as the EU implementing directives for a cross-national trading system (Crals & Vereeck, 2005). One advantage of the tradable permit system compared to taxation is that policymakers do not need to acquire all information regarding pollution. For taxation, it is crucial for governments to acknowledge the marginal external costs to reach the ideal optimum point. In contrast, with a tradable permit system, policymakers only need to determine the acceptable ideal amount of pollution, which can significantly reduce transaction costs for the government. Policymakers do not need to collect comprehensive information about environmental damage, abatement costs, or price flexibilities (Crals & Vereeck, 2005). Since corrective measures like taxation or regulation often involve significant costs related to information, enforcement, and compliance, these measures can hinder efficiency. In contrast, tradable permits offer an effective means of correcting environmental externalities (Crals & Vereeck, 2005).

Regarding RE, although ETS do not directly impose any requirements for RE production, they can induce market actors to provide more RE by naturally internalizing the externalities of RE through the application of tradable permits. This could be one of the main reasons why ETS has been selected by many OECD countries, as it is an effective tool for expanding RE capacity. Furthermore, this would explain the positive relationship between the coverage of ETS and RE capacity, since larger ETS coverage would be associated with a broader range of buyers and sellers, leading to lower transaction costs (Crals & Vereeck, 2005).

However, according to Woerdman (2001), tradable permits can sometimes have a negative effect, depending on the design of the structure and the resulting transaction costs. The level of transaction costs in a tradable permit system is greatly influenced by the "distribution and trading regime (Crals & Vereeck, 2005: p.216)". If permits can be traded freely on a large scale and the government distributes these permits for a limited time at no cost, there will be much lower transaction costs in the market. Conversely, if the tradable system is smaller and the government allocates those permits through further procedures, such as auctions, and there are many constraints on trading those permits, the tradable system would create a large amount of transaction costs (Woerdman, 2001; Crals & Vereeck, 2005).

For example, the European Union's Emissions Trading System (EU ETS) spans a vast geographic region and ensures a substantial pool of buyers and sellers for its tradable permits. It features a centralized trading hub known as the European Energy Exchange. Furthermore, the EU ETS supports an active secondary market, permitting the purchase and sale of allowances via brokers or alternative platforms. This arrangement facilitates the matching of market participants and traders at relatively minimal search expenses. In comparison to other singular ETS systems that cover only limited areas within a single nation, the EU ETS offers notably lower search costs. Additionally, the issue of environmental externalities often transcends national borders, necessitating a solution that is effective on an international scale.

Therefore, while ETS has its power and authority(in case of EU ETS) to coordinate market operations and reduce the costs associated with transactions, the specific setup of the

ETS (e.g. y how permits are distributed, traded, and regulated through the market) plays a pivotal role in providing these benefits. A well-designed ETS, specifically by broad coverage, minimal regulatory constraints, and the free flow of permits, can significantly diminish transaction costs, thereby encouraging producers to invest in RE. The reason is that a broad and dynamic market for permits enhances the process of locating and interacting with trading partners, streamlines the administration of permissions and transactions, and lowers the costs related to compliance and enforcement (Crals & Vereeck, 2005). Conversely, a constrained ETS framework, characterized by smaller, more regulated markets for permit trading, and laden with extensive trading restrictions, may unintentionally raise the costs associated with transactions. This surge in transaction costs has the potential to discourage market participants, impede the exchange of permits, and consequently decelerate the expansion of renewable energy capacities.

What kinds of transaction cost would be the core factor? Crals and Vereeck (2005) argue that set-up costs are not a significant issue to reducing transaction costs in emission trading systems. The major transaction costs arise from the design of the system, instead, including factors such as coverage, regulatory interference, and allowance methods. To investigate this important factor, this paper includes 'coverage of ETS in whole emission of each nation' as a dependent variable in the regression analysis. Crals and Vereeck (2005) suggest that a larger ETS coverage, which can be connected to a larger market size for trading permits, would generally have a more profitable impact on renewable energy (RE) growth by reducing transaction costs.

While there are other factors that could influence the degree of 'well-design', such as the level of regulatory constraints and free exchange of permits, the coverage of ETS is one of the most straightforward factors for standardized quantification and has been studied by previous research (Dolphin & Xiahou, 2022). As a result, this paper uses 'coverage of ETS in whole emission' as a proxy for the well-designing and functioning of ETS.

Furthermore, the coverage of ETS not only decreases transaction costs regarding trading allowances but also puts high pressure on trading allowance cost, ultimately leading to RE expansion (del Río, 2017). If ETS covers more industrial field, a larger number of companies would need to purchase pollution permit payments, as the number of permits is limited. Increasing demand by those buyers would bring the price high, since the number of these permits is limited by government officials. Companies that rely on polluting fuels like oil, coal, or gas require a significant number of permits due to their high pollution levels. As permits become more expensive, the cost of using these polluting fuels also increases. In the end, ETS makes RE sources relatively more cost effective compared to fossil fuel power.

3.3.3 Principal-Agent Problem and FITs & RPS

McAfee and McMillan (1986) point out that the principal-agent problem can arise between governments and private contractors due to information asymmetries and conflicting interests. For instance, government contracts with private contractors may result in a moral hazard problem because the government cannot directly monitor the contractor's efforts to reduce production costs, and the contractor's objective is to maximize its own profits rather than working in the interests of the principal. Information asymmetry is a critical issue in this context, as agents typically have more information than principals, leading to moral hazard on the part of the agents.

Blonz (2023) investigates the principal-agent problem in energy efficiency policies in the United States. Governments offer subsidies to households that upgrade their kitchen electricity appliances to more energy-efficient models. However, private contractors may deliberately install low-quality appliances that barely meet or fall just below the standards and report a large number of installations to the government to maximize their subsidies. According to Blonz's (2023) empirical research, this profit-seeking behavior generates some net benefits for agents but imposes greater costs on society as a whole. In other words, the principal-agent problem may benefit agents while imposing higher costs on society. While there are several strategies to mitigate the principal-agent problem, such as providing more information to the principal or aligning incentives between principal and agent through additional incentives and penalties, such monitoring and compliance measures also involve a certain level of transaction cost (Blonz, 2023).

Regarding the renewable energy (RE) policies, the principal-agent framework is a applicable tool for understanding the structure and the relationship between governments (principals) that implement RE policies and the producers (agents) who have to execute policies on site. When it comes to financial subsidies in RE policies, such as feed-in tariffs (FITs), this framework highlights some potential drawbacks. FITs are designed to promote the adoption of renewable energy by guaranteeing producers a fixed price for the energy they generate over a set number of years. This approach aims to provide stability and predictability for RE producers. RE producers would realize that it is much easier for them to secure financing and plan for the future (Menanteau et al., 2003). However, there are several consequences associated with this type of policy which was not meant to be (Kwon, 2015; Menanteau et al., 2003; Mitchell, 2000).

FITs with fixed prices may hinder the long-term competitiveness of RE production, as agents may not have the same incentives to invest in RE as the government does (Kwon, 2015). Menanteau et al. (2003) and Mitchell (2000) point out that FITs may not encourage producers to find more efficient, cost-effective methods of generating electricity. Since the return on investment is guaranteed regardless of the production cost, there may be less motivation for energy producers to innovate or reduce operational costs. This contrasts with competitive mechanisms like auctions or market-driven prices, where lower production costs directly benefit the producer. Additionally, FITs have faced criticism due to their high overall expenditure (Menanteau et al., 2003). There is concern that the financial burden of these subsidies, whether borne by electricity consumers through higher utility bills or by the government (indirectly taxpayers), can be too large (Menanteau et al., 2003).

On the other hand, quantity quota systems have proven to be particularly effective in addressing the principal-agent problem more effectively (Menanteau et al., 2003). Renewable portfolio standards (RPS) are a common example of a quantity quota (Kwon, 2015). RPS requires that a certain percentage of the total energy production or consumption must come from renewable sources, encouraging electricity suppliers to either increase their RE production or purchase credits from others who exceed their quotas. This creates a competitive environment where RE providers are motivated to innovate and reduce costs not only to meet the quotas but also to capitalize on the market for credits (Dong, 2012). From this perspective, RPS can lead to more sustainable and long-term reductions in production costs compared to FITs, driving the overall growth and competitiveness of the RE sector (Kwon, 2015).

In conclusion, while both FITs and RPS have their merits and limitations, the principal-agent theory offers insights into designing RE policies that effectively incentivize providers while safeguarding public interest. Although empirical studies show mixed opinions on the actual effectiveness of FITs and RPS (Menanteau et al., 2003; Dong, 2012; Gawel et al., 2015; Polzin et al., 2015; Zhao et al., 2018), this paper adopts the principal-agent theory and focuses on the limitations of FITs from that perspective.

In the data and analysis section, this study incorporates the 'duration of Feed-in Tariffs (FITs) agreements' as a variable impacting the regression analysis. Drawing from the principal-agent framework, it posits that the likelihood of moral hazard by agents increases with the extension of contract duration. In the absence of sufficient protective measures, prolonged agreements may heighten the risk of moral hazard, leading to situations where agents might prioritize their interests over those of the principals.

Nevertheless, the duration of these contracts could also signify enhanced policy stability conducive to the growth of renewable energy. The consistency of policy is crucial for investments in renewable energy, yielding beneficial outcomes over time (Johnstone et al., 2010). Barradale (2010) explored how uncertainty in climate policy impacts investments in wind energy, concluding that diminishing uncertainty is crucial for effective renewable energy policy. Furthermore, rational choice institutionalism (RCI) suggests that actors' expectations about others' future actions significantly influence their decisions. Within the realm of renewable energy policy, investors seeking to fund renewable energy projects desire a stable and predictable policy environment to evaluate the feasibility and profitability of their ventures. Extended periods of FITs contracts provide this steadiness, reflecting a government's dedication to renewable energy support, which can lower investment risks and boost investor confidence.

All in all, the length of FITs contracts has a twofold impact. It directly affects the investment timeframe, enabling investors to plan and secure returns over a longer period. This aspect is especially critical in the renewable energy sector, characterized by high initial costs and long-term returns. Additionally, extended contracts are indicative of policy stability. Such consistency mitigates regulatory and political uncertainties, frequently mentioned as substantial hurdles to investing in renewable energy. By issuing long-term FIT contracts, governments can alleviate these concerns, rendering renewable energy initiatives more appealing to investors.

Moreover, this study acknowledges that the efficacy of policies, including the influence of FITs contract duration on renewable energy growth, does not exist in isolation. Various external factors, like the investment climate, technological progress, market trends, (and perhaps economic conditions), significantly impact the outcomes of renewable energy expansion. To consider these external influences, the analysis includes multiple control variables in the regression model. This method is designed to discern the specific effect of FITs contract length on renewable energy investments and development, offering a more nuanced understanding of policy impact on renewable energy progression.

4. Methods

4.1 Measuring the RE policy instrument effectiveness

Building on this established body of research, the current paper extends the panel data analysis to explore the effectiveness of three types of RE policy instruments; financial subsidies, regulatory measures, and market-based instruments. This paper conducts the panel data regression analysis about the impact of various factors on RE expansion over specific time period.

How this paper measures the policy effectiveness is straightforward. This paper compares the degree of RE policy instrument with the amount of RE expansion. FITs are proxy for financial subsidies, RPS is a proxy for regulatory measures, and ETS is a proxy for market-based instruments. However, constructing the variables and choosing the dataset sources need careful scrutiny, since it will heavily affect overall outcomes. Luckily, since these three instruments are prevalent in many countries, many sources offer related dataset. This paper tried to choose the most reliable dataset, either from formal institutions (such as OECD data) or research institutions.

4.2 Dataset

This study employs a quantitative methodology, especially implementing panel data analysis to investigate the impact of renewable energy (RE) policy instruments across different countries over time. The choice of panel data is rooted in the nature of RE expansion, which happens gradually and is significantly influenced by the implementation of various policy instruments. Such policies may take more than years to manifest their full effect on RE markets, making longitudinal data essential for capturing these dynamics.

Panel data can track multiple observational units across different time points. This distinct feature offers a robust framework for analyzing the temporal effects of national RE policies. This type of data is uniquely designed to control for time-invariant factors, such as inherent differences among countries, that could skew the analysis. By encompassing observations from multiple countries over a series of time points, panel data allows for a comprehensive examination of how RE policies influence the growth and development of RE sectors.

Panel data analysis is a prevalent method in research field, with analyzing RE policy effectiveness over time. Researchers like Dong (2012), Polzin et al. (2015), Liu et al. (2019), and Kersey et al. (2021) have adopted panel data to explore the longitudinal effects of RE policy implementations. These studies highlight the value of panel data in providing insights into policy impacts over time, affirming its selection for this paper's analysis.

One of the primary advantages of panel data is that, it has ability to offer a consistent and reliable explanation of phenomena over time. It can integrate numerous observational units across various time frames and it mitigates the risk associated with drawing causal inferences from static data, which might not account for temporal dynamics. However, despite its powerful benefits, panel data analysis also has some challenges. There exists the potential for autocorrelation, where observations within a panel are more similar to each other than to those from other panels, and contemporaneous correlation, where observations from different panels at the same time point may be correlated. Such correlations can introduce biases into the analysis. If not properly addressed, there would be a clear limitation to the methodology (Marques et al., 2010; Polzin et al., 2015).

In addressing these challenges, this paper employs the most relevant econometric models that are designed to correct for potential autocorrelation and heteroskedasticity, thereby enhancing the robustness of the outcome.

4.3 Regression Models

Previous studies have found that when trying to determine how RE policies affect RE expansion, the geological and temporal effects can get mixed up with the policy effects themselves (Marques et al., 2010; Polzin et al., 2015; Kersey et al., 2021). This mix-up makes it harder to understand the true impact of these policies. For instance, countries in the EU might have similar policies during the same period, which could lead to similarities in their data that are not just about the policies' direct effects. Marques et al. (2010) also noted that autocorrelation and heteroskedasticity issues are likely to occur in RE panel data approach.

To tackle these complexities, it is important to deal with autocorrelation and heteroskedasticity. Autocorrelation refers to the situation that data points became too similar within a panel and heteroskedasticity means that there are certain level of inconsistencies in variable the data. To address the issues, this study uses a specific method called the panel-corrected standard error (PCSE) model. This model helps correct these problems, making our analysis more accurate.

Lastly, to increase the robustness of the outcome, we also use another complement approach called the random effects model. However, while the PCSE model is a proper tool for dealing the issues of autocorrelation and heteroskedasticity, the random effects model does not directly deal with the problems related to data points being too similar to each other over time or across different countries at the same time (Polzin et al., 2015). In conclusion, using the PCSE model helps addressing these specific data issues effectively, and using the random effects model as a supplementary approach makes a more comprehensive analysis.

4.3.1 Panel-Corrected Standard Error (PCSE) Model

For the analysis of the model, this paper adopts PCSE model to analyze panel data. There are several benefits of using PCSE model, making it the model widely-used in the investigation of econometrics.

First, it has strong applicability with this paper's dataset characteristic. The dataset method in this paper is time-series cross section (TSCS), which refers observations across various time and different spaces. PCSE model suits well with TSCS data by addressing and correcting the some challenges from TSCS data, such as outlier problems or dependent issues (Koliev, 2022; Ikpesu et al., 2019).

Secondly, PCSE is an effective ecometric tool for addressing heteroskedasticity and autocorrelation issues (Ikpesu et al., 2019). Heteroskedasticity happens when there is a variation in the variance of error terms among different observations (Angrist & Pischke, 2014). It could be a challenge in TSCS data due to varying environmental, economic, and social factors across observation units. Autocorrelation, especially in its first-order form, emerges when an error term for a specific unit at one time is connected with its error term at a preceding time, breaching the ordinary least squares (OLS) model's assumption of independent error terms. This breach results in skewed standard error calculations and, therefore, compromises the reliability of statistical conclusions (Koliev, 2022).

Especially, in this paper, the number of observation countries is 30, which is more than observation length (21 years), which means that standard assumptions of ordinary least squares models are less likely to be met. In other words, when the number of cross-sectional units exceeds the number of time periods, the risk of risks of heteroskedasticity and autocorrelation could be exacerbated.

Polzin et al. (2015), which studies the RE policy effectiveness in OECD countries, also noted that auto correlation problem could occur in RE data due to similarities in some countries' RE policy. Koliev (2022) also mentioned the risk of heteroskedasticity and first-order autocorrelation of the panel data. The estimation of ordinary least square with PCSE which is robust to unit heteroskedasticity and contemporaneous correlation across the unit would be relevant for that risk (Koliev, 2022). Therefore, this paper also used the linear regression with panel-corrected standard errors. This regression corrects heteroskedasticity and autocorrelation across not only cross-sectional but also time-series dimensions of the data.

To recap, this model select the PCSE model for several reasons. The PCSE is employed due to its robust capability to remain stable in the presence of autocorrelation and its resistance to being easily affected by outlier values. Additionally, the PCSE approach is particularly effective for analyzing complex panel data that changes over time, such as TSCS data (Ikpesu et al., 2019).

4.3.2 Random Effect Model

For the analysis of the dataset, this paper employs the random effects model as a complementary option, which is another useful tool for panel data analysis. Specifically, the RE model is well-suited for the TSCS data as it allows for the inclusion of time-invariant characteristics of the countries that might influence the RE expansion. This model assumes that such unobserved individual effects are random and uncorrelated with the regressors.

The random-effects model is generally more effective at generating precise estimates of β (compared to fixed effect model) when the number of observations for each unit is relatively small, and the correlation between the independent variable and unit effect is comparatively little (Clark & Linzer, 2015). Given that this paper is analyzing TSCS data across 30 OECD countries over a 21-year span, random effect model would be also relevant tool, since RE policy implementation and its outcomes might be influenced by inherent, unobserved national characteristics, such as economic, environmental, and social factors. It is known that socio-economic factors such as national social environments, national wealth and governance deeply affect the RE expansion (Kim, 2011). This paper also conducted Hausman test for comparison of the random and fixed effect, and the test has a p-value of 0.1465, which indicates that random effect is more relevant than fixed effects.

Moreover, the random effect model has a unique advantage over fixed effect models. In contrast to fixed effect models, which attribute these variances to the independent variables and exclude characteristics that remain constant over time, the random effects model incorporates these variances within the error term. This method retains the variation arising from unchanging characteristics, offering a more comprehensive understanding of the factors influencing the effectiveness of renewable energy policies. Essentially, the random effect model is capable of managing unobserved variability (Clark & Linzer, 2015).

However, as Polzin et al. (2015) have pointed out, the random effect model does not automatically account for serial correlation (the relationship of a variable with its past values over time) or contemporaneous correlation (the synchrony of error terms across different units at the same time). These challenges do not get addressed by merely employing the random effects model. To deal with such correlations, sophisticated econometric methods, like Panel-Corrected Standard Errors (PCSE), are frequently employed (Polzin et al., 2015).

4.4 Variables

4.4.1 Dependent Variables

Multiple indicators can represent RE production, and various research chose electricity generation from RE sources or electricity capacity of RE as a proxy of RE expansion (Polzin et al., 2015; Kersey et al., 2021). The primary reason for focusing on electricity generation is because FITs and RPS are predominantly targeted at electricity suppliers. FITs ensure a fixed price for electricity from RE sources, while

RPS mandates a specific portion of electricity to be generated from RE (Kwon, 2015). In case of heating and cooling, these may not be counted under electricity generation if RE is used directly for heating without being converted to electricity. Additionally, heating and cooling sectors often benefit from other regulatory or financial incentives, such as Barcelona's regulation requiring new buildings to produce 60% of their hot water using solar energy, or tax rebates offered in other cities as financial incentives (IRENA et al., 2020). However, such measures fall outside the scope of FITs or RPS categories.

Concentrating on the electricity sector is crucial, as it is a major source of carbon emissions. The demand for electricity is expected to rise, potentially increasing reliance on fossil fuels if sustainable alternatives are not implemented (Kersey et al., 2021). Moreover, electricity data tends to be more widely available and standardized across countries and years compared to data on total RE generation, which encompasses a variety of energy. The availability and consistency of electricity data are essential for conducting comprehensive, cross-national longitudinal studies, especially for assessing the long-term impacts of policies.

The dependent variable for this analysis is the RE electricity generation in each OECD country every year, which will be quantified as the amount of RE electricity generated annually. The data is acquired from QoG, which is originally from International Renewable Energy Agency (IRENA), covering from the year 2000 to the year 2021. IRENA (2024) dataset covers diverse RE sources, like hydropower and solar. Electricity generation, measured in gigawatt-hours (GWh), encompasses the total gross electricity output from power stations, combined heat and power plants, and other decentralized generators, recorded at the generation output points. This calculation encompasses both on-grid and off-grid electricity production and includes electricity utilized within the energy industries themselves, not solely the electricity supplied to the grid (IRENA, 2024).

Additionally, the vast scale of RE generation data measured in MWh requires the logarithmic transformation of the generated RE values for regression analysis. This statistical adjustment not only normalizes the data, making it more amenable to analytical procedures, but also helps in mitigating the influence of outliers, thereby ensuring a more accurate interpretation of the relationship between RE policies and electricity generation outcomes. This is commonly done in RE policy instrument research, such as Polzin et al. (2015)

4.4.2 Independent variables

Regarding the policy variables, there are three dummy variables and three continuous variables. Dummy variables cover the implementation of FITs, RPS and ETS from the year 2000 to the year 2021. Continuous variables cover the expenditure and length of FITs, and coverage of ETS. FITs are proxy for financial subsidies and price regulation, while RPS is a proxy for stronger top-down quantity regulation and ETS is a proxy for market-based instrument. In case of dummy data, all data were collected from various resources, since one source usually only provide limited amounts of period. This paper merged the dataset with cross-checking against several resources. In case of continuous datasets, each one variable has only one source, to reduce the risk of overlapping different measurement methods on one variable.

4.4.2.1 FITs variables

Regarding the continuous dataset, OECD data provides two continuous variables: amount of expenditure and length of contract by each country's FITs policies, from the year 2000 to the year 2019 (OECD, 2022). The OECD (2022) defines FITs as the support policies for RE, offering long-term agreements that set a stable price for electricity produced from renewable sources. This setup helps reduce the financial uncertainties often associated with renewable energy projects, making it more appealing for investors and producers to venture into this area. This dataset includes seven major types of renewable energy: biomass, geothermal, marine energy, small-scale hydropower, solar, wind, and waste-to-energy.

The dataset focuses on two main variables for each country's FITs policies: the total money spent (expenditure) and how long the contracts last (contract length). Expenditure, shown in US dollars, reflects how much financial support is given to these renewable energy contracts, indicating the level of investment countries are making in their renewable energy sectors. Contract length, shown in years, tells us how long these support conditions last, which is crucial for giving energy producers a sense of security and stability. The longer the contracts, the more likely producers are to invest in renewable energy since they have more assurance of ongoing support. The duration of these contracts is typically decided based on the terms of the power-purchasing agreements that are granted.

Regarding the dummy dataset, this paper acquired data from OECD Empirical Policy Analysis Unit. This data covers from 1978 to 2012 and defines FITs is as policy with specific rates of feed-in tariffs for RE. OECD EPAU (2013) updated this data in March 2013 after checking it against other big databases like IEA and IRENA. Our study uses this data from 2000 to 2012.

For more recent years, from 2013 to 2021, we added extra information on FITs and RPS from Zhao et al. (2018) and the IEA's 2024 policy database. The IEA database is easy to access and gives detailed descriptions of renewable energy laws. We turned this detailed information into simple yes-or-no variables to show whether FITs were in place. Especially, this paper checked any new laws or changes after 2012 to make sure the data was accurate. Furthermore, to ensure the accuracy and reliability of the data concerning FITs policy implementation, this paper conducted a thorough verification by cross-checking the derived dummy dataset against another nominal dataset from the OECD (2022) that also tracks FITs implementation.

4.4.2.2 RPS variables

This paper created RPS dummy dataset based on several sources. OECD Empirical Policy Analysis Unit provides comprehensive data for RPS implementation, from the year 1978 to the year 2012. In this data, RPS is defined as policy quota limits for RE and FITs is defined as policy with specific rates of feed-in tariffs for RE. OECD EPAU (2013) formulates the policy dataset from previous six research teams, and OECD environment directorate updated the latest data in March 2013, with cross-checking against other existing databases, such as IEA and IRENA. This paper used the OECD EPAU (2013) data from year 2000 to year 2012.

For the period extending from 2013 to 2021, this paper augments its analysis with additional data on FITs and RPS implementation extracted from the works of Zhao et al. (2018) and the IEA (2024) policy database. The IEA's database, known for its openness and accessibility, provides detailed qualitative information on the legislative context surrounding renewable energy policies, including specific laws and regulations. This study has taken the initiative to systematically convert this qualitative textual data into quantitative dummy variables, signifying the presence or absence of RPS policies. This conversion process involved a careful examination of legislative updates or the introduction of new legislation relevant to renewable energy policy post-2013.

4.4.2.3 ETS variables

In case of ETS dummy dataset, dataset is collected from Dolphin & Xiahou (2022), which covers the implementation of ETS from the year 2000 to the year 2021. According to the Dolphin & Xiahou (2022), a country is considered to implement an ETS when at least one sector or gas recognized by the Intergovernmental Panel on Climate Change (IPCC) falls under the scope of the mechanism. These instruments do not need to encompass every economic sector for this classification to hold. For example, if a country has established an ETS that applies exclusively to its electricity sector or to carbon dioxide emissions within that sector, this initiative would be acknowledged as an ETS implementation, provided the sector aligns with the IPCC's standards. However, it is important to note that Dolphin & Xiahou (2022) clarify a specific exclusion criterion: pricing mechanisms that are solely directed at non-CO_2 greenhouse gases, such as methane or nitrous oxide, do not qualify under this dataset's definition of an ETS.

The continuous variable in this research is the extent of coverage by ETS, information for which is sourced from the comprehensive work by Dolphin & Xiahou (2022), as made available through Our World in Data. This variable plays a crucial role in understanding the broadness and impact of ETS policies across different nations by measuring the percentage of a country's carbon dioxide emissions that fall under the ETS regulation. Dolphin & Xiahou's research quantifies the ETS coverage by evaluating the share of CO_2 emissions generated by each sector within a country. The logic here is straightforward: the broader the ETS coverage, meaning the more it includes sectors with high emission levels, the larger the share of national emissions it governs. This data provides an indicator of the implementation level of each country's ETS, suggesting that a higher coverage percentage signifies a stronger and mature level of ETS mechanism.

4.4.3 Control variables

In this study, four control variables were carefully selected for the regression analysis to ensure a comprehensive understanding of the factors influencing RE production: carbon emissions, land area, long-term interest rates, and Gross Domestic Product (GDP). The selection of control variables are mainly based on previous research example.

First, in case of carbon emissions, the data measures the total emissions of carbon dioxide (CO_2) resulting from the consumption of solid, liquid, and gas fuels, as well as from gas flaring. This inclusion follows the precedent set by studies like Polzin et al. (2015), which utilize carbon emissions as a proxy for a country's energy dependency. This approach assumes that assessment energy consumption patterns, influenced by carbon emissions levels might affect or be affected by country's RE production. World Bank (2023), through the QoG dataset, provides these figures in metric tons per capita, spanning from 2000 to 2022, offering a per-person quantification of CO_2 emissions to account for differences in energy usage across countries.

Second, land area is used as a control variable, which could affect the size of the RE capacities. Larger land areas might afford more opportunities for deploying RE technologies, especially those requiring substantial space like wind farms and solar panels. It is also provided by World Bank (2023), through the QoG dataset, which defines land area as a country's total area. and data covers surface area such as mountainous regions, glaciers, forests, wetlands, and also other temporarily or permanently uninhabitable regions. The data is measured in square kilometers, from the year 2000 to the year 2021.

Third, long-term interest rates are one of the key economic indicators provided by the OECD datasets. These rates affect the cost of financing RE projects, where lower rates can stimulate investment by reducing the cost of borrowing. Polzin et al. (2015) also applied long-term interest rates as control variables since interest rates would affect the investment decisions for RE. The data is measured in percentage point each year, from the year 2000 to the year 2021.

Lastly, GDP is another key economic indicator provided by the OECD datasets, serving as a gauge of a country's economic health and capacity. Higher GDP levels may indicate more resources available for investing in RE technologies and infrastructure. It is prevalent to use GDP as control variables in many previous RE policy research, including Pozin et al. (2015); Kersey et al. (2021). It is measured in local currency of each country, from the year 2000 to the year 2021.

Together, these control variables enrich the analysis by accounting for environmental, geographical, economic, and financial dimensions that could influence or reflect the status and progress of RE development. By incorporating these variables, the study aims to isolate the specific effects of RE policies on electricity generation while controlling for a broad range of influential factors.

5. Data

5.1 Dataset Sources

This paper covers a dataset constructed from several institutional or academic sources for examining the effectiveness of RE policies on RE expansion. As this paper aims to examine the effectiveness in many different countries, it is important to ensure the data is standardized among different countries for cross-comparisons.

First, the Quality of Government (QoG) Institute by Gothenburg University provides a collection of dataset, including OECD data, called QoG OECD, for cross-country comparison studies. The QoG has not only its own dataset but also compilation datasets, which means datasets were drawn from various reliable sources related to relevant concepts, and usually being cross-checked with other sources. This makes it easier to collect the several RE variables at once with high reliability. The QoG provides several common variables for RE expansion and other control variables of each nation. This paper used RE references from IRENA (2024); Teorell at al. (2024); World Bank (2023) which is provided by the QoG data.

Another main data source is the OECD Data. OECD data provides relatively profound dataset of OECD countries for cross-country comparison. It provides primary economic factors: Gross Domestic Production (GDP), long-term interest rates are available at OECD Data. Furthermore, it also provides detailed FITs implementation data. In specific, it provides two kinds of detail data: First, expenditure of each year by FITs. This data indicates how much each country has spent on FITs as an expenditure by the government. More the expenditure, more the incentives for the producers which can lead to larger amount of investment or larger number of RE industry participants. Second, length of contract by FITs. The length of the contract could be a proxy for RE policy stability, which mentioned in theory part. More investments will be drawn to RE industries with lengthy contract if they have been convinced by the clear expectations for the RE subsidies,. On the other hand, it could cause the side effects due to moral hazard problem.

Furthermore, OECD Environment Directorate's Empirical Policy Analysis Unit (OECD EPAU) also provides unique dataset for RE policies. It provides a data and report, which is mainly covering FITs and RPS dummy value records for each country.

Regarding the RE policy data, the International Energy Agency (IEA) specifically provides policy datasets for each energy sector. The policy database provides brand new legislative policy information including implement year and jurisdictions status. Especially, IEA provides RPS and FITs legislation records from countries around the world with detailed descriptions of policy/legal contents. IEA policy dataset only provides qualitative form of data and does not provide coded data or nominal data.

Lastly, Dolphin & Xiahou (2022), from Our World in Data, provides the worldwide carbon pricing dataset from year 1989 to 2022. The data includes the ETS dummy value and the coverage of carbon emission by ETS. This dataset includes countries with cap-and-trade system, where the number of emission allowance is fixed in a given country. If the country has at least one sector covered by ETS, it is coded as having ETS. Furthermore, some countries like Canada has an ETS at a sub-national level, and this case is also coded as having ETS.

Table A is a general overview of data, including defined variables, their meanings, and the sources from where they were derived.

Table A

Data: Categories, Definition and Sources

Category	Variable	Definition	Source
Dependent variables	Renewable Energy (Electricity) Production	The logged value of generated RE electricity (Gwh)	QoG
Financial Incentives	Length of FITs	The length of contract years of FITs (year)	OECD
	Amount of FITs	The amount of expenditures of FITs (Dollar)	OECD
	Dummy FITs	Dummy variables of implementation of FIT	OECD EPOC, IEA
Regulatory Measures	Dummy RPS	Dummy variables of implementation of RPS	OECD EPOC, IEA
Market-based instruments	ETS cover	The percentage of ETS coverage (percentage)	Dolphin & Xiahou (2022)
	Dummy ETS	Dummy variables of implementation of ETS	Dolphin & Xiahou (2022)
Control variables	Carbon Emission	carbon emissions in metric tons per capita (metric tons)	QoG
	Interest Rate	long-term interest rate (percentage)	OECD
	Land Area	lang area (square kilometers)	QoG
	Logged GDP	Logged value of Gross Domestic Product	OECD
	Squared GDP	Squared value of Gross Domestic Product	OECD

5.2 Case Selection

5.2.1 Country Selection

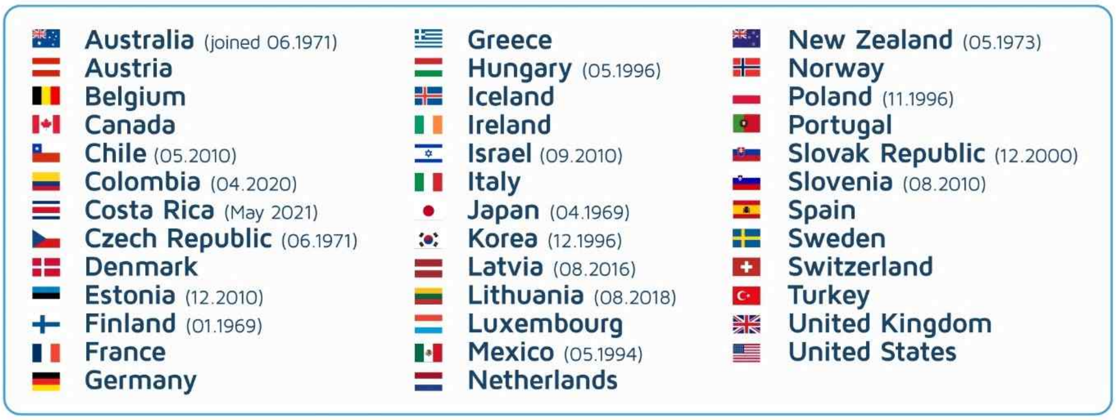

Figure 1. 38 OECD Member states. Development Aid (https://www.developmentaid.org)

OECD is an international organization including 38 member countries, which started in 1960 with 18 European states with the United States and Canada (see Figure 1). Since 2010, eight countries newly have joined the membership, and Costa Rica join in 2021 most recently. OECD countries and their key economic partners takes up about 80% of international trade and financial investment. It has a significant role in facilitating socio-economic policy discussions among member states and key partners significantly which impacts global economic governance[3]).

In 1990, OECD countries take up more than 50% of worldwide carbon emissions. After the 2010s, the share of OECD countries in global emissions decreased to less than 40%, surprisingly, but these nations still represent a significant portion of the world's emissions (OECD, 2015). This makes it important to analyze the data of the world's main

2. 3) OECD. OECD members and partners. https://www.oecd.org/about/members-and-partners/

emitters to assess the effectiveness of their policies. Moreover, it has been said that many OECD countries bear historical responsibility for climate change, providing them with strong incentives for an energy transition. These countries have been at the forefront of RE expansion, as their developed economies have greater financial and technical capacities to implement policies.

This paper specifically aims to examine OECD countries concerning renewable energy policies for several reasons. Many countries in OECD have their historical contribution to global emissions and their capacity for an energy transition. Furthermore, OECD countries play influential role in setting global standards, and have relatively long experience of RE policies compared to other countries.

Firstly, many OECD countries are often first movers in environmental and energy policies (OECD, 2015). Their policies on renewable energy, emissions reduction, and sustainability have a ripple effect, influencing non-member countries and international policy frameworks. By studying the RE policies of OECD countries, this paper seeks to understand the effectiveness and mechanisms behind policies.

Secondly, OECD countries[4)] have diversity within their members. When it comes to economic structures, energy supply and demands, and environmental policies, provides a profound comparative basis for cross-sectional analysis. This diversity allows for a nuanced examination of how different types of policy instruments—such as subsidies, tax rebate, or regulatory mandates—perform in different socio-economic contexts. It enables the identification of best practices and challenges in RE policy implementation across a spectrum of

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3. 4) OECD. OECD members and partners. https://www.oecd.org/about/members-and-partners/

developed economies.

Moreover, OECD countries have established comprehensive data collection and reporting mechanisms, providing relatively reliable quality, longitudinal data on energy production, consumption, and policy outcomes. This wealth of data is essential for empirical research and regression, allowing for detailed policy analysis, trend identification, and the evaluation of policy effectiveness over time.

Finally, by focusing on OECD countries, this paper acknowledges the significant role these nations play in global economic governance and international trade and investment flows related to energy. Their actions and policies can significantly influence global markets for renewable energy technologies, commodities, and financial resources, shaping the broader international landscape for RE expansion. In conclusion, examining renewable energy policies within OECD countries offers critical insights into the dynamics of policy effectiveness in RE expansion.

Table A presents OECD countries that are included in this paper regression. An "O" marks the presence of a policy in a given country, while an "X" denotes the absence of a policy throughout the time period. The definitions and categorizations of FITs, RPS, and ETS can vary among researchers. Therefore, this table utilized data from the definition of OECD and other research outcomes as its basis for policy categorization. The source of the data is mentioned in Table B.

As mentioned before, this paper employs the PCSE model. However, the PCSE model does not guarantee the resolution of all statistical challenges; potential biases or correlation issues may still occur (Ikpesu et al., 2019). To tackle the problems of outliers and heteroskedasticity affecting our analysis, this study includes only those countries with over ten years of data for regression using the PCSE model. Specifically, eight OECD member countries with less than ten years of policy instrument data were omitted from this study. These countries include Chile, Colombia, Costa Rica, Estonia, Israel, Mexico, the Netherlands, and Türkiye. For instance, although the Netherlands had implemented FITs, there was no corresponding data available in the OECD FITs dataset. Similarly, countries like Mexico and Chile had incomplete datasets spanning less than ten years. Most recently joined OECD members, Costa Rica, which joined in 2021, do not have the requisite data needed for this regression analysis yet. As a result, the regression analysis was conducted with data from 30 out of the 38 OECD countries.

Table B presented includes all policy instruments that were in use by 30 countries from 2020 to 2021. For example, during this time, Japan transitioned from RPS to FITs, and this change was considered as an implementation of both policies.

Table B

Data: Country Selection with three policy categories

Country	FITs	RPS	ETS
Austria	O	X	O
Australia	O	O	X
Belgium	X	O	O
Canada	O	X	O
Czech Republic	O	X	O
Denmark	O	X	O
Finland	O	X	O
France	O	X	O
Germany	O	X	O
Greece	O	X	O
Hungary	O	X	O
Iceland	X	X	O
Ireland	O	X	O
Italy	O	O	O
Japan	O	O	X
Korea	O	O	O
Latvia	O	X	O
Lithuania	O	X	O
Luxembourg	O	X	O
New Zealand	X	X	O
Norway	X	O	O
Poland	O	O	O
Portugal	O	X	O
Slovak Republic	O	X	O
Slovenia	O	X	O
Spain	O	X	O
Sweden	O	O	O
Switzerland	O	X	O
The United Kingdom	O	O	O
The United States	X	O	O

Note 1: Eight OECD countries were not included in the regression if the observation year is less than 10 years due to the omitted data: Chile, Colombia, Costa Rica, Estonia, Israel, Mexico, Netherlands, and Türkiye.

Note 2: This table features all instruments that have been used by countries between 2000-2021. (e.g. Japan switched from RPS to FITs during that period, and both of them were regarded as implementation)

Note 3: Definition of FITs, RPS, and ETS implementation can vary depending on researchers. This paper used the research outcome from OECD FITs data (2022), OECD EPAU (2013), Ritchie & Rosado (2022) as sources.

5.2.2 Period Selection

This paper covers at data from 2000 to 2021. To relevantly analye panel data, and to examine RE policies, those timeline is a key period for understanding how the world has been shifting towards using more renewable energy. This timeframe is selected for several reasons that underscore its significance in the context of global RE policy and investment trends.

Firstly, the commencement of the 21st century marked a turning point in the global energy landscape, characterized by a discernible shift towards renewable energy sources (Lins et al, 2014). The early 2000s saw the beginning of significant, large-scale investments in RE, driven by a growing recognition of the need for sustainable energy solutions. This shift was not merely incidental but represented a conscious move by several nations and the global community towards addressing the challenges of climate change and energy security (Lins et al, 2014).

The period identified by Lins et al. (2014) as the "first decade for RE progress (p.5)" from 2004 to 2014 is particularly noteworthy. It encapsulates a era of accelerated growth and pivotal developments in the RE sector. This decade was characterized by significant technological advancements, economies of scale in RE technologies. Plus, there was an enormously increasing number of countries implementing promoting policies and frameworks for RE development. Many countries started to support renewable energy more strongly through new policies, which helped the industry grow quickly.

This time period includes significant events that pushed countries towards renewable energy even more. Economic downturns and energy crises made it clear that relying on traditional energy sources wasn't always reliable, leading countries like Germany, Denmark, and Spain to create big markets for renewable energy (Lins et al., 2014)

After the 'first decade of RE', there is another important layer, the Paris agreement. Paris Agreement in 2015 adds another important layer of relevance to the chosen timeframe. The agreement represented a landmark moment in international climate policy, setting ambitious targets for greenhouse gas emissions reductions and catalyzing nations worldwide to ramp up their national alleges to RE as part of their climate action plans.

In addition, there is relatively more comprehensive and high-quality data after 2000. It was the time when countries really started to invest in renewable energy on a larger scale. For example, detailed data about the length and expenditure extent of FITs is available in OECD after 2000. It seems that, before the nineties, the collection and archiving of data related to renewable energy policies, investments, and outputs were not as systematic as after 2000 according to OECD official data. High-quality data after year 2000 allows for more accurate trend analysis, policy impact assessment.

In conclusion, if one is looking at the years from 2000 to 2021, it covers some of the most critical times for renewable energy policies. It was during these years that the foundations for RE landscape were laid (Lins et al., 2014), making it a perfect period for study to understand how policies have shaped the growth of renewable energy around the world.

5.3 Lag Structure

In case of longitudinal analyses, especially policy effectiveness on the dependent variable, it is typically assumed that the independent variable influences after a certain delay(Polzin et al., 2015). This paper also reflects this assumption by including a lag structure. This approach allows the outcome to compare the current time values of the dependent variable with various past time values of the independent variable. This method is particularly useful for considering how policy measures impact investor behavior over time (Polzin et al., 2015).

For RE policy instrument analysis, the paper will select a specific lag for our model based on its fit on data. If one assumes that policy variables (independent variables) influence the dependent variable after a certain period, necessitating the introduction of lags ranging from one to three years. This approach posits that the impact of policy variables on the amount of RE electricity generated (dependent variable), may not be immediate but delayed by at least one year. The choice of lag year will be decided based on which specific lag period most accurately captures the relationship with high level of fitness. This methodology aligns with the methods of Polzin et al. (2015), who explored a similar lag structure from one year to three years, observing that the effect of policies on RE investment/engagement decisions and the promotion of RE capacity could manifest over a period.

On one side point of view, it could be the case that investors can see new regulations coming and get their projects all set up and ready to go by the time those regulations are officially put into place. This is because the process for creating new regulations can be open and transparent in many OECD countries, so investors can have clear expectations on the market situations and new rules. On the other hand, there could be several reasons why starting an investment like a wind farm or solar park can take more time than expected.

For example, it takes quite a bit of time to actually build these large RE projects and get them connected to the power grid so they can start operating. When it comes to changing regulations, subsidies or market rules, these changes do not just happen immediately, which means at least certain period of the lag is recommended in longitudinal analyses. They are usually discussed about and announced well in advance before the new policies are formally approved and start to be enforced. This procedural approach ensures a period of anticipatory adjustment, enabling stakeholders to adequately prepare for upcoming changes (Polzin et al., 2015).

6. Analysis

6.1 PCSE Regression Results

Table C

Analysis : Fitness test for each regression model

	1 year lag	2 year lag	3 year lag
Adjusted R-square	0.9634	0.9669	0.9678

This paper conducts the PCSE regression with three models, from one year lag to three years lag. Adjusted R-square values do not show much difference among models, with high percentage fitness (all models around 96%). Therefore, this paper chooses the model with the largest number of significant variables. The one-year-lag model is chosen as a the most fit one, with having seven significant variables (see Table D)

According to the one-year-lag model, RPS dummy has positive effect with 95% confidence level. On average, if there is implementation of RPS in a country, it is likely to increase RE production by 8.6%. The ETS dummy itself has negative effect, surprisingly, but the percentage of ETS coverage has positive effect with 99% confidence level. Likewise, when there is implementation of ETS in a country, it is expected for decreasing RE production to 22% on average. However, on average, if there is one percent point increase change of ETS coverage in a given unit, it is expected for increasing RE production to 0.6%.

In case of control variables, land area consistently shows a positive relationship with RE production across all models at the 99% confidence level. This might imply that larger geographical areas might have greater capacity or potential for generating RE, possibly due to more available space for RE facilities. Carbon emission intensity shows a significant negative impact on RE production. This implies that higher carbon emission intensity is associated with lower RE production, suggesting the inverse relationship between reliance on fossil fuels and the adoption or production of renewable energy sources. The logged GDP has the highest coefficient number among all variables, which could imply that the national wealth or economic status is the crucial factor of RE expansion. According to the outcome, 1% increase in GDP would lead to 2.9% increase in RE expansion.

In addition, two-year-lag and three-year-lag model show similar result of RPS dummy and ETS coverage. However, ETS dummy is not significant in both cases. In case of the two-year-lag model, implementation of RPS is expected for increasing RE production by 12%. The percentage of ETS coverage has also positive effect. If other things equal, if there is one percent point increase change of ETS coverage in a country, it is expected for increasing RE production to 0.7%. In case of three-year-lag model, implementation of RPS is expected for increasing RE production by 11.2%. Likewise, one percent point increase of ETS coverage is expected for increasing RE production to 0.4%.

In conclusion, there are two variables that show consistent significant among all three models: RPS dummies and ETS coverage. The RPS dummies in all three models show a consistent positive effect on RE electricity production. This indicates that the implementation of RPS policies is somewhat beneficial, when it comes to RE production, with the impact magnitude varying (8%, 12%, and 11%) depending on the lag period considered. RPS has larger effect at the second-year and three-year lag than at the one year. Plus, across the models, the percentage of ETS coverage has a consistently positive effect suggesting that as the coverage of ETS increases, so does RE production. This positive impact grows over time at a decreasing rate (0.6%, 0.3%, 0.4%), which indicates the importance of not just merely having an ETS but expanding its coverage to positively affect RE production.

Table D

Analysis: PCSE Regression Results

Variable	1 year lag	2 year lag	3 year lag
Length of FIT_L	-0.000478	0.0000658	0.000486
	(-0.82)	(0.10)	(0.78)
Amount of FIT_L	0.0633	-0.00452	0.00978
	(1.22)	(-0.08)	(0.18)
ETS cover_L	0.00647***	0.00300*	0.00437***
	(4.14)	(1.71)	(2.18)
dummy_FIT_L	0.0507	0.0480	0.0632
	(1.10)	(1.02)	(1.36)
dummy_RPS_L	0.0859**	0.119**	0.112***
	(2.16)	(2.81)	(2.23)
dummy_ETS_L	-0.224***	-0.111	-0.131
	(-3.34)	(-1.47)	(-1.89)
Carbon Emission	-0.196***	-0.184***	-0.173***
	(-14.18)	(-12.84)	(-12.83)
Interest Rate	-0.00317	-0.00704	-0.00979
	(-0.37)	(-0.77)	(-1.09)
Land Area	0.000000544***	0.000000530***	0.000000530***
	(25.38)	(23.47)	(25.35)
Logged GDP	2.928***	2.898****	2.784***
	(8.79)	(9.24)	(8.71)
Squared GDP	-4.23e-10***	-4.36e-10***	-4.40e-10***
	(-7.89)	(-8.49)	(-9.37)
Constant	-19.17***	-18.94***	-17.84***
	(-5.62)	(-5.84)	(-5.36)
N	595	567	539

t statistics in parentheses

* p<0.1, ** p<0.05, *** p<0.01

Note 1: At Table C, Letter 'L' in the end of the variables refers to lagged value in actual regression result. For instance, 'dummy_RPS_L' refers to one year lagged dummy variables of implementation of RPS, while 'dummy_ETS_2L' refers to two year lagged dummy variables of implementation of ETS.

Note 2: Letter 'N' in the end of the table refers to number of observations in actual regression. N tends to slightly decrease from Model 1 to Model 3, due to use of lagged variables.

6.2 Random Effect Regression Result

Table E

Analysis : fitness test for each regression model

	1 year lag	2 year lag	3 year lag
Adjusted R-square	0.4772	0.4804	0.4771

This paper also proceeds the random effect regression for panel data as a complementary method and tool for further robustness. Table E shows the R-square value of each lagged model and Table F presents the full outcome of the random effect model. The outcome of the R-square values indicate that random effect model explains less variability in dataset compared to PCSE model (See Table A, B). All three PCSE model have more or less 96% R-squared value, while three random effect models have around 47-48% R-squared value.

Furthermore, all three models show a rho value exceeding 0.9, signifying that a major portion (roughly over 90%) of the variability in the dependent variable stems from variations among countries rather than from changes within groups over time. This suggests that the random effects model is capturing a significant amount of the variance in the dependent variable by utilizing the country-based grouping variables. In other words, random effect model is capturing variance between groups, which provides a significant advantage compared to fixed effect models.

Only ETS coverage has a significant result, in 90% confidence interval, and it is valid for all three models from one year lag to three years lag (see Table F). According to the result, on average, one percent point increase in ETS coverage when renewable energy electricity changes over time and across countries, it is expected to lead approximately 0.8% increase in RE electricity. Other dummy variables and continuous variables are not significant. In case of control variables, carbon emissions consumption, land area and logged GDP showed significant outcome in 99% confidence level. Also, ETS coverage coefficient showed consistent value range, from 0.78% to 0.85% in all three models.

Table F

Analysis: Random Effect regression result

Variable	Model 1	Model 2	Model 3
Length of FIT_L	-0.00180	-0.00161	-0.00104
	(-1.41)	(-1.21)	(-0.79)
Amount of FIT_L	0.100	0.0957	0.0708
	(0.79)	(0.70)	(0.50)
ETS cover_L	0.00850*	0.00792*	0.00788*
	(1.68)	(1.67)	(1.75)
dummy_FIT_L	0.140	0.152	0.148
	(0.95)	(1.08)	(1.09)
dummy_RPS_L	0.0366	0.0941	0.134
	(0.28)	(0.76)	(1.10)
dummy_ETS_L	-0.313	-0.293	-0.268
	(-1.35)	(-1.38)	(-1.37)
Carbon Emission	-0.209***	-0.202***	-0.192***
	(-3.80)	(-3.72)	(-3.68)
Interest Rate	-0.0171	-0.0167	-0.0131
	(-0.80)	(-0.88)	(-0.86)
Land Area	0.00000051***	0.000000495***	0.00000048***
	(5.96)	(5.75)	(5.60)
Logged GDP	2.898***	3.002***	3.026***
	(3.34)	(3.49)	(3.37)
Squared GDP	-1.16e-10	-1.46e-10	-1.64e-10
	(-1.12)	(-1.50)	(-1.68)
Constant	-19.36*	-20.47*	-20.79*
	(-2.22)	(-2.36)	(-2.28)
N	595	567	539

t statistics in parentheses

* p<0.1, ** p<0.05, *** p<0.01

6.3 Interpretation

The regression analysis presents the distinct impacts of RE policy mechanisms on the expansion of RE production. This discussion focuses the two policies that showed consistent significant valid results: RPS as a proxy for regulatory frameworks, and ETS as a proxy for market-based instruments, which all were fostering RE development.

6.3.1 RPS and FITs effectiveness

Utilizing principal-agent theory as a framework, the observed outcomes are not very similar between RPS and FITs in promoting RE. The empirical results from the regression models —indicating an 8.6% increase in RE production with the dummy value (implementation)—underscore the effectiveness of RPS as a policy tool. In contrast, the FITs outcomes did not show significance in any three models of PCSE or random effect, alongside the mixed results of contract length and the positive outcomes of contract money, suggest a complicated interaction of factors influencing the efficacy of FITs policies.

RPS policies impose all power providers to generate a minimum quota of renewable sources either by their source or buying some credits. Therefore, RPS directly addresses the principal-agent problem by aligning the incentives of electricity providers (agents) with the societal and environmental objectives (principal).

This kind of policy mechanism effectively reduces the information asymmetry and moral hazard traditionally associated with the principal-agent dilemma by establishing clear, measurable, quantifiable targets for renewable energy production. The consistent positive impact of RPS across different models reaffirms its role in providing definitive regulatory signals that reduce uncertainties for utilities and producers, which encourages them to make substantive investments in renewable energy infrastructure. This clarity and definitiveness are crucial for overcoming the inherent challenges of the principal-agent problem. In the end, it fosters an environment conducive to long-term investment and innovation in the RE sector.

On the other hand, the FITs policy, designed to offer producers of renewable energy fixed, long-term rates for the energy they generate, seems to exhibit a more complex relationship with RE production outcomes. From the perspective of principal-agent, the mixed effects of FITs could be attributed to the variance in policy consistency and the degree of alignment between the incentives of RE producers (agents) and the objectives of the policy (principal). While FITs policies aim to reduce the risk for renewable energy producers by guaranteeing a stable price for the energy they supply, the effectiveness of these policies may be diluted by factors such as contract length and expenditure.

The mixed results regarding the length of FITs contracts could reflect the tension between providing policy stability— which encourages investment by reducing uncertainty for the agent— and the potential for inefficiency due to the lack of pressure to reduce costs or innovate over the contract's duration. Longer contracts might offer security and encourage initial investment but could inadvertently create conditions where producers have less incentive to optimize production processes or invest in technological advancements, reflecting a principal-agent misalignment.

Furthermore, the positive results associated with the expenditure of contracts under FITs suggest that when contracts are sufficiently lucrative, they may indeed drive investment and expansion in the renewable energy sector, aligning the financial interests of producers with the policy goals. However, this alignment is contingent upon the careful design of the FIT policy, including the determination of rates that sufficiently motivate producers while ensuring that the costs are justified by the benefits in terms of RE expansion.

6.3.2 ETS effectiveness

The paper analyzes the role and effectiveness of ETS based on transaction cost theory. Transaction cost theory is market-oriented mechanism (as mentioned before) for greenhouse gas emission reduction. It has several functions: It facilitates the trading of emission allowances, consequently having significant effect on RE industry area. The initial implementation of ETS has been observed to exert a negative influence on RE production, suggesting that ETS, in its infancy or with limited coverage, may not immediately foster an environment conducive to RE expansion. This phenomenon may occur due to market uncertainties and the requisite period for regulatory adaptation and system maturation. This period of adjustment reflects the initial transaction costs associated with navigating the new ETS framework. In other words, ETS aligning with the transaction cost theory posits that institutional arrangements aim to minimize these costs among market actors (Hall & Taylor, 1996; Woerdman, 2001). ETS dummy outcome also shows that one-year lag shows negative correlation but two-year and three-year lag has no more significant relationship, also with decreased negative coefficient.

However, the consistently positive effect of increasing ETS coverage on RE production supports Crals & Vereeck (2005)[5], indicating that when ETS is designed with broader coverage and thereby minimizes transaction costs, it becomes an effective tool for promoting RE expansion. It is noteworthy that ETS coverage is only continuous variable that has shown consistently significant value for all three models' outcome, while ETS dummy is no more significant after one year lag model. It indicates that the structure of design and actual coverage of ETS has profound effect on RE expansion.

Specifically, if one assumes that implementation of ETS starts with only small coverage and simply calculates the empirical results of dummy and coverage of ETS, it can be said when ETS coverage exceeds 34.6%, ETS starts to have positive outcomes for RE production with other things held constant in one-year lag situation. The number 34.6% comes out when negative effect of ETS dummy (22.4%) is divided by positive effect of ETS coverage per percent point (0.647%). This shift is indicative of a threshold effect, wherein the economic disincentives for carbon emissions engendered by ETS (through the increased costs associated with non-renewable energy reliance) become sufficiently compelling to catalyze investments into renewable energy. However, this paper also notes that this mere calculation of coefficients also has a limitation in reality since there are other factors that can have profound effect on RE production.

For instance, in the case of Norway, the coverage of the ETS reached more than 35% in 2010, climbing to over 40% by 2017. Based on previous calculation, the ETS was likely to begin exerting a positive influence around 2010, contributing to a notable expansion in RE by more than 3% by 2017. Conversely,

5) According to Crals & Vereeck (2005), broader coverage of ETS, which connects to a more buyers and sellers for trading permits, would lead to more positive effect on RE growth by decreasing transaction costs.

there is another situation. Denmark's coverage exceeded 35% around 2000s, and it maintained a higher level of coverage through to 2021. This suggests that the ETS likely had a consistent and positive impact on Denmark's RE expansion.

7. Conclusion

This paper adopted the PCSE model to analyze the effectiveness of RE policy instrument. The regression outcome showed that the implementation market-based policies are likely to be connected to the expansion of RE. However, implementation itself would have negative effect on RE, if it is not designed properly. If it is designed well to lower the transaction cost, it would be the effective tool for RE expansion.

The regulatory instrument also has positive relationship with RE expansion. However, in case of regulatory instrument, more research will be needed based on the details or regulatory measurement since this paper only applies dummy variables to regression. It will be desirable for for future studies to integrate additional proxies related to policy for more analysis.

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5. 정책적 시사점

1 유럽 그린딜 사례로 보는 정책 방향

유럽의 경우 그린딜의 출범과 함께 배출권거래제 달성 목표를 강화하고, 관련 산업에 대한 지원을 강화하는 등 탄소중립 실현을 위한 재생에너지 정책 지원을 지속적으로 이어 오고 있다. 유럽 집행위원회는 확대된 배출권거래제 타겟과 커버리지에 따라 탄소 가격은 2030년까지 톤당 129유로까지 상승하는 것을 목표로 삼고 있다. 이는 화석연료 배출 비중이 높은 산업에 대한 압력으로 작용하여 재생에너지 생산을 더욱 가속화할 것으로 예상된다.

2 스웨덴 사례로 보는 정책 방향

스웨덴의 경우 그린딜 출범 이전부터 환경산업 및 재생에너지 정책을 성장동력으로 삼고 있다. 스웨덴 정부에서는 Ecological modernization[6]이라는 슬로건을 필두로 환경정책 강화와 경제 성장을 동시에 달성하려는 노력을 진행해 왔으며, 이러한 정책 방향은 민주적 정부에 의해 일정 레벨 이상의 지지를 얻어 왔다.

스웨덴은 이러한 정책 추진을 바탕으로 그린 철강(green steel)과 같이 기존 탄소배출 산업을 신산업으로 전환하여 경제성장 및 탄소중립 실현 동력으로 삼고 있다. 스웨덴 이외에도 덴마크, 독일과 같은 유럽 국가들은 이러한 방향의 환경 정책을 산업 정책과 연계하여 지속적으로 추진하여 왔다.

3 정책 제언

한정된 정부 자원과 예산을 고려할 때 재생에너지 관련한 정책을 시장기반도구를 통해 정책 집행 예산을 절감하고, 아울러 관련 업계와 피규제자 소통 및 정보 제공을 통해 시장 참여자들이 향후 재생에너지 시장에 대한 적절한 예상 및 투자 선택을 할 수 있도록 유도하는 것이 장기적인 재생에너지 확대에 효과적이다.

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6) Andersen, M. S., & Massa, I. (2000). Ecological modernization? Origins, dilemmas and future directions. Journal of Environmental Policy and Planning, 2(4), 337-345. https://doi.org/10.1002/1522-7200(200010/12)2:4<337::AID-JEPP62>3.0.CO;2-G